**New Hope Creek, a vital laboratory worthy of our protection.**

**How New Hope Creek was the laboratory for my PhD in the 1960s and how it became the incubator for my particular claim to fame in Science, 50 years later.**

**Charles A.S. Hall**

Intro by someone else…. Charlie is now retired, but he has had a rather illustrious scientific career as a professor at Cornell University, University of Montana and The SUNY College of Environmental Science and Forestry. He has become, as he told his mother, a “microcelebrity” for developing the concept of EROI, or “Energy Return on Investment”. While that concept is usually applied to oil exploration or other energy sources it got started in New Hope Creek. This article is how it happened. It is based on a taped conversation while walking Long New Hope Creek with Tom Heffner and our wives and dog, April xxx, 2021 (Figure 1).

It was a gorgeous April day in 2021 when Charles Hall and Tom Heffner and their wives and our Dog Jussi took a walk along various sections of New Hope Creek, in Duke Forest, North Carolina. The two families had come together because Charlie’s wife, born Myrna Havnaer in Washington State, was seeking her family roots in North Carolina. A long history (and a number of misspellings of the original name Hafner) led Myrna to Tom, and both Tom and Charlie discovered that they had had deep connections with New Hope Creek, Charlie because he had done his PhD research there in the 1960s and Tom because he had planned a series of developments within the watershed and had become increasingly interested in protecting the watershed over time. It turned out that despite their very different former relations with the creek Tom and Charlie got along very well. While on this walk Tom asked Charlie to explain his scientific relation to New Hope Creek. While Tom may have got a lot more than he bargained for he was very interested in the story, which fortunately we have a record of thanks to Myrna’s ability to download a tape-recording app onto her cell phone. What follows is a moderately edited and slightly embellished transcript of that conversation, which took place over about three hours as the four of them wandered along the banks of New Hope Creek. (The original recordings can be found at the bottom of this page). It turns out to be the story of much of Charlie’s life, and the story of how science can progress in very unexpected ways.

**Charlie’s story**

**Background**

“I came to Chapel Hill in 1967 and was very excited to be working with the great systems ecologist Howard Thomas Odum. I was in another PhD program at the time I was accepted at Chapel Hill, but when got a great acceptance letter from the Zoology Department I knew I had to check it out, so I came to Chapel Hill to see. I was well aware of Dr. Odum’s reputation as I had read and liked very much a number of his papers in my master’s program, but I was quite unprepared for what was to come. The first time I met Dr. Odum he made a big impression: 6 feet 4 inches, maybe 240 pounds, bright red hair and a big smile. He was walking from place to place on campus, even building to building (he was professor in three departments) followed by what I came to know well: the “Odum train” of about half a dozen people waiting in line to talk with him, and for him to answer their questions and requests. As one person had his questions answered he would go off to implement whatever he or she had found out, and another person would usually come along and take their own place at the end of the train. He had students from all over the place, grad and occasionally undergrad, other people's students, exotic (to us) people from various other countries, whatever. He was always very friendly and helpful and to me a real southern gentleman, which to me is defined by the statement “A gentleman never mistreats the help”, i.e. he never mistreated people with less power than himself, although he could be real tough on his graduate students and sometimes his peers. Scary, sometimes.

On that first day that I met him Dr. Odum had to go to a hardware store to get some materials for his daughter’s Jr. High school science project. This was about the time that hardware stores, or some of them, were evolving into carrying more consumer items rather than just nuts and bolts. While we were waiting for a salesperson H.T. was looking at some domestic items. His eyes came to rest on a wide goldfish bowl, a small fan and a record player turntable. He said to me (I am not kidding!): “Look at this, we can make a model of the Gulf Stream. He put the goldfish bowl on the record player turntable, turned on the fan to blow across it making a current in the goldfish bowl, and then he said “now we have to add the coriollis force” and gave the record player a little spin to the right. Sure enough, something like the jet stream began flowing in the goldfish bowl, and the goldfish had to start swimming to keep his place. Utterly fascinated, I said to myself: “Well this is not going to be the same as my education so far! I think I am going to like this”. It was my introduction, special but characteristic, to the next three and a half years of my doctoral program. It was just an amazing experience. I already had a master’s degree in ecology, but now I had a whole new intellectual scaffold to think about ecology based on physics, on systems science (how do whole ecosystems and entire social systems work, what are the principles, the relation to physics and chemistry, the commonalities, the linkages) and learning about the critical role of energy –that which makes it all happen. As we would say at the time “my mind was totally blown!” Later on we graduate students would comment about standing by while he would be explaining how something worked: We felt that you were standing next to a great energy source, like a big dynamo, with your hair standing out and your mind totally set on fire. It was an incredible experience. We all felt that.

When I started I knew I wanted to work with water, fish and the ecology of streams, because that was always my interests and what my master's program was on, but I had no clue as to a specific project. I also had no clue where my stream work would lead….

(We are now walking from Whitfield road down a gravel road to the “Concrete Bridge” which was close to my main sampling site).

**A walk to the Concrete Bridge Station**

Charlie: “Wow look at this! My main sampling site, which I called “The concrete bridge station” gets its own official plaque up by Whitfield Road! Back in the day I had “the key to Duke Forest” so that I could unlock what looks like the same gate and drive my little MGB, often loaded to the gills with traps and material for my weirs, down this road to my main station. I did this more or less every day for nearly two and a half years. I loved it and it is so exciting to be back!

OK back to how I came to be studying fish migration in New Hope Creek. “The reason that I became interested in fish migration at the University of North Carolina was that in the Zoology Department we had a wonderful speaker series, and one week we had Dr. Peter Larkin come from the Fisheries Department at the University of British Columbia. He was one of the world authorities on the population dynamics (that branch of ecology that deals with the numbers of a species over time) of salmon. He gave a talk on what was then cutting edge research on the population dynamics of Pacific salmon. The salmon were an extremely important economic resource for British Columbia and one consequence was that in many rivers they had counting weirs and other devices to get a fairly accurate estimate of the number of adult salmon returning to spawn, and also the number of young salmon that went down to the sea. At that time it was thought that since each adult laid some 3000 eggs, from a population point of view it was thought that there were “excess” spawners, which might as well be taken by the fisheries. The question was how many of the adults were excess, and Dr. Larkin presented a lot of mathematics that various researchers were using to determine the “optimal” catch of returning adults. Since they were dealing with many millions of salmon this was a critically important issue economically and of course biologically, from the salmon’s perspective. For me it was incredibly interesting and heady stuff.

That evening, at a beer and potato chips party at the Chairman’s house, Dr. Odum took Dr. Larkin and myself into a corner, said, “I don't think anybody is studying migration from a systems perspective”. In that second I knew what my dissertation and eventually my life path would be! It was so characteristic that Dr. Odum could intuitively connect me and my enthusiasms into the ecosystems and general systems perspective that he was developing. That was how intuitive he was. Dr. Larkin invited me to come to Vancouver on his nickel and study the real thing the next summer. I was out of my gourd with excitement.

But I had two problems: what, exactly would I study to connect animal migrations and ecosystems and where would I do it in North Carolina?

I was very familiar with migrating fish in my Massachusetts hometown, which had migratory shad, herrings, eels and so on that used the freshwater rivers for spawning migrations. The main river was called Weir River, after the fish traps once found there. I did not think that there were migratory fish in inland rivers because at that time the stream fish literature, which I was fairly familiar with, tended to focus on territoriality, i.e. fish staying in one location and defending that place. So initially I went to the coast where the University of North Carolina had a Coastal ecology Institute, where I thought there might be migratory fish. But that did not work out too well because the people I met there did not seem too enthusiastic and the ecosystems were huge, which I felt would be very difficult for me to sample personally, which is what I wanted to do. So I was initially pretty discouraged. At that point I had been talking a lot but not doing much. I think that Odum thought maybe that I was more show than go, and once he even said that maybe I should look for another advisor. This threat of excommunication did wonders for me.

So then I thought, well what I like is streams, so I will go and study a stream which will be much easier to do than some big river at the coast, even if migration is not a big deal there. I wanted to work on a stream but I did not know which stream. I traveled all around Central North Carolina with Bob Kelly, another graduate student, but to my horror all the streams were obviously polluted. I wasn't interested in pollution, I wanted to study nature. And so, Bob said the place you want is New Hope Creek. It was in the middle of protected Duke Forest and not readily accessible. He told me how to get in there and I remember very clearly coming up to a bluff like the one we were walking on, and looking down and seeing beautiful New Hope Creek and saying “This is the place” – like what the early Mormon leader Brigham Young said when he saw the valley that became Salt Lake City.

For me, this indeed was, and is, the place, and it was just reminiscent of what I thought a river ought to look like. Maybe with southern temperatures I don't know. So for six weeks I went out to New Hope Creek and collected lots of oxygen and fish data from the stream without saying a thing to Dr. Odum.

I built a weir ---- I was familiar with Weirs from New England -- we have them there to catch fish commercially. I went to the hardware store in Carrboro and bought many dozens of feet of hardware cloth, lots of aluminum bars and hundreds of pop rivets to put it all together. So, just with hardware cloth across the stream and soon I was the best pop riveter there ever was and made all these cages that would fit into the weir. The first day with a crude prototype that I put out right there -- I remember pulling out my traps and looking into them and there was, I don't remember exactly, some 15 or 20 fish in the upstream trap, they were pretty big ones, say 6 to 15 or more inches, and maybe another similar number but smaller in the downstream trap.

I weighed every one of them individually. And I said to myself on that day “I've got a dissertation”. And I was right. My results after two and a half years were more or less the same that I got on that first day. In other words, the pattern was repeated day after day: big fish are going upstream, little fish are more common going downstream, and so on. The fish moved most strongly in the spring, when they often had signs of breeding conditions (bright colors etc) with a smaller peak in the fall. I had some weirs upstream too, where I found the same pattern, but with different fish, a little bit mysterious still. In time I put tags on most of the fish but caught surprisingly few at the wooden bridge a number of miles upstream, although the movement pattern there was the same.

Oh, and I stayed up all night and day taking oxygen samples. So the oxygen right now is going up because sun is shining and plants are making oxygen as they photosynthesize, and the oxygen goes down at night, as all of the ecosystem is using energy. So nature is a balance of producing energy from the sun, and using it in rough balance. Except New Hope Creek is not quite in balance as I will explain later.

And so I did all this, and after 6 weeks I went to Dr. Odum, and I showed him my data and next thing I knew he had financial support for the summer and then for the rest of my PhD. In other words I had shown him that I was go as well as show. I was no longer in threat of excommunication! Whew!

**An aside on Phosphorus**

I was originally interested in migration in terms of fish moving phosphorus.

Edward Deevy, one of Dr. Odum’s teachers at Yale, has said “There is something special about the biogeophysical cycling of phosphorus that makes phosphorus relatively rare compared to its needs by life at this particular geological time.” Phosphorus is relatively rare in nature. But it's very valuable because you (and fish) have much phosphorus in your bones, and also in something called ATP (adenosine triphosphate) which is the little cellular energy storage batteries in yourself, and your DNA has phosphorus as part of its structural foundation. That's why phosphorus is an important agricultural fertilizer. While I was reading up on salmon after Dr. Larkin’s visit I was interested to find that in Alaska investigators had found that migrating salmon brought in phosphorus from the sea to their upstream spawning grounds, streams and lakes because they came back so much larger than they were when they left. In fact the adult salmon were increasing their own genes in the world in part by fertilizing their offspring’s food supplies with the ocean-derived phosphorus in their bodies. (In fact, I am still working on migrating salmon and published a paper on that just recently (see references at bottom).

I can remember clearly once early in my studies in New Hope Creek working hard out in the stream (maintaining the weirs was physically very difficult) and feeling “eyes on my back”. I turned around and a bearded man was standing on the rocks and staring intently at me. He asked, really demanded, what was I doing, so I told him the salmon story about phosphorus and said I was trying to see if it might be true in New Hope Creek. He asked me more and more pointed questions until I said “Who are you, anyway”. He introduced himself as Dan Livingston of Duke University, who I knew to be one of the world’s leading authorities on Biogeochemistry, essentially the topic of my dissertation at that time! But he worked in Africa, and here I was studying biogeochemistry in his own back yard!

It turned out the phosphorus was not the big deal of my dissertation I had initially hoped, but fortunately I found a better story with energy. When I was all done phosphorus is a little bit interesting, but not as interesting as with migrating salmon. But what was interesting with New Hope Creek was the energetics. And because of that (and Dr. Odum’s influence) I am today a total energy freak. How much energy does a fish use in migration and how much does it gain from being in areas of higher productivity? Why would they use upstream areas and downstream areas for different things in their life cycles?

The concept worked beautifully conceptually in New Hope Creek and it's well supported by the data. However I think the idea works even better for Pacific salmon.”

….

**STREAM**

**(Now we have come down to the creek and the concrete bridge)**

“Okay now, I like this bridge, because I could measure the water flow easily because the water was restricted to these four pipes where I could measure its velocity easily. I had to do hydrologic measurements, i.e. how much water is going down in New Hope Creek. Look, the water has been over the bridge earlier this year, probably here. I remember I came back once from a flood. And I found parts of my weir that were up there, and down below the bridge through there. But mostly I did not work or even go below this bridge at that time. So let's go up to my principal sampling site which is about 100 meters above the bridge.

Let's go up this path. So 50 years ago I parked my car, my MGB, up there on the path to my personal sampling site which I called the concrete bridge station.

(we come to my principal sampling site from 50 years earlier)

New Hope Creek is gorgeous, and the rocks I remember, I love the rocks of this Creek. Somebody told me that that part of the geology here was Triassic. Did you see me azalea right there it's worth coming back and looking at.

**EROI**

And there is my rock. I'd sit there at night, waiting to take my next oxygen sample, and think, often, about fish and energy. So, this is where the concept of energy return on investment was derived – on this rock (Figure 3). Yeah right here this is where I'd sit right and think.

So, I put my first weir right about there, at the narrow section. The idea of the weir was to make a diagonal barrier in the stream to funnel the fish going upstream into one trap and the fish going downstream into a different trap, over here. I soon found that I wanted a wider section of the stream, because when it was flooding I had troubles. I observed that when a flood came it would rise up twice as much in a narrow section as at the wider section. This was less a problem in the wider part of the stream, so that with a given increase in flow the velocity would be faster here than there. I had the original weir at that narrow place. I built the subsequent weir at the wider section, 10 meters upstream. A second problem was that in the fall the leaves would plaster on the hardware cloth and push it over. So what I did was I took a bunch of one and a half inch electrical conduit tubing pipes and then I put some plastic sleaves on either end. This made a barrier with half inch slots that let the leaves through but not the fish.

At that time I figured that this was just about the northern limits of doing this kind of work, to run such a study over an annual cycle, because I had my hands in the water looking for leaks for hours at a time. I had to pay a lot of attention to that because I caught one of the first fish I tagged with a numbered Floyd tag #008, a black bullhead, three days in a row moving upstream without caching him going down. So somehow he snuck under the weir! But checking for leaks with a skim of ice on the water was tough.

What is it now, mid April? The fish are moving now. I think April's the biggest time for fish moving, but they often are moving some. I almost never saw them swimming in the stream but when I put in the weir and in fact there they were. Lots of them every day. I did this for 27 months over three years. I kept a daily log. I said at the end of my PhD, I would have done it even if nobody gave me degree at the end of it. It was so interesting. Oh wait a minute, I got to go see if there is still a Louisiana waterthrush singing … Where did I have my wooden platform. Yes, it was about right here under this tree. Here I had my little table, where I weighed my 10,000 fish, one at a time.”

Tom: “My son in law is gonna love this.”

Charlie ”Well, we'll send it to him. Would you like to listen to this recording?

I'll show you exactly where I derived the concept of energy return on investment.

I also spent a lot of time measuring the basic energy available to the fish in different parts of the stream at different times of the year, which I will discuss in detail in a bit.

But I think right on this rock is where the concept of energy return on investment was derived (Figure 3).

**Energy Return on Investment**

The concept, quite frankly developed better for other fish than in New Hope Creek, is that the large fish swim upstream to put their eggs into shallow environments with concentrated energy resources (the energy as sunlight and leaves and bugs enters per square meter and is used in the volume, just as coastal areas are more productive per volume than the deep ocean even though each receives the same amount of input energy per square meter).   The little fish, once they get a good start in life, then move downstream at some months old to deeper, less stressful environments. This was the pattern I observed again and again, and the productivity/stress concept made sense to me because there was a drought one of my summers, and the upstream shallow environments dried up completely but the deeper downstream environments remained as a refugia, even if less productive. I calculated that the energy returned to the migrating fish, or its progeny, was about 5 times greater than the energy used to migrate up to the more productive upstream waters. It's a good story and is probably true, but I think it is even better developed for salmon (see second page of [www.bpeinstitute.org](http://www.bpeinstiutute.org)). “ It is also a very general process thorough out nature: look at those trees across the river. Each one is making critical decisions about how to invest its own energy into growth or defense or obtaining nutrients or other things. energy return investment in nature is relentless is, what, what, I believe, natural selection is based upon.

New Hope Creek

Tom: “Does the stream look about as clear as you remember it 50 years ago?”

Charlie : “Well: it was a really clean creek back then , such as I could tell, a really nice creek. I think it was often a little clearer than it is today but maybe often about like today, slightly turbid. During storms it would get brown colored from silt. I took a lot of samples for phosphorus and nitrogen, and they are stored in my full dissertation, which is in the Zoology library and also published by the water resources of North Carolina who made a lot of copies of it. But the copy of the original with all the appendices is in the Zoology department at Chapel Hill.”

Tom: “But I never see fish in the stream!”

Charlie “I never saw any fish either, except in my trap. Maybe at night, I'd see a few minnows, but at the time I did this idea to focus on stream fish the biological concept was on territoriality. And not movement.

I figure that big fish like red horses would be in the deep pools, some up to my neck even in summer. Big red horses will be here in this pool. I think it gets quite deep up here in these long deep pools.

**Aquatic insects as indictors of water quality**

(an aside to Tom) “Now, come back here a minute. I'm not very adept anymore, can you possibly reach one of those rocks? I would like to look at the insects on the bottom, I can tell a great deal about a stream from the insects found there. Mostly people judge water quality by the chemical composition of the water, and that certainly helps. But when you take a sample of the water some industry might not be releasing their toxins at that time. But the bugs must live through it 24-7-365. And so if you're missing some insect species that should be there you have an important clue. We know that from different insect species. For example, if you have stone fly larvae on almost every large stone in the water the water has to be really clean. If you have only alder flies, *Sialis*, that probably means that the insect communities have been exposed to acidic water at some point and so on. Here on this rock bottom we have a few mayflies, indicating pretty good water quality. It’s a good sign. New Hope Creek still seems healthy.”

I remember I had to take out all my pipes and hardware cloth and everything at the end and put it there where it was trucked to the dump!

Take a picture, we will never know what we are going to do with this.”

Tom: “I would hope to publish this in The New Hope Creek Journal, and I'm also going to send that over to the Nicholas School of the Environment a Duke.”

“And one of the important conclusions I had is about half the energy that's running this stream is coming from the forest from the leaves and bugs that are falling in. Back then somebody at Duke had measured the leaf fall per square meter independently. When I calculated his number in calories it gave about the same number in calories that I had figured out from the oxygen use-- from the difference between photosynthesis and respiration. And so that was a satisfying thing. Absolutely. But the main thing I came up with was energy return on investment.”

**How would I measure the energy availability? A diversion on Oxygen**

“So, okay so let's talk about oxygen. It is not possible to measure energy used or energy fixed from the sun directly, but we can measure these things from the changes in oxygen that are associated with energy used and fixed. So, when I took a sample for oxygen, say at this time of the year, right there, right off that rock, the oxygen concentration might be about 10 parts per million parts of water (ppm). I would take day and night samples from midnight to midnight round the clock. Nine samples: 12,3,6,9 and so on. And then I began to be interested in the spatial distribution. So I go up to the wooden bridge. And then eventually the Blackwood station, where I actually got my nicest samples. I did this with a chemical test that are called Winklers. Winklers use a special bottle about this (6 inches) big and you have to use an anti diffusion cork so that you do not contaminate your water sample with atmospheric oxygen. If you did not use that the atmospheric oxygen mixes in but you just want to know what it is in the water when you take the sample. So, I take a sample with this special cork and the temperature and record it. And then I take two bottles for duplicates. Next I add special chemicals that replace the oxygen mole for mole with manganese then iodine, then later back at the lab I titrate the iodine with sodium thiosulfate which tells me how much oxygen was originally in the sample. The concentration changes day to night depending on the year, and the temperature also. And I did this every three hours around the clock for 24 hours, many dozen times. When I was going to other stations as well as the Concrete Bridge location I would get in my car or occasionally the university department station wagon, and go to my other station and take a sample and then rest for an hour or take a little nap and then come back to this place. So I took lots of Winklers. Thousands.

And what you find is that during the daytime the oxygen increases due to photosynthesis. And at night, the oxygen goes down due to no photosynthesis but all the fish and the underwater insects and the bacteria and even the plants must use oxygen for all their activities of life. In the daytime the oxygen increase is a net increase, because oxygen is being simultaneously pulled down by the respiration of the ecosystem. Respiration means using oxygen to use organic fuels. You and I are respiring right now, we're using oxygen to burn fuels from our last meal or last several meals within our bloodstream or the sugars stored in our liver or whatever.

And so the whole stream has a metabolism – we call it ecosystem metabolism. And, in New Hope Creek you have about twice as much respiration as there is photosynthesis, indicating that there's twice as much energy that is being used as is produced from sunlight. Where is that additional energy coming from? From the forest, as leaves and insects falling into the stream, which gets used by all the animals and decomposers of the stream for food. As you go upstream, the amount of energy added from the forest increases relative to that added from photosynthesis. For the Blackwood station I would find that the difference between photosynthesis and respiration was great. Downstream the stream widens so that sunlight can get in, and you get more photosynthesis proportionally, although the forest input remains high. So you find as you went upstream the whole ecosystem is changing. What you're having is the same amount of energy coming in per square meter, but it gets used in less ecosystem depth. So you have a concentration of energy resources, which I hypothesized was a greater energy base for the fish. And, I have to admit, that remains a hypothesis, but it still makes sense to me. And it's something I have also found in other ecosystems. For example all kinds of salmon and trout literature is about fish going up into very small streams to spawn. So, I'm biased in part on that.

One thing that originally threw me for a loop was that my first upstream station was at the wooden bridge. And that wooden bridge I would get a smaller oxygen change than down here at the concrete bridge. And given my hypothesis, that you are getting more concentrated energy resources in shallow upstream regions, it did not make sense and my dissertation seemed in big trouble. So I finally went up above the Wood bridge Station and what did I find? The deepest and longest pool in the whole stream! But that's not the case at Blackwood. So, fortunately, when I switched my upstream station from the Wooden bridge to Blackwood, my dissertation was saved. So these are some of the things I wrestled with.

So, as we finish talking about oxygen we would find that the production of this stream is highest just about now or maybe a few weeks ago, before the canopy fully develops over the stream, in response to increasing sunshine in the spring. And then as the canopy develops more and more fully over the summer the photosynthesis declines. But the respiration stays high, and your fuel for this is bugs and leaves falling in from the forest. Then in the fall the leaves fall off and you get a little pulse of photosynthesis. In the winter, everything is pretty slow. And so it goes. But as you know I've sampled out here all winter long. There's always some biology going on. Not as much as maybe about now or a little later. As the water temperature goes up, respiration goes up. Temperature is the great regulator of life! This is as true for an ecosystem like New Hope Creek as it is for an individual plant or animal.”

During my dissertation Dr. Larkin invited me to British Columbia, where I got to talk to all the great Salmon Biologists and greatly enrich my knowledge of migrating fish. This was at the University of British Columbia and the Federal research station at Nanaimo. It was all part of my dissertation and just a mind blowing experience for just a little kid who liked to fish … to have all of this happen

**How I used the concept of energy return on investment later in life**

“Tom, you're probably pretty used to thinking about things in terms of money and so forth. But money by itself doesn't have value. You can burn paper money and heat your lunch, but that’s not very valuable. Silver would have some genuine value and you can use gold in a computer or to fill your teeth, etc. But mostly we just give them value because they are relatively rare, and people have agreed to consider them valuable. But was really gives value to money is that money is a lien, a promissory note, on energy. In other words society will give you, makes a promise to you, that it will use about five mega joules of energy (which is about half a coffee cup of oil) to generate the good or service! you want to trade your dollars for.

Let me give you an example: if you buy a bagel in Chapel Hill it just doesn't appear by magic. What probably happened is something like this:

First you need the basic materials of a bagel which are mostly carbon and roughly 10 % nitrogen. While any green plant can use CO2 from the air, they cannot get nitrogen. This is a problem for plants, and hence us, as plant (and animal) proteins are made largely of nitrogen. In principle nitrogen should be easy to get since the atmosphere is 78 percent nitrogen. But in practice it’s not, because the two atoms of nitrogen are held together very tightly by triple chemical bonds, (N2), that is, it is unavailable to plants because the two atoms are held together very tightly. Before 1908 nitrogen fertilizer was pretty hard to get. It took a lightning bolt or a very special bacterium, or birds would concentrate it in their excrement or guano. This worked, but there was not too much guano relative to the needs of the world’s increasing population.

Then in 2008 a German chemist named Fritz Haber found that if he heated a metal tube filled with air and natural gas while compressing it (and with the right catalyst) he could split the N2, have it combine with hydrogen to make ammonia (NH3). For the first time humans had unlocked the secret to access the abundant Nitrogen in the air --- use lots of energy in the right manner. Carl Bosch took Haber’s ideas and ramped it up to a large scale. Unfortunately, ammonium nitrate is both gunpowder and fertilizer, so this allowed the Germans to prolong WW I for another 4 miserable years, but it also allowed a huge increase in humanity’s ability to make food.

Back to our bagel: So the Haber Bosch process is used in, say, Louisiana to make nitrogen fertilizer, which is then barged up the Mississippi River to Nebraska using diesel, distributed to and then on the fields using diesel powered trucks and tractors, which are then cultivated and harvested using more diesel, ground into flour and then shipped to North Carolina on diesel -powered trains. So then a truck takes the flour from the train to wherever you're making a bagel in Chapel Hill. And then, if you've got a good baker, she mixes it up with an electric blender, then runs the oven and boils the water using electricity. So that by the time you have a bagel you might have spent some large part of a dollar just for the energy required! But for sure no energy, no bagel. This is an example of how money is a lien on energy. And so all of these things will happen, or have happened, in anticipation of you buying a bagel. No energy, no bagel. And it took roughly five mega joules of energy to do that.

Now we are at another place at New Hope Creek, a place I'm not particularly familiar with. “Tom, how far we from Blackboard station?” “We are a mile and a half downstream.” How far is the Wood bridge station?” “I walked up here once maybe I've walked on here but probably not but let's call them my main station.”

“Okay, so the idea is that even though Odum introduced this idea (He called it net energy), I got a little bit famous because I came up with the phrase “Energy Return On Investment” (EROI) and applied it not only to migrating fish but also to looking for oil and many other things, both biological and economic.

With oil what we find is that we've exploited all the best Texas oil and it's mostly gone. Then we have to go through much greater energy investments to get the next barrel of oil. One goes from the land to marshes to shallow water to deeper water and the arctic. If this progresses enough it takes a barrel of oil to get a barrel of oil. That is the end of oil as an energy source for humanity! And it doesn’t matter what the price is!

But it doesn't even have to get that low because of the many steps in supplying that oil: e.g. food, health care, education for workers, support infrastructure like roads and bridges and ports etc. We've calculated that you need at least something like a 10 to one return to have anything like modern civilization.

Now the big question is whether we can do that from renewable energy. Now that's a really tough question, we don't know the answer at all.

Something that's been quite extraordinary is that we did all this work on EROI and the relation of energy to our economy back in the early 1980s, much of it in very visible papers in the prestigious Journal Science. Curiously I was denied tenure at Cornell University after 13 years as an assistant professor on the week that my students and I had the cover issue of Science! That was my third paper in Science or Nature … but I've got a dozen now. The results were reported on page 1 of the Wall Street Journal.

So anyway, that's a long story but I don't really understand it except to say that seemingly prejudice also can apply to white males. I was a systems ecologist and very unconventional to many of the other ecologists. Fortunately I went on to other great jobs and getting dismissed from Cornell was very fortunate for me personally!

Curiously the scientific establishment, perhaps not used to thinking about constraints on “progress”, was not interested in encouraging these studies. In the 1980s and 1990s I could not get any money for doing energy studies from the National Science Foundation or even the Department of Energy, and when the price of gasoline came down almost nobody was paying much attention to energy anymore. But I had graduate students to support and was able to get considerable money to do other things so, inexplicitly, I worked on the global carbon budget, not the energy budgets I thought more important. Specifically, I worked on tropical land use change and deforestation where I could use my modeling expertise and increasing experience in the tropics to translate information on land use change into results on carbon uptake and release from the effected land. I believe that my team’s estimates are still the best numbers on release of carbon from tropical land use change (destruction of tropical forests) for 1980 and are still seen as the first defensible numbers to be published, and they are about what the best estimates are today for that time. I found it curious that so much attention and money was spent on carbon when I thought the real issue was peak oil, and I still believe that, but that’s where the money (i.e. research support) was (i.e. anything related to atmospheric CO2 and climate change). Oh Well I thought, my favorite composer is Gustav Mahler, who was greatly admired as a conductor but almost ignored in his time (1910 or so) as a composer. But then I read that he said, ‘Would that I could perform my symphonies for the first time 50 years after my death!’. Leonard Bernstein came along 50 years ago and became famous in part by re introducing Mahler’s symphonies. So I thought I would love to give my lectures on EROI in 50 years, when everyone will understand their importance.

**Getting my own energy batteries recharged in the new millenium**

But in 1998 two people with distinguished records in the oil business, Colin Campbell and Jean Laherrere, a Brit and a Frenchman, wrote a paper in the prestigious and influential Journal Scientific American called “The End of Cheap Oil”. I was astonished and delighted, since we had not heard anything about oil in the scientific literature since our papers in the early 1980s. Maybe energy was not a dead issue in the public or general scientific eye after all. But not much else seemed to happen, or at least in the Americas. I had started to work a little more on EROI of oil, but I seemed alone. However in Europe a number of energetic people began to have meetings called ASPO, or Association for the Study of Peak Oil. About 2004 people a guy named Dick Lawrence, who knew of my energy work in the 1980s, said that I really should pay attention to what they were doing, and go to one of their meetings. The next one was soon and in Lisbon. I said I don't have the time or money to do that but he said, look, I feel so strongly about this that I'll pay for you to go. So, I call them up but it was late and the conference agenda was full. I said to the guy who answered the phone “look I know its late but can I get admission to this conference?” I guess I pleaded. So he said, Yeah, I’ll squeeze you in. What's your name? I said Charles Hall and the guy went silent and then said “not that Charles Hall”. And I said, “Well, if it comes to oil, I guess so.” Oh my god, he says. (And I think “Somebody remembers! That’s great!) Then he said , Look the agenda is all full, we've got all the speakers lined up already but I'm going to make you a slot, we want to hear what you have to say about peak oil.

So I got to Lisbon and while signing in I heard someone say that Jean Laherrere and Colin Campbell were going to a bar on the next street. So I hustled over there and offered to buy each a drink, which I did. Well though I was dead on my feet with jet lag we stayed up for hours eating and drinking until late. The next day I was totally wired and gave a hell of a talk on EROI for oil before 150 people who really knew about oil, and then for the first time since my years with Robert and Cutler I had friends, a lot of friends, to talk about EROI of oil, a concept that many were extremely interested in. And I became good friends with many of them, especially Jean whom I exchange emails nearly every day. Also Colin Campbell. The Frenchman and a Brit who has written a paper in the Scientific American called the End of Cheap Oil even though we hadn't heard about oil as an issue, or anything like that for 19 years! And I generated a quite a bit of excitement on energy return on investment for oil with a new audience of Europeans, who were, and are, much more sensitive to the issue than Americans. And so I was able to get a little money on oil again and was able to support some good graduate students on these issues in my last decade of being a professor. We wrote some 30 new papers, analyzing EROI of various fuels which made quite a splash here and there.”

And going back 50 years in my mind here I'm driving my little green MGB convertible down the Concrete Bridge Road again with a big fish trap on the back luggage rack, and also thinking about while it all started here eventually, what happened here at New Hope Creek eventually translated into what I am today. I told my mother a decade ago that I had become a micro celebrity. Most importantly we started a whole new approach to economics called BioPhysical Economics, based on the natural sciences rather than the limited perspective of consumer choices and supply and demand of conventional economics. We found several hundred enthusiastic colleagues, formed the International Society of physical economics and have been having more or less annual meetings of 50 or 100 people each over about 15 years. But we still had no impact with most conventional economists.

**EROI in the past year**

However, in the last year, since about last July, a half dozen high level investors and executives in large investment and oil companies contacted me independently. They said, basically, we have to make these big investment decisions with many millions of dollars. In the past the logic was easy, if a bit tawdry, we would use DCF (discounted cash flow–essentially monetary profits). But now we're asked by our stockholders and others to use ESG (environmental, social, and governmental) to provide a criteria that would be more civilization-friendly. But there are no guidelines, nobody knows what good ESG means! In lieu of rules or guidelines the usual default position is to look like a project will reduce CO2 release – but compared to what? They were unhappy because they thought they had to invest their stakeholders’ money into bad investments that were painted green., i.e what they were being asked to do was basically greenwashing. So they got on the web, examined various ways to do economics, and we think that BioPhysical economics and EROI offers a better set of guidelines: a quantifiable, repeatable, explicit and much more scientific approach that we can use to judge the quality of our investments.

There were six of these investment people who contacted me about the same time. I got the group all together and we had zoom meetings for two hours every Saturday for many months. The net result is that we set up a new BioPhysical Economics Institute. And this institute now is a great going thing, for these are very serious business types who know how to do organizational things right (although that costs real money – which we raised)! SO now we have a very professional website, very serious research and so forth, and I'm going to let you go to the website. Make sure you find the salmon EROI page (it's down the bottom of the second page) and you'll see how we're putting this all together from the frame of investors because they, or at least these six people, are all sensitive to, aware of, and think about the fact that real economics is biophysical. The current economic approach (neoclassical) deals only with present prices. BioPhysical economics makes evaluations based on the conditions that are coming, which is: post peak oil, depletion and a decline in energy return on investment. This will mean that we have to divert more and more of whatever available energy remains to getting the next unit of energy. And if we are able to build a world powered by renewable energies there are going to be enormous energy costs, for new investments. Ultimately this will have to diverted from consumption, from spending that is discretionary. People will see it as less wealth available, and they will be very angry at oil companies who will be saying, well, if you want the next barrel of oil, you're gonna have to pay more for it than your oil today, or more governmental or industry subsidies, as we're doing now with shale oil.

An example is that many people who are taking co2 out of the atmosphere with mechanical fans and chemicals. But when my colleague June Sekera used a systems and BioPhysical Economics approach to look at 200 studies of removal of CO2 from the air, she found that when you include the energy to make and run the machinery and what was done with the CO2 removed not one of them was a net removal of CO2. Or can we have an electric future when an electric car uses 3 times more copper than a conventional one? Copper is a good example of depletion and energy costs: we used to mine 40% copper ore in Butte, Montana, and then we mined 4% in 1920 and zero point four percent today, increasing the energy costs so if we're going to go to a world of electric cars would use about three to four times more energy for copper for car as an internal combustion car oh you know maybe they last long, complicated really, that's the kind of question we might be asking in our instance. …

So all of this started at this very rock.

**The irony of protecting an area**

Now I want to tell you about the fall physical economic system. So, as we talked a little bit about before, the six B people from pretty heavy hitting financial institute show oil Mellon and so forth were contacted me individually, and they said that they had been

You know you can say all kinds of things. Now the interesting thing in a way that I would look at New Hope Creek as a system of production and consumption, wjhere the concumption is highly subsidized by energy inputs from the forest treres.. And guess what, North Carolina economy is the system. The new hope Creek is subsidized from the forest trees. Just as North Carolina is subsidized by Texas and Saudi Arabia.

Other thing I don't like is the discovered, and there's an awful lot of development that I feel the shoe fits be offended that. My sense is that everybody thinks, Okay, industry is your enemy. The oil companies, or the, you know, particular industries or whatever but I felt, you know, I spent a lot of my time trying to keep the new Hawk Creek clean, trying to keep Flathead Lake clean is, what it does is it makes it attractive for development, or more people are moving. And you kind of shoot yourself in the foot, or you don't, I mean I don't want newhope Creek to be dirty, and I don't know. You know, I pretty rock. I don't know. You know I I can't complain. Avoid cities pine trees come out. And they're not to be stuck to where the tree where the branches came out, no pull back the whole pole, the whole wall. All thing. You see this, probably a stub on the other side of the tree is cut off the one that didn't make an energy product. But if you go up top there on all sides, because they get enough sunlight. Yeah, no, throw good. So you know what are we gonna throw off in society or whatever oil becomes scarce, which components,

development, Wyoming, Montana and places like that. The big crack is what we see on the East Coast, are people from sale 500,000 acre ranch, the eufy more compact development taking

see everything but you got the whitefish new the ski area, an hour north of us there's just condos and everything. If you. What we see what affects us psychologically the most is big beautiful agricultural business which we like being turned into ranchettes. You know everybody wants. I think there's been so much money, because of the changing in the tax structures that have benefited the rich from Reagan to Georgia first Georgia second. I mean mostly Republicans, but not exclusively, you know, when I was a kid, I was delivering newspapers. I read them sometimes, the Boston Herald or whatever, Boston Globe. I remember reading at some point, might have been 1955. The wealthy paid. Come on, you see come away. The wealthy paid

85 or 90% of their tax at least above a certain level, as in the middle class pay 30% And I said, well that makes sense. But now the wealthy.

Okay, let's turn off the reporter to fit in the rich from Reagan to comics in thought about that is a more measurable quantitative.

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