Nate Hagens (00:00:02):

Energy is a topic we discuss often on this podcast, but today we're going to focus not on the creating or the delivering of energy, but the storage of it. My guest today is Graham Palmer, who currently works at the University of Melbourne in Australia. Graham does research in biophysical economics and is a technical specialist in energy, hydrogen, energy modeling, and particularly energy return on investment. Today, we discuss the role storage has played in the human past, the role it will play in our future, and how we think about the energy mix and the energy scale in coming decades. Please welcome Graham Palmer. G'day, mate.

Graham Palmer (00:01:28):

G'day, Nate.

Nate Hagens (00:01:32):

I always love to say that on my very few Australian guests. Do people really say that there when they see each other?

Graham Palmer (00:01:39):

Look, "G'day," is pretty common, but it's not, "Hi," whatever. I guess we like to play it up a bit as well.

Nate Hagens (00:01:47):

All right. Good. Yeah. I mean, a lot of my Australian phrases come from '90s movies and food commercials like, "Bloomin' onions," and, "Shrimp on the barbie." But we digress. You and I are here to talk about energy. We've never met until right now, but we have a lot of common colleagues and researchers in common. And I think among other things, you and I both wrote our PhD thesis on EROI and net energy, which that's probably not too many people in the world have done that.

Graham Palmer (00:02:21):

Yeah, that's right.

Nate Hagens (00:02:22):

Yeah. So let's get right into it. You and Josh Floyd co-wrote a book called Energy Storage and Civilization: A Systems Approach. And I've had a lot of guests on the show talking about fossil energy and oil depletion and renewable energy and nuclear. We've not yet talked about the importance of storage. So let's just start at a high level. What is energy storage and why is it important?

Graham Palmer (00:02:54):

Okay. Well, to start with, when I was writing the book, people would say, "Oh, look, are you going to include such and such, battery technology or whatever?" But really, this book isn't about that. It's really taken a high-level perspective and trying to go back to basics. What is storage all about? So one way to think about it is thinking about stocks and flows. So if we think of energy carriers. So the quintessential stock and flow idea is the bathtub. So if you put the plug into a bath and turn on the tap, the water coming through the faucet is the flow. The water building up in the bath is a stock. And as long as the plug is in the bath, the water stays there. And then, of course, you can pull the plug out. Now, this is a really good starting point for understanding energy because certainly pre-Neolithic, humans lived with the natural flows, the natural flows of the sun, the diurnal cycle, the seasonal cycle.

Nate Hagens (00:03:56):

So the bathtub was empty then from an energy perspective. It got refilled every day, and that's what we used.

Graham Palmer (00:04:04):

That's right. Yes. And so nature has its own storage mechanism. So for example, biomass is stored sunlight, effectively. And then, of course, fossil fuels are also stored sunlight except on a geological scale. And so, humans were using energy stocks, but they were much more limited. So this is a basic way of thinking about it.

Nate Hagens (00:04:28):

Yeah. So in my work, I write about, well, I got this from Wes Jackson, the five major pools of carbon that have given humans access to an energy surplus: soil, trees, coal, oil, and gas. So how does this theme align with your work on the major energy storage transitions in human history? A big part of your book was not about our current situation but how important energy storage was to humans in the past.

Graham Palmer (00:05:00):

Yeah. So, Josh and I were trying to think about, how do we think about storage from a historical perspective? How do we wind the clock back and look at where we've come from and where we are now? One of our insights was that the Neolithic transition, one of the ways of looking at the energy transition is through an energy storage lens. So the Neolithic transition involved generally a transition from nomadic behavior, hunter-gathering, to sedentary agriculture.

(00:05:30):

Now, one of the really interesting things about the Agricultural Revolution is that although it's considered to be almost something waiting to be discovered, the anthropological literature is actually very unclear about the cause of the Neolithic transition and the very many paradoxes of the transition. So for example, when we think about grains and cereals, they're inherently much more difficult to process, to turn into something useful, for example. If we think about proteins and fruits and so forth, it's much easier to convert into something useful to eat.

(00:06:13):

A second aspect of Agricultural Revolution is trying to fit grains and cereals into a narrative of human diets. We're naturally inclined to go towards fats and sugars when they're available, whereas grains and cereals are naturally... They're carbohydrates. So as a food source, they're okay in themselves, but there doesn't seem to be a reason why we'd naturally gravitate towards grains and cereals from the perspective of nutrition.

(00:06:43):

Another aspect of the Neolithic transition was the transition to sedentary agriculture, as in Domus and so forth. And so once people started living in larger groups, it encouraged diseases such as measles, mumps, and diptheria. So these were unknown before large settlements. One of the interesting things from an anthropological point of view, noting that Josh and I aren't anthropologists, is that studies that have been able to compare people coexisting in sedentary agriculture along with hunter-gatherers generally show that hunter-gatherers were generally better nourished. They were healthier. This is by looking at bone samples and so forth.

(00:07:31):

So what we see is that from a health point of view, it didn't seem to offer any benefits. And so, one of the interesting questions is, well, why do humans adopt sedentary agriculture? And in fact, in the anthropological literature, this is still a source of debate. Now, one of the books that we came across when writing this was James Scott's book Against the Grain, and he offers a theory which I think runs in parallel with our book. So he argues that, in fact, people generally didn't want to participate in agriculture, but they were forced to, and this was the origins of states, slavery, and so forth.

(00:08:12):

In our book, we offer a theory that is, I think, similar, but I would say more runs in parallel, and that is that what grains provided was a source of energy storage. So in other words, it's a stock of energy. Now, what a stock enables you to do is accumulate and then regulate the flow in the time and place that you choose to, and this is really a critical transition.

Nate Hagens (00:08:41):

So for the first time we were able to fill the bathtub and then have a stopper in the bathtub, and then, all of a sudden, we need someone to control the stopper and when the flow comes out and how fast, et cetera.

Graham Palmer (00:08:56):

That's right. And so what this did is this opened up potential evolutionary pathways that just simply weren't available beforehand. And so, Joseph Tainter's theory of complexity is useful to think about here, the availability of energy, being able to control the time and place that energy was directed. It labeled hierarchies and complexity to form. And this is really critical.

Nate Hagens (00:09:22):

Let me ask you a question there. This is kind of an aha moment for me. Joe Tainter was on this program. I know him well. I've always used the language that the Neolithic and the Agricultural Revolution was because humans suddenly had access to energy surplus, but surplus itself, like a higher EROI or a higher total net energy for the village or the nation, from what you're telling me, isn't as important as the energy storage because the storage evened out the flows of the surplus so that it could be directed and controlled and maybe hierarchies created from it. So you're making the distinction between the benefits to human societies from energy surplus versus energy storage. Yes?

Graham Palmer (00:10:14):

That's right. So essentially, you need some form of surplus to enable storage, but without storage then you're not able to utilize the stocks at a later time. I mean, I think it's useful to think about two counter examples that we used in our book, the !Kung Bushmen in the Kalahari Desert. There was actually an EROI study done of these people in 1969 by a person called Lee. So what he noticed was that they really didn't need to spend much time on food production. They spent most of their time on recreation, games, talking, socialization, et cetera. In other words, they essentially spent their surplus with their daily activities enjoying life. And they weren't thinking about storage.

(00:11:07):

The other example is Australian Aborigines. So the Australian continent has its own unique challenges, particularly with El Niño and agriculture that people discovered long after European settlement. A person called Bill Gammage wrote a book called How Aborigines Made Australia, and he raised the point that a lot of the practices were the types of things we would now recognized as natural resource management. So they burned, they herded, they hunted, they constructed weirs and so forth, but none of this was part of sedentary agriculture, and this is really the critical distinction. And in much the same way as the !Kung tribesmen had a surplus, Australian Aborigines have also existed with a surplus, except they didn't accumulate it. So this is really a critical distinction. And of course, the Australian Aborigines have inhabited the land for roughly 65,000 years, which is pretty extraordinary.

Nate Hagens (00:12:10):

So basically, the hierarchy and the nation states and the priests, accountant, guardians, warriors, city mayors, all that happened when we put a stopper in the bathtub, effectively.

Graham Palmer (00:12:26):

That's right, yes. So not only could people control the time and place of energy flows, but they could control the intensity. So for example, we can then think about armies and force and so forth. If you can control energy flows, then that translates to social and political power as well. So we can see that social and political power structures must have, were dependent upon energy storage.

(00:12:57):

I don't know whether we actually mentioned at the start the three major transitions that we discuss in the book, the first of which was the Neolithic transition, the second of which was the Industrial Revolution, and the third was the Age of Oil. So we construct a story based around energy storage, and each of those transitions was based on a particular type of energy storage that offered features that weren't previously available before.

Nate Hagens (00:13:25):

Okay. So the first transition was the Neolithic when we started to store surplus and grains. And then what was next?

Graham Palmer (00:13:33):

So the Industrial Revolution, so otherwise known as the coal, steam revolution, beginning in Great Britain, we identify as the second major revolution. So the interesting thing is that there are certain parallels between the Industrial Revolution and the Neolithic. So to begin with, coal wasn't the preferred energy source for a long time. So for example, steel makers preferred charcoal. People didn't like to burn coal in their homes. I mean, it's much more pleasant burning wood. And coal isn't available everywhere. But the one thing that coal provided is that it was an energy stock that wasn't dependent upon the seasons. It wasn't dependent upon anything other than people's willingness to dig it out.

(00:14:27):

Interestingly, early steam engines were actually very inefficient. So we're looking back at the Smeaton and Newcomen and so forth. They were something like only 1% efficient. So, Watt's innovation got that up to about 4%. And so we're still looking at very inefficient machines, which meant there was a lot of coal for only a modest amount of work. So the interesting question is, well, why did people pursue it despite these fallbacks, these drawbacks? Why did they pursue it? I think looking at this from an energy storage lens elucidates this because we can see that, as I said, coal wasn't subject to the seasons. It was only limited by people's willingness to dig it out. And then once a certain point was reached, it created a positive cycle, a positive reinforcement cycle, so that coal and steam enabled...

(00:15:23):

Well, first of all, coal was originally used, steam engines were originally used to pump water out of coal mines. So you have this sort of contradiction. You're using coal to pump water out of coal mines. But then it had wider use. It became used for steel making. And then once you can make steel, you can build rail networks. And then they're running off coal. And the actual rail networks themselves are made of steel. So you get this positive loop. And this was the Industrial Revolution. So viewing the Industrial Revolution through an energy storage lens opens up another way of thinking about it. Then we have Britain's preeminence. We have the pound sterling as the dominant currency. We can see the politics, the geopolitics, currency, it all comes together under this banner of coal and steam.

(00:16:17):

So the next transition that we discuss is the Age of Oil. Now, coal was very important, but oil created this new way of thinking about mobility. Prior to cars, for example, we sometimes think of people having horses, but people didn't have an individual horse and get around. But once people had a car, it enabled freedom. I mean, this was really a critical thing. It enabled people to do things that they couldn't before. So what we see in oil, looking again from an energy storage perspective, is that as a liquid, it's much more convenient. It can be pumped. It has a high energy density. It's a liquid at normal temperatures and pressures. So it has these features that enable all these different things, air travel and so forth.

Nate Hagens (00:17:09):

So the quality of oil is very high, but the storage of oil is also very high.

Graham Palmer (00:17:18):

That's right. So we argued that looking at it from an energy storage point of view is really critical. So it's not just the energy content, it's the storage aspects. Then with US preeminence and oil, we see the US dollar is becoming the dominant currency, and we see a shift from the British Empire to the American empire. And we argue this is tied up with the energy source. We see now that America with shale oil has become a major oil producer once again. Now, I don't know how long that will last for and what impact that will have, but having that sense of energy independence, it just strengthens the US in terms of its geopolitical influence. The power of the US dollar. It doesn't look like anything else can challenge the US dollar at least for the foreseeable future. And these are really big picture issues.

(00:18:21):

So if we take those out of the equation and we imagine, well, okay, without energy storage, what will the world look like? I mean, it may be, some ways, it might be better. People might say, "Well, look, if we're not dependent upon oil, then that will take away those difficult geopolitical challenges that we're currently dealing with." But what will take its place? Will it be hydrogen? I don't know. I mean, hydrogen's going to have its own problems and it's certainly not going to be as cheap and easy as what oil has been. So I think it really opens up a whole range of questions about the way that we live and the types of structures we'll have and how we manage that transition. Are we going to hold onto fossil fuels until we can't? I mean, I think in Australia, from a local generation perspective, we're getting off coal, but I think we still want to hang onto gas. And of course, we're still a major coal and gas exporter. Even once we stop using coal ourself, we're a major coal exporter.

Nate Hagens (00:19:27):

You don't want to hold onto gas, you want to hold onto consumption, and that requires gas.

Graham Palmer (00:19:33):

That's right. Yes. There's no easy answers, and it's going to be interesting to see how this all unfolds.

Nate Hagens (00:19:41):

So there is a Venn diagram of how much energy surplus you have and how much of that is storable. Arguably, we are at a point where the global societal metabolism is around 19 terawatts continuously, and not all of that is storable. Can you briefly outline the different kinds of energy, either kinetic or potential or however you describe them? Because that'll be relevant to some of my further questions.

Graham Palmer (00:20:15):

Okay. Well, in nature there are various forms of energy. So simply, there's energy stored in mechanical devices. So motion, simply something in motion. There's chemical energy. Really, from a human point of view, the energy that we use, well, certainly in fossil fuels, we classify that as chemical energy. There's potential energy, for example, when we talk about hydro and dams. That is essentially potential energy. So it's from energy that we derive from gravity. From a nuclear point of view, there's the energy... We can talk about the nuclear forces. The nuclear forces have derived from nuclear synthesis, which is in the early origins of the universe. And so nuclear extracts energy via heat from what was the remnants of nucleosynthesis.

Nate Hagens (00:21:10):

So how does electricity fit in today versus these other sorts of chemical and stored and potential energy relative to the past, to energy transitions, the Neolithic and the industrial?

Graham Palmer (00:21:28):

Yeah so electricity is really a special case, and from the overall energy storage perspective, it's really important to think about where electricity fits in because it is a flow. Electricity is storable in minute quantities in things called capacitors and inductors. But other than that, electricity is not storable, per se. So when we talk about, say, a battery, it's really a conversion into chemical energy and then back again. So when we talk about storing electricity, it's really just shorthand for two energy conversions, one in and one out of something else.

(00:22:05):

So this is a really critical thing in thinking about where electricity fits into energy transition because it is a flow, it is essentially a demand-driven flow. So generation traditionally is associated with demand. So generators will fire up when they're needed. There used to be a story in, I think it was the 1950s, '60s England, where the generators would know when there was an ad on TV with a popular TV show because people would go and put their kettle on. So this is the way that electricity systems operate. And so thinking about how to incorporate natural flows as in wind and solar flows into that, of course, is part of the challenge of what we're dealing with.

Nate Hagens (00:22:55):

So traditionally, though, like back in the '50s and the '60s, electricity was electrons moving based on demand. So it was a flow, but it was based on a stock. The stocks were sitting there and we could turn them on when needed, a coal or a natural gas plant. Whereas now we have some of that, but we also have the electrons when the wind blows and the sun shines, and we have to use them then or store them in batteries or something like that. So it's become more complex. Yes?

Graham Palmer (00:23:29):

It has become more complex, and I think getting back to Tainter's theory of sustainability that all of these things seem to becoming more complex, all of these things have solutions, but it inevitably seems to involve more complexity, more detail, more management and so forth, it's difficult to shift away from the reality that transition will involve greater complexity.

(00:23:57):

Now, of course, with electricity, there is what's called firming generation. Well, firming generation is switching more towards gas-fired generation, and so we're still ultimately relying on energy stocks. So whether we're using, say, natural gas, which is a geological stock of stored sunlight, or whether we're using batteries, which is a short-term stock, or pumped hydro, which is often a stock accumulated over days or weeks or months, it is the stocks of energy that provide that control, that fill in, that ensure that supply always meets demand.

Nate Hagens (00:24:39):

I don't know if you ever read a paper that I published, it was part of my PhD thesis, but I took the EROIs of nuclear and wind and natural gas and I handicapped them for their storage and their intermittence. And this gets to why storage is so important, because we value not the mean or the average output of a thing, but we value it based on the mean divided by the standard deviation of its availability.

(00:25:15):

So I used to work on Wall Street, and there's something called a Sharpe ratio, which is the return of an asset divided by its volatility. And so what your and Josh's book is about is the long-term trend of humans having energy storage, which reduces the variability of intermittence in our lives. So now we're heading towards a place where either for carbon reasons, because we can't afford to burn more hydrocarbons for our ecosystem limits, or for depletion reasons, that peak oil and the minerals and carbon is getting more costly to extract, we're going to gradually or inexorably head back more towards intermittent flows. And so that's why storage now, how can we store and/or combine new lower throughput lifestyles for these challenges ahead? What do you think about all that? Then I have some follow-up questions.

Graham Palmer (00:26:19):

Yeah. Well, the critical thing is we've constructed lives based on the available fuels that we have, fossil fuels, and so reverting to a world in which we're much more reliant on natural flows will be challenging. I think that it's hard to imagine what such a future will look like precisely, but it's going to be different to what it is now.

(00:26:42):

One of the critical measures of electricity supply reliability is the outage rate. So electricity operators have various measures of reliability, of outage rates and so forth, and the number of hours, of probabilistic hours, that the electricity system may not be able to meet demand. And we've become used to a virtually 100% on electricity system. Now, I'm not advocating for a less reliable electricity system, but in the future we have to think about, look, do we need that? What level of reliability do we really need? And what price are we prepared to pay for that, both monetary and biophysical?

Nate Hagens (00:27:25):

In the paper that I just mentioned to you, we showed a correlation between the reliability of electricity and GDP, and it was almost 100% that those countries that had a lot of intermittence or brownouts or blackouts had starkly lower GDP per capita, and the most reliable countries that had 99.98% had the highest GDPs per capita. I mean, it's really quite striking and informative about the future.

(00:27:58):

So we've got intermittent sources are becoming very popular, solar, wind, where there's an uneven availability of the power. And now batteries and hydrogen and pumped hydro and a lot of these things, people are starting to recognize the importance of storage. Can you just give me briefly what some of these things are probably over-hyped and which things you think have most promise in a future with more intermittent power added to our systems?

Graham Palmer (00:28:37):

Well, from a short-term storage point of view, so from up to several hours, say, then it's clear that batteries have become the best form of energy storage. The cost has come down, but there's still issues around the material demand, the material requirements, particularly at scale. When you put the numbers down, it's really large, and it's hard to see how this is all going to play out. Of course, technology improves. There's different types of battery technology. One way or the other, it looks like there's going to be a lot more material throughput in terms of mineral wars and so forth.

(00:29:19):

Pumped hydro has a big advantage that it can be done at scale. We've got a large-scale plant that's been constructed at the moment in Australia. Australians would be aware of the Snowy Hydro 2.0. Now, it's turned out to be a lot more costly than what was expected. When the project was originally announced it was going to be a $2 billion project. I actually contacted an engineer who's worked on hydro projects and I did a blog post on it and asked him what he thought about the costs, and his back of the envelope costs were going to be at least double that.

(00:29:57):

Now, the costs have blown out. I'm just thinking here, Bruce Mountain from the Victoria Energy Policy Centre thinks that it could be closer to 14 billion. So what we see from a transition point of view is that, yes, we can do hydro, but these are often very large-scale projects. They're civil engineering projects with geology. There's a lot of uncertainties. So hydro is an ideal energy source for balancing electricity systems. It's a question of scale. How many of these can be built? How quickly? What are they going to cost and so forth? Then we can move to hydrogen. So, people think that hydrogen might be useful for seasonal storage. And so the benefit is is that we could store very large amounts of it, maybe stored in, say, salt caverns or so forth.

Nate Hagens (00:30:51):

And the way we would do that is we would overbuild solar panels and wind turbines more than we would need, and so when they were over the demand, we would use the excess via electrolysis or methanation or something like that to create hydrogen. Yes?

Graham Palmer (00:31:10):

Yes. So, people were envisaging in Australia that we may have a hydrogen export industry, in which case if there's a lot of hydrogen being produced anyway, there would be some available for electricity storage. Of course, hydrogen has its own challenges, one of which is low round-trip efficiency. Cost is high at this stage. From a long-term perspective, in the absence of fossil fuels, humans are going to have to work out some form of storage. Now, whether that's hydrogen or something else, it is almost inevitably going to be more expensive. And we have to get our heads around what is the future going to look like without fossil fuels?

Nate Hagens (00:31:52):

So are there any storage options that are not like complicated lithium batteries that require intense environmental and social impacts on the Global South or the abyssal oceans, et cetera? Are there ways to create batteries or storage systems with simpler materials that may not give us as much energy, like a full bathtub worth, but still have the ability to store some energy and are potentially scalable around the world, like sodium batteries, for example? Is there anything on the horizon that you think favorably on?

Graham Palmer (00:32:37):

There's a lot of teams working on different chemistries, battery chemistries. The challenge always with batteries is that there's a lot of different parameters we need to look at. There's energy density, there's safety, there's power density, cost, et cetera. It's a holy grail to try to get a battery that is highly dense, that is low cost, that is safe, that has everything, has high round-trip efficiency. Trying to get things commercialized is always difficult.

(00:33:10):

At the moment, lithium technology has taken the lead. It's a little bit like the Beta versus VHS. Once one technology gets in front, the others have to be able to surpass what has already been achieved. And so lithium is well down the learning curve. I mean, this is always a challenge with technologies, that we get technology lock-in, that the one that is out front achieves scaling quicker and so gets further down the cost curve. So new batteries will have to come in very competitively, otherwise they just simply won't compete.

Nate Hagens (00:33:48):

So compared to what happened before we needed batteries, is the limited lifetimes that are measured in hundreds or a few thousand full charge cycles, is that a fundamental limitation given that those things will have to be rebuilt and redone every 20 years or something like that? How big of a barrier is the limited lifetimes of charging these things?

Graham Palmer (00:34:18):

Yeah. We're used to infrastructure lifetimes of 50 years, 40 or 50 years. And so some of the new technologies almost certainly won't have technologies that long. Some things such as solar panels, a lot will be expected to last a long time, but in terms of batteries, they almost certainly won't last that long, and therefore there'll be replacement cycles. Now, the impact of the replacement cycles will depend on part on recycling, but of course, recycling itself takes energy and materials. It isn't a zero environment.

Nate Hagens (00:34:56):

And we're not recycling that much right now.

Graham Palmer (00:34:59):

No, no. Look, a lot of people are doing work on recycling. There's a lot of good work being done, but it's not translating into something practical at the moment.

Nate Hagens (00:35:12):

So earlier you mentioned, Graham, energy density and power density. It's funny how energy blind our cultures are because we see news stories in CleanTechnica that we just found enough mineral deposits under Norway to power our civilization for 100 years of batteries. And while on one level that could be true, on another level, you could also say, well, if you drill down far enough, you could get enough for 500 years. It's there, but it's going to cost a lot of energy and complexity and materials to get there. But as far as energy density goes, are these stories we see in the news about flying airplanes and cargo ships and long haul trucking using batteries, what's the validity of that stuff in your opinion?

Graham Palmer (00:36:11):

Well, I mean, the news outlets like to report technology stories. I mean, this is what they do. I mean, people like to read about new technology. We are a technological society. And of course, technology proceeds. One way I think about it is that we can take a micro perspective or a macro perspective towards some of these things. So we can look at batteries, say, and people might say, "Look, this new battery chemistry, it doesn't use as much of such and such materials. It doesn't use cobalt, et cetera."

(00:36:48):

But what we see when we look at the macro indicators of the planet is it's a straight line. We look at cobalt use since the 1960s. It's going straight up. We look at lithium, nickel, et cetera, everything is going up. So we can see that at a macro perspective, we're using more of everything. Now, it may be that certain technologies improve that situation, but what we can see at a macro scale is that whatever it is we're doing, it isn't working. Everything in terms of overall, the macro indicators are all going up.

Nate Hagens (00:37:32):

So getting back to the grand arc of your story that human societies and nation states were adaptive responses to those cultures that had access to energy storage, as we look ahead to a post peak oil world in coming decades, we don't have to debate on when it will happen, but it will happen, will those nations that focus on energy security and having a full bathtub have adaptive advantages in coming years relative to those that are more flow-based?

Graham Palmer (00:38:12):

This is an interesting question. The advantages with the flow-based is that we can rely on them. So if you're relying on solar, well, you can count on solar energy continuing. But then there's an issue of the reliability of the system. How do you deal with natural disasters, for example? I mean, let's say you're reliant on an electricity system largely reliant on natural flows. What happens if there's a disaster? It knocks out transmission, and two interconnected areas were previously able to share energy, but suddenly they can't. What do you do with that? I mean, ultimately I think that we are going to rely on some forms of energy storage. It's going to be difficult to see how we can exist with a just-in-time energy system.

Nate Hagens (00:39:05):

Well, it's kind of like living as a human being on a just-in-time income system. That's why we have bank accounts because that gives us optionality to buy things that, of course, you and I know have energy embedded in everything. But money is our little bathtub, that we hope the drain is not too large and that the spigot is reasonably flowing. But I think sometime in the future, the bathtubs of individual humans will have a dissonance with the giant bathtub of society's energy. I'm getting a little meta here on you, Graham, but I do think that energy storage and monetary storage are linked.

Graham Palmer (00:39:54):

Yeah. So it's kind of interesting thinking about how money and energy are linked and in what way they're linked. The way I think about it is that energy is real, it is the physical world, whereas money is the world of abstraction and symbolism. And money works by social convention. We agree that if I hand you over a $20 note, you'll hand me something back in return, but it's entirely a social convention. And so in that sense, money is not real in the way that energy is real.

(00:40:30):

And the way that we think about a future with a different type of energy system will no doubt affect the type of financial system that we have as well. We don't have the expectation that there's going to be new oilfields discovered and we are going to have copious amounts of oil, for example. I mean, how that plays out, really, I don't know. That's beyond my pay grade. But I think it's almost inevitable that the financial system will have to evolve in some way with the energy system.

Nate Hagens (00:41:05):

So at your pay grade, let me ask you this question, how would a country, a nation, perhaps Australia, start to think about planning for a more intermittent, more costly energy future, given what you know about human history and what you know about all the different batteries and storage options and what you know know about EROI and energy depletion? What are some of the key questions that you think they should be thinking about and working on right now?

Graham Palmer (00:41:42):

Well, Australia is progressing quite well with transition.

Nate Hagens (00:41:48):

You have a lot of coal and a lot of gas, but not a lot of oil, right?

Graham Palmer (00:41:51):

That's right. Yeah. Well, oil is Australia's main energy vulnerability, and we don't stick to the IEA's 90-day reserve requirement. This has been a point of contention over many years. So if there was some sort of problem in the South China Sea, for example, and there was some sort of embargo, Australia would run out of diesel and petroleum very quickly. So yeah, that's our main point of vulnerability.

(00:42:17):

As far as the electricity system is going, the electricity system operator, AEMO, has been working on what's called an Integrated System Plan for many years. They update the plan every two years. So this is a long-term plan in trying to work out how to transition to either 100% or near 100% renewable. Australia is pretty uniquely placed. We have a lot of wind and a lot of solar.

(00:42:48):

Now, the people working on this are pretty confident, but there's a lot of uncertainty still. Now, the fallback for Australia is ultimately natural gas. In fact, the 2050 scenario still has 10 gigawatts of gas-fired turbines. So these could, in theory, be run on hydrogen as well. So when the system operator has done their assessment... So they're doing a very complex assessment including reliability. They're looking at the geographical and technological diversity and so forth.

Nate Hagens (00:43:26):

Well, I'm just curious how much either cost or EROI, how much does the EROI get handicapped once you include storage in some of these intermittent sources?

Graham Palmer (00:43:37):

Yeah. Well, I did a paper, I think it was in 2012. I did it as a case study of off-grid solar and storage. So I was using the data that was available at that time. And it's pretty clear that with very high storage requirements as are needed with an off-grid solar system, the EROI drops very high. In fact, you would say that it's too low to be viable at large-scale. So an individual person can decide to spend the money on an off-grid system, and that's fine, but if we look at that at scale, it's just not viable. But the proviso is is that the amount of storage that you need in such a system is very high.

(00:44:21):

Now, once we look at a larger system, the situation changes. It depends on how much storage. And really, the storage requirements is really a critical question. I think one of the things Josh and I did is that we looked at storage from an overall civilizational perspective. So you can look at the storage needs in a specific electricity system and come up with a model and say, "Look, we think you can operate such a system with such amount of storage." But if we stand back and say, "Well, humans have been using seasonal storage since Neolithic transition, we've been using fossil fuels, would we really be running on what is effectively a just-in-time energy system? And how would that work?" And really, I don't have the answer to that. I think that it's possible to construct a system possibly without a lot of storage, but trying to reconcile that with the way that human beings have lived I think is difficult.

Nate Hagens (00:45:24):

So this is a big debate right now with someone who's been on the show here before, Simon Michaux, who's also Australian. He taught me the correct pronunciation of, "G'day, mate." But he is in some arguments with people on Twitter and the energy community about actually how much storage we need. Is it hours or days or weeks or months? And he's done some sensitivity analysis because the answer to that question then infers how much copper, lithium, cobalt, nickel, et cetera, is going to be needed. And I think it's his point that there are times that if you really need access to electricity, there are times that weeks go by without the wind blowing or the sun shining. What does your work and opinion on that suggest?

Graham Palmer (00:46:20):

Well, looking at AEMO's work on their detailed studies, the fact that they're including 10 gigawatts of gas-fired capacity in addition to pumped hydro, a lot of batteries, et cetera, there's expected to be a lot more storage capacity, generally, they believe from a reliability point of view, it's still going to be necessary to have what is essentially a lot of storage.

(00:46:46):

So if we think about gas from a storage point of view, it essentially represents unlimited storage from an operational perspective. So you could just run a gas turbine indefinitely. So it doesn't run out as a battery will run out, providing you've got the gas, of course. And so on an operational timeframe of weeks, let's say, then that you're going to have the gas available. So I think for me, that would be the best guide.

(00:47:15):

Now, I've been told, or some people have said that the Australian plan is one of the most advanced in the world in terms of understanding where we are and where we need to get to. Australia already has a high penetration of solar in particular and also wind, and it's increasing, and I think Australia will be an interesting case study as to what the limits will be and what will be needed.

Nate Hagens (00:47:43):

But Australia is using natural gas as the battery.

Graham Palmer (00:47:47):

That's right, yes. So that is-

Nate Hagens (00:47:48):

So what if we wanted to go 100% renewable in some country that they didn't have natural gas, like suddenly Germany, and places in Europe after Nord Stream, and Russia don't have that injection into the bathtub of natural gas, then how big of battery, how much storage do we feasibly need, do you think? Is it hours, days, weeks, months, what?

Graham Palmer (00:48:14):

Well, if I had to pluck a figure, I would say weeks. The issue of seasonal storage is a serious one for high latitude regions. I think one of the problems is that at this stage I would argue we just don't know. I don't know whether it's an indeterminate question, but nobody has operated such a system, a large-scale system to be able to actually truly know how that will work.

Nate Hagens (00:48:43):

Who's the closest?

Graham Palmer (00:48:45):

Yeah. Well, there are systems with a lot of hydro, so, of course, that's renewable. But in terms of wind and solar, there is no large-scale electricity systems that are operated anywhere near close to 100% wind and solar, and so it's an unknown.

Nate Hagens (00:49:02):

I think it would be doable if we partitioned society into this section of society, these manufacturing plants that make polysilicon wafers or whatever, they need 100% priority electricity, but these residential areas over here could be on a rolling brownout. People play Parcheesi with candles or go for a walk with their dogs, like a split-level society and a more intermittent... Because, otherwise, if we try and power everything we have today that allows me 24/7 or anyone in the world to turn on their light switch, the amount of backup that would be needed to maintain that, we would be like eight billion locusts stripping the planet bare of materials and metals, I think.

Graham Palmer (00:49:55):

Another perspective is Buckminster Fuller's solution. So, Buckminster Fuller believed in you solve problems by making the problems obsolete.

Nate Hagens (00:50:05):

Yep, that's right.

Graham Palmer (00:50:06):

Yeah. Which is a great way to think about it. So his idea was to have essentially a global grid, essentially a cable, a DC cable that ran around the entire globe. And so you used our solar and we used your solar. And he said, "Look, we would need double the capacity because we'd need to supply our own plus yours." Now, it's kind of a crazy idea, but it's one of those brainstorming ideas that's worth throwing around as a kind of a concept.

Nate Hagens (00:50:39):

Is anyone looking at that currently, credibly?

Graham Palmer (00:50:42):

People have looked at global grid concepts. The practicalities of it are very difficult. There's one project in Australia that's been talked about called the Sun Cable Project, which envisages sending electricity from Northern Australia to Singapore. So this would be a couple of thousand kilometers of DC link under the sea. Now, these things are always difficult until they've been done, and the first person that does it, then it seems obvious afterwards, but probably the major problem with this concept is the vulnerability. It's single points of failure, and it's electricity, so it's a flow. So you cut off the electricity and, all of a sudden, it's gone. It's not like, say, shipping oil around the world in a tanker. If one tanker is lost, you don't lose your energy supply. With an electricity cable, you're reliant on real time flows and it's a single point of failure.

Nate Hagens (00:51:48):

I mean, I just know when we have blizzards here and suddenly the power is out. For me, because of my job or my unique biochemistry, I'm sitting in my car trying to charge my cell phone. When the electricity stops, everything stops pretty fast. I think we're incredibly reliant on it.

(00:52:11):

Excellent, Graham. I think energy storage is very important, and you've offered some new things for me to think about. I know you periodically at least watch my podcast because you've sent me some critiques and some suggestions via email. So you know I'm going to ask you some closing questions. I know you've been to ASPO conferences in the past. I'm not sure ASPO is still around. But given your lifetime of thinking and writing on these issues, what sort of personal advice do you have for the viewers of this program going into a less certain energy and societal future?

Graham Palmer (00:52:56):

I think one aspect is to be more of a generalist. I think that the trend has been towards specialization and this is the world we live in. And I think, I mean, it's okay to specialize from a work point of view but also develop more generalist skills as well because we don't don't know what skills we're going to need. Sometimes it's framed in terms of a T, the idea that the top of the T is the idea of you have your general knowledge, and then you have one area where a lot about, the vertical component of the T. I suspect this will be more important.

Nate Hagens (00:53:34):

Well, and another way to look at that is being an expert in something is a flow, and being at least competent in a bunch of things is you have a stock in reserve. What about young people? You work at the University of Melbourne. Do you teach students, or is it mostly research, your work?

Graham Palmer (00:53:57):

Yeah. Well, I did my PhD at the University of Melbourne. I'm now working at Monash University.

Nate Hagens (00:54:03):

Okay. Monash, right.

Graham Palmer (00:54:03):

So I'm doing, yeah, LCA work mainly on green hydrogen and associated chemicals such as ammonia and methanol. I'm actually doing wind analysis at the moment, which is a project looking at re-analysis data. So I'm just a researcher. I don't lecture. But if I was given advice, I think adopt a view of critical thinking. I think often the easiest thing to do is to adopt the mainstream perspective on a range of issues, but be prepared to think critically about things. Some of my work has run counter to, I guess, what you call the green growth philosophy. I think certainly in the renewable space, which is, I mean, green growth has become the dominant philosophy, not adopting, well, being critical of green growth does run counter and I think-

Nate Hagens (00:54:56):

It reduces your energy storage.

Graham Palmer (00:54:59):

It certainly does.

Nate Hagens (00:55:03):

Your advice. Go on.

Graham Palmer (00:55:04):

Yeah. So be prepared to think critically and adopt and consider views outside the mainstream. The other thing that I've tended to do is I think compartmentalize different aspects of my life. So most of my career I've been an engineer. I've actually worked in industry. So I've only been in academia for the last four years. So a lot of my academic work was actually done in my own time while I was working in business. And so what I've tended to do is compartmentalize different aspects. And so, I mean, on the one hand I may be critical of green growth, for example, but then when I'm working in a commercial enterprise, I'm an ordinary capitalist, if you like. I mean, business is competitive and to survive you need to play the rules of the game, and I think often compartmentalizing is a good way to reconcile different ideas.

Nate Hagens (00:56:04):

I don't know if you've read mine and DJ White's book, but becoming a generalist and compartmentalizing, learning that skill are two of our main recommendations. So I agree with both of those. What do you care most about in the world, Graham? Personal question.

Graham Palmer (00:56:22):

Look, right at the moment, I think more of a local issue is that housing in Australia has become a huge issue. Houses have become too expensive for new home buyers. Rents are going up. I think Australia does really well on some things. We have a very good healthcare system. Education, there's universal access to education. But shelter is a basic human requirement and a lot of people are really struggling. Houses have become part of the financial infrastructure. Houses are assets, they're bought to make money, and it's become part of the investment structure. Younger people in particular are shut out. It's very difficult.

(00:57:08):

I mean, I don't know the solution to that. I mean, on the one hand, I assume that supply must play a role. It's kind of interesting that any regions within, say, three hours of the capital cities have all become very expensive. And so it's not just the capital cities that are expensive. Maybe we think about houses, I mean, housing, it's a basic human need, and so something has gone wrong somewhere along the line. I mean, obviously part of that is low interest rates because monthly repayments are related to the interest rates. So I'm not sure whether you're aware, but in Australia, interest rates are variable, mostly variable. It's not like the US where you take out a fixed rate. And so interest rate movements are reflected in mortgages. So really, right at the moment, I think that's a huge issue that I don't know that we have any great solutions to. Federal government is trying to address it with public housing, which is part of the solution but not the whole solution.

Nate Hagens (00:58:11):

So in contrast to that, what things are you seeing or things that you've experienced in Australia that give you hope or motivation or excitement about the future?

Graham Palmer (00:58:24):

So I recount a story. The other night I was walking the dogs.

Nate Hagens (00:58:27):

Dogs plural. I love it.

Graham Palmer (00:58:29):

I love walking the dogs. It's one of the simple joys. I normally listen to podcasts, including yours, while I walk the dogs. Yeah, it's great. It was probably about seven or eight o'clock. It was dark. And I noticed on the other side of the road a person was on the ground. Another person was helping them. A person was having an epileptic fit. I asked if they needed help, and I went over, and I helped out. The thing that was remarkable was everybody that went by wanted to help. The bus, the 765 bus that stopped, the driver got out. People were driving by.

(00:59:07):

And it's on a related topic, I see people, I see carers looking after people, people with illness or dementia or handicaps, and it's almost like there's a parallel universe happening. There's the parallel universe. There's one universe of the market-based capitalist system. People are working, earning money, spending money. And there's another parallel system of people caring about others, of doing things for others that's completely outside the market system. That gives me hope. I mean, so much of our lives now have been brought into the market, and I don't know the solution to that.

Nate Hagens (00:59:56):

Yeah. You're talking about the caring economy, and I think once the bathtub is less full because the spigot on the top is not as large, I expect we will see a lot of responses like you saw by the 765 bus the other night. So have you seen a kookaburra today by any chance? I'm just curious how common they are.

Graham Palmer (01:00:20):

No, not today, but they are around. There's lots of magpies, currawongs, cockatoos, but normally kookaburras, they hang out in pairs, and there's not a lot of them, but you can certainly hear them.

Nate Hagens (01:00:37):

Okay. I'm probably coming there to speak to some government people next year, and on my bucket list isn't so much to see Australia, but it's to see a kookaburra. If you could wave a magic wand, Graham, and there was no personal recourse to your decision, what is one thing that you would do to improve human and/or planetary futures?

Graham Palmer (01:01:03):

I think Joseph Tainter's theory of complexity, of diminishing returns of complexity is really an interesting theory. You might know that his theory of sustainability as it applies to sustainability is that sustainability is itself part of the energy complexity spiral. It is a problem-solving exercise. So for example, Tainter uses the example of hybrid motor cars, that the hybrid motor car is a solution to high fuel consumption, and so we build more complex motor cars to solve this problem. I think this is a real challenge from a sustainability point of view. So I think resolving that challenge would be one aim.

(01:01:57):

I don't know what the solution to that is. Sam Alexander and Josh Floyd have written about this. I think they argue that localization is one adaption to that. I mean, I think there's the broader problem that our economic system is just not accounting for the biophysical realities, and I don't know how we resolve that. You're probably aware of the technocrat movement in the 1930s, the idea of an energy-based currency. So that was one explicit way of trying to include energy into a monetary system. Now, I don't think that's a great idea for a few reasons, but the principle of it, of trying to account for biophysical realities into the market system, and, I mean, I suspect some solutions to that may resolve Tainter's sustainability paradox, I don't know, but I think these are all interesting things to think about and ideas to throw around.

Nate Hagens (01:03:02):

Excellent. Thank you. I've been asking this question of late. If you were to come back after I've done this initial overview with you on your work on energy storage, but if you were to come back next year or something, what is one research topic, one thing that you'd like to take a deep dive on that you're either working on now or you're passionate about or curious about, a single topic deep dive?

Graham Palmer (01:03:28):

Well, that's an interesting question. I think trying to understand what we really need for a good life. Trying to quantify that would be an interesting way to think about it. I think Vaclav Smil has commented that people in, say, for example, the 1970s, they lived perfectly reasonable lives. And we look at the per capita energy consumption since the '70s, for example. It's gone up. So what would we be prepared to forego in order to get back to, say, for example, '70s per capita consumption? I think this is an interesting question.

Nate Hagens (01:04:06):

And there's a related question. It is what would we be able, be willing to forego? And then, "How would we get there?" is also-

Graham Palmer (01:04:14):

Yeah, well-

Nate Hagens (01:04:15):

… a second question. Graham, it was so nice to meet you finally and have this discussion, and thank you for your important work on energy storage. Hopefully, you and your colleagues can figure out some answers in Australia and beyond.

Graham Palmer (01:04:31):

Okay. Thanks, Nate. Thanks for having me.

Nate Hagens (01:04:33):

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