Losing electrons, gaining electrons, why does it matter?

Why does it matter?

Well, we made a solid last week.

Today, the answer is obvious.

It matters because of Danish wind, obviously.

43%, in 2014, 43% of all the electrical energy in Denmark came from wind.

It's higher now.

But see, now, this is a quarter of the Danish wind.

I only gave you a two minute hemodialysis why this matters on Wednesday.

So I'm going extended today just a little bit.

Danish wind, people are very dependable.

So over a three-month period, this is how much we need, energy, electricity.

But look at the wind supply.

Sometimes it's really there for us.

Sometimes it's not at all there.

Sometimes it's predictable.

Sometimes it's not at all predictable.

With that much of your electricity coming from this type of unreliable resource, that is a huge challenge.

I mean, even if you go out to Arizona and you talk about solar subsidies, Arizona is sunny all the time.

No, not sunny all the time, most of the time, more than Boston.

But this is the sun in Arizona.

That's the power you're getting from it.

And look at this, these are just clouds.

Because Arizona does have clouds.

And they passed by and they blocked the sun.

Do you know what a nightmare this is for a grid operator?

If a lot of your customers get their energy in this way, you know, and all of a sudden, half of the your supply of energy just turns off, I mean, that's a huge problem.

And this is one of the most limiting factors for increasing, to a large extent, the amount of renewables we have on our grid.

And so, of course, I know a lot of you are thinking, well, just store it.

And that's what we need to do.

But it turns out that really one of the only ways we have to store energy at this large scale is pumped hydro.

And you see, we're pumping water up a hill.

When I have access, I pump water up a hill.

And then when I need, I roll it back down and I turn a turbine with it.

I'm literally just trading energy, potential energy.

And then I bring it back, kinetic energy.

And then I make electricity.

The problem is that, you know, well, as you can see, pumped hydro is going to be good where there's hydro, where there's water.

So that's limiting.

But it also is a very low areal density.

And there are also a lot of environmental challenges with making this work in a way that doesn't harm the environment.

So there are a lot of issues with scaling up pumped hydro, a lot of issues as a storage.

And so I ask, well, what else can we pump up hills?

And we know what the answer is because it's what we're talking about-- ions.

Where are they?

Ions, we can pump ions up hills.

There's my picture.

Look at that.

Ions, and you know what this is, it's a battery.

A battery is two different materials, two different metals, a and b, where one of them has an ion, I don't know, like lithium, for example, that can go back and forth.

And the electrolyte is this thing in between that only allows that ion through, OK?

Now, here's the thing.

So if I'm a metal and I lose a positively charged atom, well, then I got to stay neutral.

And the only way to stay neutral is to pump an electron out, all right?

So if I want to draw electrons out of this, that's fine as long as I draw ions out of it.

And then both of them can do work.

And then they come back and they roll down an energy hill.

That's what they're doing and going back and forth, shuttling back and forth, back and forth.

They're rolling down a hill, literally, of energy.

You know, when it's in one metal, it's higher in energy.

And then, when I, you know, plug my phone in, it rolls down that energy hill.

And as it does, it travels across to the other metal, gets lower in energy, and the electron has got to come around and do work for me.

Because otherwise, it wouldn't stay neutral.

That's what a battery is.

It's all about ions, all right?

It's all about ions.

It's like a ski lift.

I like to think of it, you know, it's like these ions are getting into a ski lift and they're just getting pumped up the mountain.

And then when you plug it in, they're ready to ski down and they go down.

And that's just cruising across this electrolyte.

And I don't know what the electron is in this analogy.

But that's all a battery is.

You plug it in and the ski lift takes it up when you charge it.

And now, you power your phone on and it rolls back down.

Well, see the thing is that batteries have seen a Moore's law of themselves.

If you look at the Moore's law for batteries, it doubles.

So this is the energy storage of batteries over the last 150-ish years.

It doubles every 60 years.

That's not a very good Moore's law.

But that's completely changed.

That's completely changed recently.

And the reason is all about ion shuttling materials and ion storing materials.

This is why this has happened.

This is why we've had a revolution in electrochemical energy storage, all right.

Because 150 years ago, we only made batteries out of about 10 different materials.

And today, there's well over 80 that are commercialized.

There's many hundreds in research labs.

What is making the difference is that those materials now allow the shuttling to happen.

It allows the shuttling to happen more easily, maybe faster.

And it allows more of them to be stored per volume.

It's all about the chemistry that houses those ions.

It's all about the chemistry of the ions.

So that's why this matters.

Now, we roll things down hills to power our world.

I told you this already in the first or second lecture.

We roll things down hills all the time, all right?

So like methane is the core ingredient in natural gas.

And what we do-- and we talked about combustion already-- is we light that methane on fire.

But see, the thing is that what nature has done is it has put all this stuff up the hill for us.

So over tens of millions of years, nature has pushed the chemistry up a hill.

That is literally what it's done in energy.

Because, you know, it's made it so that if I light this on fire, it will go down the hill.

It will roll down the hill and give off energy.

Nature has done that for us.

But see, we need to be able to do this as well as nature.

And so in the last minute of why this matters, I want to explain why this is so challenging.

We need to be able to match.

Because if you look at the energy per weight versus the energy per volume of a material, that's a very important metric.

We plot this all the time if you work on energy materials-- the volumetric versus the gravimetric energy density.

This is good, a lot of energy per weight and volume.

Well, look at where gasoline is.

I want to do some math here.

Because I think this is very important.

Because I want you to see, now, if I take one liter of gasoline, so if I take one liter of gasoline, now, the cost is around $1.

Well, it fluctuates, but, you know, in this country right around now it's about $1.

OK, now, if I look at how much energy is in that gasoline, the energy stored in those bonds that nature has pushed up a hill over millions of years, the energy stored is about 33 megajoules.

OK, good.

Now, I'm going to make a comparison.

One MIT professor, one MIT professor operates at around 60 watts.

Now, this is something like-- well, this is equal to 60 joules per second.

Now, I know some professors who can operate a little higher than that and maybe some a little lower.

But that's like the average-- 60 joules per second.

Now, the thing is, if I want to get 33 megajoules out of this professor, then I get, at this rate, 33 megajoules takes the prof 153 hours.

Now, here's why this matters.

Because 153 hours will cost about $1,530 at the MIT professor salary, which is around $10 per hour.

And, OK, but look at this.

I dug something out of the ground that nature spent 100 million years making, fine, OK.

And I burned it.

And I got it for a $1.

I got the same amount of energy that it would have taken me literally $1,530 to pay for it.

That's our challenge.

Now, you can plot other things here.

But look at this. ethanol, wood, OK, liquid hydrogen, we're still trying to compress it.

But look at this, batteries are way down there.

This is why this matters.

Because we're not even close to being done.

We're not even close.

See that great uptick in electrochemical storage.

We need another order or two of magnitude still in storing energy, efficiencies, costs, et cetera.

So that's my "why this matters" for today.