ZEB building

Start with whirring of fan

Tore Kvande: When we hear that sound, I think we are earning money, because …we are generating more electricity than we use ourselves. So we are selling to the rest of the university. It’s great. It's money.

NB: But it’s more than money, really. That whirring sound? It’s the sound of how we can save the planet, one little sunbeam at a time, as a bank of transformers takes the energy from a huge roof made from solar panels and powers a four story office building with enough left over to sell.

One thing you need to know about this roof, though, is that it’s at 63 degrees north latitude. This is a place where there’s just 4 and a half hours of sunlight on the darkest day of the year. But the really big thing here is that one of the key components in the system is WAX.

Cue podcast music

I’m Nancy Bazilchuk, and you’re listening to 63 Degrees North, an original podcast from NTNU, the Norwegian University of Science and Technology.

Depending upon when you listen to this, COP27, the big international climate meeting scheduled in Egypt in mid-November, is either underway or over. The big hope, of course, is that there will be some desperately needed political breakthroughs at this meeting — but my crystal ball is cloudy on this one.

Instead, what I’ve got today are two stories of hope — not about politics and negotiations— but about real technological advances that can cut greenhouse gas emissions now. The advantage of these advances is that they can save money in the long run, too, like you heard at the top of the podcast.

And here's the hope: Just five years ago, the scientific consensus was that global average temperatures would increase between 4-5 C by the end of this century. Now, it's looking more like 2.8 C. As David Wallace Wells wrote in a recent article in the New York Times, "Thanks to astonishing declines in the price of renewables, a truly global political mobilization, a clearer picture of the energy future and serious policy focus from world leaders, we have cut expected warming almost in half in just five years."

We're not there yet, folks, and if you have listened to the first of these special podcast episodes I've published on COP27 with Edgar Hertwich, you know we have a lot of work ahead of us. But not only can we do it, we must.

My first story today is about an entire office building built to run on the energy of the sun and the power of three tons of wax — and this in Trondheim, Norway, which in case you didn't know, is just 500 kilometres south of the Arctic Circle.

The second is about a Norwegian engineer who, in the 1980s, rediscovered a way to use CO_2 instead of harmful chemicals to heat and cool buildings — and how his students, now scientists in their own right, are moving that technology into the marketplace. It's efficient and it saves money. And it's really taking off — in places as close as the heating and cooling system in your electric VW to as far as the Large Hadron Collider at CERN.

NB I’m in this trapezoidal-shaped building with one end that rises in a sharply angled roof — 42 degrees— to be precise. The building is very shiny and black — to my eye, it looks a little ominous, like Darth Vader or the Death Star. The whole structure has been built by NTNU and SINTEF, one of Scandinavia’s largest independent research institutions, as a test lab. It’s a concrete way — although there is actually very little concrete in the building anyway— that scientists can help societies build a zero emissions future.

Our guide to this structure is:

TK Tore Kvande. We are now in the ZEB Laboratory, which is the Zero Emission Building lab at NTNU. And I'm the manager of the building.

NB: It was Tore at the top of the podcast, describing his delight at hearing the transformers sing.

So the reason the building is black and shiny is because the design uses what are called Building Integrated Solar Panels — 701 in total, to be exact.

Half of them are on the angled roof, which is the reason for the steep pitch, while another chunk are placed on the sides of the building, to take advantage of the low-angle sun during the winter, spring and fall. And they do a good job, producing about 156 MWh per year in addition to making the building look really cool. Still, that’s not why I’m here. Tore explains.

TK: Now we are in the Energy Central and in front of us we have a big box filled with vegetable oil. So that's phase changing material. So it's a thermos where we store heat. That's the easiest way to explain it.

NB: Phase changing material sounds like something out of a science fiction novel or Star Trek, but in truth, in this case, it's WAX.

Why does this wax matter?

Well, Tore called the wax a thermos. But another way to look at it is that it is a kind of battery. Heat is energy, and by melting or cooling the wax you can either store the heat or release it. Here's how Tore explains it.

TK: During the day we melt the wax, we are using leftover heat from the building, heating the wax, so it's liquid. And then we store a lot of energy. Energy we use in the morning, when we start to heat the building.

So I usually start early in the morning, and then it's always liquid stuff in there. And between seven and eight o'clock, it starts to take out the extra energy and it went from liquid to solid. And we can see now it's solid in the bottom and we have some liquid in the top. So we are still taking heat out of the system.

NB: It's really cool because the big wax-filled tank has a round window in it, exactly the same size as a porthole on a ship. When I was there, around 7:30 in the morning, the bottom half was full of lovely white crystals that looked like delicate frost feathers — while the other half had already melted and was transparent.

That's not the only reason it's cool, though. Society needs to come up with innovative ways to store energy so that it can be used when the demand is greatest. It's called peak shaving. Peak energy use is when everyone wakes up in the morning and they turn on all their gadgets, or when everyone is using electricity on really hot or really cold days. If the electric grid can't supply enough energy at those times, then the power can go out.

Engineers and policymakers design systems so that they can always keep the lights on. So they build power plants that turn on and off only during these peak times. These are usually the most expensive power plants because they have to be available at a moment's notice, and they have to be built to withstand the shock of going from idle to full production really fast. But when they're not needed, they otherwise sit there, waiting, like an expensive bodyguard or something.

NB: So is this going to help us get to net zero — is this kind of invention going to help us cut our carbon emissions? So we don't, yeah, fry the planet?

TK: Definitively, because every system, especially in an environment, the campus, the heating system is dimensioned for the peak in the morning, peak energy use in the morning.

And if you have a system like this in most of the buildings, we can reduce the peak so we don't burn that much oil for the heating or to take feed water from the central system.

NB: There are lots of other cool aspects about this building — but I'm just going to talk about one other. And that's wood.

Tore explains.

TK: If we are building with wood, that's CO_2 inside the building materials, and we are not producing it for the environment.

NB: Developers are building more and more wood office buildings, especially in Scandinavia, where the world's tallest wooden building, the 85 meter high Mjøstårnet, was built in 2019 just outside of Oslo. As Tore said, using wood as the main construction material means the CO_2 that trees have absorbed while they are growing remains locked away in the building structure itself.

Here at the ZEB laboratory, however, they have pushed the boundaries on wood construction in their quest to make the structure emissions free. The elegant wooden spiral staircase is an example.

TK: it's made of massive wood. It's panels with massive wood 15 metres long.

TK: Normally when you are making a stairway like this you use quite a lot of steel plates in the connections and so on. But we made it without these steel plates.

TK: I don't like steel, because producing steel makes a lot of CO2 to the atmosphere. So one kilo of steel makes one kilo of CO2.

NB: Instead they used lots of 30 centimetre long screws! There are steel plates in the building overall, but other design elements helped eliminate the need for lots of them.

One was the way in which the building’s horizontal beams are connected to the vertical supports.

TK: The steel plate down there is itself not that many kilos, but if you added up all the connections, it would have been a lot of kilos, so we didn't like it. So we found a new way of connecting the beam and the steel.

NB ...Forward march around the corner. Alright, we're walking through a room with a big, high ceiling. That's an angle. And now we're going to a big laminated beam.

TK: That's the column. Yeah. Yep. And we can see the beam up there. So we widened the column enough to have the beam on the top of it.

NB: What struck me immediately is a slight resemblance to Norway's famous wooden stave churches, which were mostly built between 1150 and 1350. Of course they didn't have any steel at that time.

TK: It's more like they did in the old days when they didn't have steel. And we have the same 30 centimetre long screws. And we have two of those in the bottom to fix the beam to the column and to the top. And no steel plate in the connection. So just by taking away that steel plate in most of the connection we saved one-and-a-half tonnes of steel — that's more than one-and-a-half tonnes of co2.

NB: They also framed the elevator in the building using thick beams.

TK: CLT, cross laminated timber is surrounding the elevator.

NB: Not every house or office building can be built like this, but the ZEB building shows how smart design, right down finding ways to avoid the use of steel plates as much as possible, can cut CO_2 emissions. And this building really is Zero emission —the CO_2 emissions from production, transport, construction site, construction of buildings, and operations, for 60 years have to be compensated by energy production by the building. That makes the building completely carbon neutral. We can do this!

NB: Next up is Armin Hafner, a professor at NTNU's Department of Energy and Process Engineering, who has focused his entire academic career working on what are called "natural refrigerants," meaning substances like carbon dioxide (yes, the greenhouse gas) and ammonia. And you'll be interested to hear that one of the most important drivers in pushing the development of mechanical refrigeration was BEER!

AH: Natural refrigerants have been utilised since the early days of mechanical refrigeration. About 150 years ago, mechanical refrigeration was introduced, because there was an urgent need of having cooling also, during the summer, before that it was harvesting ice on the lakes in Norway and elsewhere, but Norway was a huge ice exporter in the late 19th, until 1915. Because in that period, it was just the uptake of mechanical refrigeration in the late 1880s, (Carl von Linde) and others, they invested.

NB: Linde is Carl von Linde, a German scientist and engineer who led early advances in refrigeration and who founded a company that subsequently became the largest producer of industrial gasses.

AH: They investigated that mechanical refrigeration will help, for example, breweries to brew beer all year long. So that was the strongest intention around Germany to invent this new technology of producing ice blocks or other ways of cooling for warehouses, but mainly breweries. So within a few years he sold 750 large ammonia systems. And here you see already this is a natural fluid, ammonia has been used.

NB: But during the 20th century, something changed. Chemists were inventing all kinds of chemicals, like PCBs or DDT, to solve some of the world's problems. It was the age of "better living through chemicals". They also came up with refrigerants like CFCs, chlorofluorocarbons, which worked great — as refrigerants, anyway. But like DDT, they were terrible for the environment. What happened next was the Montreal Protocol, a landmark international agreement signed in 1987 that phased out the production of these chemicals, because they were found to damage the earth's ozone layer.

AH: And then the late Gustaf Laurenson, professor at NTNU. He rediscovered, and with a team at SINTEF, he developed different kinds of systems, as an answer to the Montreal Protocol. He said, "We should focus on natural fluids, because these properties we know, and we know the impact too, so it's not harming the environment.” And that's why we focus only on these kinds of fluids, we are focused on ammonia, we focus on carbon dioxide, and hydrocarbons can also be used. Everybody has a more or less hydrocarbon fridge at home. So the fridge in our homes is utilizing butane as the working fluid inside the loop, which is not harming the environment.

NB: The chemical companies that made CFCs (which are also powerful greenhouse gasses) came up with a variety of chemical alternatives that were less harmful to the ozone layer, and eventually gasses that were considered to have a low global warming potential, but that are still very harmful to the environment. These chemicals…

AH: … live only 10 days in the atmosphere, and then they break up and per definition, this means they have a very low global warming potential. But this is just a technical trick because it is not finished after these 10 days. Because these decomposition products they're not good for our environment, for our health, because they are accumulating in the drinking water, in mother's milk, and you can find them everywhere — even on Spitsbergen you find the traces. ….These are the family of fluids you want to avoid and that's why we focus on natural working fluids.

NB: I’m not going to try to explain the technical details of how a heat pump works. The important thing you need to know is heat pumps take advantage of the physical characteristics of what Hafner calls working fluids. The key aspects are their boiling point and the point at which they condense, meaning when they change from a gas to a liquid. One side of a heat pump is warm, the other side is cold. And they are far more efficient than more traditional ways of heating buildings, like panels or oil-fired burners.

One area where heat pumps have made great inroads, especially in Norway, is in supermarkets and hotels.

AF: We focus on CO_2 applications for supermarkets. That is kind of a no-brainer in the northern part of Europe.

NB: That's because while all supermarkets need cooling and freezing for their products, in northern Europe, they can also warm their buildings with the heat that the heat pump generates as it makes cold air. That may be less important in southern Europe — but the cost savings is great enough that these supermarkets are also adopting the technology.

AH: Now even in the southern part of Europe, large supermarket chains have understood we don't need chemicals in the future. We can do it with CO_2 and they can save a lot of energy as well which is good. And in the northern part we use these fluids because we can do a nice heat recovery.

NB: Hotels are increasingly adopting this approach too. To understand this next little story from Hafner, you have to know that Trondheim's airport, Værnes, is right next to a little town called Hell. Hell means fortunate or lucky, but for reasons I don't need to explain, all English speakers find this extremely amusing.

AF: this hotel stuff is global, I mean the hotel is always cooling and it always needs hot water. So we can apply these systems really on a global scale.

AF: So that's why if we implement CO_2 in these kinds of systems, they can produce the chilled water on one side to maintain comfort in the building. And on the other side, we produce all the hot water they need, when all the people are taking showers and spa and whatever they have. So they can significantly reduce the energy demand. And as a good example, you can go to the airport in Trondheim, there is a hotel in Hell, which has a CO_2 heat pump.

AF:And They have reduced the electric power consumption by more than 70% since they have converted the whole hotel from being entirely electric heated to a CO_2 heat pump.
So that's a very nice story, to have a CO_2 heat pump, even in Hell.

NB: Another place where this heat pump technology is making inroads is with electric cars. Armin explains.

AH: the challenge with the electric car, if you have just an electric heater, more than half of your battery just goes for the heating. So you will never reach your destination. So the challenge is really how to save energy and to do this heating in an efficient way. And that's why more and more car manufacturers go for co_2 heat pumps. The CO_2 system is nice, tiny, more compact, which is very important in mobile applications. Because space and weight is a big constraint. So that's why you see more and more of these systems.

NB: In fact, part of his PhD dissertation 20 years ago was developing a reversible heat pump for mobile air conditioning and heating.

AH: Now we can see these kinds of systems in the new electric Volkswagens, they have the reversible CO_2 heat pump. Whenever you buy a Volkswagen in Norway, you have a CO_2 heat pump in your car now, that's something we started with 20 years ago, that's good, good to see — but it takes time.

NB: Hafner is also head of a project that is building a new CO_2 based cooling system at CERN, the home of the Large Hadron Collider. The main motivation is to move away from the harmful refrigerants, and CO_2 can do the job.

AH: The tough stuff is that CERN equipment needs to withstand very very harsh harsh radiation. That means in these colliders and the detectors which need cooling, you can't employ a fluid which is decomposing when a particle hits it. So that's why you need very, very strong molecules and CO_2 is one of these. So that's why they are converting the cooling system of many of these detectors now in the next generation towards CO_2 Because CO_2 is not decomposing when when it is hit by radiation and they need cooling.

NB: I asked Hafner if he felt optimistic about society's ability to implement these technologies and cut our carbon emissions by reducing our electricity demands?

AH: I strongly believe we can do this and when I see my students, there is hope. We clearly see that they are eager to help to bring new solutions. And to clean up what we messed up in the past. So I think we have a great chance and the market will show but the politicians have their share to do. And we the technology providers will do our best to develop systems which can do this clean in a clean way, not only green by putting a green colour on everything, we can do it clean, we don't harm our health, nor the environment. So that's our mission here, to help students to understand how to design the next generation of heat pumps and cooling systems without compromising on environment, or energy efficiency.

Nancy: I'm Nancy Bazilchuk, and you've been listening to 63 degrees North, an original podcast from the Norwegian University of Science and Technology. If you want to know more about what's going on in Norway in terms of other climate related measures, check out my podcast episode on carbon capture and storage — you'll find a link in the show notes. And as always, If you'd like to learn more about the speakers on today's program, or look at some of the academic publications used to write this script, you'll also find this information in the show notes. Thanks for listening.