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DAVID HSU: My name is David Hsu. I'm a professor at MIT in the Department of Urban Studies and Planning. And this is another installment or another lecture in my series of lectures on urban energy systems and policy.

Today, we're going to talk about the notion of energy efficiency. The notion of energy efficiency or the idea of energy efficiency is something I've worked on for a long time, and I think it's worth examining what energy efficiency is, what energy efficiency is not, and what it may or may not achieve. Materials for today are on the syllabus. You can link to all of them in the PDF if you have the PDF copies.

And it's worth, I guess, starting today's lecture with this kind of profile of Bruno Latour. He's called here a post-truth philosopher. I actually don't think that captures what his work is about. He was quite influential in the time I was in graduate school and I think quite influential since in terms of talking about how humans interact with the natural world and environment.

At the time, I was in graduate school in the '90s, and the author-- a lot of his work was focused on science and technology, namely, how science, scientific facts, and how technologies were produced. So he writes about the high speed rail. He writes about the early internet in France. He goes on to write about other topics about how do humans relate to the natural world.

And so, in this magazine profile, *The New York Times Magazine,* they write in the subtitle, "He spent decades deconstructing the way that scientists claim their authority." A lot of his work is about how institutions and systems create kinds of knowledge or create certain cultures. So I would argue that he's not, perhaps, a "post-truth" philosopher as much as one who examines the systems and institutions that surround certain technologies.

And that's a theme I want to bring forward in this class. I think you've probably heard me allude to this a number of times before. How we create institutions, how we create markets, policies-- those all shape how technologies develop.

It's also relevant this week because Bruno Latour just died, actually, a few days ago. This is a obituary in *The Guardian.* You can read obituaries in other major newspapers. A lot of newspapers say that he's one of the most misunderstood French philosophers, but his work was inherently interdisciplinary. He does touch on how humans create what we consider to be objective scientific realities, but also how that shapes how we see the world.

And so this is a theme I want to bring forward to talk about what is energy efficiency. We could take this very abstract definition. I kind of came up with this very pared-down definition that I thought nobody could possibly disagree with. It's the efficient provision of energy services. Instead of simply focusing on the efficient use of energy, I've tried to reposition it a little bit, focusing on the services we get from energy and also the provision. This energy does not come from nowhere. It comes from systems.

So if we break down this pared-down definition of energy efficiency, we'll focus on services. We can question what the meaning of service is itself. What is a reasonable expectation of service? Here in North America, or at least where we're having this class this year, we expect to have energy fairly abundant and reliable and cheap. We expect to be able to get access to electricity any time we flick on a switch. We expect to be able to gas our car any time we need to.

Of course, we know that, when those systems are disrupted, such as in a hurricane, as in Hurricane Ian, which Florida's just recovering from now, we know service can be disrupted. We know wildfire can disrupt service. And so this-- we don't expect it to happen in these, quote unquote, I guess, what we call "disasters" or "periodic disasters." But we also know these things happen fairly frequently and increasingly frequently in our older grid. So we have to ask ourselves for the future as we plan what our systems are going to look like in the future, what is the reasonable expectation of service?

Of course, we also should recognize that our ideas about what energy services are will vary according to our expectations and norms and institutions. Those all vary by places, by people, and by culture.

If we talk about energy, we have to ask ourselves, what counts? For example, if we consider renewable energy, we consider it renewable because we get essentially wind and solar energy from larger geophysical forces or from the Sun, which is essentially an infinite source of energy falling on the Earth, which also powers ecosystems.

But consider where we draw the boundary for what we consider energy. We consider renewable resources to be essentially infinite because they come from the Sun. At the same time, we consider fossil fuels to be relatively finite, not only in the amount that's produced, but also, of course, the amount that the atmosphere can absorb of carbon dioxide or other greenhouse gas emissions.

But also consider if we draw our boundary around cities. As I mentioned in the first lecture, we have upstream emissions, and we have downstream emissions. Consider trash. Trash was originally consumed materials. Those required energies to manufacture them, thus upstream emissions. We consider the place of consumption quite often to be cities. And then we consider the downstream emissions, the energy or the emissions associated with disposing of trash.

If we trace through energy in the same way, there's obviously embodied emissions upstream. There is the consumption, what we consider to be consumption, in, let's say, cities. And then there's embodied energy going out with the trash. Of course, it requires energy to get rid of trash. Also, energy can be generated from trash, as in waste-to-energy incinerators. So how you account for what counts as energy matters, and how we think about energy efficiency.

And, of course, provision-- like I said before, energy doesn't come from nowhere. It has to be provided by somebody or by some agency. We know that provision of energy is not equal to all people. We expect that we have access to as much abundant energy at a reasonable price as we want. That's clearly not true in some parts of even North America. Not everyone has enough money to pay the utility bills.

And there's many issues raised by provision. Do we expect people to pay for all their energy? We obviously subsidize other activities and other aspects of life, other public goods, such as transportation. Why don't we subsidize energy? We have a system built where ratepayers or users pay for exactly how much they use. What does that mean for how much they pay for how much we invest? Or should we invest, in the future, in other kinds of energy? These are all questions about energy efficiency.

So, again, this gets back to the question of how do we define efficiency, which brings me to the Elizabeth Shove article I assigned for today, which is titled, I think, quite usefully, "What is wrong with energy efficiency?" Just to summarize some of the critiques of energy efficiency in her article, the first one is that the recognition that energy efficiency is not going to meet climate change on its own. Even if we consider the theoretical limits of energy efficiency, as one of the other articles also considers, we also, I think, should recognize that we are unlikely to reach the theoretical limit. But even the theoretical limit is not going to reduce greenhouse gas emissions completely.

Also, there's a question of rebound effects, and this is an area that's been studied quite a bit in literature. It's also called the Jevons paradox, after a British economist, who looked at the likely scarcity or the British Navy running out of coal. Of course, he studies this paradox and sees that the British Navy then transfers or changes over to oil for its ships and uses more energy than before. So it's kind of given this rebound effect also-- the idea that if you use more efficient technology, user expectations rebound, and people actually use more energy than before.

Another simple example is, do we actually save energy in energy efficiency? We have a more efficient car. Do people feel less guilty or less, let's say, constrained to drive more if energy efficiency or gas prices are a constraining effect? There's also the critique of energy efficiency that it's simply improving the system rather than overhauling or rethinking the system completely.

And, of course, the main point of Shove's article, which actually references Bruno Latour quite a bit, is that, when we think about energy efficiency, we're basically counting some things rather than others. This is what Bruno Latour calls purification. You basically purify the object of study. We focus on energy itself without thinking about all the political or social entanglements of the energy to get there in the first place.

For example, we talk about reducing our oil use. We may not be focused necessarily on where the oil comes from, as in discussions of energy independence or energy dependence. If we are getting oil from Venezuela and Nigeria and Iran and Russia, as we quite often do in global oil markets, we're basically focused on making our use of oil more efficient without necessarily taking into account some of these other factors. So, obviously, discussions of national security often take into account the idea of energy efficiency as reducing our dependence on foreign sources of oil, is a phrase you'll hear quite often.

And, finally, the main critique of energy efficiency that summarizes some of these other critiques is that it's essentially a status quo view of energy. It basically frames or bounds the problem in certain ways. It says that we expect to have a certain level of service. We may not take into account what our future rebound effects are or by simply maintaining the status quo, by framing the problem in a certain way, rather than radically rethinking the problem.

MacKay takes a different approach. In going through these texts, I want to show you how the texts reflect different viewpoints or rhetorical framings. MacKay says in chapter 19, every big effort helps. We've established the UK's present lifestyle can't be sustained on its own renewables. So what are our options if we wish to get off fossil fuels and live sustainably? We can balance the energy budget either by reducing demand or increasing supply or, of course, by doing both.

But he skips down to say in the second paragraph, "Have no illusions. To achieve our goal of getting off fossil fuels, these reductions in demand and increasing supply must be big." So his emphasis is that we have to do big things, that energy efficiency should basically reflect this sense, which is what matters is the total impact on the problem of energy use and climate.

And if you had to characterize it as an equation, it's simply impact equals the volume of the problem times change. So, as he says, if everyone does a little, we'll only achieve a little. We need big changes in demand and supply. But if we make changes, we have to apply those changes to large volumes or the entirety of the problem.

From the Cullen and Allwood papers, the 2010 papers, you see they use this equation a couple of times. The potential for saving energy is the scale of energy flow, and then multiplied times the difference between the target efficiency and the current efficiency. This fundamentally reflects a different view of energy efficiency. It matters how efficient we can get compared to our current level of efficiency.

So what matters is the potential for energy savings measured versus current efficiency. The delta effect essentially just depends on this bracketed term, the difference between target efficiency and current efficiency. This is a very different view because, as Cullen and Allwood point out and I'll highlight later in one of the tables, that our current use of energy is only about 10% or 11% of the primary energy we consume is actually harvested or used as final services. So as they argue, if we can increase our energy efficiency, we can drastically reduce our use of primary energy or greenhouse gas emissions.

If you look at how they characterize the problem, they also say up front in one of their papers, "The reasons for using energy more efficiently are clear." And then they go down to say there's this Kaya identity, which is essentially a product of four drivers-- population, per-capita wealth, energy use intensity, which is energy per unit of wealth, and carbon intensity, which is CO_2 per unit of energy.

And they go right to say, "The first two drivers are socioeconomic and are difficult to limit in practice." Getting back to the Bruno Latour view or Elizabeth Shove's critique of energy efficiency, we have to critique whether or not these first two drivers are, in fact, difficult to limit in practice. But also, when we often say that climate change is no longer a technical problem-- it's a social and political problem-- we have to question whether or not we can simply take these first two drivers and leave them off the table.

They spend most of the time in their two papers, usefully, I think, focused on the third and fourth drivers, which are technical options, which, of course, require energy to be used more efficiently and the decarbonization of energy supplies, something we've talked a lot about in this class. But what I'm trying to re-emphasize in this class, and the reason why I started off by talking about Bruno Latour and Elizabeth Shove, is that we cannot avoid the entanglement of some of these technical issues with social and political context. And we have to address the social and economic drivers of energy consumption, namely, per-capita wealth and per-capita energy use in wealthy countries.

Of course, they do go on to say that "significant socioeconomic barriers also limit the uptake of new efficient designs. These include market imperfections, such as a lack of adequate information and financing, higher perceived costs, and differential benefits to the owner and user." You will recognize many of these factors, including behavioral barriers, such as consumer trends and habits.

You'll recognize many of these factors are things we identified in previous readings, such as the reading by Blumstein et al., 1980. As I said in the previous lecture, I teach that article every year because all those barriers still exist. There are still barriers that we need to overcome.

But let's get into the meat of their analysis, if only because I think they do some useful defining in some ways, chunking the problem, breaking down the problem into a more practical set of problems. They make this distinction between convergent devices and passive systems. They classify things as energy sources where they essentially transform fuels. There's some fuel loss in going to refined fuels and electricity, for example, when we go from petroleum to gasoline, there's some fuel loss. If we go from coal-- we can't necessarily use coal in our homes, but we can use electricity. As we know, we lose energy to generation distribution. And then this goes all the way through to end-use conversion.

What we ultimately want is a set of services. Let's say we want light in our homes. That light in our homes requires electricity. So we have to go through the set of losses to get to the end-use conversion. The end-use conversion converts electricity into light.

And, as they say in the article, once things have converted to this end use, it's very hard to harvest them again. In other words, there's some final service that we want. There's some useful energy that goes into that final service, but there's a whole series of losses-- the fuel loss, the generation loss, generation distribution loss, conversion losses, and system losses, and that's the total losses. And they distinguish the final service as the thing we want.

And passive systems are essentially systems that do not transform energy again. They receive energy at the end. They're essentially the nodes at the end of the system.

Another way to look at energy use is that we have some historical level of energy use. We may have a lower, hopefully, level of current energy use. Note, as I've shown you before, current energy use is probably higher than it was historically. But the point they want to make is that we have potential to realize energy efficiency. We have our current level of energy use.

There's some level of reduction in energy use, which is economic. In other words, it would actually save money or is cost effective to, say, use the energy by, let's say, deploying new technologies or policies. Having said that, our economic potential reduction-- here, about 40%-- is lower than our technical potential because, theoretically, we could reduce our energy use by 55%, it looks like here, if we applied every possible technology.

But the difference between technical and economic potential is that some things are economically cost effective. Some things are technologically possible but not yet economically cost effective. So that's the difference between these two lines. And, of course, our theoretical potential is a theoretical calculation of about how these systems could possibly work most efficiently to reduce their energy consumption completely.

And so these three distinctions-- economic, technical, theoretical potential-- are something you'll see quite often in energy efficiency. We also have the question, necessarily, how these potentials are calculated. Economic potential is obviously defined in terms of a certain set of market conditions now. Technical potential is based on a certain set of technologies that exist now. And theoretical potential is how we calculate the potential. But, obviously, a new technology or a different set of demands might actually reduce energy consumption just as much as these potentials.

Having said that, again, you'll see these different definitions of potential used quite often. This is from the DOE Energy Efficiency Potential Studies Catalog. You'll see they draw it a different way. Technical potential is one circle. This is how much we could reduce energy use technically. Economic potential is a subset of that.

Achievable potential is smaller still because that's considered, let's say, what's socially achievable or politically achievable, which is not the same thing as economically realizable, and then achievable. And then, finally, program potential-- there's a skepticism even from the Department of Energy about how effective social or government programs can be. The program potential is smaller than the technical, economic, or theoretically achievable potential for any given policy, technology, or market.

But they do a useful catalog, I guess, showing studies at the utility level, showing that there's studies that-- economic and achievable electricity savings between 1% and 1.5%. They show that the utility performance is here, looks like maybe averaging around 0.5% to 1%. There's a higher achievable potential, and there's a higher economic potential, especially out here at the end. You can see they categorize 36, 38, and 50 studies.

They also emphasize in this catalog that most studies focus on certain sectors. They focus on residential, industrial, and commercial sectors. They do much less focus on agriculture, distribution, irrigation, and street lighting, which brings us back to our Sankey diagram of the US economy in 2021. Here's our four major sectors here-- residential, commercial, industrial.

You'll notice, in that previous diagram, they don't show transportation because we obviously have many ways to make transportation more efficient. But it's essentially considered somewhat different, partly because it's outside the jurisdiction of utilities. We know we directly fuel our vehicles. We pump gasoline. We think of that as essentially a different system than our system for energy efficiency for residential, commercial, industrial, which is largely governed by utility companies.

What's useful, I think, about the Cullen and Allwood papers is a lot of diagrams that show how things connect. For example, they show that we have three possible energy sources here on the left-- oil, gas, and coal. We have three convergent technologies-- petrol engines, diesel engines, and electric motors. We have three modes of transportation-- cars, buses, and trains. And we have a final service that we want to get, which is passenger transport.

The key thing about this horizontal slice through these various technologies is that some fuel sources or energy sources can only connect to certain conversion devices, which connect to certain vehicles. For example, oil can only produce petrol or diesel. We know we have car, bus, and train versions that use petrol or diesel to get passenger transport.

But if we want to use an electric motor, we can only, in this paper, get our electricity from gas and coal sources. And we have to electrify our cars, buses, and trains. Of course, it's also worth thinking about what this chain leaves out. It obviously doesn't include something simple like walking. E-bikes or micromobility might use electric motors.

But walking is not something that's counted as a energy source. It may fulfill our need for passenger transport, and it actually may fulfill other needs, like, let's say, increased psychological benefit or increased health. But that's not necessarily captured in how we measure these things.

There's that often quoted saying-- you can't manage what you don't measure. These papers are all about measuring certain things and thinking about how to make them more efficient. Of course, when you measure certain things, you're not counting other things.

I think it's attributed to Einstein, but it's not necessarily clear if he said it. He said, not everything that can be counted counts, and not everything that counts can be counted. That's not necessarily what he said, but it's a famous quote attributed to him. This is the point of energy efficiency also. We need to count certain things, but we also need to value some things that can't necessarily be counted.

If you look at some of the vertical slices, though, there's some very useful back-of-the-envelope figures for you to look at. We have the total amount of energy use for an energy source. About the majority of it is used is-- more than half of it is used in direct fuel use. About 40% of it looks to be used in electricity. And a very small portion is used actually as heat directly.

The energy sources are overwhelmingly oil and coal. This is from 2010, so it may be superseded. Gas is probably higher. Renewables are probably higher. Biomass and nuclear are probably roughly the same.

In terms of conversion devices, we overwhelmingly use conversion devices for transforming energy are diesel engines, electric heaters, electric motors, and biomass burners and gas burners. If you look at the passive systems, appliances, heated and cooled space, heat systems, and driven systems dominate our passive systems.

You can see if we break down our 475 exajoules of energy, buildings and factories are quite high. Vehicles are actually relatively low. But, of course, all these things mix in to get all of our final services. We need vehicles, we need buildings, we need factories all mixed together.

So if you look at the breakdown of final services, you can see they try to clock by how we use our energy. Thermal comfort and sustenance are relatively high, but structure, freight transport, and passenger transport are still relatively high amounts of energy because they consume material, because they consume embodied energy, as well as direct fuel use.

So one thing to point out of the Sankey diagram from the Cullen and Allwood paper is that some of these things are shown as flows, but through each these vertical slices, you can't necessarily trace energy all the way through. For example, if you go from oil, oil can only be used in diesel engines and petrol engines and oil burners, so we can account for all this direct fuel use.

But we use some portion of oil, some portion of gas, coal, nuclear, renewables to generate electricity. But as you start to move through these vertical slices, it gets harder and harder to account for where these flows go directly. For example, let's take trucks. We go from diesel engines and petrol engines. They may map, to some extent, to cars and trucks. But you can see these flows don't quite line up because, across the vertical slices, it's very hard to account for how many diesel and how many petrol trucks we have.

Having said that, we also know some portion of our trucks, planes, and ships and trains go with freight transport. They categorize these in various ways. How do you categorize truck transport versus car or passenger transport? We know, in the United States, SUVs are classified as trucks, which makes them exempt from previous efficiency standards.

So the point is, as you go across these vertical slices in this particular Sankey diagram, you can't always trace all the flows in the same way that you can in the previous Sankey diagrams we looked at. You can see that there's a few gaps in between some of these flows because, where does electricity go? It goes to a lot of these different systems, not necessarily just the heating and cooling space. But it may, let's say, go to industrial uses.

Having said that, we should also look at exactly what they're trying to measure in this paper. They make a very clear-- well, they make a series of distinctions between exergy, energy, and entropy. They quote this Rosen and Dincer paper of 2008 saying that "exergy is a measure of the usefulness or value or quality of an energy form." This is "defined using thermodynamic principles as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment."

And the reason why they make this distinction is because-- I've said before and also MacKay writes in his book-- that there's high-grade forms of energy and low-grade forms of energy. And the intrinsic distinction between these is entropy. For example, electricity or mechanical work is the kind of energy that can be captured quite easily and recaptured and can also be used for many different things. But if you try to heat up a space, once you put heat energy into a room, it's very hard to recapture that energy.

They make a distinction-- the first electricity or mechanical work is a high-grade form of energy. And MacKay calls heat a low-grade form of energy. They make a distinction here by exergy, saying exergy is how much output work can be captured from the maximum theoretical work that can be captured.

Here's their definition in their papers. They say exergy efficiency is based on the first and second law of thermodynamics. They use it because they want to provide an equitable measure of conversion efficiency. They define it as mechanical work because mechanical work, like electricity, can be captured and recaptured quite easily. If you put it into a storage system, whether or not it's physical or mechanical or chemical, you can quite often recapture a very large portion of the energy.

That's not the same thing for a heat battery. Let's say you put, as I said last week, heat into a hot water heater. You can store the energy for a long time, but it's very hard to take the heat energy out of the water and recapture it for future use or converting it back to, let's say, electricity or fuel.

So the reason why we look at this Cullen and Allwood paper-- this is actually more like a traditional Sankey diagram because they actually are much-- they find it easier, I think, in this paper to measure exactly what the theoretical efficiency limits are. They can trace exactly where the energy sources go.

Because they're not going into different services or different categories of services, they define things more clearly as going from energy sources to direct fuel use to conversion devices. They don't have the same vertical slices the other diagram does. And you can see quite clearly in this paper exactly where our energy goes to.

We start with 475 exajoules. This is global energy demand in 2005, and it's probably much higher almost 20 years later. But the point is that we only get to about 11% of the total energy is converted into useful energy, namely in these forms of motion, heat, and cooling, light, and sound. The other 89%, we lose to combustion, heat exchange, oxidation, mixing. As we transfer heat, we lose energy through heat exchange, exhaust, heat losses, and electrical resistance in friction and fission.

This is not to say that they say the theoretical limit is recovering the 89% of energy efficiency or energy that's lost. Having said that, we know that we have existing technologies and systems. All of these various losses are because of conversion losses. The technologies we have, the systems we have convert energy in certain ways into certain kinds of end uses that we want, like light and heat and motion. And all those conversion technologies may be inefficient.

And what the point of this paper, these two papers, is that, how theoretically efficient could we be? They argue that we could be 89% more efficient. 89% more efficient would reduce our primary energy use quite a bit and reduce our climate change problems also.

So if you look at how they define energy efficiency, they have a quality factor and exergy efficiency. The "e" column to look at it here, I think, is the right-hand side. You can look at it exactly how efficient our various technologies are.

For upstream conversion, you can see that electricity generation from oil is relatively efficient, actually, but much less efficient than fuel transformations, such as preparing direct fuel use or renewable energy resources. You can see that oil, biomass, gas, coal, and nuclear are much less exergy efficient than renewables or fuel transformations. Combined heat and power and heat are also relatively low in terms of their exergy transformation.

The other thing to notice here is that this kind of quality factor gets at the idea of how easily you can convert the energy to exergy. And so they put in 100% basically as a plug here. It basically accounts for, let's say, fuel losses or transformation losses. And you can see that nuclear, renewables, and fuel transformations, such as direct fuel use, are all relatively efficient, if only because renewables and nuclear power use electricity. Electricity is-- relatively little is lost in terms of transmission compared to other types of energy.

Fuel transformation is considered to be relatively efficient because it's going to be produced as a direct fuel. This is only measuring the efficiency of the upstream conversion, not necessarily the end use down the road, which we'll see in this next, actually, table. This table shows the exergy efficiency of end-use conversion devices. You can see across the board all of our end uses for motion, for heat, and for other services are all relatively low. All devices convert about 25% of the possible theoretical maximum exergy. And you can see that's true for almost all of our different technologies-- diesel, petrol, aircraft engines, oil burners, biomass burners, and so on.

One point I always make to engineers in this class is that, if you look at these two tables and the Sankey diagrams, if you're working with these technologies, that should hopefully be motivating because you improve one of these technologies a little bit-- if that technology can be scaled and adopted widely, that can have a huge impact on our total use, efficient use of energy.

If we look at the compound efficiency, which takes into account fuel transformation, electricity generation, and end-use device conversion. Again, for some, actually, these-- electricity generation does not factor into what the aircraft engines or coal burners. They put 100% of the plug here. But the key point is you multiply these factors together, and you get a compound efficiency.

So we started out with a very efficient fuel transformation in direct fuel use, as in aircraft engines, diesel engines, and petrol engines. But then we exhaust a lot of the energy out because we have to burn the fuel directly. A lot of heat goes out the tailpipe or the back of the engine. So we actually get fairly low compound efficiencies.

Again, across all the conversion devices where we get final services, you can see that the overall average is quite low. We have overall average of 11% of actual final energy use or final services from the original primary energy going in.

And so we can take this thinking further. This is the report by Griffith et al. It's called "Rewiring America"-- argues that we can have basically a highly electrified, decarbonized US energy sector, basically providing all the same services that the US economy currently provides, and argues that we have massive efficiencies in electrification.

They actually trace all the energy use through all the US government reports they can find. They identify places where some of the Sankey diagram they find either misleading or duplicative because we're actually using fossil fuels. They argue that there's some large portion-- about 8% of the energy economy is misleading accounting of existing primary energy. If we eliminate fossil fuels, we'll get rid of this 8%.

If we have current losses in residential, commercial, and in the industrial sector because we use fossil fuels, if we electrify these things, they'll eliminate another-- it looks like about 15% or 16% of energy use. If you electrify vehicles, they eliminate 10% electricity use.

And you can see what they're trying to do is they're getting from the 97 or so quads, the US [INAUDIBLE] 100 quads. And they're trying to increase the percentage of energy services at the end, energy services increasing to 27%, and trying to get rid of what they call, with quotes, "waste." They argue that some of this waste can be captured through electrification.

They also do this in a Super Sankey diagram. I encourage you to go to the PDF if you click on this interactive link. What's quite useful about this interactive diagram is you can click on any of the final services we desire, and it'll show you where all the energy comes from in its history or path.

The reason why this is really useful is, if you think about efficiency, we have a set of final services here that we demand at the right. We have a set of primary energy sources going in on the left. If you can reduce consumption on this right-hand side, you eliminate all the upstream [INAUDIBLE] from happening.

And, crucially, you eliminate all the previous inefficiencies or losses. In other words, if you reduce consumption, let's say, 1% here, you are going to reduce much more than 1% of primary energy use on the left because all the efficiency gained by simply not demanding the final service in the end.

So this is, again, why we focus on consumption in class. I want you to think of efficiency as percolating through the whole system. If we reduce our consumption or demand, how much efficiency does it lead to upstream?

And this brings me back just to this set of final services. We desire passenger transport, freight transport, structures, sustenance, like food, hygiene, and thermal comfort, communication, illumination. What I want you to think about is, if we make these things more efficient either in our conversion devices or in our demand or use of them-- for example, we know about a third of all food in developed countries is thrown away. If we were to reduce our demand for food by being less wasteful, how much would we reduce upstream both in terms of our vehicles, factories, and buildings, but, ultimately, the direct fuel use and motion that actually went into producing a third of food that is wasted?

We also know that we could have different demands for thermal comfort. Based on the calculation we did in class last week, if we simply wore a sweater or simply lowered the degree on our thermostats by 1-- lower our thermostats by 1 degree, we know that we would actually reduce quite a bit of energy use that goes into thermal comfort, one of the largest categories of energy use.

So what we're going to think through in class on Thursday is I want you to think of yourself as a member of Team Heat or Motion or Other. And we're going to ask ourselves these questions in groups-- how much energy or greenhouse gas emissions could theoretically be saved for your team? Which single technology improvement for your team-- this can be a technology in terms of fuel conversion or electricity generation or end-use conversion-- would achieve the greatest production of energy and greenhouse gas emissions?

What reduction of primary energy could your team achieve with a 20% reduction in final services? How could you achieve a 50% reduction in primary energy? And which technology would you not try to improve? Or why? I'd just like you to think through these whole chains of technologies, systems, and demands. Thank you very much, and I'll see you in class soon.