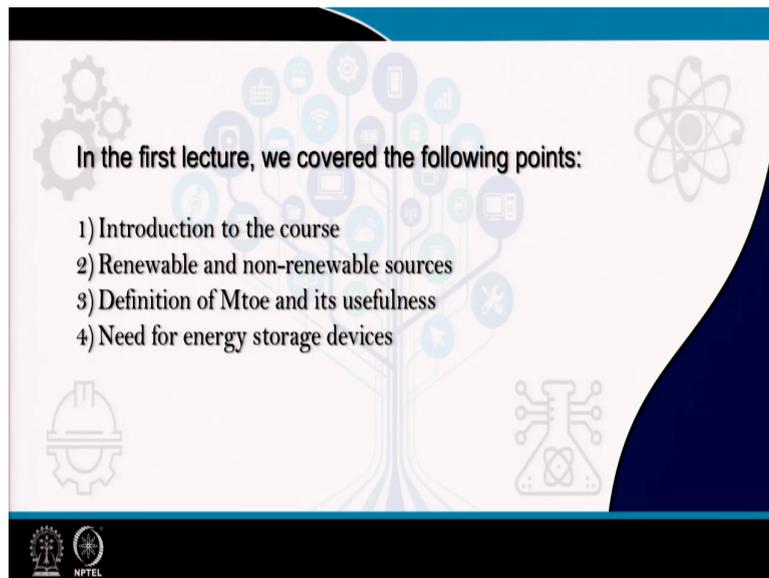


Physics of Renewable Energy Systems
Professor. Amreesh Chandra
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Lecture: 02
Energy Sources

Welcome back to the second lecture of this course on, Physics of Renewable Energy Systems. Today, we would like to start with our second topic that is Energy Sources.

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So, as you must have seen in the first lecture, it was more like an introductory lecture, where we gave you a brief introduction to the type of things we will cover in the course. A definition was given to the renewable and non-renewable energy sources, how are they similar, what are the characteristics which differentiate the two types of systems or sources.

And then the definition of Mtoe was given to you, which is a unit used to differentiate the energy which is being generated by a large-scale generation unit. And finally, before I ended, I had talked to you about the necessity of integrating energy storage devices into all future renewable energy-based landscape. So, this was what we did in the first lecture.

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CONCEPTS TO BE COVERED IN THIS LECTURE

- Classification of energy sources, according to their nature.
- Introduction to:
 - ✓ Thermal energy sources
 - ✓ Mechanical energy sources
 - ✓ Photovoltaic sources

The slide features a background with a stylized tree of icons representing various energy and technology concepts. A speaker is visible in a video inset on the right side. The NPTEL logo is at the bottom left.

So, in the today's class, let us go a step further and see what are the classification of energy sources according to their nature, you may talk about various types of energy sources, but let us give some specific classifications and then try to bring the known technologies or sources under a particular sub-heading. So, we will give you a classification scheme, which is based on the nature of the source and the three sub-classifications which we will talk about are the thermal energy sources, the mechanical energy sources, and the photovoltaic sources.

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KEY POINTS

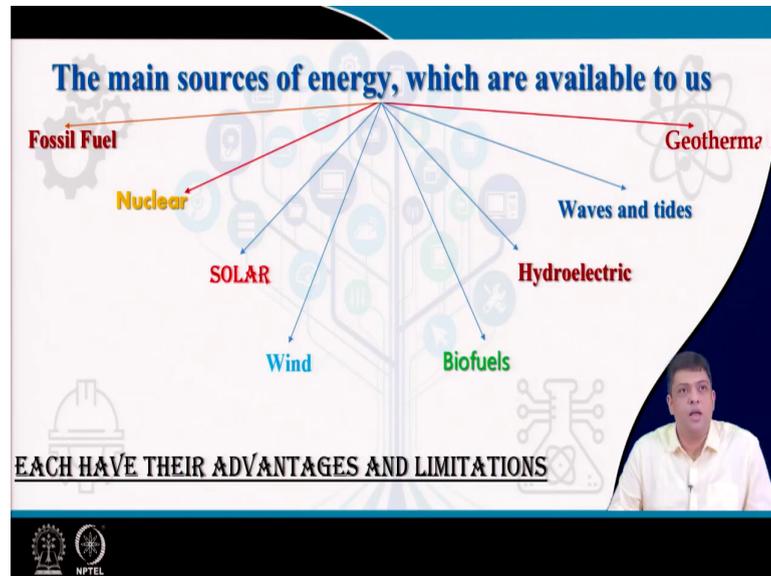
- Renewable energy sources are essential for sustainable energy growth.
- Reducing production cost of renewable energy conversion processes would make them economically viable.

The slide features a background with a stylized tree of icons representing various energy and technology concepts. A speaker is visible in a video inset on the right side. The NPTEL logo is at the bottom left.

And hopefully, by the time I finished the second lecture, you will be able to understand that renewable energy sources are essential for ensuring sustainable energy growth for our

country. And they will only become useful to us if we are able to bring down the cost of the production. So, we have to reduce the cost so, that it becomes economically viable and socially acceptable.

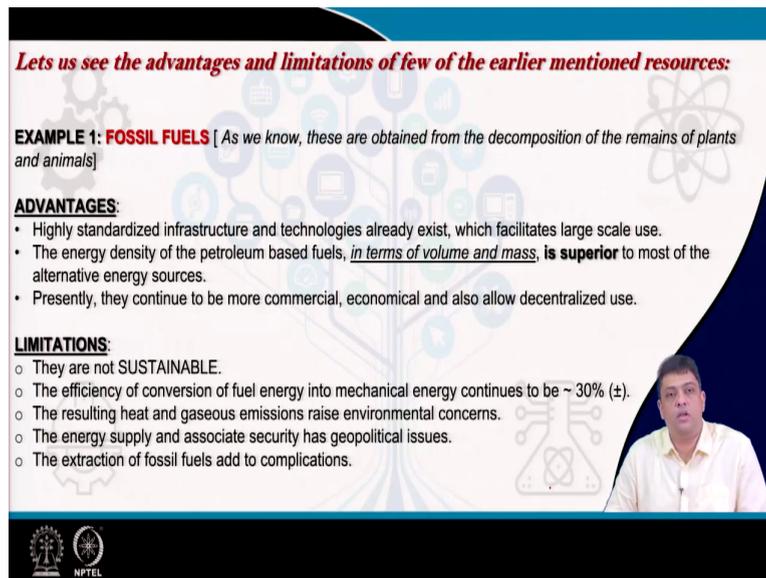
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So, let us start the lecture today. If you look around then the main sources of energy which are available to us are the fossil fuel, nuclear energy, the solar-based systems or sources, the wind energy, biofuels, hydroelectric, waves and tides, and geothermal these are the main energy sources which are available to us.

Now, I have listed so many of them in front of you, which one to use. The answer is each one of them have their own advantages and limitations, which one to use will depend on the final application of the energy source which we are going to utilize. So, please remember that there are various types of energy sources each of them have their advantages and certain limitations are associated with them and then we choose which is the best for us according to the end user requirement.

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Lets us see the advantages and limitations of few of the earlier mentioned resources:

EXAMPLE 1: FOSSIL FUELS [As we know, these are obtained from the decomposition of the remains of plants and animals]

ADVANTAGES:

- Highly standardized infrastructure and technologies already exist, which facilitates large scale use.
- The energy density of the petroleum based fuels, *in terms of volume and mass*, is superior to most of the alternative energy sources.
- Presently, they continue to be more commercial, economical and also allow decentralized use.

LIMITATIONS:

- They are not SUSTAINABLE.
- The efficiency of conversion of fuel energy into mechanical energy continues to be ~ 30% (±).
- The resulting heat and gaseous emissions raise environmental concerns.
- The energy supply and associate security has geopolitical issues.
- The extraction of fossil fuels add to complications.

The slide features a background with faint icons of a gear, a lightbulb, a computer monitor, and a molecular structure. A small video inset in the bottom right corner shows a man in a white shirt speaking. The NPTEL logo is visible in the bottom left corner of the slide.

So, let us see the advantages and limitations of the few of the earlier mentioned resources. As I had said, each one of the sources are associated with certain advantages and limitations. What is the most common fuel which we are using, it is the fossil fuel. So, let us start taking fossil fuel as the example. As we know that the fossil fuels are obtain from the decomposition of remains of plants and animals and it takes few hundreds of years to get formed.

What is the major advantage which is associated with this technology. I said the major advantage, not advantages. The major advantage is that as of today, there exists a highly standardized infrastructure and technologies for its large-scale use. So, you have petrol pumps, you have gas stations, you have oil rigs so you can take oil **the**, take out the fossil fuel, you can take it to refinery, refine, and then use it.

So, the infrastructure and technology already exists and is vastly used, that actually makes its use extremely useful. Second, if you compare the other advantages, which can be associated with fossil fuel use the energy density of the petroleum-based fuels when you compare them with other resources, you will find that in terms of volume or mass they are mostly superior than most of the alternative energy sources.

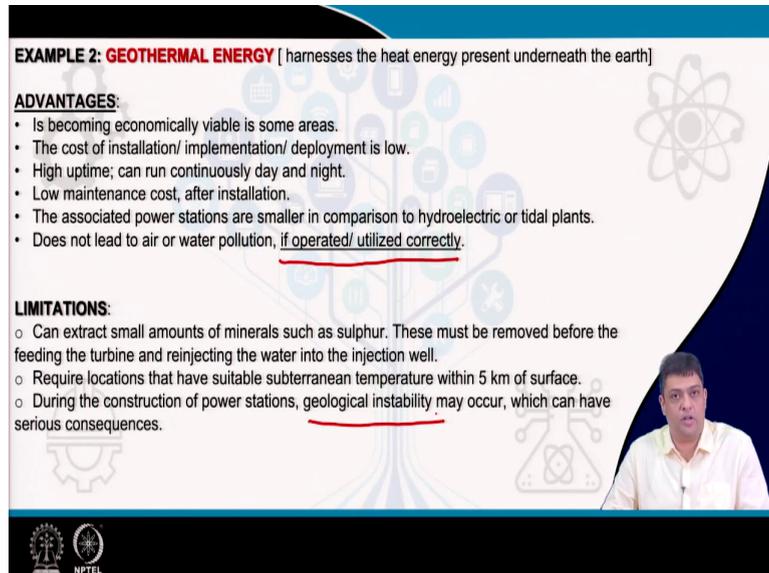
This makes them commercially viable, economically and socially also it is more acceptable. The second factor which makes it socially more acceptable is that it allows decentralized use. You don't need to be very near to the generation unit that you can use a system, it can be used far away from the place it is being actually produced. So, this is a classic example of a

non-renewable system, what do I mean by that, I mean that it is not sustainable, you use it, you lose it. So, use to lose.

Along with that, when you are using fossil fuel, then you have to convert this fuel energy into other forms of energy, so that your technologies, your devices, or your turbines, your motors can run. And this means that there is a conversion process associated in using the fossil fuel and this conversion process for example, if you convert fuel, fossil fuel into mechanical energy, then it is approximately 30 percent efficient. What do I mean, I mean that 70 percent of the energy which would have been available if we were extracting all the energy is lost.

This results in heat and gaseous emissions and the environmental concerns are known to everyone. Another limitation which is faced by India is that we don't have **reserves** of fossil fuels. And if we have, they are very limited. So, we are mostly dependent on outside world to cater our demands. This many at times leads to geopolitical issues. Along with that, the extraction of fossil fuel adds to the complication of utilizing fossil fuels. So, these are the advantages and limitations associated with fossil fuels.

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EXAMPLE 2: GEOTHERMAL ENERGY [harnesses the heat energy present underneath the earth]

ADVANTAGES:

- Is becoming economically viable in some areas.
- The cost of installation/ implementation/ deployment is low.
- High uptime; can run continuously day and night.
- Low maintenance cost, after installation.
- The associated power stations are smaller in comparison to hydroelectric or tidal plants.
- Does not lead to air or water pollution, if operated/ utilized correctly.

LIMITATIONS:

- Can extract small amounts of minerals such as sulphur. These must be removed before the feeding the turbine and reinjecting the water into the injection well.
- Require locations that have suitable subterranean temperature within 5 km of surface.
- During the construction of power stations, geological instability may occur, which can have serious consequences.

The slide features a blue header, a white background with a blue and white abstract graphic, and a small video inset in the bottom right corner showing a man in a white shirt speaking. The NPTEL logo is visible in the bottom left corner.

Let us take the second example. I have chosen certain examples, randomly it is not like, I have specifically chosen. So, I have taken this as the second example as geothermal energy. What is this energy? This is the energy which we harness from underneath the Earth.

So, what do we do in geothermal energy, you dig two wells, from one well put water inside and from the second well it goes down it gets because of the heat in the earth core it gets

heated, steam is generated and from the second well when the steam comes out, you use that steam to run a turbine. So, this is what you do while you extract geothermal energy.

So, there are certain advantages and limitations again associated with geothermal. And the main advantages which are associated with geothermal are, they are actually becoming viable in terms of implementation and economics associated in installing the geothermal units at many places. Many places means where the conditions are ideal that you can go the core is not very hard and you can go dig the wells and then you can put water in the well.

So, **you place**, there are places where it is actually becoming economically viable. And the cost of installation and implementation is not very high, why because you have to basically dig too deep wells and the technologies already exist, where you can have these kinds of wells being dig in areas where the crust is not very hard. So, you do not have a very, very hard crust. It has a high uptime, that it can run continuously day and night.

So, it is not a system which is intermittent why, because the core of the Earth is continuously heated. So, it you have heat at in the core of the Earth. So, it does not depend just like solar that during daytime you have sun and in the night time the sun is not available as the source for a particular region where there is night. So, you have very high uptime for geothermal energy.

Once installed, the maintenance cost is quite minimal. And along with that, if you compare with other units, which are using water as the source of extracting energy, namely hydroelectric or tidal plants, the power stations based on geothermal energy are much smaller. And they do not lead to air or water pollution, it is absolutely understand, is important to understand that I have drawn an underline once again this sentence if operated and utilized correctly.

So, if you do not operate the whole unit properly, you may end up sending impurities down the earth core, and or you may end up extracting impurities or minerals from the core and your water which is being used in the whole cycle may get contaminated. So, if it is operated and utilized correctly, it does not lead to air or water pollution. And that is where the first limitation comes into the picture.

While you are extracting steam out of the second well, which I mentioned earlier, you may also extract some small amounts of minerals such as sulphur or others. And if they are not

removed, before they are fed into turbines, then they may end up leading to serious corrosion or other detrimental effects may be visible.

And secondly, if you now use this water where you already have some impurities and then some more impurities get mixed up when the water was going through the turbine and then **the** to the smaller reservoir and then being pumped into the first well, then again, you are throwing impurities down the well and that could lead to the corrosion of the walls of the well.

So, if it is operated properly, you can avoid these limitations. In addition, it requires locations that have suitable subterranean temperatures within 5 kilometre of surface. So, the, if you dig a well and the temperature of the core at that place is not appreciable, then the water will not get converted to steam and will not have enough energy that it can flow out from the deep. So, then you have to use a suitable place and the choice of subterranean is absolutely critical.

And because you are trying to make this power stations at various locations where the terrain is getting dislodged, that means you are having deep digging taking place, you can lead to geological instabilities and that can have serious consequences. So, if you are digging deep well you can have, locally you can stimulate a condition of earthquakes and that can have serious consequences. So, these are the limitations associated with geothermal energy.

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EXAMPLE 3: HYDROELECTRIC ENERGY [harnessed from the ENERGY in WATER. Mostly, the downward flowing river is forced to a single location with a dam or a flume. This concentrated pressure and flow can be utilized to operate turbines or water wheels, which are connected to electrical or mechanical converters]

ADVANTAGES:

- Can lead to significant increase in the full capacity.
- **By maintaining** water flow, electricity generation process is stable and nearly constant.
- **Once installed**, the power stations lead to low pollutions.
- Is renewable and sustainable.

LIMITATIONS:

- Construction leads to serious socio-, political-, economical and environmental issues.
- Cannot be installed everywhere!
- Failure of containment areas can have catastrophic consequences.
- Requires long transmission lines.

The slide features a background with various icons related to technology and energy. A video inset in the bottom right corner shows a man in a white shirt speaking. The NPTEL logo is visible in the bottom left corner.

So, the next example which we will take is the hydroelectric energy. Here, we harvest energy which is there in water. So, what do we do, mostly the downward flowing river is forced to a

single location. Let us say in a dam, and this concentrated pressure and flow of water is utilized to operate turbines or water wheels, which are connected to electrical or mechanical convertors.

So, this is what you do in hydroelectric energy the details will cover in coming few lectures, we will have a couple of dedicated lectures on hydroelectric energy generations. But what are the advantages which are associated with hydroelectric plants, they can lead to significant increase in full capacity and it is near-instantaneous. So, if you operate, once it is operated the capacity increases significantly.

By maintaining the water flow, the electricity generation process is stable and nearly constant. So, if the flow of water down, which is flowing downwards, **if** and then it is getting concentrated to some localise region, if you can maintain this flow, then the output is nearly stable, this is very important, you have an stable output. Once installed, please remember, I am circling this.

Once installed, the power stations lead to low pollutions. I am not talking about while it is being installed or commissioned, this is a major limitation. But the final advantage of hydroelectric energy that it is a typical example of renewable energy which is sustainable. But the limitation which is always ranked one, when you talk in terms of hydroelectric plants is associated with its construction.

During construction, you will see serious socio, political, economical, and environmental issues, each one of them are not easy to counter. You will have various people who will try to convince that the building of dams are not necessary, you will have a lot of money required while you construct dam. And then you have environmental impacts and social impacts are also there that where you build these reservoirs, you have to remove whole communities and move them.

So, you are asking people to shift from a place where they may have been living for ages and that is not easy. So, construction leads to serious issues. And it cannot be installed everywhere, that is evident you need to have a downward flow of water and then you cannot install these hydroelectric plants everywhere. The failure of the containment areas can have catastrophic consequences.

So, if you have these reservoirs, where you are storing water and if it rains, then many a times you may have heard that the dams had to be opened because reservoirs were overflowing. And then just by opening of the dams, you will see flooding. This is a control opening of the doors of the dams. But consider a case where it is, there is a failure of the containment areas, you do not have any control then the, the consequences would be catastrophic.

And because they are being installed at faraway places, you require long transmission lines to be brought into the power generation or substations. So, these are the advantages and limitations of hydroelectric energy.

So, if you compare the earlier two slides with this one, you can see that okay, some of the energy sources are useful in one of the terms, while the other supersedes the earlier ones in some other cases. So, this is what I always meant that each one of the energy sources is associated with the advantage and certain limitations.

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EXAMPLE 4: SOLAR ENERGY *(uses solar radiation as the primary source)*

ADVANTAGES:

- Imparts no fuel costs, is renewable and sustainable.
- Large scale implementation (both grid and off-grid)
- Many different types of applications.
- Cost of steadily falling.
- Has seen lot of science and technology development.

LIMITATIONS:

- Intermittent. ✓
- Requirement of a DC to AC converter; leads to energy loss.
- Energy payback time is still limiting large scale use, without subsidy.

The slide features a background with a stylized tree of icons representing various energy and technology concepts. A small inset video of a presenter is visible in the bottom right corner. The NPTEL logo is at the bottom left.

Similarly, if you talk about solar energy because everybody is always quite excited when you talk about solar energy, then the advantages associated are, it imparts no fuel cost. So, you have sunrays as long as it is a sunny bright day then the source is available. So, you can use it you do not have to pay to use the sunlight, it is renewable and sustainable.

So, a classic renewable energy source. It can have large scale implementation that both grid and off-grid, so you can take it to remote areas and locally you can use it, you do not need to integrate with the existing grid. It can have many different types of applications, you will see

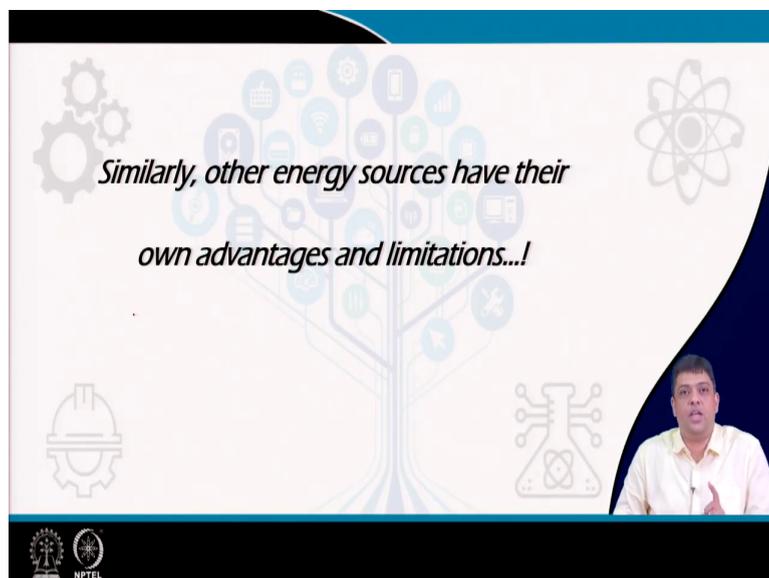
in coming lectures then when we start talking about solar energy, then it has various types of applications. Solar energy is actually can also be used for energy storage or energy generation. So, you have various types of applications of solar based devices.

And if you talk in terms of Science and Technology over the last three or four decades, there has been massive improvement in the knowledge of solar based systems. So, **the know how** which is required to take a technology to the market is now easily available with us.

So, the industries are fast coming up. Limitations, it is intermittent. We have talked about it many times and I will not repeat. It is available during daytime, not available in the evenings or nights. It, as the generation is in DC you need to convert into the AC. So, that it can be utilized by the devices. So, the requirement of this conversion process leads to energy loss.

And if you compare as of today, if there is no government subsidy or there is no subsidy available from other sources, then the energy payback time that is the amount the time required to extract the money back which I had invested to utilize or install this solar based unit is still high. So, the energy payback time is still limiting its large scale use.

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And I have talked to you about four systems. But if you look into the other energy sources, which were given in the slide, prior to the slide where I started talking about the limitations or advantages of a particular energy source, you will find that each of the energy sources have

their own advantages and limitations. Again, their final use depends on the application, where I want to use it.

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According to the kind of energy they deliver, the sources can be broadly classified as:

- Thermal Energy Sources
- Mechanical Energy Sources
- Photovoltaic Sources

So now, I know what are the energy sources which are there. Let us talk to you about the broad classification of energy sources. So, you will find that although there are various sources which are available to us, we try to classify them into sub headings. And according to the kind of energy they deliver, the sources are broadly classified into three sub headings. One, the thermal energy sources, the second, the mechanical energy sources, and finally, the photovoltaic sources. Let us see what the thermal energy sources are.

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Thermal energy sources

These are sources, which store chemical energy in a form of potential energy associated with the **chemical bonds of the molecules of a fuel.**

The burning the fuel breaks the bond and release energy, mostly in the form of thermal energy.

For example,

- Nuclear fission reactions release potential energy stored in the nuclei that undergo fission and convert it into thermal energy in the core of the reactor.
- Conventional coal fired power plants.

The conversion of thermal energy into mechanical energy is governed by the laws of thermodynamics. The efficiency is controlled by the conversion process.

Various Sources of Thermal Energy

Source	Percentage
Coal	77.20%
Petroleum coke	2.50%
Fossil fuel waste	3.90%
Plastics	1%
Waste oil	1.30%
Used food	1.20%
Rubber and used tyres	1%
Agricultural waste	1%
Others	1%

Reference: Silva et al. Environmental performance assessment of building products based on Life Cycle Assessment.

The thermal energy sources are the ones which store chemical energy in the form of potential energy associated with the chemical bonds of the molecules of a fuel. So, you have bonds,

which are there in a molecule and when you burn this fuel, these bonds break and they release energy. So, these types of sources are actually classified under the thermal energy sources.

For example, you have nuclear fission, where the nuclei undergo fission and conversion done, you get energy as thermal energy in the core of the reactor. You have conventional coal-fired power plants, where coal is continuously being burned. And the conversion of thermal energy into mechanical energy is governed by the laws of thermodynamics. And therefore, the efficiency of the overall process is controlled by the conversion process.

And they are defined by specific laws of thermodynamics. These are the two examples which I took, but there are other sources of thermal energy be it be petroleum coke, be it be plastic, be it be fossil fuel waste, be it be rubber, waste oil, used foods, agricultural waste, charcoal and others.

There are many. You can just go on listing them. But, if you look into the typical numbers, these may vary from time to time and by the time you take this course, the exact values may have changed from one literature to the other, but roughly if I see the present literature and the data available, then you will find that your thermal energy sources are mostly based on your petroleum systems. So, this is the definition of thermal energy sources, which is again been dominated by petroleum-based sources.

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Mechanical energy sources

These sources deliver mechanical energy directly (eg. wind turbine).

- ❖ *The thermodynamic limitations of thermal to mechanical energy conversion are avoided.*
- ❖ *The efficiency can be significantly higher than other processes.*

The slide features a background with a tree-like structure of icons representing various energy and technology concepts. A small video inset in the bottom right corner shows a man in a white shirt speaking. The NPTEL logo is visible in the bottom left corner.

The second, which is the mechanical energy sources. The mechanical energy sources are the ones which deliver mechanical energy directly. So, you use them and you get mechanical

energy directly. For example, wind turbines. So, you use wind and then the wind is making the turbine to rotate and that can be converted to electrical system for conversion.

And the moment I say that these sources are able to give the mechanical energy directly you are able to counter the thermodynamic limitations which are associated if you have to convert, let us say thermal energy source to a mechanical energy source. So, this limitation which was there in the previous case, is now eliminated. And because you are removing this limiting step the efficiencies can be significantly higher than other processes.

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The slide features a blue header with the text "Photovoltaic sources". Below this, a red headline states: "A photovoltaic system can directly convert sunlight into electrical energy." A red checkmark is placed to the left of the following text: "Immediate consequence: able to avoid the thermodynamic limitations of thermal to mechanical energy." At the bottom of the slide, a smaller line of text reads: "However, there are a large number of other factors that limit the efficiency of the solar based - systems and conversion processes, which we will see later." The slide is decorated with various icons including gears, a lightbulb, a laptop, and a molecular structure. In the bottom right corner, there is a small video inset of a man in a white shirt speaking. The NPTEL logo is visible in the bottom left corner.

And finally, we have the photovoltaic sources. A photovoltaic system can directly convert sunlight into electrical energy. And the immediate consequence is that this kind of system is able to avoid the thermodynamic limitations of thermal to mechanical energy conversion. So, just like mechanical energy, where the source was directly giving you mechanical energy.

Here, what you get you are using a system which converts sunlight directly to electrical energy. So, there is no, involvement of this thermodynamic process, but here also we should expect that the efficiency would be very high and comparable to mechanical energy systems or sources. The values are still much lower, because there are other, large number of other factors that limit the efficiency of the solar-based systems. And also, the conversion processes, which will be explained to you in due course of time.

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CONCLUSIONS

- 1) There are a large of energy sources, which can be useful to us.
- 2) Each of the energy sources have their own advantages and limitations.
- 3) The energy sources can be broadly:

- **Thermal Energy Sources**
- **Mechanical Energy Sources**
- **Photovoltaic Sources**

The slide features a background with a stylized tree of energy icons and a small inset video of a speaker in the bottom right corner. The NPTEL logo is visible in the bottom left corner.

So, let us summarize today's lecture, we have tried to classify the energy sources into three broad headings, the thermal, mechanical, and photovoltaic sources. Each of these energy sources have their own advantages and limitations and their final applicability depends on the place and the requirement of the end user.

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REFERENCES

- "Physics of Energy Sources" by George C. King
- "Advance Renewable Energy Systems" by S. C. Bhatia.

The slide features a background with a stylized tree of energy icons and the NPTEL logo in the bottom left corner.

So, these are the two references which I have followed and you will get more detail about the course which was discussed today in these two references. And I will also be answering your queries in the discussion sessions. So, thank you very much for attending this lecture number 2.