H. DOUGLAS LIGHTFOOT's

NOBODY'S FUEL

Energy supply is more important than climate change

— Script & Interviews —

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1 Slide: Copyright notice

1 Slide: Energy supply is more important than climate change

Welcome to Nobody’s Fuel.

This presentation analyzes the often proposed solutions to carbon dioxide emissions and the world’s energy supply problem. It will make you more aware of the importance of fossils fuels to the well-being of each of us, and how important they are to preserving our environment. As we will see, it is becoming increasingly obvious that high quality fossil fuel reserves are finite.

Nobody’s Fuel presents a set of objectives which, if achieved, could result in a solution to the world’s energy supply problem when fossil fuels are no longer abundant and affordable, as well as protecting the environment,.

This presentation explains why conservation, increases in energy efficiency, renewable energies, and the hydrogen economy cannot solve either the threat of climate change or the world’s energy problem. However, nuclear fission using fast breeder reactors can provide the world with energy for tens of thousands of years. Carbon emissions would also be reduced to acceptable levels.

Starting now to make the transition from fossil fuel to nuclear fission may avoid catastrophic future energy supply disruptions.

This presentation is the culmination of steady research since 1992. It is a robust analysis based on sound science.

1 Slide: Section 1 – Prisoner’s Dilemma – fossil fuels & what energy means to us

5 Slides: Fossil Fuels

This section discusses where fossil fuels come from:

[↓] What are they?

[↓] How much we use.

[↓] How we use them.

[↓] And finally, how important are they to us?.

7 Slides: Where do fossil fuels come from?

Nuclear fusion that powers the sun is the ultimate source of fossil fuels.

Nuclear fusion refers to combining atoms to generate heat whereas the nuclear energy we use today to generate electricity comes from nuclear fission – splitting atoms to generate heat.

[↓] Some radiation from the sun is in the form of heat which warms parts of the earth, causing winds. Other radiation energy evaporates water that rains or snows at higher elevations and provides hydro power.

[↓] Visible light drives photosynthesis for growing plants, which are the source of all food on earth. Only 0.1-0.5 % of sunlight falling on plants is converted to plant material [1].

[↓] Hydro, wind, solar, and biomass represent the renewable energies, those available in real-time, season after season.

[↓] It required millions of years of ancient sunlight to accumulate plant and animal material.

[↓] This was buried and transformed into coal, oil and natural gas.

[↓] These are the non-renewable fossil fuels, and are really concentrated solar energy stored in the earth's crust.

6 Slides: What are fossil fuels?

Fossil fuels are chemical compounds of carbon and hydrogen called hydrocarbons. The proportion of carbon to hydrogen determines the characteristics of the various compounds.

[↓] For example, as the hydrogen content increases the compounds become lighter, changing from a solid, such as coal and tar, into a liquid, such as oil, and finally with enough hydrogen, into a gas, such as natural gas and propane.

Coal is a solid containing much energy by volume. Coal was first used in China, as early as 3000 years ago, to smelt copper. Coal is retrieved from the ground by coal miners in caverns deep underground or, closer to the surface, by strip mining, where huge steam shovels strip away the top layer of earth and then layer after layer of coal.

Next are the liquid fuels that power our transportation systems—gasoline, diesel and jet fuel. Oil was formed, not from plants, but when millions of tiny sea creatures, known as diatoms, died and piled up on the ocean floor. Earth’s tectonic plates have shifted and folded over millions of years, resulting in pockets of oil distributed worldwide.

Liquid petroleum is mixture of complex hydrocarbon molecules. In the past, when petroleum sank deep enough in the earth the excessive heat and pressure broke these molecules into shorter hydrocarbons, making natural gas—mostly methane (CH_4)—the chemically simplest fossil fuel.

Natural gas is used to generate electricity and is piped to our homes for heating and cooking. Propane can easily be liquefied for storage in containers for home heating or small applications such as barbeques, where portability is important.

Finally, hydrogen is a valuable chemical [2] and this is by far the major use. Very little is used for its energy content except for specific applications such as spacecraft propulsion. Most hydrogen is manufactured from fossil fuels, especially natural gas.

[↓] In an effort to reduce carbon emissions, a certain amount of coal for generating electricity has been replaced with natural gas because, for the same energy input, natural gas has 60% of the carbon emissions of coal, and oil has 70%.

[↓] Coal contains 76,635 million joules per cubic meter. Next, gasoline is a liquid with a high energy density per unit of volume. Natural gas and hydrogen have a very low energy density per unit of volume.

[↓] Coal is used as fuel for generating electricity and making coke for steel furnaces, etc.. Oil is refined to make liquid fuels, such as gasoline and diesel, used to power the transportation sector. The energy concentration of liquid fuels allows the relatively small tank in your car to provide a range of hundreds of kilometres. Liquid hydrocarbons are easy to pump, distribute, control, and they vaporize readily for use in engines. Oil also has industrial uses and can be made into various products, such as nearly all forms of plastic—plastic bottles, bags, toys, electronics, etc—or even clothing, such as polyester.

Natural gas is used primarily for electricity generation and heating. More than 90% of hydrogen gas is used as a chemical and reacted during various chemical manufacturing processes.

[↓] Finally, tar and asphalt are used for roads. Tar, or bitumen, in the Alberta tar sands of Canada, is reacted with hydrogen to make a synthetic crude oil.

Interview

Interviewer: We've heard a little bit about fossil fuels being a primary form of energy. What is primary energy and is there a secondary energy?

H. D. Lightfoot: Primary energy is energy as it naturally occurs, such as coal, oil, natural gas, sunlight and wind. We cannot use these forms of energy directly so they are converted to secondary energy, the energy we actually use, such as gasoline in the tank of our car or electricity at the wall plug. It is the gasoline which actually moves our car and the electricity which actually runs our vacuum cleaner.

The fossil fuels, coal, oil and natural gas, are the most important forms of primary energy today simply because they are concentrated solar energy which has been stored up over millions of years. Gasoline refined from petroleum allows us to harness concentrated sunlight to run heavy equipment and power our cars. Gasoline is very concentrated energy. For example, one gallon of gasoline was once roughly 100 tons of vegetation, or 40 acres of wheat[3].

Interviewer: Where do renewable energies fit into the picture?

H. D. Lightfoot: The reserves of fossil fuels can be thought of as being like a giant bank account from which funds are withdrawn on which to live. Unfortunately, the funds are being used up and not being replenished.

Renewable energy comes from the sun and is so dilute that it takes a lot of time to accumulate significant amounts—that is why it took millions of years to accumulate our fossil fuel bank account in the first place.

Renewable energies are like having a small daily income. It's a bit like living pay-check to pay-check, except that sometimes the pay-check does not come through. For example, wind and solar deliver energy, mostly as electricity, intermittently and often depending on the weather—the electricity must be used as it comes in or it is lost. Hydro is better because water can be stored and used to make electricity as required, and for short periods can be used faster than water is being replenished.

Biomass is a form of stored energy, usually in solid form. Much of it grows and is eaten or decayed over the course of one season. However, biomass in the form of trees can be stored for many seasons until harvested. For centuries wood was the world's fuel of choice. Today in developed countries, wood is rarely used directly for fuel because there is not nearly enough of it, and it is not as concentrated and easy to transport as fossil fuels. Liquid fuels, such as methanol and ethanol, can be manufactured from solid biomass such as wood and grains, thereby making transport easier and biomass useful in a much wider range of energy applications. But these processes don't help because they are energy intensive. For example, growing corn and manufacturing it into ethanol requires a very large contribution of energy from our fossil fuel bank account, almost the same amount of energy as in the ethanol itself.

3 Slides: World energy consumption (EJ/yr)

This bar graph represents world energy consumption in 1970 [4]. Please take note that renewable energy comprises a tiny portion of this energy mix, with 93% supplied by fossil fuels.5

The unit of energy used throughout this presentation is the "exajoule", or the abbreviation "EJ", which is equal to the number ten followed by eighteen zeros. One exajoule is the amount of energy in the petroleum contained in 105 super tankers the size of the Exxon Valdez, or approximately 28 billion litres of gasoline, which is enough to fill the tanks of 500 million cars.

[↓] By 1995, world energy consumption had grown substantially from that of 1970. As nuclear energy and hydro consumption grew between 1970 and 1995, the percentage of fossil fuels i.e., coal, oil and natural gas, dropped by about 8 percentage points from 93-85%, and has remained at 85% since then. The drop in fossil fuels occurred because nuclear energy grew from close to zero to about 7% of total world energy. Renewable energies are 8-9% of world energy.

[↓] World energy consumption has grown from 227 EJ in 1970 to an estimated 457 EJ in 2005 [6]—an increase of 100% in 35 years.

The point is that fossil fuels are 85% of current world energy supply, and only fossil fuels can supply today's world energy requirements. Any alternatives to fossil fuels have to replace most of the 388 EJ of fossil fuels to effectively control carbon emissions. This energy replacement target will rise as world energy demand rises.

6 Slides: Renewable energy (EJ/yr)

The term “renewable energies” usually covers hydro,

[↓] biomass,

[↓] wind,

[↓] geothermal

[↓] and solar.

By “Renewable” we really mean “inexhaustible”.

Renewable energies enter the world energy system as electricity and their contributions can only be compared through the quantities of electricity produced. In this slide, the heights of the columns under “Renewable energies” are proportional to the amount of electricity produced from each renewable source.

[↓] Is it possible to increase the 9% contribution of renewable energies to replace 388 EJ of fossil fuels? Let’s look at the history of renewable energies as fuel.

8 Slides: 300 years of US renewable energies

Fuel supply in the United States up to 1850 was virtually 100% wood [7].

[↓] In England by 1700, trees for fuel had become scarce and people turned to coal. But, the coal mines were flooding and there was no good way to pump out the water. Some mines had to be abandoned.

In 1712, Thomas Newcomen invented the steam engine specifically to pump water out of coal mines. Up to then, small amounts of power had been supplied by wind mills and water power—but these were limited by wind currents and proximity to rivers. Coal and Newcomen’s engine provided portable energy for the first time [8]. James Watt’s contribution was to greatly improve the efficiency of the Newcomen engine.

[↓] The mid-1800s was the time of steam boats on the Mississippi River system. To provide fuel, trees were gradually being cut farther and farther from riverbanks. Forests were being depleted to provide fuel—trees were cut down faster than new ones could grow.

[↓] The switch to coal, or stored solar energy, began in about 1850, followed by

[↓] natural gas

[↓] and oil.

[↓] The use of what we call today "renewable energy" declined from 100% to its present level of 7-8%, and today is mostly provided by hydro power. The decline occurred for good technical reasons—renewable energies simply could not supply enough reliable energy. The switch to fossil fuels was beneficial for the environment because it allowed forests in the United States to recover, and today there is more forest than in the late 1800s.

[↓] It is also interesting to note that slavery ended soon after the switch to fossil fuels.

Interview

Interviewer: Are you drawing a parallel between increased energy use and the end of slavery?

H. D. Lightfoot: In a sense, yes. Although there is no question about a moral component, slavery is recognized to be a fundamentally economic phenomenon, used to benefit those in power. The ancient Egyptians enslaved 20,000 people in order to build the pyramids. Agriculture required tremendous numbers of slaves, throughout history.

Why would you need an indentured Victorian scullery maid to wash your dishes, when you can just turn on a dishwasher? Why house, feed, administer, and intimidate 20,000 slaves in the middle of the desert when diesel-powered machinery and an engineering team can build a bigger and better pyramid much faster. It can also be argued that increased energy consumption has lead to the destratification of society. Class structures in society are far less pronounced than they were in the past, thanks to increased energy use.

Interviewer: What do you want viewers to take away from this section?

H. D. Lightfoot: What is important to recognize from this topic is that we used to power our society using biomass, such as firewood. However, there was not enough wood to power the world centuries ago when energy consumption was several times less than today. This is why we switched to coal in the first place, to harness the stored solar energy in the ground. When people talk about the return to biomass, such as producing ethanol from corn and methanol from wood, they do not seem to be aware that this strategy did not work 150 years ago. They appear to underestimate the scale of world energy use.

Interviewer: Please explain.

H. D. Lightfoot: Many ways of generating electricity are possible on a small scale in a laboratory. But, when we evaluate these methods against the quantity of electricity the world uses, most are not practical, often for several reasons. That is why about one-third of the world's electricity is generated by burning coal, another third by hydro and nuclear together, and the remaining third by natural gas and oil. Understanding the scale can make a huge difference when assessing the possible contribution of any energy source. For example, renewable energies supply about 9% of world energy today, or about 40 EJ [9]. This is a small part of the target to replace most of the 388 EJ of fossil fuels consumed in 2005, and percentage-wise is not likely to increase for good technical reasons.

3 Slides: World energy uses and sources

Electricity generation consumes about two fifths of all world energy and uses all forms of primary energy. Fossil fuels account for about 60% of electricity generation – coal alone accounts for about one third. All of the renewable energies are included in hydro – they are small and produce electricity.

The importance of electricity cannot be overemphasized in today's world. It powers our communication, control and lighting systems and the machinery and equipment in our factories and offices. There are no substitutes for electricity.

[↓] Transportation, consumes approximately one fifth of world energy. It is supplied 95% by oil [10], simply because there are no substitutes for oil on the scale required. Liquid fuels are concentrated and easy to handle.

[↓] Residential, industrial and commercial account for about two fifths of world energy demand and consume oil and natural gas, mainly for space heating, plus all of the electricity from electricity generation.

4 Slides: Future world energy consumption

The line of red triangles line represents actual world energy consumption from 1970 to 2005.

[↓] This line of red circles represents the "Business as Usual" scenario IS92a prepared in 1992 by the Intergovernmental Panel on Climate Change [11]. This scenario suggests world energy consumption would quadruple between 1990 and 2100.

Scenarios such as IS92a are uncertain because no one can predict the future. However, "Actual" consumption very closely matches the IS92a scenario between 1990 and 2005.

Four times current world energy demand is a tremendous amount of energy. It will become increasingly difficult for fossil fuels to supply this energy as reserves dwindle.

[↓] This line of red squares represents carbon-free energy. To limit the concentration of carbon dioxide in the atmosphere to 550 parts per million by volume (ppmv)—twice that of pre-industrial days—carbon-free energy would have to be available in sufficient quantity to follow this line to about 1200 EJ in 2100 [11]. We will talk more later about carbon dioxide levels in the atmosphere.

[↓] The "Business as Usual" scenario line includes a 1%/year decline in energy per unit of output, which results mostly from increased energy efficiency. We will talk more later about energy efficiency.

Why is there such a large increase in world energy consumption? In part, it is caused by a predicted increase in world population. However, a more important factor is growth in energy consumption per person, as shown on the following slide.

5 Slides: Energy use per person vs. income

The red dashed line shows a strong positive correlation between Annual energy consumption per capita and Annual Gross Domestic Product per capita for 166 countries [12]. GDP per capita is related to income per capita and will be used from now on.

Energy use creates wealth, freedom and a better life for people.

[↓] The people living in the countries shown in the upper right corner use one hundred times more energy and have one hundred times more income

[↓] than those who live in the countries shown in the lower left corner.

They have much more control over their lives, more freedom of choice, better medical care, more and better food, clothing and shelter.

Most people in the world are trying to move up towards higher income and, therefore, more energy consumption per person. This includes the people who listen to this presentation—few, if any, people are exempt.

Most of the world's population live in countries shown in the lower left of the chart and must use more energy to increase income per person and break out of poverty. This is why energy consumption is expected to grow rapidly throughout the century.

[↓] China and India together represent one-third of the world's population. Their people are at the lower end of the red line and are vigorously trying to move higher up the line.

[↓] These next eleven countries also represent about one-third of the world's population.

All together these 13 countries represent almost two thirds of the world's population, and most are at the lower end of the red line.

4 Slides: US energy consumption per capita

US per capita energy consumption up to about 1900 was just under the equivalent of four thousand litres of gasoline [13]. This energy came mostly from firewood.

[↓] By about 1950, US per capita energy consumption had increased to about the equivalent of eight thousand litres of gasoline. Large rural electrification projects during the Great Depression had extended electricity to most Americans.

[↓] Today, energy consumption per capita is equivalent to almost twelve thousand litres of gasoline.

[↓] The main point is that during the period from 1850 to 1900, the switch to fossil fuels occurred and energy consumption per capita tripled. Adding this information to the previous slide, we get a surprising result.

1 Slide: US energy use per person vs. income

This slide demonstrates that the United States used more energy per capita in 1850 than almost 60% of the world uses today. The wealth of the United States compared to that of the rest of the world can be attributed, at least in part, to consuming relatively large amounts of energy for more than 150 years. This reinforces the message that people living in underdeveloped countries must have more access to energy, and use it effectively, in order to develop.

2 Slides: CO_2 emissions per person vs. income

This slide demonstrates that energy per capita and carbon emissions per capita have a parallel relationship with respect to income per capita [12]. This is to be expected because the world's fuel supply is 85% fuels.

Thus, reducing carbon emissions per person results in a proportional loss of income—a 25% reduction in carbon emissions results in a 25% loss of income. This is true, unless fossil fuels can be replaced with carbon free energy on the scale required. Once again we see that the problem of scale is a significant issue.

[↓] Just like for energy consumption, those countries with the lowest carbon emissions per person have the lowest income per person. These figures for energy and carbon emissions are average for the world. A specific country like Canada may have a slightly different carbon/income line because fossil fuels are about ten percentage points lower than that of the world average, mostly because of hydro power. However, the overall trend line is the same.

Interview

Interviewer: But isn't income versus energy consumption just a correlation?

H. D. Lightfoot: No, it is not just a correlation. There is a direct "cause and effect" relationship between the use of energy and the resulting income. In the beginning, it was people's energy that provided food, clothing and shelter from the land by hunting, tilling the soil, building shelter, etc. Harnessing animal power increased the amount of land one person could use to raise food, and income moved up the trend line. This has been proven by archaeological evidence—that farming provided time for development of civilization; trades, arts and culture. Using a tractor and gasoline, one person could produce even more wealth—and time became available for leisure, cultural activities, education, health control, etc. Again, incomes moved farther up the income trend line. It is important to understand that if the tractor were taken away because there was no more gasoline, incomes would slide quickly down the line.

The fact that energy consumption per person determines our well-being and gives us freedom and control over our lives cannot be overemphasized. Fossil fuels magnify the work output of people and create more goods and services for their use and benefit.

Interviewer: Your implication is serious – that if there is not enough energy, our income slips.

H. D. Lightfoot: Yes! Consider carefully the very negative effects of reducing use of fossil fuels without having an alternative energy source available on a scale large enough to replace them. There's the scale concept again—one can never get very far from it.

Interviewer: But there is another side to decreased energy use: deliberately reduced consumption through legislation or taxes. Does this play into the equation?

H. D. Lightfoot: Capping or forcefully reducing energy consumption will reduce people's income. Because there is a direct cause and effect relationship between energy consumption per capita and income per capita, reducing carbon emissions by 25% will reduce income per capita by 25%. Such a reduction can only occur painlessly if there is adequate replacement energy—up to 388 EJ of fossil fuels in 2005—there's the target again. People need to understand the seriousness of this situation.

Interviewer: But, as you've already said, this has a serious implication for the bulk of humanity, living at the bottom of the income scale.

H. D. Lightfoot: The peoples of the world now living in poverty must learn how to use more energy to break the bonds of poverty and participate in the world of today. The world must consume more energy, not less.

Two billion people around the world still do not have electricity [14]. Fifty percent of them live in Asia, 35% in India alone [15]. In an era when an average European cow is subsidized by $250 per year, one billion people in developing countries try to survive on less than $200 per year.

In developing nations, such as Kenya and Nepal, 2.4 billion people still rely on traditional energy sources—wood and animal dung—for cooking and heating fuel [16].

Everyone, on all sides of the political spectrum, is trying to improve the economic outlook for the people in these countries. By definition, this guarantees an increase in energy consumption per person.

6 Slides: Income per person

What does income per person really mean to us? "Income per person" is represented by all of the goods and services we consume or have at our disposal. This is the wealth that fossil fuel energy has created for us. These are the things that give us control over our lives – they help us to live full and useful lives – they are:

Clean water & air, safe & abundant food, good sanitation, pollution control, protection of the environment . . .

[↓] Health care: medicines, hospitals, doctors, nurses . . .

[↓] Houses, apartments, hotels, cottages, lawns, parks . . .

[↓] Schools, malls, factories, heating, air conditioning, lighting, pets, toys, fashion . .

[↓] Communication: newspapers, TV, movies, cameras, computers, email . . .

[↓] Transportation: cars, trucks, trains, ships, airplanes, roads, bridges, canals, airports.

And the list goes on . . .!

2 Slides: Income per person continued

“Income per person” is represented by all of the goods and services we consume.

The average person in poor countries does not have access to most of the items on the previous list. The background of this slide is a picture of the world at night. It is clear that there is a tremendous amount of economic activity throughout Asia, particularly in Japan and South Korea.

[↓] However, North Korea seems to disappear at night, highlighting its poverty and low standard of living [17].

Interview

Interviewer: This begs the question: which items would you remove to cut energy use by 25%?

H. D. Lightfoot: Exactly. This involves very difficult choices. Everyone’s list will be different. We all would eliminate that which we do not have.

Transportation, which consumes one-fifth of world energy, and electricity, which consumes about two-fifths, are essential parts of every thing in our lives.

Interviewer: How do you mean?

H. D. Lightfoot: Everything in your home has come from somewhere. Every ball-point pen, every bar of soap, every article of clothing. In fact, with the modernization of the economy through globalism, items often travel between countries during the manufacturing process. As soon as humans stopped being nomads, they moved everything in their lives around instead.

Lets look at the specific example of food, which is something everyone can relate to: consider where our food comes from: the average item in a supermarket has travelled over 2500 kilometres to get there [18]. For every one calorie of carrot flown into Britain from South Africa, 66 calories of fuel were used to get it there. The processing and baking of breakfast cereal takes 4 calories of energy for every calorie of food delivered to the bowl. Manufacturing a 2 pound box of breakfast cereal burns the energy of about two litres of gasoline.

Thirty-five years ago, a club sandwich was considered exotic. No one in North America had heard of sushi, hummus, sun dried tomatoes, pesto, or Starbucks. The modern palette has been developed, marketed and delivered using energy.

The items on the list we have just seen are examples of exactly what wealth, freedom and a better life means for each of us. Every item is there because of fossil fuels. Reducing fossil fuel consumption will reduce the number of these items and their size. People and the environment will suffer in many ways unless adequate replacement energy is available.

1 Slide: Section 2 – Aladdin's Lamp – how much fossil fuel is left?

2 Slides: We are using oil faster than we can find it

Oil is very important to us. This slide shows the past discovery of oil in the 20th century. It is clear that the amount of fresh oil being discovered is decreasing dramatically [19.

[↓] The more disturbing trend however, is that since 1984, oil has been consumed faster than it is being found.

The law of diminishing returns is also setting in. It takes more energy to extract oil from the ground – especially recovering bitumen from tar sands and converting it to oil. In the 1940s it took the energy contained in 1 barrel of oil to find 100 barrels. Today, each barrel spent only gives back 10 barrels [20].

If finding or extracting oil requires the equivalent of 1 barrel of oil as energy in, for each barrel out, then normally the field is abandoned.

However, if the input energy is not from oil, but from a source such as nuclear, in the future it may be possible to put in 3 units of nuclear power to get 1 unit of oil energy out, if the oil were valuable enough, such as for military use. We do this with electricity because it is so valuable to us. We put three units of fossil fuels or nuclear energy in for each unit of electricity we get back. This would not solve the oil supply problem, but would extend the time that oil is available, although probably at a much higher cost.

3 Slides: How big are fossil fuel reserves?

The oil and gas reserves shown on this slide are from estimates made by the U.S. Department of Energy and converted to exajoules for comparison with information on the previous slides.

The reserves in exajoules have been divided by consumption in 2005, to give an estimate of how long the reserves might last. This is not an accurate method for oil, but does give some idea of what might happen. We cannot take out oil at a constant high rate and have the flow suddenly stop. Production will hit a point where it no longer exceeds consumption – this is the “peak” we hear about. The peak will certainly occur before the 36 to 44 years shown here, even though smaller flows will continue for, perhaps, centuries.

In summary, the life of oil is about 40 years [21],

[↓] for natural gas it is about 60 years [22]

[↓] and for coal it is over 200 years [23].

6 Slides: USGS view on world oil reserves

This slide shows the U.S. Geological Survey’s estimate of how much crude oil there is in the world [24]. Consumed oil is oil we have already used to date.

[↓] Proved Reserves is the amount of oil which has been validated to be present in the world’s oil fields.

[↓] Undiscovered represents the amount of recoverable oil which might be found.

[↓] Reserves growth refers to oil that might be obtained through more effective recovery procedures.

[↓] The USGS estimates that there is a 50% probability that this amount of oil can be found and recovered in an economically viable way [24].

[↓] The remaining oil is deemed unrecoverable. It will be impossible to recover all of the oil in the ground because it is in porous rock – something like being in a sponge made of rock – except rock cannot be squeezed like a sponge to recover the oil [25].

It has been argued that this prediction is overly optimistic. For example, Undiscovered oil and Reserves growth are estimated by the USGS to be larger than all the oil we have consumed to date. In other words, it assumes we are going to find and develop more oil in the next thirty years than we consumed during the last hundred years.

1 Slide: Campbell-Laherrere view on oil reserves

There is an ongoing controversy about the true size of oil reserves. This estimate was prepared by Colin Campbell, a UK geologist, and Jean Laherrere [25]. Both spent many years in oil exploration and other facets of the oil industry and have wide international experience. It is a more conservative, and may be a more realistic estimate. The point is that good information about oil reserves is not readily available because the owners of the oil are becoming more secretive as reserves diminish.

The fact that oil companies are trying to exploit the more difficult sources of oil, such as drilling in the deep ocean and exploiting tar sands, is a good indication that oil is becoming much more difficult to find and to extract.

11 Slides: Reserves vs. production rate

There are two key points to consider when analyzing fossil fuel reserves.

Firstly, reserves and estimates about how much of the oil can be recovered are independent of time.

[↓] Secondly, however, consumption and production are time related, and are measured in barrels per day. When production per day cannot keep up with consumption per day, a production peak has been reached, and shortages occur.

Reserves and production rate are independent of each other. Production rate is the most important because it determines current supply. Reserves of various kinds may be enormous, but if oil cannot be produced from them fast enough there is a critical supply problem.

[↓] Oil is not like other minerals, such as uranium [26], where the volume of reserves increases as the price goes up because lower concentrations of the mineral become economical to mine. The nature of an oil field is such that total volume is fixed. The rate at which oil can be recovered diminishes as more and more is removed. The effect of increasing oil prices is to lengthen the time that oil can be recovered, but at smaller production rates every day.

[↓] "Unconventional oil cannot be extracted fast enough to meet demand. Most unconventional oil production is an industrial mining operation where the ore is removed from the ground and processed into synthetic crude oil. The facilities and raw materials, such as water and natural gas for heat and hydrogen, are huge compared to drilling a hole and pumping out crude oil ready for the refinery.

[↓] As potential for finding new oil deposits shrinks, four sources of unconventional oil that become attractive. The tar sands of Alberta are the easiest to exploit and have potential to produce 300 billion barrels of synthetic crude oil.

In the eight years from 1997 to 2004, $34 billion dollars was invested and production increased from 0.18 to 0.36.billion barrels per year. Plans are in the works to invest about $70 billion dollars in the years 2005 to 2015 and increase production from 0.36 to 0.9 billion barrels per year [27].

This is "a drop in the bucket" compared to current consumption of 31 billion barrels per year.

The simple fact is that tar cannot be recovered and converted fast enough for the Canadian tar sands to be more than a small contributor to world oil supply. Nevertheless, the tar sands are a very large and valuable resource and may be exploited for hundreds of years.

[↓] The production rate problem is even worse with oil shale. Oil shale is a rock containing an organic material called kerogen that converts to oil when heated to about 500^{o}C. Estonia, Russia, Brazil and China currently mine oil shale, however production is declining due to economic and environmental factors [28].

[↓] Heavy oil in Venezuela can be converted to oil suitable for refining after extraction and upgrading. Again, production rate is the problem as investment in huge facilities is required.

[↓] Deep in the ocean, there are huge quantities of methane hydrate, which is natural gas held in a matrix of water just above freezing, deep in the ocean. Undersea mining is difficult. There are no current recovery operations and none expected for a few decades. Again, huge investment and facilities for recovery and conversion to liquid fuels are required, and production rate is likely to be small, compared to demand.

The production rate of liquid fuels from unconventional oil is likely to continue to be far too small to meet demand, and for the longer term future, all are finite and expendable.

4 Slides: USGS probability of oil production peak

This line displays the actual oil we have produced to date. The United States Geological Survey predicts three different dates for peak oil, based on the probability of increasing recoverable reserves [24].

[↓] The first date is 2026 with a 5% probability that the peak will be reached by then.

[↓] The second is 2037 with a 50% probability that the peak will be reached by 2037. That is the same probability as flipping a coin. With oil being so important, to count on reaching 2037 before peak oil is not a good bet.

[↓] The third is 2047 with a 95% probability that the peak will be reached by then.

Interview

Interviewer: Peak oil occurs when the maximum possible production rate of oil is less than consumption. When we reach peak oil, what role do you see “unconventional oil” playing, such as the tar sands or oil shale?

H. D. Lightfoot: “Unconventional oil” will always have a small role in world oil supply. It is important to understand that reserves of “unconventional oil” are not related to production rate. Synthetic crude oil cannot be produced fast enough from “unconventional” sources to come anywhere close to meeting even current world oil demand.

Interviewer: But won't increased oil prices actually extend the supply?

H. D. Lightfoot: Yes, but not by much. A few new oil fields may be found in difficult to reach places, such as the deep oceans. The amount of oil in a field is fixed and will not increase with higher prices. As the production rate from an oil field diminishes, smaller production rates become economically viable with higher prices, and a bit more oil will be recovered than if the price were lower.

Much, if not all, of the easily recovered oil has been found. That's why off shore oil was developed and also explains why there is interest in "unconventional oil".

There are no perfect alternatives for any of the fossil fuels, and certainly not for the liquid fuels from oil that are vital for road and air transport. There are some alternatives to liquid fuels, but they are really only small niche applications and are not available on the current scale of about 100 EJ per year, or the equivalent of about 700 billion US gallons (2800 billion litres) of gasoline world-wide. There's the concern for scale again.

Considering the importance of oil, it would be prudent to start preparing now for shortages of liquid fuels. The date of peak oil production may not yet be known with certainty, but it may occur at any time. It is essential that we view the situation realistically.

1 Slide: Section 3 – Core of the matter – CO_2 and the environment

8 Slides: CO_2 in the atmosphere

If there were no carbon dioxide in the atmosphere, the earth's atmospheric temperature would be minus 18ºC [29] and the earth would be a frozen planet.

There is a correlation between carbon dioxide and the earth's temperature.

[↓] The ice ages correlate with a carbon dioxide concentration of about 180 ppmv.

[↓] Concentration was about 275 ppmv, when the ice melted and most of the planet became habitable by humans.

[↓] Today the concentration is about 380 ppmv. The record of this correlation goes back for 400,000 years based on the Vostok [30] and Siple Ice Cores [31] taken in Antarctica.

[↓] The Benchmark is the WRE 550 line [11], and is 550 ppmv, twice the level of

275 ppmv in pre-industrial days. It is often referred to as “double carbon dioxide”. It is a benchmark used by scientists to estimate how much doubling the concentration of carbon dioxide in the earth’s atmosphere would affect atmospheric temperature, climate, and other factors.

As late as the early 1980s, some scientists were predicting the earth was about to enter another ice age [32]. These predictions began to change as a result of measurements of the concentration of carbon dioxide in the atmosphere at Mauna Loa in Hawaii started by Charles Keeling in 1959 [33], when the annual average was 315 ppmv. As the average increased in the following years, people began to realize the extent to which carbon dioxide concentration in the atmosphere was rising. All other factors being constant, an increase of carbon dioxide in the atmosphere will warm the earth’s atmosphere.

[↓] The Intergovernmental Panel on Climate Change “Business as Usual” scenario IS92a represents an estimate of the rate of carbon dioxide increase in the atmosphere if fossil fuel consumption continues to grow as in the past. On this path, carbon dioxide concentration will meet the 550 ppmv benchmark by about 2050.

[↓] The Kyoto line, calculated by James A. Edmonds [34], represents the estimated rise in carbon dioxide levels if all of the countries that signed on to Kyoto were to meet and maintain their commitments. This path would delay reaching the benchmark of 550 ppmv by about ten years, or to about 2060. The level of carbon dioxide would continue to rise above 550 ppmv at the annual 1990 rate of about 1.5 ppmv. This rate is likely to increase because more than half of the world's population has not signed onto Kyoto, and they represent the greatest potential for increase in energy consumption per person.

[↓] The only control we might have over the atmospheric temperature would be to limit the rise caused by carbon dioxide by eliminating, or sharply reducing, carbon emissions. It appears that the lowest level that we might have a chance to achieve would be “double carbon dioxide” because replacing fossil fuels will take a long time.

Since pre-industrial days, there has been a smooth 35% rise in the concentration of carbon dioxide in the atmosphere. However, a history of atmospheric temperature shows that at a given level of carbon dioxide atmospheric temperature can fluctuate widely by several degrees [35]. The earth’s temperature does not react smoothly to an increase in carbon dioxide concentration because, from time to time, one or more natural factors can temporarily override its effect.

5 Slides: Atmospheric temperature – natural variables

Several natural variables affect the world's atmospheric temperature. Carbon dioxide is the most important of the greenhouse gases and nourishes all plant life, which is at the bottom of the food chain.

[↓] Under certain conditions, water is a more powerful greenhouse gas than carbon dioxide and contributes to keeping the climate warm enough for us to live. However, on any given day, moisture as clouds can be reflecting sunlight or retaining heat.

[↓] Radiation received by the earth from the sun varies according to variations in the sun's energy output, the distance the earth is from the sun and variations in the earth's declination.

[↓] Sulphur aerosols and dust from volcanic eruptions lower the atmospheric temperature by reflecting the sun's rays away from the earth, and volcanic gases warm the atmosphere.

[↓] Methane is a natural and small component in the atmosphere and about half comes as "swamp gas" from wetlands. Its effect is small in comparison to that of carbon dioxide. Although it has about twenty times the warming effect of carbon dioxide, it breaks down to carbon dioxide and water in about ten years.

5 Slides: Atmospheric temperature – man-made variables

Several man-made variables affect the world's atmospheric temperature.

By far, the largest of the man-made sources of atmospheric carbon is carbon dioxide from the production and burning of fossil fuels.

[↓] Methane is a smaller factor and is released by several human activities, such as farming of ruminant animals, such as sheep, where part of their digestion is a fermentation process that releases methane, as well as growing rice or burning wood and other biomass at too low temperature.

[↓] The use of Freon is being phased out by the Montreal Protocol since 1987 because alternatives are available.

[↓] Sulphur aerosols reflect sunlight and are discharged to the atmosphere when the sulphur in fossil fuels is burned.

[↓] Nitrogen oxides from the burning of fossil fuels have a warming effect.

2 Slides: Global average near surface temperature

The green baseline for this graph is the average of the green dots, 1961 to 1990 [36].

An example of the effect of naturally occurring factors can be seen by the three red dots just above 1990. The upper one is the temperature of the earth's atmosphere in 1990. The middle one is the temperature in 1991, which was reduced by discharges from the eruption

[↓] of Mount Pinatubo on June 15, 1991. Sulphur aerosols and dust reflected sunlight and cooled the atmosphere. The lower red dot shows further cooling in 1992.

Another example of the effect of natural factors can be seen by a drop in atmospheric temperature between about 1940 and 1970 even though the carbon dioxide concentration increased by about 25 ppmv, or 8%.

In spite of all the variation, for one or more reasons, there is a measurable increase of about 0.8°C in the earth's average atmospheric temperature since the late 19th century when the atmospheric concentration of carbon dioxide was about 295 ppmv.

How much will increasing the concentration of carbon dioxide from 275 ppmv to 550 ppmv raise the earth's atmospheric temperature? The estimates range widely from 1.5 to more than 4.5°C [37]. Just from doubling of carbon dioxide, the temperature rise should be about 1.5°C. Figures above this are the result of estimates of the effect of feedbacks that magnify the temperature. The current debate is over the magnitude of the feedbacks.

Interview

Interviewer: There is no argument that atmospheric carbon dioxide levels are rising. They have been measured directly since 1959 and this is clearly the trend. However, there has been some debate as to whether this causes global warming. What is your position on this?

H. D. Lightfoot: All other things being equal, increasing the concentration of carbon dioxide in the atmosphere from the 275 ppmv in pre-industrial days to 550 ppmv [37] will increase atmospheric temperature by about 1.5°C. How much warming will actually occur depends on how the feedbacks work. For example, temperature increases may trigger something that raises the temperature even higher. A major concern of scientists today is to try to determine feedback factors and quantify their effects.

There is no doubt that there is global warming. Even the changing arrival dates for birds and the northward expansion of butterfly ranges are telling us this. The only question is about how much warming will occur.

If atmospheric temperature rises by 4.5ºC or more and there are serious negative effects, then we will need ample energy to adapt. If, on the other hand, the increase in temperature is about 1.5ºC, warming may not be as serious a problem.

But that is not the point I'm trying to make.

Interviewer: How so?

H. D. Lightfoot: In the event of significant climate change, or even that which we experience today, we must have sufficient energy to adapt to the negative effects. For example, we may need to respond to famine, evacuate people from natural disasters, house refugees and deal with a myriad of unforeseen problems. All of these take significant amounts of energy.

As we saw previously, we also need adequate future energy supply to raise poor nations out of poverty and maintain the well-being of everyone.

Thus, it becomes clear that future energy supply is much more important than climate change. This doesn't say that climate change is not important, just that without adequate energy we cannot adapt to climate changes, maintain the well-being of people and protect the environment.

6 Slides: Section 4 – Common sense is not so common

[↓] Common wisdom says climate change & energy supply can be solved by a combination of:

[↓] Carbon dioxide sequestration

[↓] the wide-scale practice of energy conservation

[↓] improvements in energy efficiency; and

[↓] the adoption of renewable energies. This section explains some of the serious limitations and impracticalities with these ideas and how common wisdom appears to be out of step with reality.

6 Slides: Carbon sequestration

Carbon sequestration refers to a process whereby carbon dioxide is captured and stored so that it cannot get back into the atmosphere. Sequestration is often suggested as a way of reducing carbon emissions from the burning of fossil fuels. For example, carbon dioxide might be captured from the most concentrated of the emission streams, such as power plant smoke stacks.

The capture of carbon dioxide gas from smokestacks is energy intensive because it is usually diluted to a range of 3-15% [38]with other gases, mostly nitrogen in the air used to burn the fuel. The energy required to concentrate the carbon dioxide before capture is 14-28% [38] of the energy input to the power plant. Large scale sequestration of carbon dioxide would consume huge quantities of energy, thereby requiring more sequestration and burning significantly more energy.

[↓] Because it requires the burning of extra energy, sequestration reduces fossil fuel reserves at a time when future fuel supply is more important than climate change.

[↓] Large-scale sequestration is impractical.

[↓] There are small niche applications for capturing carbon dioxide from emission streams. For example, carbon dioxide is captured from certain flue gases and sold commercially as dry ice, which eventually returns the carbon dioxide to the atmosphere. Some is used for pressurizing oil wells to increase production and is captured underground, possibly, permanently.

[↓] Capture of carbon by natural methods such as in forests and oceans is not permanent or reliable as we shall see on the next slide.

4 Slides: Carbon cycle, billions tonnes carbon

Beginning in the 1700s, humans began to burn fossil fuels, and today every human activity uses energy and releases carbon dioxide to the atmosphere. All energy use sectors are represented by generation of electricity, transportation, residential, industrial and commercial.

[↓] The amount of carbon released annually is about 7 billion tonnes [39], or about 1% of the total of 750 billion tonnes in the atmosphere. Currently, about 80% of human carbon emissions is from burning fossil fuels and the remainder is from land use changes [40].

This carbon cycle is given in terms of pure carbon even though carbon dioxide is released when fossil fuels are burned. Carbon can be combined in many forms with other chemical elements so it gives a better overall picture than does carbon dioxide. For reference, one tonne of carbon is equal to 3.67 tonnes of carbon dioxide.

This new source of carbon from burning of fossil fuels is relentless and keeps growing. Currently, about half remains in the atmosphere and increases the concentration each year.

[↓] Currently, about one quarter of this new carbon goes into the oceans. On average, 92 billion tonnes of carbon are absorbed each year and 90 billion tonnes released [39]. Thus, over hundreds of millions of years, this small difference has caused immense quantities of carbon dioxide to be accumulated in the deep ocean. This process continues today.

[↓] The remaining one quarter of carbon emissions is absorbed on land in vegetation and soils. Historically, on average, carbon accumulation on land has been in balance. However, with the new source of carbon from burning fossil fuels, 61.7 billion tonnes are absorbed annually and 60 billion tonnes released. However, the difference in favour of vegetation and soils for storage of carbon is small. If, for example, atmospheric temperature increased, thereby increasing decay rates and insect populations, more carbon would be released to the atmosphere than is absorbed.

The carbon cycle is a very dynamic system recycling about one fifth of the carbon in the atmosphere each year. For this reason, vegetation, soils and oceans are unreliable storage places for carbon because a slight change in conditions can cause each of them to release more carbon than they store.

4 Slides: Vegetation is dynamic

Through photosynthesis, plants use carbon dioxide so quickly during June to September that the concentration of carbon dioxide in the atmosphere drops sharply. Throughout the year, when plants die, decay or are eaten or burned, carbon dioxide is released back into the atmosphere. Humans are part of this cycle because the carbon in our food eventually ends up as carbon dioxide emissions.

Most of the world's land is in the northern hemisphere which is why the northern summer has such a large effect on plant growth.

[↓] Each year the level of carbon dioxide increases in the atmosphere—it increased by 1.5 ppmv between 1989 and 1990.

[↓] The difference between years 2002 and 2003 was 2.8 ppmv [33].

[↓] This rate of 2.8 ppmv is not representative. The average rate over fourteen years from 1989 to 2003 was 1.6 ppmv. The continual input of carbon from fossil fuels increased the concentration of carbon dioxide in fourteen years by about 20 ppmv, or by about 5.5%.

This relentless average increase of 1.6 ppmv will not be reduced until fossil fuels can be replaced with carbon-free energy.

Interview

Interviewer: Tree planting is often purported to be a solution to carbon emissions. If vegetation is so dynamic, how do trees affect the carbon cycle?

H. D. Lightfoot: Tree planting is desirable from many points of view. However, all new trees, like all vegetation, eventually give off all the carbon dioxide they have stored as wood, roots, and leaves. This may happen to some extent seasonally in deciduous forests as leaves fall to the ground, and eventually for all trees and vegetation, as they die and decay or are eaten by insects, consumed by fires, etc.

Interviewer: So it doesn’t seem to mitigate carbon dioxide concentration.

H. D. Lightfoot: That is correct. Planting trees simply expands the amount of carbon that is available for recycle in the carbon cycle. If temperatures rise and decay rates increase, forests could be a source of carbon dioxide and not a storage system. Trees do not lock carbon away in the ground, as fossil fuels did for millions of years.

Some decaying vegetation, such as that decaying in swamps, releases carbon as methane gas, which is about 20 times more effective in warming climate than carbon dioxide. Methane is also released by the digestion process in termites and sheep. Fortunately, methane in the atmosphere converts to carbon dioxide over a period of about ten years.

Furthermore, increasing concentration of carbon dioxide in the atmosphere is not all bad.

Interviewer: How do you mean?

H. D. Lightfoot: Carbon dioxide is essential for the growth of plants. Generally, the higher the concentration, the faster they grow and require less water. This suggests that plants, forests, and crops will thrive in more hostile environments [41], expanding into areas where they have not been able to grow before. And this is already happening—this has already been demonstrated in the Yatir forest of the Negev desert.

There is evidence that increased concentration of carbon dioxide in the atmosphere has increased the mean yield for certain cereals, grains, fruits and vegetables [42].

We have seen that the Global Carbon Cycle is very active. It recycles about 20% of the carbon in the atmosphere every year. Therefore, small changes in conditions, such as atmospheric temperature, can change vegetation, soils and oceans from storage of carbon to sources of carbon. The point is that vegetation, soils and oceans are not storage places we can count on to keep carbon stored permanently.

5 Slides: Energy conservation – personal choice

Conservation is a conscious choice to reduce energy consumption for a specific purpose. For example: manufacturing light bulbs which are more efficient is an increase in energy efficiency. However, the consumer's decision to buy a more efficient light bulb, even though it is more expensive, is a conservation decision.

The true amount of energy that people are able to conserve represents a relatively small amount of overall energy that the world uses. The main advantage of energy conservation is that it extends fossil fuel reserves.

[↓] People use energy in a discretionary way to make themselves feel better in many ways.

[↓] The energy to keep four dogs is about the difference in energy consumption between an SUV and an ordinary car [43]. Look at the long shelves of pet food in your supermarket and consider the amount of energy required to grow, harvest, process, package and transport it there before you drive it home.

Some people have four-wheeled SUVs and others have four-legged SUVs. This is not a promotion for SUVs or is it against dogs—it just points out that we are all part of the problem in our discretionary use of energy to enrich our lives.

[↓] It highlights that conservation is often a matter of opinion. We all enrich our lives with our own "SUV" category of energy use, such as pets, long and hot showers, leaving outside lights on all night, or whatever. We could all say, "Ban what I think is a frivolous use of energy!"

Trying to be judgmental about someone's discretionary use of energy is made more difficult because we do not know how much energy is involved in most discretionary uses, and the amount is variable. For example, if someone decides to give up imported food, how much energy have they saved, compared to someone who rides their bicycle to work? Who gets more credit? It is often very difficult to be certain that energy conservation really works.

[↓] Considering the problems just discussed, it is very difficult for a democratic and open-society to legislate energy conservation. Who decides what items, as a society, we should give up?. The best that can be done is public education, and encouraging people to practice energy conservation however they can. But, once again, this is not something which can be relied upon.

3 Slides: Energy per unit of output

Energy per unit of output refers to the amount of energy used to produce a given value of product—energy units per dollar, for example.

This solid line represents the 1% historical average annual rate of decline in energy per unit of output extended from 1990 to 2100 as in the "Business as Usual" scenario we saw earlier. This rate reduces energy consumption for doing the same job from 100 units in 1990 to 33 units in 2100.

[↓] The decline is mostly increases in energy efficiency [44] shown by the dashed line.

[↓] The difference between the two curves shown by the vertical line is the contribution of sectoral changes. These are the result of a shift in energy use from high energy intensity industries to low energy intensity industries, such as from iron and steel to service industries.

It is uncertain whether or not the energy per unit of output line can be achieved considering that many energy applications do not have the potential for reducing energy in 2100 to one third of that in 1990.

However, for purposes of this analysis we will use the one 1% per unit of output line and the corresponding 1,453 EJ per year in 2100 of the “Business and Usual” scenario.

Interview

Interviewer: Please tell us more specifically why you think the decline in energy per unit of output cannot be increased beyond 1% annually?

H. D. Lightfoot: The information about energy efficiency is the result of a detailed analysis of the limits of energy efficiency for many energy applications in all energy use sectors. The analysis was initiated because it was claimed that if the average annual reduction of energy per unit of output could be raised from 1-2%, our energy problems would be much less difficult. As it turns out, the statement is correct, but unachievable, because of physical limitations. It will be difficult to even to maintain the 1% average experienced to date to 2100.

Interviewer: Do you have any examples, as a frame of reference?

H. D. Lightfoot: Yes. We have already made the easy increases in energy efficiency and further increases are smaller and more difficult to achieve. As an analogy, consider a 100 meter Olympic sprinter. The world record for the 100 meter dash is about 9.83 seconds. Think of someone who has never sprinted before. They may improve their time from, say,17 seconds to 12 seconds in a matter of weeks. Improving from 12 seconds to 11 seconds will require much more effort, dedication and training. The efforts required to go from 11 seconds to 9.83 seconds may take years of strenuous effort, or may never happen at all. Energy efficiency works in the same way. It gets harder, and costs more to improve efficiency each time. Eventually the trade-off of effort versus reward is not worth it.

Interviewer: Do you have any specific examples of why this is not achievable?

H. D. Lightfoot: The limit of energy efficiency for hydropower turbines and large electricity generators was approached more than half a century ago. Hydroelectricity is already 85% efficient [45] and it makes up nearly 20% of the electricity we use. And, steam-electric generating systems, whether powered by nuclear or fossil fuels, are limited to about 35% efficiency by the laws of thermodynamics.

Thus, there is little potential to increase the efficiency of the two-fifths of world energy used to generate electricity. For the remaining three fifths of world energy consumption, average energy per unit of output would have to drop to one tenth that in 1990 to maintain the 1% historical rate. Physical limitations prevent this. Therefore, we will need more energy in 2100 than the 1,453 EJ in the “Business as Usual” scenario, but we will use this value for purposes of this analysis.

Interviewer: There are new lights, based on LED technology. They are purported to consume very little energy compared to standard lighting. What effect would a switch to lights like these make to the efficiency picture?

H. D. Lightfoot: All increases in energy efficiency are good. But to put it into perspective, lighting accounts for about 4% of household electricity consumption. Thus, even if every light were replaced with the new very high efficiency LED lights, the overall effect would be relatively small. LED lights would reduce air conditioning energy required in the summer, but would increase heating energy in winter to replace the loss of heat from incandescent lights.

The most potential for energy efficiency increases around the home is better insulation and windows. It can also come from replacement of refrigerators built before the mid-1970s. The energy efficiency of refrigerators has increased 300% since 1974. Not much can be expected from space heating because the efficiency of forced air house furnaces was in the range of 70-90% in the 1940s [46].

Increases in energy efficiency are important to extend fossil fuel reserves, and give more time to find appropriate solutions. But increases in energy efficiency have often resulted in increased overall energy consumption.

Interviewer: That’s a surprising statement.

H. D. Lightfoot: Certainly, take computers for example. In the 1960s, computers were large and consumed much power—so much so that they were housed in air conditioned rooms to keep them cool. The total amount of power consumed was negligible. Today, individual computers are much more efficient, but there are billions of them in many forms and electricity demand has increased significantly just because of them [47].

1 Slide: Section 5 — Can renewable energy replace fossil fuel?

Can renewable energies replace fossil fuels? Only in small doses. They cannot do so on a large scale as we’ll see, because of various limitations.

The 39.7 EJ [48] of renewable energies is about 9% of the current 457 EJ/yr. of world energy consumption. Therefore, keep in mind that renewable energies must replace 388 EJ that fossil fuels currently supply. And by 2100, they must replace more than four times that amount—a tremendous amount of energy.

There are good reasons why the contribution of renewable energies fell from 100% a couple of centuries ago to about 9% today. The reasons are still the same today and make it difficult to maintain, let alone increase, the current 9% of renewable energies as world energy demand grows.

We will discuss renewable ach energy in turn, except volcanic geothermal will not be discussed because it is small and limited to a few specific geographic locations [49].

5 Slides: Hydroelectric power

Hydro power is potential energy recovered from rain and snow falling at high elevations. This potential energy is concentrated by rivers and stored behind dams for use as required.

Hydro power is almost the perfect form of energy. Potential energy is stored as water behind a dam and gravity forces the water through turbines to generate electricity.

[↓] The water flow can be changed almost instantaneously to meet our electricity demand. Dams have also proved successful in controlling floods and providing irrigation water to nearby farmland.

[↓] Hydropower displaces about 30 EJ of fossil fuels. Hydropower plants supply about 20% of the planet's electricity, bringing electricity to more than one billion people [50]. There are currently over two thousand hydro power plants in the United States alone.

[↓] Expansion of hydro is limited by suitable sites, and world potential is about half developed. Hydropower potential is already 65% developed in Western Europe and 76% in the United States.

[↓] If the full potential of world hydro could be exploited, it would displace about 60 EJ of fossil fuels.

7 Slides: Ethanol from corn as a biomass fuel

As we saw earlier, people turned away from biomass fuel because they ran out. England began to use coal as fuel about 1700 [51] and the US in about 1850 because the forests were depleted and firewood was in short supply .

Currently, U.S. energy consumption is more than 35 times higher than in 1850, therefore, it is impossible to return to firewood and other biomass fuels as a significant source of energy.

All forms of biomass will continue to be relatively small niche contributors. For example, current biomass of 7.5 EJ per year is mostly waste from lumbering, pulp and paper, and agricultural waste, such as sugar cane stalks.

[↓] It is often proposed that solid biomass be converted to liquid fuels for use as transportation fuel, such as converting corn to ethanol. However, almost all of the energy in the ethanol comes from fossil fuels, and the energy gain is less than 10% [52].

[↓] The approximately 60% surplus energy is low grade energy – it cannot be used to drive cars or to make more ethanol.

[↓] The fossil fuel energy input for ethanol, from planting to distillation, comes 70% from coal, 15% from natural gas and 15% from oil.

[↓] This leads to the rationale that ethanol displaces imported oil on a seven to one basis.

[↓] However, there is little energy gain. Mitigation of carbon emissions is minimal, if it exists at all.

A more efficient and environmentally friendly way of using corn as fuel is to burn it directly to displace coal. Carbon dioxide emissions are two and a half times less than fermenting corn to ethanol and displacing gasoline.

[↓] Ultimately, corn for ethanol production competes with food supply. This is serious competition in poorer countries which often already have trouble feeding themselves.

Thus, as in the past, commercial biomass will always be a small niche contributor to world energy supply. Non-commercial biomass, often called traditional biomass, such as wood, animal dung, etc. is used in developing countries, mainly in the residential sector for heating and cooking. The Intergovernmental Panel on Climate Change estimates the amount at about 45 EJ/yr [53].

Interview

Interviewer: In your estimation, what is the key weakness of biomass as an energy source?

H. D. Lightfoot: Biomass grows relatively slowly and requires much more land per unit of energy than any other renewable energy. It has proved to be inadequate several times throughout history including in England in 1700 and in the United States in 1850. People in undeveloped countries are forced to use biomass as wood, scrounged from wherever it is available as well as animal dung for cooking and heating. Excessive harvesting of wood is common and devastates the local environment. Burning of dung hurts the environment both by eliminating it as a fertilizer for the soil, and by releasing black carbon to the atmosphere as it burns, thereby contributing to global warming [54].

Interviewer: But there are different biomass fuels?

H. D. Lightfoot: Certainly. Trees are the preferred fuel for biomass, because they are more concentrated than crops, such as corn or sugar cane. Trees concentrate their energy as wood, growing vertically for years, up and out of people's way. By contrast, corn and sugar cane are short and spread horizontally out over the ground. They have to be harvested every year.

However, earth's forests are already well used. There is not much spare capacity. Wood is already a significant source of energy for industries, such as pulp and paper mills. During the paper making process, wood is chemically treated to recover half the wood as cellulose for paper. The remainder, such as lignin, is burned to provide heat and electricity for the manufacturing plant. Wood also supplies building materials for most countries in the world.

Once again, scale is important. Manufacture of ethanol from sugar cane, corn or switchgrass is possible, but not on a scale that will make a significant difference to world transportation fuel supply or an impact on carbon emissions. There's the scale concern again.

1 Slide: Wind always needs a reliable helper

This is a record of wind variability in the control area of E.ON, a large wind farm operator in Europe [55] [56]. This record of wind electricity input to the grid in 2004 shows that it varied continually from 0.2% to as high as 38% of daily peak grid load.

Because of the variability shown, the average electricity delivered ranges from one-quarter to one-third of the installed capacity. Because of the intermittent nature of wind, electricity generated by wind power cannot stand alone—it always requires a reliable helper.

When the wind speed drops below 4 metres per second, exceeds 25 metres per second [56], or the temperature is too cold [57], the turbines stop turning and the helper must supply all of the electricity. Therefore, the helper must be large enough to supply all peak load electricity—it cannot be smaller when supplemented by wind electricity.

7 Slides Wind: intermittent electricity

Some of the energies required to manufacture electricity, such as fossil fuels and hydro, can be stored and used to make electricity as needed. However, wind cannot be stored for future use. It must be used to make electricity when it is available.

Because large-scale electricity storage is not possible, production and consumption is balanced on a “knife-edge” of supply and demand. At any given moment, only enough electricity is produced to exactly equal the amount being consumed.

[↓] Wind cannot deliver power when needed because the wind blows only intermittently. This is a serious limitation, because it does not interface well with human energy use patterns, which require electricity to be available when needed.

[↓] Thus, wind is always coupled with a reliable source of generating electricity, such as a fossil fuel of hydro powered generating station.

[↓] Wind electricity is always less than 10% of the electricity delivered by the reliable source of energy.

[↓] Why this limitation? Simply because too much variability in electricity flow into the grid can cause it to become unstable, either whole or in part, and shut down.

[↓] We know this from practical experience in Europe and the U.S. [55] [58].

[↓] The capacity of the reliable source must always be large enough to supply the full peak electricity demand because wind electricity can stop at any time. Thus, wind electricity requires a duplication of generating facilities, but can save up to 10% of fossil fuel and carbon emissions, or water stored behind a dam.

This is one reason why wind will always be a small contributor to world energy supply.

5 Slides: Wind: its affect on the reliable helper

The boilers burning fossil fuels to make steam for turbines to generate electricity are very large and cannot be quickly shut down or started up. When wind electricity is supplied to replace the electricity generated by the fossil fuel system, the fuel flow to the boilers is reduced, but not stopped and the generators continue to turn, but no electricity is produced. The system is in “spinning reserve mode”.

Fuel is being burned, carbon is being emitted, no electricity is produced but, importantly, the system is ready to deliver electricity the instant the wind electricity flow stops. In other words, wind does not completely displace the fuel required for its helper.

[↓] “Spinning reserve mode” is something like having your foot on the brake of your car waiting at a red light. Your car doesn’t move, but the engine is still running. And the engine must run, because when the light turns green, you need the power immediately.

[↓] Unfortunately, just like your car at a stoplight, spinning reserve mode consumes energy.

[↓] As we saw earlier, wind electricity can supply up to 10% of the that supplied by its helper and save up to 10% of the fuel. However, because of “spinning reserve mode”, the fuel saving is somewhat less. In other words, even with the maximum wind electricity, overall the fossil fuel plant still releases more than 90% of the carbon dioxide as it would without wind power.

[↓] Hydro as a helper has the same 10% limitation as fossil fuels. Continually changing wind electricity flow results in continually changing river flows [56]. On the positive side, wind can save up to 10% of water behind a dam.

1 Slide: Wind power is remote: Canada

On the Canada Wind Map [59], the best wind land is shown in turquoise or above on the scale, and is far from where most people live.

This is another limitation of wind power—there is not much available where it is needed.

1 Slide: Wind power is remote: US

The situation is similar in the United States. The best wind land is far from where electricity is needed [60].

4 Slides: Wind power heavily subsidized

Wind electricity is inherently difficult and would be rarely used were it not for generous tax breaks. In the United States, “two-thirds of the value” of a wind energy project comes from federal tax breaks [61].

[↓] The situation in Canada is similar. For example, Hydro Quebec is studying proposals to buy wind electricity at 6.5 ¢/kWh [62] plus 1.3 ¢/kWh for integration and connection plus 0.9 ¢/kWh for balancing for a total of 8.7 ¢/kWh delivered to a substation.

[↓] Hydro Quebec cost for hydro electricity is 2.8 ¢kWh, or about one-third that of wind electricity.

[↓] In Germany in 2004, E.ON Netz, a large wind farm operator in Europe, was paid 9 Euro cents/kWh, which is equivalent to 13 cents Canadian/kWh.

Interview

Interviewer: You’ve mentioned a 10% limit. However, it is regularly reported that countries, such as Denmark, produce up to 20% of their electricity by wind power.

H. D. Lightfoot: There are so many misleading statements about wind power. Firstly, it is true that about 20% of Denmark’s electricity is supplied by wind power. This appears to be greater than the 10% upper limit, but is actually much below. Denmark’s wind electricity is about 2% of the Nordel system overall electricity output [63], of which Denmark is a part along with Norway, Sweden, and Finland.

Interviewer: What do you see as the biggest misleading statement in the wind power debate?

H. D. Lightfoot: It is often said that wind can supply electricity for, say, 100,000 houses. The fact is that wind cannot supply electricity to even one house unless it has a reliable helper. The fact that a reliable helper is required is rarely, if ever, mentioned. If wind electricity exceeds 10% of the helper, the system becomes unstable and shuts down. And, the helper cannot be smaller because it must supply all of the electricity when the turbines shut down, which they do when the wind is too slow, too fast or too cold.

Wind power is inherently difficult to use because it is intermittent and erratic, and there are no really good ways to store large quantities of electricity. In the past, a good application in rural areas was for pumping water. A correctly sized water tank could be filled in times of good wind, and it would last through calm periods to the next good wind.

Nevertheless, there are good small niche applications for wind power in remote areas with very high diesel fuel costs, good wind resource and small enough for battery storage as the helper [64].

There are realistic constraints preventing wind power from growing significantly. Wind power is remote and requires lots of land—20,000 sq. km. per exajoule [65]of electricity produced. Turbines must be spaced apart by ten times their rotor diameter, otherwise they will steal each other's wind. Even if it were possible to provide all U.S. electricity for 2003 from wind power, it would require an area of good wind land equal to a corridor from New York to Chicago, a distance of about 1150 kilometres, and about 200 kilometres wide.

Over the long term, wind electricity may well be a temporary phenomenon. If there were some reason to reduce the generous subsidies, then interest in wind power is sure to wane.

The key point of this analysis is that wind power is a small energy source now for very good technical reasons, and always will be.

7 Slides: Solar power – always small

Solar electricity, like wind, cannot stand alone and has the same intermittency problems.

[↓] Large scale generation of solar electricity connected to a grid would require "spinning reserve mode" as backup for the effects of clouds and nightfall.

[↓] Very often, the concept of net-metering is proposed as a means of adding solar electricity to the grid. Net-metering is where people with solar power panels on their home can sell their excess electricity to the public utility and simply buy it back when they need it. In effect, this exploits the public electricity infrastructure as a giant battery. However, the flow of electricity to and from the utility is completely unpredictable as people turn on hair dryers, stoves, etc. at random times. This variability, together with changing cloud cover, limits the total contribution of solar to the grid to up to 10% of annual electricity production [66].

[↓] Large scale solar requires much dedicated land. For example, in Tucson, Arizona, which averages the most sunlight in the U.S., 2000 sq. km. of land is required to produce 1 EJ of electricity [67], which is less than 2% of world electricity demand. Sites near Seattle or Montreal would require three times the land area for the same annual electricity output because of lower sun angle and less solar radiation.

Just finding 2000 sq. km., or more, of land suitable for large arrays of photovoltaic cells in Arizona is not easy, nor is 6000 sq. km. near Seattle or Montreal.

[↓] The land must be non-remote, have helper electricity supply nearby, and be horizontal or slightly tipped southward with no nearby features to cause shadows. The land must be suitable for roads between solar arrays for regular cleaning of the surfaces and other maintenance.

[↓] Suitable land is prime land and is already occupied and being well used.

[↓] Solar electricity is excellent for many small niche applications, where batteries can be used to store electricity for future use.

9 Slides: Footprints: various energies (km^2/MW)

Renewable energies are usually considered to be desirable sources of energy because they are natural and inexhaustible. There are positive and valuable aspects to each renewable energy. However, every renewable energy has a land footprint and a footprint on the environment.

This slide shows graphically the land footprint area required to produce 1 Megawatt (MW) of electricity from various primary energy sources [68].

Biomass fuel, such as wood and liquid fuels from corn, switchgrass, etc. is a land-hog for the amount of energy is produces. That is why it is small and will remain small.

[↓] Although wind power is more land efficient, it exerts a strong ecological footprint. A range of groups oppose new installations of wind turbines, and press for removal of others. The winds that attract wind power installations are often migratory routes for birds, which are often killed by turbine blades - tip speeds of the blades approach 300 km/h. Vibrations transmitted through the ground and noise from the blades passing the tower annoy people living nearby. Objections to wind turbines in scenic locations are becoming more common.

[↓] Ocean tidal energy is remote, intermittent and small and will remain small.

[↓] Solar energy provided by photovoltaic solar cells is an improvement in land intensity for equal energy output, but as we have seen, it has other limits.

[↓] Solar-thermal energy consists of mirrors focusing the reflection of the sun on a centralized location. which heats up to produce steam to generate electricity. Although it requires slightly less land per unit of energy output, it is geographically limited.

[↓] Volcanic geothermal energy requires very little land per unit of output, however it is geographically limited to specific hot spots in the earth’s crust, such as Iceland. Corrosion, scale build-up and pollution are often problems.

[↓] The range of area required by hydro to produce electricity varies greatly. This is because of the vast differences in flood plains between hydroelectric project. In mountainous countries, such as Switzerland, Norway and Canada, flood plains are small and contained by mountain valleys. In relatively low-lying countries, such as Thailand and Brazil flood plains are often much larger.

Hydro power exerts a physical and ecological footprint. Objections to building more hydro dams are raised because flooding of land forces people to move from their homes and archeological sites are destroyed. Downstream, the nature of the river changes and fish and other species become endangered or extinct as traditional spawning grounds are cut-off [69].Older dams are often removed rather than maintained [70], thereby restoring the health of river and opening it again to fish and other water creatures.

[↓] For comparison the footprint of coal is shown.

[↓] Finally, nuclear energy has the smallest footprint except for volcanic geothermal, which, as we have seen is limited.

1 Slide: Section 6—The Hydrogen Economy: NOT a simple chemistry experiment

5 Slides: The “Hydrogen Economy” is far away

Today, more than 90% of hydrogen is manufactured from fossil fuels.

[↓] More than 90% of hydrogen produced today is used as a chemical, where hydrogen is essential to the process.

[↓] Hydrogen is not a fuel today; it is made from fuel.

[↓] More than one-half of all hydrogen is manufactured from natural gas, which requires one and a half units of natural gas energy for each unit of hydrogen energy produced. This method of hydrogen production means that one and a half times more carbon dioxide is produced than if the natural gas had been burned directly to produce electricity.

[↓] Therefore, hydrogen made from fossil fuels adds to carbon dioxide emissions, and reduces fossil fuel reserves, especially if the natural gas could have been used directly for the same purpose.

7 Slides: Hydrogen by electrolysis

Large scale electrolysis of water to manufacture gaseous hydrogen and oxygen is not the simple process it seemed in your high school chemistry class.

The world used about 65 EJ of road and air transport fuel in 2005. Suppose we wished to manufacture only 1 EJ/yr of hydrogen gas, which is five to six days of transportation fuel for the world.

[↓] The electrochemical plant itself housing the electrolyser cells would be truly massive, over the size of 500 football fields.

[↓] Average water consumption would be 217 million litres of water per day [71]—the daily consumption for a city the size of Tucson, Arizona.

[↓] Not just any water, but impurity free water similar to distilled water purity to prevent build-up of impurities in the electrolyte, thereby destroying its properties. The water purification process would not only consume a substantial amount of energy but, depending on the water supply can leave behind many tonnes of impurities for disposal.

[↓] Hydrogen production rate is limited by the production rate of hydrogen per unit of electrode area, i.e., about 1.2 cubic metres/hr/square foot of electrode area – twice the amount of hydrogen requires twice the electrode area.

[↓] Electricity consumption would be about one fifth of current world hydro electricity production.

[↓] Eight kilograms of oxygen would be produced for each kilogram of hydrogen, or about 7000 thousand tonnes/hr, twenty four hours a day.

Oxygen is a hazardous material. Oxygen concentration in the atmosphere is 20.8%. If a jacket sleeve were to catch fire, there would be time to jump up and put it out. If the concentration of oxygen were five percentage points higher, a total of 25.8%, the whole sleeve would be on fire before anyone could move [72].

To be safe, the oxygen must be diluted in air to a safe level of 23.5% [73], or less, before it leaves the production facilities. On average, this requires the amount of air that would be in a line of Goodyear blimps, like the Spirit of Akron [74], nose to tail 1500 km long every hour.

This analysis is for hydrogen gas production only. It does not include energy or facilities for liquefaction of hydrogen, or for other means of storing hydrogen on a vehicle.

5 Slides: Hydrogen as road & air transport fuel

We can get a good perspective on what it takes to power the world's road and air transport by estimating what it would take to replace the roughly 65 EJ of oil used for this purpose in 2005.

[↓] To replace this would require about 65 EJ of hydrogen, depending on how it is used.

[↓] If the hydrogen were made by electrolysis of water, the 65 EJ would require the continuous output of electricity from about 3000 electricity generating stations of 1000 MW capacity. These could be powered by fossil fuels, hydro or nuclear.

Total installed capacity would be about 3,000,000 MW. Electricity production would approach twice total current world electricity consumption.

[↓] If the electricity supply for the electrolysis process is from wind, which is intermittent and has a capacity factor of about 35%, then the necessary installed capacity is increased by a factor of three to 9,000,000 MW. Also, because electricity is delivered only an average of 35% of the time, three times as many electrolyser cells are required for the same output as for continuous electricity.

The land required for wind mills would be about 1,200,000 sq. km. Or about 20% smaller than Alaska or 20% larger than Ontario. There is just not that amount of good wind resource near where people live.

[↓] The average capacity factor for solar in a high solar area is about 25%. Thus, solar electricity installed capacity would be four times that of continuous electricity or 12,000,000 MW, and the electrolysis plant would be four times as large as for continuous electricity. The area required in a good solar area would be about 130,000 sq. km., or the size of New York state or Greece.

Although wind and solar electricity may be viable for production of hydrogen in small niche applications, both are just not viable for the large scale production of hydrogen required to power the world's road and air transport.

The hydrogen economy is not going to arrive until there is a large source of energy from which to manufacture the hydrogen.

4 Slides: What makes a good transportation fuel?

The most important and biggest single problem affecting society when oil is no longer affordable is the supply of fuel for road and air transport.

The best transportation fuels are liquids derived from oil and have high energy to volume ratios, such as gasoline and diesel fuel.

[↓] Uranium has a major advantage over petroleum based fuels in some applications. For example, for the same range, aircraft carriers require very much less weight and volume of fuel, and range is more easily extended. Uranium is not a fuel for vehicles like cars, trucks or airplanes because the weight of shielding to protect the occupants from ionizing radiation is prohibitive.

[↓] Batteries are heavy, recharge is slow, the rate of using electricity from the battery is low, and the power to weight ratio is low. In fact, electric cars have been around since the 1800s, and were looked upon favorably as they took horses off the street, as well as the twelve hundred tons of manure they produced each day in New York City alone. But as soon as the road network was built, electric cars could no longer compete on distance with fossil fuel-powered cars. This is still the case today.

It is sometimes argued that electric vehicles reduce carbon emissions. This is not the case in the United States today, for example, where the majority of electricity is generated by burning coal. Mass-scale use of electric cars does nothing but displace where the fossil fuels are being burned. It can be argued that electric vehicles may solve air pollution problems in cities, but not that they will solve total greenhouse gas emissions.

[↓] Hydrogen gas has higher energy per unit of weight than gasoline, but is difficult to store on a vehicle.

4 Slides: Hydrogen is not a good transportation fuel

Hydrogen is liquid only at -253°C. Even with good insulation, hydrogen gas is continuously vented. You have seen this venting when watching the Space Shuttle on its launching pad before takeoff.

The liquefaction process takes lots of energy because it has to cool the hydrogen to such a low temperature. In fact this takes up to 25% of the energy in the original hydrogen [75].The characteristics of hydrogen are such that it cannot be kept as a liquid just by pressure, such as propane—as liquid it must be kept very cold.

[↓] The alternative to liquid hydrogen is to store the gas at very high pressure, about nine thousand pounds per square inch, at which pressure the energy to volume ratio is about the same as that for liquid hydrogen.

[↓] Even when hydrogen is liquefied, it has only a quarter of the energy for the same volume of

[↓] gasoline. In very basic terms, this means a vehicle would need a much larger and special fuel tank, or refuel more often.

Interview

Interviewer: Are you saying that hydrogen is a manufactured fuel, that there is no net energy gain?

H. D. Lightfoot: Exactly. It always requires more energy to make hydrogen than can be recovered when it is burned. Hydrogen is not a source of energy, but is an energy carrier similar to electricity in some ways. Hydrogen has different characteristics than electricity and might eventually provide some solutions to specific energy problems.

Interviewer: The main weakness of hydrogen seems to be it's unsuitability to power the transportation sector. Is this correct?

H. D. Lightfoot: Yes. Once the supply problem has been resolved, the question of how hydrogen would be used as a road and air transport fuel still has to be resolved.

The National Academy of Engineering speaks about hydrogen as a transportation fuel in the following statement: "….dramatic progress in the development of fuel cells, storage devices, and distribution systems is especially critical. Widespread success is not certain" [76]. They suggested this work might take fifty years.

The reality is that there are no substitutes for oil as road and air transport fuel on the scale required. Alternatives are difficult to achieve and many years away. It is essential that oil, coal and tar sands be used only for fuel for road and air transport until a suitable alternative is in place, which may not be before the end of the century.

For global energy production, the question of scale is always important and especially so when discussing the possible contribution of hydrogen.

Interviewer: Can you give a specific example of what you mean?

[H. D. Lightfoot]: Hydrogen produced from wind and solar is often proposed and is possible on a small scale. You can buy "off the shelf" systems to do this. But, when the scale of hydrogen to power road and air transport is considered, compared to continuous electricity such as that from nuclear, wind and solar electricity require three to five times the installed capacity, three to five times the number of electrolyzer cells and far more transmission lines. Large scale wind and solar hydrogen is just not going to happen.

At one time, it was often suggested that we "fill the desert with solar cells" and power the world with hydrogen. Apart from scale, deserts are dry, dusty and lack the large volumes of water required as the raw material from which hydrogen is extracted.

A hydrogen fuel economy is very far away, and the first requirement is to solve the hydrogen supply problem.

1 Slide: Section 7—Nuclear Energy—power to the people

5 Slides: Nuclear energy today

As of June 2006, there were 442 nuclear plants generating electricity in 30 countries [77], and

[↓] 27 new ones under construction in 11 countries.

[↓] Why is nuclear energy attractive?

[↓] Nuclear energy also produces no carbon dioxide emissions and generates no air pollution.

[↓] Much more energy per unit of weight for uranium, and very much less material to handle.

3 Slides: Energy density: nuclear vs. fossil fuels

For example, to produce 1000 MW of electricity for one year requires: 3.8 million tonnes of coal. For a simple comparison, let's assume that this amount of coal represents the entire surface area of planet earth 78].

[↓] It would require only 160 tonnes of uranium using the current thermal reactors to generate the same amount of energy. Compared to the surface of the earth, this would be roughly twice the size of New York City.

[↓] Furthermore, it would require a mere 1.6 tonnes of uranium using the one hundred times more fuel efficient fast reactors. Compared to the surface of the earth, this represents a city roughly the size of Ithaca, New York.

This comparison shows why countries with little or no coal resources find nuclear power very attractive.

5 Slides: Nuclear energy consumption

[↓] Nuclear grew rapidly from 1970 to 1995.

[↓] Since then, however, growth has slowed significantly.

[↓] World electricity consumption has more than tripled since 1970.

[↓] The growth rate of world electricity consumption has declined only marginally over the period.

[↓] The Energy Information Administration expects world electricity demand to grow by 57% to 79 EJ/yr by 2020 [6].

It is difficult to believe that nuclear will not grow again as it did during the period 1970 to1995.

2 Slides: Future world energy consumption

For purposes of this analysis, renewable energies are generously forecast to maintain the current ratio of about 9% of world energy demand from today through to 2100. During the same period, the world’s future energy consumption may well more than triple.

[↓] The gap, or shortfall, between what is required and the contribution of renewable energies is about 1300 EJ. This gap is about three times current world primary energy consumption. By 2100, oil and natural gas will be scarce, no longer “abundant and affordable”, and the easiest and best coal will have been mined.

Interview

Interviewer: Renewable energies are often portrayed as the solution to energy supply and climate change. But your research seems to contradict this.

H. D. Lightfoot: Yes, although renewable energies attract a lot of attention they are, in fact, now and in the future, very small contributors to world energy demand. The scale on which they can be used falls far short of replacing the 388 EJ of fossil fuels used in 2005.

The gap between renewable energy supply and possible world energy required in 2100 is large and very real.

Oil and natural gas will no longer be abundant and affordable well before 2100. It appears that coal will last for one to two centuries.

We have seen that energy conservation has a small effect and would reduce the gap slightly. Energy efficiency increases are physically constrained and the 1% average annual reduction in energy per unit of output is not likely to be sustained, thereby increasing the gap.

Now, the problem can be accurately identified.

Interviewer: That being?

H. D. Lightfoot: In short, energy must be found to replace fossil fuels on the scale required to fill the gap between the contribution of renewable energies and world primary energy demand today and in 2100. Otherwise, income per person will begin to slide and the well being of everyone and the environment will suffer.

4 Slides: The problem is identified

We need more energy.

[↓] Energy supply is far more important than climate change. It may also become a crisis in the not too distant future.

[↓] We need sufficient energy to adapt to climate change, whatever the cause may be now, or in the future. We need sufficient energy if we are to protect the environment, otherwise the environment will be destroyed as, for example, in poor regions where every tree has been burned for fuel.

[↓] The crucial question is, “Where or how can we obtain more energy?”

6 Slides: Two prime sources of energy on earth

There are only two sources of primary energy available to us on earth:

[↓] nuclear fusion, which is combining of atomic nuclei, and

[↓] nuclear fission, which is splitting atomic nuclei.

Relatively small amounts of energy are available from:

[↓] Hydroelectricity, which results from the earth’s gravity forcing water collected behind a dam through hydraulic turbines.

[↓] Geothermal energy, which results from radioactive decay of elements in the center of the earth that keep it warm. “Hot spots” in the earth’s crust expose this energy where it can be exploited.

[↓] Ocean tidal energy, which results from the earth passing through the gravitational field of the moon can be used to generate a small amount of electricity.

Nuclear fission is the only one of these sources that is here now and has sufficient capacity to replace fossil fuels on the scale required.

Fusion reactors may one day provide heat for steam to generate electricity. However, experiments have been carried out for decades, and success is just as far away—several decades at best, and further away still to be deployed on a large enough scale.

6 Slides: Nuclear fission

Nuclear fission requires fuel which is mined as uranium and/or thorium. Thermal reactors use uranium to produce heat.

[↓] Heat from thermal nuclear reactors is used for generating steam to drive electric generators and provide electricity.

[↓] Nuclear reactors are also used in specialized transportation applications such as the propulsion systems of large ships and submarines. It was used to propel the New Horizons space probe recently sent to Pluto, once it was in space.

[↓] Nuclear fission technology is well enough developed that its use can be expanded into residential, industrial and commercial energy sectors and, possibly, into other transportation applications.

If all world energy today could be provided by nuclear power, there would be enough uranium for only ten to thirty years [79]based on reserves at a price of $80 US/kg. Thermal reactors use only 0.7% of the energy in the uranium [80]. The remainder is waste and some is radioactive enough to be of concern for thousands of years.

[↓] However, fast reactors use virtually all of the energy in the uranium and are 100 times more fuel efficient than thermal reactors.

[↓] Replacing thermal reactors with fast reactors would, therefore, increase the life of uranium reserves to 1000 to 3000 years. With reprocessing, existing waste from thermal reactors is fuel for fast reactors, and there is enough to supply all of the world's energy needs using fast reactors for more than 150 years.

Fast breeder reactors are not new. The first nuclear electricity ever produced was by a fast reactor in the U.S. in 1951 [81]. A fast reactor has been delivering electricity in Russia since 1981 [82] and another in France since 1974.

1 Slide: Nuclear fusion - Nuclear fission

Nuclear fusion powers the sun and provides the renewable energies, which are far too small to replace fossil fuels. The supply of coal, oil and natural gas, which accumulated over hundreds of millions of years, is limited. Oil shows signs of becoming scarce within a decade or two.

Only nuclear fission using fast reactors has the capacity to replace fossil fuels.

1 Slide: Nuclear fission

The key point is that "Nuclear fission using fast reactors must be made to work very well if the world is to have sufficient energy!"

There is just nothing else on the scale required, either now or in the foreseeable future.

7 Slides: Thermal reactors vs. Fast reactors

Safety of thermal reactors is proven. The design and operation of fast reactors involves similar procedures to those for thermal reactors. The small differences tend to favor fast reactors. Both types of nuclear reactors can grow because safety is under control—it is not and engineering problem—if this were not true, then 27 new nuclear generating plants would not be under construction as we speak.

[↓] Proliferation possibilities are reduced by using metal fuel in fast reactors and electrochemical reprocessing in which plutonium is never pure, but always mixed with other materials [85].

[↓] The UN procedures for thermal reactors have been proven to work and are applicable to fast reactors.

[↓] The neutrons in a thermal reactor are slowed by a moderator such as carbon or water. Slowing the neutron increases the probability that a ^{235}U atom will fission and release energy when struck by the neutron. These slow neutrons cannot fission the ^{238}U which is 99.3% of naturally mined uranium.

[↓] There is no moderator to slow neutrons in a fast reactor. The fast neutrons can convert ^{238}U into plutonium and fission the plutonium. Thus, they can use virtually all of the uranium as fuel, versus 0.7% for thermal reactors.

[↓] That is why fast reactors are 100 times more fuel efficient than thermal reactors.

[↓] The waste from fast reactors is more easily managed because the fast neutrons split almost all of the long-lived nuclear waste products associated with thermal reactors. The radioactive materials remaining from fast reactors are of concern for less than 500 years, rather than thousands of years.

Interview

Interviewer: If fast reactors have such a large fuel economy advantage over thermal reactors, why are there not more fast reactors in use today?

H. D. Lightfoot: The answer has three parts. First, uranium has been so inexpensive that there was little incentive to use it more fuel efficiently, and storage of the unused uranium and other nuclear waste is manageable.

Second, thermal reactors were the first to be introduced commercially and have been continually improved. So thermal reactors have had a real head start.

And third, up until recently, our fossil fuel energy supply was perceived to be secure. However, concern about secure energy supply is now generating renewed interest in developing modern, commercially available fast reactors. For example, in order to extend their nuclear energy resources, India [83], China and Japan are investing in programs to develop advanced fast reactors. This is of particular interest to Japan, because they have no indigenous uranium supply.

Interviewer: Can you tell us a little bit more about how fast breeder reactors work?

H. D. Lightfoot: Uranium as mined has two kinds of uranium atoms—some are radioactive and some are not. When a radioactive atom splits, it releases an atomic particle called a neutron and lots of energy. The design of thermal reactors slows the neutrons because the reactor works better that way, but the reactor can use only the radioactive portion, which is about 0.7% of the total. The design of a fast reactor retains the speed of the neutrons and uses them to convert all of the 99.3% of the remaining uranium into plutonium, all of which can be fissioned to release energy.

Advanced fast-neutron reactor technology uses metal fuel [84]. The recycling process for metal fuel does not involve pure plutonium at any stage, thereby minimizing the risk that spent fuel from energy production would be used for weapons. At the same time, it squeezes the maximum energy out of the nuclear fuel [85].

Interviewer: But is there still an issue of waste from fast reactors?

H. D. Lightfoot: This is an important difference between today's thermal reactors and fast breeder reactors. The waste from fast reactors is much less radioactive than that from thermal reactors and is of concern for less than 500 years [86], rather than for thousands of years. Furthermore, existing nuclear waste from thermal reactors is good fuel for fast breeder reactors, and there is enough on hand to power the world for 150 years.

Interviewer: There is a lot of controversy about nuclear energy. What do you think the average citizen should know about nuclear energy that they're not being told?

H. D. Lightfoot:. Nuclear fission is the only alternative energy source with the capacity to replace fossil fuels, and deliver power when and where it is needed. In addition it has a much smaller physical and ecological footprint than fossil fuels or most of the renewable energies.

We must make fast breeder nuclear fission work if we are to have energy for everyone.

There is an urgency to start converting world energy supply to fast reactors because it will take decades to make the conversion. The point at which fossil fuels will no longer be abundant and affordable is uncertain, but appears to be approaching too quickly.

5 Slides: Uranium price vs. electricity price

The economical recoverable reserves of uranium in the ground depends on its price [87].

The energy in uranium is so concentrated that at $80 US/kg, its contribution to the cost of electricity is only 0.17 cents/kWh.

[↓] If the price of uranium were to increase 100 times to $8000 US/kg, the contribution to electricity price would be 17 cents/kWh.

[↓] The North American range of electricity prices is 5 to 15 cents/kWh.

[↓] The price range with uranium at a price of $8000 US/Kg, would be 22 to 32 cents/kWh—which would not be unmanageable.

[↓] So, the bulk of price paid by the consumer is the cost of the nuclear power plant itself. The advantage is that these costs are known and relatively fixed. With fast reactors, burning uranium even at the price of gold, the increase in electricity price delivered to the consumers is only 0.3 cents/kWh.

Nuclear fission is the only source for generating electricity that can provide long term stability of electricity prices—because more capacity can be added as needed. As natural gas and oil become scarce, people will be forced to convert to electricity for heating and cooking.

5 Slides: **Supply of uranium fuel**

It is essential that we have a good understanding of the long term supply of uranium.

The economically recoverable reserves of uranium in the ground are related to the price of uranium. The higher the price the more that becomes economically viable.

[↓] The supply also depends on using the 100 times more fuel efficient fast reactors.

[↓] The United States Geological Survey indicates that 3,192,000 tonnes of uranium are economically recoverable if the price is US$80/kg

[↓] If the price were doubled to $160 US/kg, then the USGS says that ten times that amount would be economically available. There would be enough for 500 years based on providing all world energy by nuclear fission at about six times present world energy consumption.

[↓] If the price of uranium increased by almost 100 times to the price of gold at $14,000 US/kg—although gold is now closer to $20,000 US/kg—vast quantities of uranium would become economically recoverable. Estimates of world energy for at least 50,000 years, or more, are not unreasonable when using fuel efficient fast reactors.

Thorium is also a nuclear fission fuel and there is reported to be three to four times more thorium than uranium. Nuclear fuel can also be manufactured using a fusion reactor.

5 Slides: **Safety and proliferation of nuclear materials**

Safety issues always get resolved. There are many examples of this in automobile and aircraft safety as well as in many other areas.

[↓] Nuclear safety is under control. In addition to the atomic energy regulators of many countries, a section of the United Nations is dedicated to coordinating these procedures and ensuring they are followed world-wide. Procedures for security and safe handling of the many varieties of radioactive materials from thermal reactors are equally applicable to fast reactors.

[↓] The incident at Three Mile Island showed conclusively that with the proper design the core of a reactor could be melted with negligible release of radioactive materials to the area.

[↓] Chernobyl was the result of unauthorized operation of the reactor. Operation of the reactor became dangerous and the computer gave alarms to shut it down. The people operating the reactor silenced the alarms and continued towards disaster. The reactor was moderated with graphite, which caught fire, thereby spreading nuclear materials into the atmosphere. This reactor was designed specifically to make plutonium. Most reactors today are moderated with water, and the few proposed with graphite moderators are of quite different design.

[↓] Proliferation of nuclear materials is a concern and is manageable through the UN regulations.

4 Slides: Developing timely fast reactor capacity

The two main problems encountered in converting the world to fast reactor nuclear fission energy are: (1) how to build fast reactors quickly enough, and (2). how to provide timely quantities of the fuel required for starting a fast reactor. They can be started on approximately 15% enriched uranium two thirty-five or plutonium.

This shows how much nuclear electricity would be required in 2005 and 2020 if all electricity were from nuclear except for hydroelectricity.

[↓] With current thermal reactors we are about one-quarter of the way to supplying all electricity in 2005 by nuclear except hydro [88].

[↓] Here is an estimate based on current thinking of where we will be next using advanced light water thermal reactors.

[↓] Here's an estimate on the same basis of when and how quickly fast reactors can be built and commissioned. The line is about the same slope as that of increasing electricity demand. In other words, at the proposed rate of building and commissioning fast reactors we are not closing the gap between carbon free supply and demand.

We must do much better than this convert to all electricity to nuclear without severe disruption of supply as fossil fuels are depleted.

If we are to avoid energy supply problems, there has to be an acute sense of the importance of nuclear fission energy to the world's people, and a sense of urgency about building and commissioning fast reactors.

H. D. Lightfoot

The importance of energy cannot be overemphasized. There will be many necessary changes in our energy system, but there has to be enough energy. The warning signs are there now for oil and natural gas. It will take many years to get nuclear expanded to displace fossil fuels.

It is urgent that we understand the situation now and begin to work in the right direction to avoid future energy supply problems.

The sooner we start to close the gap shown on the previous slide, the better.

We need to have a specific result for which to aim and a coherent plan of action that might achieve it. These are suggested on the next two slides.

6 Slides: The best result for everyone

The following is an appropriate set of results for which we should strive.

[↓] It is clear that as Humankind, we are all looking to:

Lift poor nations out of poverty—each poor person must have access to more energy.

[↓] Maintain the well-being of everyone—income per person is directly proportional to energy consumption per person.

[↓] Adapt to climate change—without an adequate energy supply, it will be impossible to adapt to negative effects of large changes in climate, from whatever cause, of the sort that have occurred in the past, or even to relatively small changes.

[↓] Protect the environment— this relies on the world having an adequate source of energy that has minimum impact on the environment. If such energy is not available, forests will disappear as people use them for fuel and the land is used to grow food. Standards for air, water and food quality depend on energy and will slip when energy is in short supply.

[↓] Protection of the environment includes reducing carbon dioxide emissions to the desired level.

8 Slides: An energy supply plan

The following is a plan with a set of objectives that if achieved would give the desired results:

[↓] We must all practice conservation in our own way—the result is to extend fossil fuel supply and give us more time to implement change to our energy supply.

[↓] We must use energy as efficiently as possible, even though it may increase overall energy consumption. Increased energy efficiency may result in extending fossil fuel reserves to give us more time to implement change to our energy supply.

[↓] Use renewable energies where they are effective. Together, renewable energies have a small but important role in world energy demand.

[↓] We can start now towards producing all electricity by nuclear fission. Railroads can be electrified. Ships can be nuclear powered. Residential space heating and cooking and commercial space heating can all be provided by electricity.

Our electricity generating and distribution systems must be made robust and have excess capacity. As fossil fuels become scarce, people will replace them with nuclear generated electricity in non-transportation energy applications, such as space heating and cooking. We have all seen what happens to the grid during a heat wave and millions of air conditioners are plugged in without anyone warning the utility.

[↓] We must reserve liquid fuels for transportation purposes. This will extend our fossil fuel reserves until we develop the technology to power the transportation sector by nuclear energy in some form, possibly by manufacturing a liquid fuel of some sort.

[↓] We must encourage the conversion to all large ships to nuclear power.

[↓] We must use thermal reactors immediately because they are “on the shelf”. We must ultimately convert from thermal reactors to fast breeder reactors to use the energy remaining in spent fuel, to minimize nuclear waste and to have adequate energy for thousands of years.

H. D. Lightfoot

It is clear that providing future energy is a far more important problem to solve than climate change. That is not to say climate change is unimportant, but without adequate energy it will not be possible to adapt to negative effects of large climate change.

There are no perfect substitutes for fossil fuels. Because nuclear fission fuel is available on a large enough scale, nuclear fission energy is much closer than any other alternative to replacing fossil fuels. Further, nuclear energy capacity can be expanded as needed to match the rate at which energy is used.

Finding an alternative to oil as road and air transportation fuel is not going to be easy and will take a long time. In the meantime, we must reserve oil, coal, tar sands, etc., to provide liquid fuels for road and air transport. It will require much time and effort to find an alternate energy for road and air transport.

Now that we know the objectives that have to be achieved to give the desired result, we can make more appropriate decisions along the way towards it.

For example, converting all fossil fuel electricity generation to nuclear would reduce Canada's carbon dioxide emissions by about one-fifth, and those of the U.S. by about one-third. Ultimately, all electricity must be generated by nuclear, so there is a good incentive to start now.

Nuclear fission is the "new coal" and the path to the world's energy future.

4 Slides: Final comments

Interviewer

[↓] This presentation is an objective, science based picture of the world energy situation. It points out the importance of fossil fuels to the well-being of everyone, the importance of having enough energy to replace them, and the solution available to us.

It is the culmination of many years of research, which began officially in 1992. The presentation itself has gone through many iterations since the first one in February of 2000. A technical paper of an earlier version is also available [89].

It is not a doomsday scenario, but does not deny the difficulties that will be faced in achieving a solution.

[↓] H. Douglas Lightfoot is a retired mechanical engineer.

[↓] and is completely independent.

[↓] He is a member of the Global Environmental and Climate Change Centre (GEC3), McGill University, and have been associated there since 1992.

The complete text with references is in a separate file on the DVD, and can be accessed by computer.

1 Slide: www.nobodysfuel.com

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