5. ENERGY STORAGE FOR SUSTAINABLE FUTURE—A SOLUTION TO GLOBAL WARMING

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Abstract. The most dramatic challenge we are facing today is climate change induced to a considerable degree by human originated greenhouse gas emissions, especially the correlation between CO_2 concentrations and temperatures. The reduction of energy consumption and greenhouse emissions is among the issues of greatest interest for the prevention of global warming and climate change. Hence, developing and deploying more energy efficient and environmentally friendly energy technology is critical to achieving the objectives of **E**nergy security, **E**nvironmental protection, **E**conomic growth and social development known as three **E**'s. Energy Storage systems—a tool in forming the structure of sustainable energy for sustainable future—can play a key role in decreasing emissions that lead to global warming.

Keywords: Climate change; global warming; greenhouse effect; emissions; energy storage; energy conservation; sustainable future

5.1. Introduction

There is little doubt that we live in an age of rapid and accelerating change. Indeed, in today's world everything at times seems to be in flux.

The break of the third millennium coincided with important challenges for the energy sector. The demand for energy is increasing and so is the notion that we should take care of the environment. Our challenge today is to solve this apparent contradiction. Environmental concerns gain ground mostly on economic considerations, but above all decision makers now face crucial long-term energy policy choices. The opportunity therefore should be the increasing role of energy policy using renewable energy sources and production on global level.

For decades people have tried to achieve more of everything: more mobility, more comfort and more consumption. The signs are becoming increasingly evident that this cannot go on forever; too much burden is put on the environment and natural sources are becoming exhausted (Figure 12). Human

H. Ö. Paksoy (ed.), Thermal Energy Storage for Sustainable Energy Consumption, 87–99.

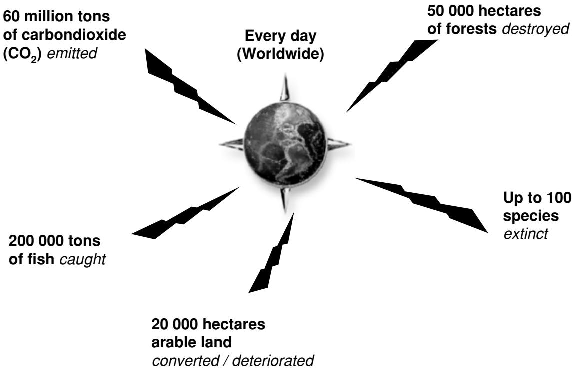

Figure 12. The daily toll

kind is approaching a critical turning point. We are already beyond limits of the Earth's carrying capacity. The new target is to change this tendency from "more" to "better", from "quantity" to "quality".

Mankind's impact on the global climate and whether pollution from modern energy use is indeed warming the Earth have become important issues for national and international policy makers. Political pressure and public sentiment are based on complex data sets that, alone, cannot tell the whole story. The ultimate question is whether our climate is becoming warmer because of the slow build-up in atmospheric greenhouse gas concentrations (1). The answer is not clear, because much of what we know about global climate change is inferred from historical evidence of uncertain quality.

5.1.1. CLIMATE CHANGE—WHAT IS THE PROBLEM?

Lack of reliable measurement is the first reason, as reliable ground-based measurements by scientific instruments have been made just in this century. These measure conditions only at the location of each instrument, and they are usually land-based, although 75% of the Earth is covered with water. We have been able to take precise, direct measurements only in the last four decades, and not until the advent of precision space borne instruments in the 1970s were we able to measure global temperatures at a range of altitudes across the entire atmosphere.

The presence of water as solid, liquid, and gas is a feature that makes Earth unique in the solar system and that makes life possible as we know it. The transport of water and the energy exchanged as it is converted from one state to another are important drivers in our weather and climate. One of the key missions is to develop a better understanding of the global water cycle at a variety of scales so that we can improve model forecasts of climate trends, predictions of short term and regional weather events, and even their impacts on society's regional and global activities.

Although water vapor is the most important greenhouse gas, we have not adequately sampled its four-dimensional variability—across space and time—over the globe. Recent analyses of global satellite data have produced many new observational data sets that describe the vertical and horizontal structure of moisture over the last 10–20 years. These data sets are being analyzed and validated to document the satellite measurements' capability to describe accurately, various components of the hydrologic cycle. In some cases, the trends observed by satellites are consistent with predictions by computer models, while in others, there are significant discrepancies. Understanding when and why the models are right or wrong and the nature and limitations of satellite data is key to their intelligent use in climate studies

The most dramatic challenge we are facing today is climate change induced to a considerable degree by human originated greenhouse gas emissions, especially the correlation between CO_2 concentrations and temperatures. The reduction of energy consumption and greenhouse emissions is among the issues of greatest interest for the prevention of global warming and climate change.

According to the National Academy of Sciences, the Earth's surface temperature has risen with accelerated warming during the past two decades (2). There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities. Human activities have altered the chemical composition of the atmosphere through the build up of greenhouse gases—primarily carbon dioxide, methane, and nitrous oxide. The heat-trapping property of these gases is undisputed although uncertainties exist about exactly how earth's climate responds to them.

5.2. Global Climate Change

Climate is the average pattern of weather over the long term. The earth's climate has warmed and cooled for million years since long before we appeared on the scene. There is no doubt that the climate is growing warmer currently; indications of that change are recorded and discussed by scientists.

Though climate change is not new, the study of how human activity affects the earth climate is. The exploring climate change encompasses many fields, including physics, chemistry, biology, geology, meteorology, oceanography and even sociology. I shall try to present you some evidences, uncertainties and conclusions about climate change.

The earth receives tremendous amount of energy from the sun. The land, sea and air absorb some of this energy and reflect back into space. The over all description of this process is called the earth's energy budget. The balance between energy absorbed by the earth and energy reflected back into space is fundamental in determining how warm or cool the planet becomes. The proportion of radiation reflected away by a surface is called its albedo. Albedo can range between 0 (no reflectance) and 1 (complete reflectance like a mirror) The earth's average albedo is 0.31 which means that overall, the planet reflects about 31% of incoming solar radiation back into space. But forests and deserts, oceans, clouds, snow and ice all have different albedos—and changes in these types of ground cover can therefore affect how much solar radiation the earth receives. For example, the albedo of forests lies in the range 0.07–0.15, while deserts have an albedo of around 0.3 (3).

The albedo of earth surface varies from about 0.1 for the oceans to 0.6–0.9 for ice and clouds which mean the clouds, snow and ice are good radiation reflectors while liquid water is not. In fact, snow and ice have the highest albedos of any parts of the earth's surface: Some parts of Antarctic reflect up to 90% of incoming solar radiation.

5.2.1. GREENHOUSE EFFECT—A PROBLEM OR ACTUALY ESSENTIAL TO OUR EXISTENCE?

The green house effect is one aspect of the energy budget. Solar radiation passes through the clear atmosphere: some solar radiation is reflected by the earth and the atmosphere and most radiation is absorbed by the earth's surface while some of the infrared radiation passes through the atmosphere and some is absorbed and reemitted in all directions by greenhouse gas molecules. The sun warms the earth and certain gases (CO_2 and water vapor) act like a screen, hence, trapping heat and keeping the planets surface at a hospitable 15 °C warm enough to support life (with no greenhouse effect the earth's average temperature would stabilize at about −18 °C).

5.2.2. WHAT ARE GREENHOUSE GASES?

Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Certain human activities, however, add to the levels of most of these naturally occurring gases:

Carbon dioxide is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal) and wood and wood products are burned.

Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock. More information on methane.

Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.

Very powerful greenhouse gases that are not naturally occurring include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), which are generated in a variety of industrial processes.

Each greenhouse gas differs in its ability to absorb heat in the atmosphere. HFCs and PFCs are the most heat-absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide. Often, estimates of greenhouse gas emissions are presented in units of millions of metric tons of carbon equivalents (MMTCE), which weighs each gas by its GWP value, that is, Global Warming Potential.

Problems may arise when the atmospheric concentration of greenhouse gases increases. Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. These increases have enhanced the heat-trapping capability of the earth's atmosphere.

Studies show that most of the warming over the last 50 years is attributable to human activities which have changed the chemical composition of the atmosphere through the built up of greenhouse gases, resulting in increased global temperatures—or as scientists call "global warming" (4).

A key issue in understanding global climate change is measuring humanity's effect on the concentration of green house gases. Scientists generally believe that the combustion of fossil fuels and other human activities are the primary reason for the increased concentration of carbon dioxide which may cause a significant warming trend. Plant respiration and the decomposition of organic matter release more than 10 times the CO_2 released by human activities; but these releases have generally been in balance during the centuries.

Once, all climate changes occurred naturally. However, during the Industrial Revolution, we began altering our climate and environment through changing agricultural and industrial practices. Additionally, through population growth, fossil fuel burning, and deforestation, we are affecting the mixture of gases in the atmosphere.

What has changed in the last few hundred years is the additional release of carbon dioxide by human activities. Fossil fuels burned to run cars and trucks, heat homes and businesses, and power factories are responsible for about 98% of carbon dioxide emissions, 24% of methane emissions, and 18% of nitrous oxide emissions. Increased agriculture, deforestation, landfills, industrial production, and mining also contribute a significant share of emissions (5). For example, in 1997, the United States emitted about one-fifth of total global greenhouse gases.

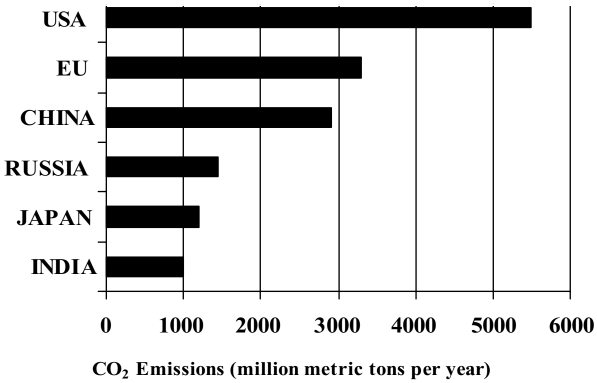

Figure 13. Total CO_2 emission (according to UNFCCC)

Estimating future emissions is difficult, because it depends on demographic, economic, technological, policy, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. For example, by 2100, in the absence of emissions control policies, carbon dioxide concentrations are projected to be 30–150% higher than today's level.

The Intergovernmental Panel on Climate Change (IPCC), a group established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) reports that the average surface temperature of the earth has increased during the twentieth century by about 0.60 ± 0.20. This may seem like a small shift, but although regional and short-term temperatures do fluctuate over a wide range, global temperatures are generally quite stable. In fact, the differences between today's average global temperature and the average global temperature during the last Ice Age are only about 5 °C. Indeed it is warmer today around the world than at any time during the past 1,000 years, and the warmest years of the previous century have occurred within the past decade. But climate change is a better description as some areas may cool.

The total CO_2 emissions of some countries are given in Figure 13.

The US pollutes more, absolutely and per head, than any other country (it also produces more wealth). Its greenhouse emissions have raised by more than 11% since 1990: its Kyoto commitment was to reduce them by 6%. It is the only country to have signed the protocol and then to have repudiated it. President Bush said in March, 2005 the US would not ratify Kyoto, because he thought it could damage the US economy and because it does not yet require developing countries to cut their emissions. His domestic and foreign critics think the US will lose economically by staying alone.

The EU wants a rigorous application of Kyoto, allowing only restricted use of its flexibility mechanisms: these allow countries to go some way to meeting their pollution reduction targets by paying for improvements beyond their frontiers. The EU says countries should meet at least half their targets by cutting emissions at home. It also opposes widespread use of forests and other carbon "sinks" to absorb pollution. While the green blocs in several northern European governments remain rigorous, the UK is trying to rebuild bridges with the US. But the EU will probably remain united in seeking Kyoto's early entry into force.

China is an Annex II country, not yet required to cut its emissions. But it is reported to have cut its emissions of the main gas listed in the protocol, carbon dioxide, by 17% since the mid-1990s. In the same period its economy has grown by one-third. Accounting for a fifth of the world's population, with hopes of a better life, China could obviously soon emit enough to dwarf any reductions agreed by the Annex I countries. But its leaders recognise that climate change could devastate their society. China encourages the protocol's supporters to believe that Kyoto is already helping to make a difference.

Russia, a developed country, is part of the "Annex 1" bloc of countries committed to cutting emissions under the protocol. But its economy has shrunk so drastically since 1990 that it cannot afford to burn the fuel that would produce the emissions Kyoto entitles it to. Its emissions have fallen by almost 40% in a decade. So it favours emissions trading, selling its unused entitlement to developed countries wanting to emit more than the protocol allows them. Russia will ratify Kyoto, because it recognises it as a way of earning desperately needed money. It plans to use the cash for energy efficiency projects.

A major world economic power, Japan is a leading Annex I member of Kyoto, committed to cutting emissions. It feels an attachment to the protocol, named after the Japanese city where it was concluded. It recognises the argument that its economy could gain from seeing the treaty in force, as Japanese companies could capture markets for new, clean technology. But Japan is very reluctant to ratify Kyoto unless the Americans do so as well. Without Japanese ratification the protocol is very unlikely to attract the support it needs to become international law.

Developing countries like India are listed under Kyoto as Annex II countries, and they are not obliged to make any cuts in greenhouse emissions reduction yet. But as they raise living standards their emissions will obviously increase: India's have risen by more than 52% since 1990. Under Kyoto, they will have to accept reduction targets in a few years from now. The protocol's architects say it is fair to allow them a grace period, because the problem has been caused by the industrialised countries. But India, with more than 1 bn people, will soon be a major polluter.

What proof do we have? The proofs are listed below:

- It is getting warmer.
- Long-term temperature changes.
- Rising waters.
- Arctic sea ice decrease.
- Fossil fuel emissions increase.

Measurements from a variety of sources have suggested that the earth's average atmospheric temperature has raised over the last several hundred years—but by how much? Taking the average temperature of the earth's atmosphere is a very difficult measurement problem. First, measurements must be taken in a large and diverse enough range of locations to ensure that their average is truly a measure of global temperature and is not biased toward one region or another. Second, those locations must be chosen so that individual measurements are not thrown off by sources of unusually high or low temperatures, such as cities (which tend to be "heat islands" warmer than the surrounding landscape). Third, no measuring device is perfect—all measurements include some amount of error, or "noise." Understanding the kinds of errors associated with different measurement techniques is a key element in evaluating the accuracy of a given temperature value. In addition, the study of climate requires measurements over very long time periods, so sources of paleoclimate data (data on climate from the distant past) are key to understanding climate change.

Two kinds of problems make this an exceptionally difficult question to answer.

First, the enormous complexity of the earth's dynamic climate system including the interacting air masses, winds and, ocean currents, and patterns of evaporation and precipitation makes long-term climate prediction extremely problematic. Estimates drawn from reports by the Intergovernmental Panel on Climate Change (IPCC) project increases in average global temperatures ranging from 1.4 °C to 5.8 °C by the year 2100. These numbers may seem small, but because average global temperatures are actually remarkably stable over long periods, this range actually represents a very significant rise in the earth's temperature over a very short time.

A second problem complicating the picture is the unpredictability of human behavior. At what rate will the human population—and its production of carbon dioxide—grow? As formerly undeveloped countries expand their industry, often using cheaper (and more polluting) fossil–fuel technology, their contributions to greenhouse gases will rise and add to the problem—but by how much? To what extent will new, cleaner technologies (such as cars powered by hydrogen fuel cells) be developed and adopted by countries around the world? These kinds of uncertainties make the tough problem of predicting climate change all the more difficult.

Thirdly the oceans play a key role in regulating the earth's climate—and yet they remain mysterious, because so many of the basic processes underlying ocean dynamics are still poorly understood. Their fundamental role in climate is based largely on their storage and transport of heat around the globe. The oceans store vast amounts of heat, much more than the heat stored by the atmosphere, because water is 1,000 times more dense and has a heatholding capacity four times that of air. Ocean currents are primary highways for the transport of heat around the globe.

Fourthly living things do not just respond to the climate—they affect it as well. Plants consume carbon dioxide and produce oxygen through photosynthesis. Earthbound plants take carbon dioxide directly from the air; drifting photosynthetic micro-organisms called phytoplankton use carbon dioxide dissolved in water.

It is estimated that photosynthesis is a "sink" for around 60 billion tons of carbon every year, by far the strongest mechanism for carbon dioxide removal from the atmosphere. (This removal is almost exactly balanced by the respiration of animals, which combines oxygen with hydrocarbons to produce carbon dioxide and water vapor.)

Increases in the level of carbon dioxide in the atmosphere could promote plant growth. If the planet's vegetation grows stronger and more widespread, it could take in more of the atmospheric carbon dioxide, preventing a runaway greenhouse effect. This controversial "greening hypothesis" has led to more research exploring the connections between global climate and the earth's biological systems.

The extremely complex interrelations between human activity and natural forces—air masses, winds, ocean currents, evaporation, and precipitation—means that researchers from many fields pool their efforts in an attempt to understand how the climate is reacting to changes. But this complexity also means that knowing what the climate will be like in 50 or 100 years is among the most challenging problems in science.

Some of the changes researchers in all these areas are exploring may seem small, especially in relation to the typical temperature changes associated with daily and seasonal cycles. But although regional and short-term temperatures do fluctuate over a wide range, global temperatures are generally very stable. Indeed, during the last Ice Age (about 20,000 years ago), the average global temperature was only about 5 °C cooler than it is today.

- Greenhouse effect is essential to our existence.
- Oceans cover more than 70% of the earth's surface play a fundamental and complex role in regulating climate.

- Changes in climate dramatically alter the planets snow and ice covered cryosphere.
- The effects of climate change on plants and animals are difficult to measure, but potentially dramatic.
- Interpreting past and present climate data is difficult, but predicting future climate change—and its possible effects—is even more challenging.

The relationship between greenhouse gases and temperature in Antarctica over a 420.000 year period confirms global warming. Although these measurements cannot prove what factors caused climate changes, these data do strongly suggest that atmospheric gas concentrations and temperatures are related.

There is scientific consensus on global warming, but no consensus about its cause (6).

The fact that seemingly small changes can have dramatic effects is one reason why an understanding of the data, techniques, and controversies of global climate research is so fundamental to understanding the phenomenon itself.

5.3. Why Store Energy?

World wide perspective of energy storage is that:

- Existing energy systems are not sustainable.
- Diversification of supply is essential (a solution only to a part of the problem).
- Efficiency with renewables is the strategic mission to sustainability.

5.3.1. MOTIVATION AND CHALLENGES

Considerable efforts are being made to economize non-renewable energy resources by sensitizing experts in the field of energy who in turn will look for alternatives, thereby removing the dependency on non-renewable resources. The motivation and challenges for storing energy are focused mainly on three important facts.

- Energy security/reliability—using new energy technology.
- Environmentally friendly techniques for climate protection, hence, contribution to environmental conservation—commitment for reduction of CO_2—obligations of Convention on Climate Change, Kyoto Protocol.
- Economic feasibility—using market principles.

Developing and deploying more efficient and environmentally friendly energy technology is critical to achieving the objectives of **E**nergy security,

Environmental protection, **E**conomic growth and social development known as three **E**'s. The mission is to implement an environmentally friendly energy system. If we are to achieve sustainable development, we will need to display greater responsibility for energy, economy and environment.

The environmental benefits of TES is utmost important and discussed within the framework of UN Convention on Climate Change and Kyoto Protocol which is a significant issue of critical debate among countries nowadays (7).

5.3.2. WHY ENERGY EFFICIENCY AND CONSERVATION?

Energy efficiency and conservation are necessary, because energy consumption is a major cause of environmental degradation. All types of energy use result in environmental costs, it's just a matter of degree. And most modern activities seem to involve energy consumption. Transportation, food production, manufacturing, governments, recreation and household management all consume energy.

At the same time, our major energy supplies (oil, coal, and gas) are finite. They are not renewable, yet we burn through these fuels as if there were no tomorrow. The energy supplies which are renewable (solar, wind, thermal) are not being used as widely or thoughtfully as they should be.

Given these facts, we need to reduce our energy consumption and environmental damage to the extent we can, and come into balance with natural energy recovery and production processes. We need to develop truly sustainable energy consumption practices for a sustainable future (8).

Therefore, Storage systems can play a key role in decreasing emissions that lead to global warming and ozone depletion. TES (Thermal Energy Storage) contributes significantly to energy efficiency (9). Consequently storage techniques can be used as a tool in forming the structure of sustainable energy for sustainable future.

Energy storage technologies are a strategic and necessary component for the efficient utilization of renewable energy sources and energy conservation. There is a great technical potential to substitute burning fossil fuels by using stored heat that would otherwise be wasted and using renewable generation resources.

5.3.3. EXPECTED BENEFITS

- Better management of energy resources.
- Increase energy efficiency.
- Use alternative energy systems.
- Reduction of harmful emissions.

- Decreasing dependency on fossil fuels.
- A brake to global warming.

Creation of a new understanding how to make TES happen is crucial, hence the introduction of the correct economic and environmental instrument is the single most important factor controlling the sustainable growth of renewable technology, hence effective international collaboration and awareness have an increasingly important role.

5.4. Conclusion

Many governments have committed to reduce CO_2 emissions into the atmosphere. They have decided to strengthen their national efforts to increase the deployment of energy conservation technologies and the utilization of renewable energy sources. So far in most industrialized countries, renewable energy sources contribute only marginally to satisfy energy demand. This is due to several reasons, in particular because some new energy systems are not yet economically competitive with the combustion of fossil fuels, long-term reliability is not yet proven, and there are still some regulatory and market barriers which have to be overcome. Therefore, further attempts are being made to resolve these issues. This is especially true for many new energy storage technologies and concepts that have not yet been implemented on a large scale in the market Research into the future alternatives must therefore be urgently conducted. The principal task is to secure energy supplies for both the short and long terms. In order to cope jointly with energy problems many countries have come together for research to conserve energy, to reduce dependence on oil, to reduce the environmental emissions associated with energy and to pursue research and development. The mission is to implement an environmentally friendly energy system.

Over the last few years, the emphasis in research has shifted towards storage technologies that improve the manageability of energy systems or facilitate the integration of renewable energy sources.

If fully exploited, storage systems can play a key role in decreasing emissions that lead to global warming and ozone depletion. Additionally the usage of such techniques will lead to energy conservation in the range of 40–80% in terms of fossil fuel and electricity, and improves energy efficiency when compared with conventional systems. Consequently storage techniques can be used as a tool in forming the structure of sustainable energy for sustainable future.

We have not fully integrated energy with the economic and environmental pillars of development. If we are to achieve sustainable development, we shall need to display greater responsibility for energy, economy and environment. Achieving sustainable development is not an easy task. Significant changes will be needed—in decision making at the highest levels and in day-to-day behavior—if we wish to reach our goal of development that meets the needs of today without sacrificing the ability of future generations Tens years ago in Rio de Janeiro, governments committed themselves to just such transformations, but commitments alone have proven insufficient to the task. I see ourselves, as members of IEA ECES, a mediator between research, policy, business and the public to end the "cold war" between the three E's.

Taking this into account I look forward to a productive NATO Summer School with new motivation to shift to energy conservation techniques of the new millennium in meeting Kyoto Targets for the reduction of greenhouse gas emissions in order to combat climate change.

We are all on the same boat—the Earth, the important thing is what we do together for the optimization of the worlds conditions through environmental measures and energy conservation.

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