An Indispensable Truth

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How Fusion Power Can Save the Planet

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Preface

Al Gore's book and video, *An Inconvenient Truth*, has raised the public consciousness about the dangers of global warming and climate change. This book is intended to convey the message that there is a solution. A solution not only to global warming caused by anthropogenic emissions of carbon dioxide, but also to the depletion of fossil fuels and to the wars in the Middle East related to our dependence on their supply of oil.

The solution is the rapid development of hydrogen fusion energy. This energy source is inexhaustible (it is seawater); no greenhouse gases are emitted; and the dangers of nuclear power are avoided.

Most legislators and journalists have regarded fusion as a pipe dream with very little chance of success. They are misinformed, because times have changed. Achieving fusion energy is difficult, but the progress made in the past two decades has been remarkable. Mother Nature has actually been kind to us, giving us beneficial effects that were totally unexpected. The physics issues are now understood well enough that serious engineering can begin. An Apollo 11-type program can bring fusion online in time to stabilize climate change before it is too late.

Seven nations have joined together to form and share the cost of ITER, a large machine which is an important step in achieving fusion. These nations contain more than half the world's population. A community of international workers, as well as schools for their children, has been set up at the ITER site in Cadarache, France. More on ITER will come later. There is a plan and a timetable to pursue the ultimate solution to civilization's most pressing problems. There is no downside to fusion.

So much has been written about climate change and alternate energy sources that almost every magazine has an article on these topics. By repeating the data given by Al Gore, journalists have found an easy way to meet their deadlines. Readers are hard pressed to distinguish fact from conjecture and sensationalism. We therefore start with a summary of climate change and energy sources, trying to give a concise, impartial picture of the facts. Here, I am out of my depth; I am not an expert on these topics. I get my information from the same newspapers, magazines, and websites that you do. But I think it is important to put fusion in the proper context within the general scheme of the world's future.

However, that is not what this book is about; it is about controlled fusion. The physics of fusion is highly technical, but the difficult problems and ingenious solutions can be explained so that everyone can appreciate what has been done. This is a difficult task, and I ask you to be patient. Although our explanations are longer and gentler than the succinct language of scientific journals, you cannot flip through the pages as with an ordinary book. This book is written for a variety of readers, from "green" enthusiasts with no science background to Scientific American magazine subscribers. There is a lot of information contained in many new concepts, but they can be understood by anyone with a college, or even high school, education. If you get stuck, do not give up. Your can skip ahead to more practical and less scientific material. The bottom line – what has yet to be done, how long it will take, and how much it will cost – may surprise you.

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Prologue: Toward a Sustainable World

Several hundred million years ago, light from the sun produced trees on the earth, and these were eventually converted into fossil fuels in the earth's crust. This legacy of easy energy allowed mankind to develop the advanced civilization that we enjoy today. But it is fast running out. The sun is the ultimate source of 90% of the energy we use, but it is mostly in fossil form. The everyday influx of solar power is too dilute to supply all energy that we use. We depend on the fossil fuels stored away from forests grown by the sun eons ago. Controlled nuclear fusion, or "fusion" for short, is about making an artificial sun on earth. It is not easy; but we hope to show that it is not only possible, but necessary (Fig. 1).

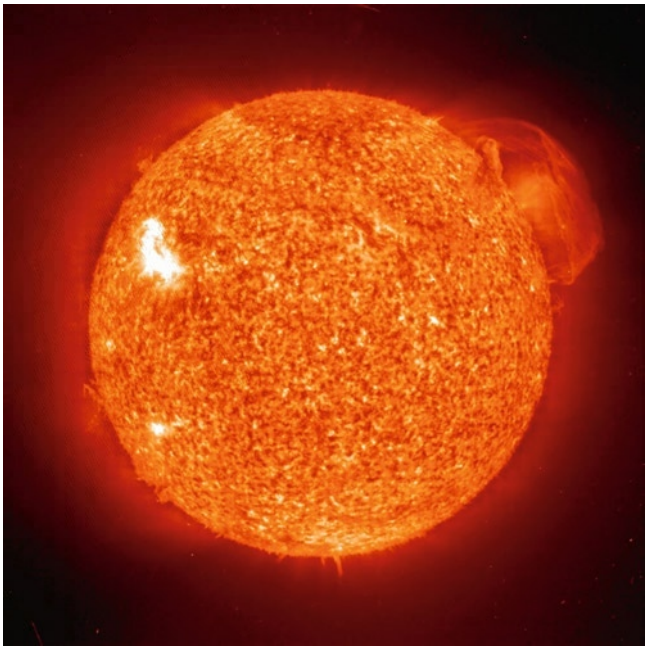

Fig. 1 The sun, the source of our energy

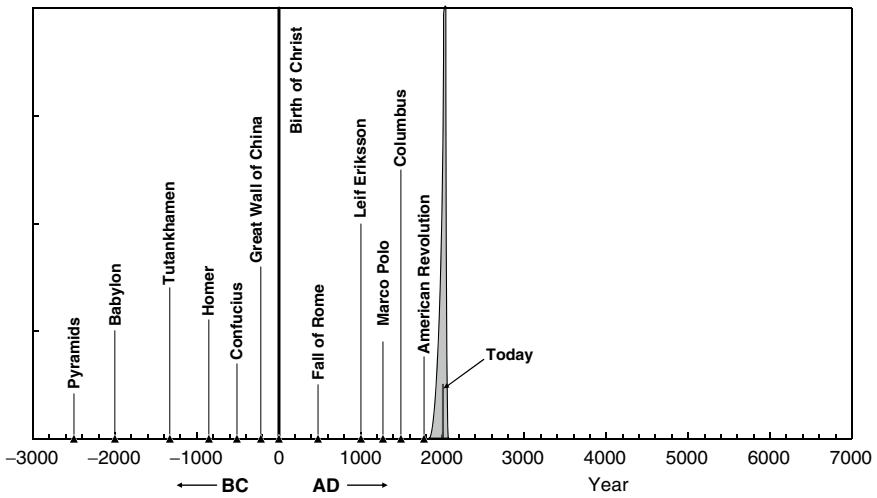

Fig. 2 A timeline of our civilization extending 5,000 years in the past to 5,000 years in the future, should we survive that long. Dates of a few historical markers are shown. The *shaded peak* is actually a plot of the annual usage of fossil fuels and shows the narrow segment of human history that it occupies

Let us take a look at how fossil fuels fit into the scheme of human history. Figure 2 shows a timeline from the beginning of recorded history to several thousand years in the future, showing several significant events along the way. The large, narrow peak in the center, known as Hubbert's Peak, represents the rate of mining and use of fossil fuels. It begins with industrialization in the 1800s and will end less than 100 years from now with the depletion of readily accessible deposits. This will happen within the lifetimes of our children and grandchildren. We are extremely lucky to be here during this very brief slice of time in the history of mankind. If our civilization is to continue as far into the future as it has existed in the past, it is clear that fossil fuels will have to be replaced by other energy sources. Energy conservation and known renewable energy sources will not be enough to sustain our civilization.

In considering either climate change or energy sources, it is important to separate three very different time scales that are involved. The first time scale is a short one, a few months to a few years, the time it takes to implement immediate but temporary solutions. For climate change that might be making an agreement like the Kyoto Protocol or issuing carbon credits which can be traded on the market. For oil or gas shortage, that might be limiting the speed limit to 55 miles per hour, offering tax credits for renewable energy installations, or starting a war in the Middle East. The second time scale is longer, 10–50 years, the time it takes to develop new sources of energy which will not burn fossil fuels and generate CO_2. The third time scale is far into the future, 100–5,000 years, perhaps the life of human civilization on this planet as we know it today. The band-aid solutions of the near term are mostly

political. The problems of the far future cannot be solved now, since we do not know what they will be. However, the problems of the second (intermediate) period are upon us now, and there is barely time for effective action. Global warming and sea level rise will accelerate in the next ten years. Fuel prices will rise as fossil fuels become scarce and hard to burn cleanly. It is time to complement the efforts spent on temporary solutions with a serious program to solve the bigger problem.

Fusion power is a solution which will take time and money to bring to reality, but no more so than putting a man on the moon. We live in a glorious age when we can afford to send satellites to explore the solar system and to build huge particle accelerators to probe the structure of matter on the smallest scales. But we are not taking care of our future. The outlook is not quite that bad, however. As will be described in future chapters, the International Thermonuclear Experimental Reactor, ITER, is being supported by seven nations representing more than half the world's population. Costing some $21 billion and located in France, it will test sustainability of a fusion reaction – a continuous "burn." It is to be completed in 2019 and operated for ten years or more. Another large machine will be needed simultaneously to solve engineering problems not included in the ITER project. After that, the first power-producing fusion reactor, DEMO, is planned, but not before the year 2050. The path is clear, but the rate of progress is limited by financial resources. In the USA, fusion has been ignored by both the public and Congress, mainly because of the lack of information about this highly technical subject. People just do not understand what fusion is and how important it is. Books have been written light-heartedly dismissing fusion as pure fantasy.[1] The fact is that progress on fusion reactors has been steady and spectacular. The 50-year time scale presently planned for the development of fusion power can be shortened by a concerted international effort at a level justified by the magnitude of the problem. It is time to stop spinning our wheels with temporary solutions.

The following chapters will tell the fascinating story of how the tricky problems of creating a miniature sun on the earth are being solved, as well as give a realistic account of what is left to be done and the likelihood of success. *Controlled fusion energy is not a pipedream*. It can replace fossil fuels and curb global warming. The world will benefit from a concerted effort to bring fusion reactors into the power grid sooner rather than later.

[1] For instance, C. Seife, *Sun in a Bottle, The Strange History of Fusion and the Science of Wishful Thinking* (Viking Books, 2008).

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