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ENERGY EFFICIENCY IS KEY TO CLIMATE-CHANGE MITIGATION

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Abstract

This article discusses the role that the man-made Enhanced Greenhouse Effect (EGE) plays in global climate change. While considerable uncertainty remains about the efficacy of global climate change models and methodologies, there is no uncertainty about the enhanced greenhouse effect and the causal relationship it plays in the warming of our planet. Following a brief introduction to concerns about global climate change, the article traces our knowledge of the EGE from when it was first postulated almost 175 years ago, to our understanding today, upon which our scientific concerns about global warming are solidly grounded. It is suggested that the problem of the EGE is so pervasive that if the sun does in fact play a role in climate change then the EGE adds to it, thereby exacerbating the problem. While some degree of global warming is thought to be inevitable due to carbon dioxide's long atmospheric life, the various source-mitigation options of particular interest to energy engineers are discussed with a view to mitigating the longer-term effects. Energy efficiency is key to these climate-change mitigation efforts. The degree of difficulty and complexity facing energy engineers in positioning the climate-change issue with potential clients is clearly illustrated in this article. The article is representative of the type of modern-day public relations and marketing strategy that must be deployed by practicing professionals in order to effect the changes necessary for a more sustainable energy future.

What is Climate Change?

A great number of the world's leading scientists believe that the Earth's atmosphere is gradually warming and that this is perturbing our global climate systems. Further, it is believed that the warming is being caused by the accumulation of heat-trapping gases in the atmosphere—primarily carbon dioxide (CO_2) released as the result of burning fossil fuels, and deforestation.

In the coming decades, and without appropriate mitigation of these so-called "greenhouse gases" by humankind, this perturbation is expected to increase dramatically and change the very nature of the planet upon which we live. Melting polar ice caps, receding glaciers, widespread flooding, release of stored carbon dioxide from permafrost, migration of tree lines, spread of insect-borne diseases, and sea-level rise are all part of a future that climate change promises without corrective action today.

The Enhanced Greenhouse Effect

While the role of the sun should not be discounted, there is no question that man-made carbon dioxide emissions have the effect of enhancing global warming. The process under which this takes place is known as the Enhanced Greenhouse Effect (EGE) and climate change is its symptom. And importantly, whereas there is uncertainty in the climate-change models, there is no uncertainty about the Enhanced Greenhouse Effect.

The scientific community first began studying its effects in 1827 when Baron Jean Baptiste Joseph Fourier (1768-1830), the French mathematician and physicist, pointed out the similarities between the behavior of heat in our earth's atmosphere and its behavior in a greenhouse. Fourier was the first to recognize the warming effects of the gases in a greenhouse and had the "notion that some of the heat generated by solar radiation is absorbed and reradiated downwards by the atmosphere. This thermal envelope warms the globe."[1] It was Fourier's

continued from page 1

work that led to the term "the greenhouse effect." His work was followed, in the middle of the 19th century, by the Irish physicist John Tyndall (1820-1893), who demonstrated and "*measured* the absorption of infrared radiation by carbon dioxide and water vapor."[2]

In 1896 the first calculations for the EGE began to emerge with the work of Swedish chemist and Nobel laureate Svante August Arrhenius (1859-1927), whose interest lay in "the idea of linking long-term variations in atmospheric carbon dioxide to climate change."[3] He showed that carbon dioxide in the atmosphere acts as a "heat trap" because it is completely transparent to incoming high-frequency sunlight but opaque to low-frequency infrared radiation, which the Earth re-radiates back toward space.

He "*calculated the effect* of an increasing concentration of greenhouse gases"[4] and suggested that even a slight rise in carbon dioxide levels would raise the Earth's temperature markedly. He estimated that when Earth reached the point where the concentration of carbon dioxide in the atmosphere had doubled, the Earth's global average temperatures would have increased by five to six degrees Celsius. Remarkably, a century later, this estimate is not far from the understanding of scientists today.

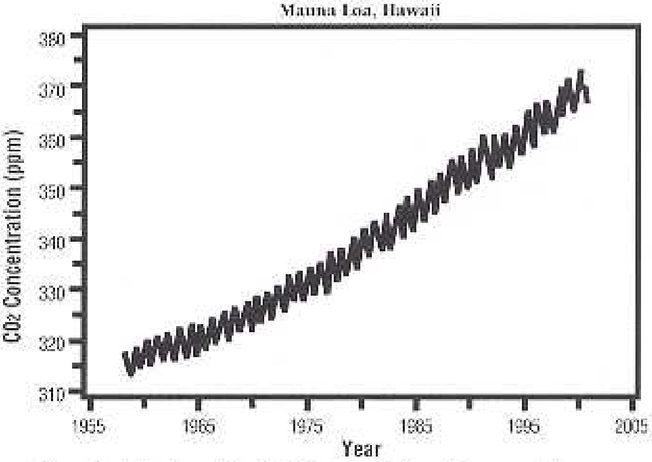
One of the key features of Arrhenius's famous carbon dioxide model was that it included what became known as a "positive feedback loop"—rising atmospheric temperatures would cause increased water evaporation, which would increase the amount of water vapor and, therefore, the absorption of heat (infrared radiation). This self-perpetuating cycle would have the potential to accelerate, and the resulting "runaway greenhouse" could throw our climate into chaos.

For the next 60 years a few scientists continued to work on the EGE and some even predicted global warming but there was general consensus in the scientific community that the oceans, with their large capacity to store carbon, would absorb almost all carbon dioxide emitted into the atmosphere. At an international symposium of eminent scholars meeting at Princeton University in 1955 on "Man's Role in Changing the Face of the Earth" this consensus was affirmed. There was no mention of the greenhouse effect. It had virtually disappeared from the scientific research agenda.

Then, in a 1957 landmark paper on carbon dioxide exchange between the atmosphere and the ocean, published by Roger Revelle and Hans Suess of the Scripps Institute of Oceanography, the researchers reported "that the ocean had *not* absorbed as much carbon dioxide as everyone had previously assumed. Significant amounts would remain in the atmosphere and could eventually warm the Earth."[5] At that time—over 40 years ago—Revelle and Suess wrote that:

> Human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in the sedimentary rocks over hundreds of millions of years.[6]

Soon after, David Keeling, a colleague at Scripps, invented an instrument to measure atmospheric CO_2 concentrations. Selecting a site "far from any man-made sources of pollution,"[7] 11,000 feet above sea level on a mountaintop at the Mauna Loa Observatory in Hawaii, he began taking measurements. Four air samples are taken *every hour* and from 1958 to 2000 it has been demonstrated that the levels have been increasing annually. Since 1958 the recorded concentrations at Mauna Loa have increased from 315 ppm to 370 ppm (parts per million)—with 370 ppm representing a 32% increase above the pre-industrial level of 280 ppm recently determined from ice-core records.



Source: David Keeling and Tim Whorf (Scripps Institution of Oceanography).

But how do we know that fossil fuels are causing this warming?

The Certainties:

Several "lines of evidence prove conclusively that the recent buildup of carbon dioxide arises largely from human activities."[8] Working in conjunction with the data-gathering at Mauna Loa and many other monitoring stations around the world to support and explain that the buildup of greenhouse gases is human in origin, these lines of evidence are:

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1) There are discernible differences between the nuclei of carbon atoms emitted under natural conditions and those emitted by burning fossil fuels.

Coal, oil, and natural gas were formed deep underground tens of millions of years ago, and the fraction of their nuclei that were once radioactive has long ago changed to non-radioactive carbon. But the carbon dioxide emitted from natural sources on the Earth's surface retains a measurable radioactive portion. As carbon dioxide has been emitted through fossil fuel combustion, the radioactive fraction of carbon in the atmosphere has decreased. Forty years ago scientists provided the first direct evidence that combustion of fossil fuels was causing a buildup of carbon dioxide and thereby diluting radioactive carbon in the atmosphere by measuring the decreasing fraction of radioactive carbon-14 captured in tree rings each year between 1800 and 1950.[10]

2) Ice-core analysis shows buildup of greenhouse gases to be recent in origin.

Ice buried below the surface of the Greenland and Antarctic ice caps contains bubbles of air trapped when the ice originally formed. These samples of fossil air, some of them over 200,000 years old, have been retrieved by drilling deep into the ice. Measurements from the youngest and most shallow segments of the ice cores, which contain air from only a few decades ago, produce carbon dioxide concentrations nearly identical to those that were measured directly in the atmosphere [by David Keeling's instruments] at the time the ice formed. But the older parts of the cores show that carbon dioxide amounts were about 25% lower than today for the 10,000 years previous to the onset of industrialization, and over that period changed little.[1]

3) There is more carbon dioxide in the air of the industrialized Northern Hemisphere than in the Southern Hemisphere.

The final line of evidence comes from the geographic pattern of carbon dioxide measured in air. Observations show that there is slightly more carbon dioxide in the Northern Hemisphere than in the Southern Hemisphere. The difference arises because most of the human activities that produce carbon dioxide are in the north and it takes about a year for Northern Hemispheric emissions to circulate through the atmosphere and reach southern latitudes.[12]

Doesn't nature produce carbon dioxide also?

Carbon dioxide is released to the atmosphere by a variety of sources, and over 95% of these emissions would occur even if human beings were not present on Earth. For example, the natural decay of organic material in forests and grasslands, such as dead trees, results in the release of about 220 billion tons of carbon dioxide every year. But these natural sources are nearly balanced by physical and biological processes, called natural sinks, which remove carbon dioxide from the atmosphere. For example, some carbon dioxide dissolves in sea water, and some is removed by plants as they grow.

As a result of this natural balance, carbon dioxide levels in the atmosphere would have changed little if human activities had not added an amount every year. This addition, presently about 3% of annual natural emissions, is sufficient to exceed the balancing effect of sinks. As a result, carbon dioxide has gradually accumulated in the atmosphere, until at present its concentration is 30% above pre-industrial levels.[10]

Although carbon dioxide is our subject here, it should be noted that several other greenhouse gases contributing to "climate forcing" were identified in the 1980s. These include methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Recently, there has been more attention given to the climate-forcing potential of anthropogenic tropospheric ozone (O_3) and black carbon (soot) aerosols.

Direct atmospheric measurements of other human-produced greenhouse gases have not been made in as many places or for as long a period as they have for carbon dioxide. However, existing data for these other gases do show increasing concentrations of methane, nitrous oxide, and chlorofluorocarbons over recent decades. In addition, ice-core data are available for methane and for nitrous oxide that demonstrate that the atmospheric concentrations of these gases began to increase in the past few centuries, after having been relatively constant for thousands of years. Chlorofluorocarbons are absent from deep ice cores because they have no natural sources and were not manufactured before 1930.[11]

This, then, is our basic understanding of the enhanced greenhouse effect: several greenhouse gases absorb various wavelengths of infrared radiation re-emitted by the Earth; the buildup of greenhouse gases in the atmosphere is primarily the result of burning fossil fuels; and the atmospheric concentration of greenhouse gases has been rising every year since the beginning of the Industrial Revolution in the 1750s. The inescapable conclusion is that if the sun has a role, and global warming is in part due to natural variability, then the human condition is made more precarious still because of the enhanced greenhouse effect. Regardless of what the actual climate impacts might be, we can only conclude that the enhanced greenhouse effect will ensure that the effects are worse than they might have been if the EGE had not been augmented by constant daily injections of greenhouse gases into the atmosphere.

Further, a National Academies report commissioned by the White House earlier this year points out that CO_2 "removal time" exceeds several hundred years. "A removal time of 100 years means that much, but not all, of the substance would be gone in 100 years. Typically, the amount remaining at the end of 100 years is 37%; after 200 years, 14%; after 300 years, 5%; after 400 years, 2%."[11] Because greenhouse gases stay in our atmosphere for so long, and emissions are not currently being abated, some warming is inevitable and Arrhenius's feedback loops are more likely. The challenge for us all is to find solutions to this problem.

What is the role for energy engineers?

While a full discussion of the options is not possible here, the following is an overview of a "framework for solutions" upon which country strategies are currently envisioned. This will lead us to the various source-mitigation options of particular interest to energy engineers.

Within the climate-change-policy community it is generally acknowledged that solutions fall into two broad categories: climate-change adaptation and greenhouse-gas mitigation.

Climate-change adaptation is a damage-avoidance or economy/health protection strategy. For example, low-lying coastal communities and small island states might build seawalls to protect against sea-level rise. Other regions might seek measures to adapt to melting polar ice caps or permafrost, receding glaciers, and widespread flooding or to prevent the spread of insect-borne diseases such as malaria and dengue fever. Adaptation takes the view that climate change is inevitable and there are indicators that climate change is taking place. Sadly, it is those nations most at risk who appear to be least able to protect themselves and, as a result, adaptation measures are very high on the list of concerns for international funding support.

Greenhouse-gas mitigation measures reduce, eliminate, or store emissions in the hope that climate change is either a manageable or avoidable problem. Mitigation is the realm of the energy engineer and is subdivided into two distinct areas of activity: sink-based or source-based mitigation.

Sink-based mitigation includes the sequestration (capture, storage, or disposal) of carbon dioxide, and the enhancement of soil and forest sinks. Such activities might include, for example: the decarbonization of fossil fuels, improved forest management and tilling practices, smokestack CO_2 capture, and geologic or deep ocean storage of carbon dioxide. Typically, sink-based measures are at the cutting edge of R&D today.

Source-based mitigation is the reduction or elimination of emissions from the sources of production and consumption. It is generally agreed that this covers five specific options: energy conservation; fossil-fuel switching; clean, renewable energy; nuclear energy; and energy-efficiency improvements.

1) Energy conservation, as distinct from energy efficiency, is the culture of waste. The more energy we waste, the more carbon dioxide we emit into the atmosphere. This is considered a public education problem. For example, encourage people to walk to the corner store instead of driving, and, amazing to contemplate, to close windows when the air conditioner is running. The selection of gas or solar water heating over electric heating is similarly a conservation measure, not an efficiency measure.

2) Fossil-fuel switching is a carbon efficiency measure. For example, from an emission perspective, natural gas is cleaner to use than coal because it contains much less carbon per BTU of fuel. As a result, there is tremendous impetus to now switch our global electricity infrastructure from one based on coal to one based on natural gas. This one-dimensional focus on fossil-fuel switching to natural gas is shortsighted. A better approach would be to deploy fossil-switching measures as a transition strategy in parallel with, and in support of, serious efforts to deploy renewable energy, energy efficiency, and energy conservation measures. Fossil-fuel switching should also include considerably more planning and support for our transition to a hydrogen economy. Here fossil fuels are reformed into hydrogen, the carbon sequestered, and pipelines carry the hydrogen to markets developed for hydrogen fuel cells and combustion engines deployed in integrated electricity production and transportation applications. Some forward-thinking governments and organizations have developed this scenario. Iceland has committed to a 100% hydrogen economy and is already in the process of implementation.

3) Clean, renewable energy is an integral part of a carbon-free future. Apart from the obvious carbon-free benefits of wind, solar, and hydroelectric energy, these energy sources promise to play a major role in a hydrogen economy. Here, intermittent wind and solar energy or remote hydropower is used to produce hydrogen from water by electrolysis. The key here is that hydrogen, unlike electricity, is storable and can be manufactured whenever the wind blows, the sun shines, or the river flows. Hydrogen is considered the "bridge to a renewable future" and creating a fossil-fuels-to-hydrogen infrastructure is the first step in building the bridge. There are also other renewable energy applications of importance, for example, clean biogas from wastewater treatment plants and landfills, and bioenergy production—the latter has potential as a carbon-neutral strategy.

4) Nuclear energy remains on the table. It is a long-term consideration bedeviled by seemingly insurmountable waste-storage problems, but no one doubts its potential contribution as a source of carbon-free energy. R&D is currently focused on next-generation nuclear cycles and technologies which hope to answer concerns.

5) Energy-efficiency improvements are the most attractive short-term option, although it should be pointed out that all five source-based mitigation measures should be integrated into electric power, process energy, and transportation planning. There have been significant advances made in demand-side energy efficiency technologies recently, such as lighting, fenestration, building envelope, motors, appliances, and energy-management systems. These are being deployed primarily because they not only reduce energy consumption but they are economically attractive. Advances have not been as rapid in supply-side technologies but there are major energy efficiency

continued from page 4

opportunities that can be realized with better energy policies and planning. For example, combustion engines emit carbon dioxide and other gases implicated in global warming in direct proportion to the amount of fuel they burn. Because cogeneration applications, also known as CHP (combined heat and power), can be better than 90% thermally efficient this means that, wherever they are feasible, these applications are the best for mitigating greenhouse-gas emissions. Simply put, cogeneration is the ultimate energy production measure for mitigating greenhouse-gas emissions.

Contrast cogeneration performance to simple-cycle and combined-cycle turbine efficiencies and emissions. Today's best simple-cycle gas turbines are about 35% efficient. That is, if they were to produce power 24/7, they would consume about 235 mcf (thousands of cubic feet) of natural gas to produce 1 mWd (megawatt-day). In burning 235 mcf they would also emit about 13.75 tpd (tons per day) of carbon dioxide.

The most efficient combined-cycle gas with steam turbine system built today is about 60% efficient. This system consumes about 136 mcf of natural gas to produce the same 1 mWd in the previous example. Reducing fuel consumption to 136 mcf reduces carbon dioxide emissions to about 8.0 tpd.

A 90% efficient simple-cycle cogeneration system will still produce 1 mWd and 13.75 tpd CO_2 emissions while burning 235 mcf of fuel. But this system also puts to maximum use the exhaust (and cooling water) heat of the engines to *displace* additional heating or cooling loads which would *otherwise be serviced by separate energy sources*. For example, these separate energy sources could be a gas supply to fire boilers, or even the electric output of a combined-cycle power plant to provide air conditioning. The displacement is substantial and represents a *saving* of upwards of 8.75 tons per day in carbon dioxide emissions and 150 mcf in gas consumption were the cogeneration system not installed.

Conclusion

While the United States struggles with its response to the Kyoto Protocol and nations attempt to negotiate a binding international agreement to limit greenhouse-gas emissions (United Nations Framework Convention on Climate Change, 1992), it is clear that the Enhanced Greenhouse Effect will be with us for generations to come. It is also clear that many of the solutions are extremely complex, and changes in legislative and regulatory frameworks will be required to facilitate the widespread introduction of many new and emerging energy technologies. A key issue concerns federal New Source Performance Standards (NSPS) for major new sources of pollution. These standards currently provide incentives for end-of-pipe controls, not efficiency in processes, thereby ensuring that the best (most efficient and carbon-mitigating) technologies are not necessarily deployed. This must change.

In the interim, there are options we can pursue which reduce both our energy consumption and our greenhouse-gas emissions. As we seek the ways to construct meaningful energy and environmental policy through legislative and regulatory processes, greater effort must be focused on energy efficiency—both in end-use and energy-production measures.

Energy security and climate change are not strictly technology issues but are in fact primarily public relations and marketing issues. Marketing tomorrow's energy technologies and infrastructure to meet the demands of a growing, environmentally constrained world requires that audiences not only identify with new technologies but also acknowledge the need for change. Energy engineers can take the lead in this process by educating their families, friends, and customers about the Enhanced Greenhouse Effect and the challenges we face in implementing the infrastructure and engineering changes necessary for a sustainable future.

Endnotes

1. Crawford, 1996, p.149
2. Houghton, 1994, p.21
3. Crawford, 1996, p.148
4. Houghton, 1994, p.21
5. Oppenheimer & Boyle, 1990, p.36
6. *ibid.*
7. *ibid.*
8. UNEP/WMO, 1997, http://www.gcrio.org/ipcc/qa/cover.html, last visited August 1st, 2001
9. *ibid.*
10. *ibid.*
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13. *ibid.*
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ENVIRONMENTAL NEWS

Fall 2001

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