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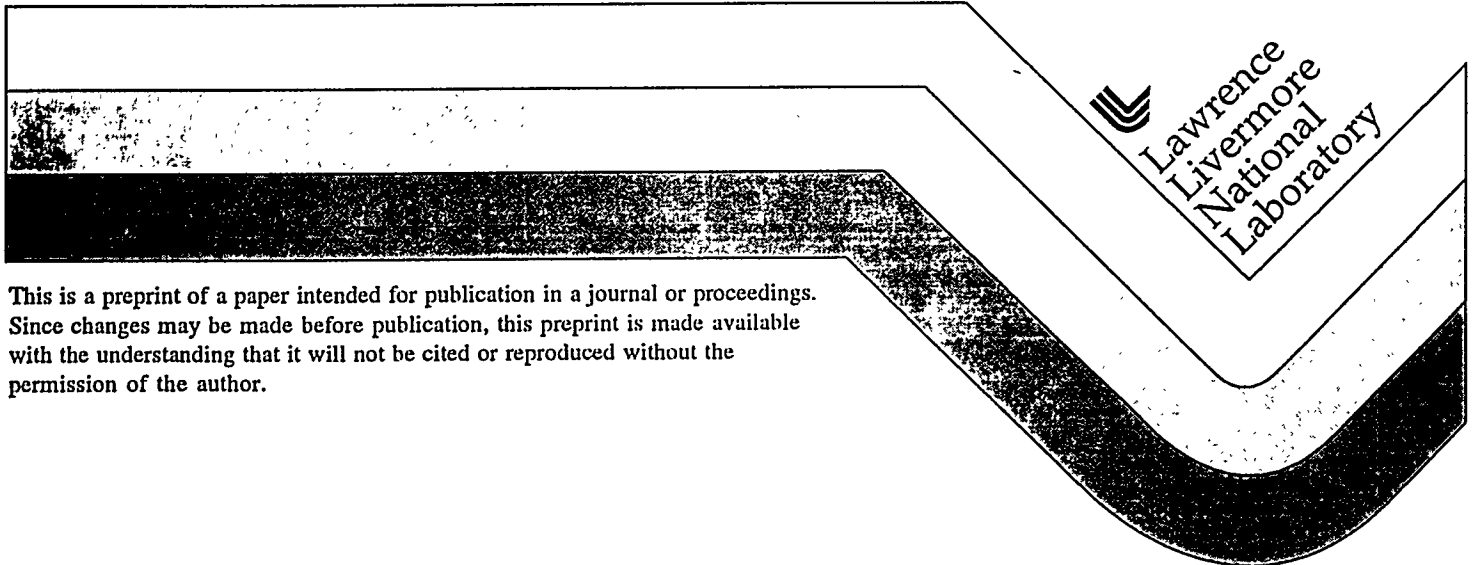
Industrial Ecology at Lawrence Livermore National Laboratory Summary Statement

Thomas J. Gilmartin

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Second Annual World Congress on Zero Emissions
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Thomas J. Gilmartin
Energy and Environmental Systems

It is very exciting and appropriate for us, Lawrence Livermore National Laboratory, to participate in this Second World Congress on Zero Emissions. We are managed by the University of California for the United States Department of Energy; we bring together the resources of universities, the government, and private industry to solve important national problems and to push science and technology over the horizon. And what more important problem is there than to sustain life with high quality and preserve our planet into the indefinite future.

This quest has many aspects, some socio-political or economic and some technological, and some in which the soft and hard sciences become indistinguishable, as in visionary national strategies, like Holland's, and futuristic regional and city development plans, like those of Kagoshima and Chattanooga, of which we are learning at this Congress.

Vision for Livermore Laboratory

The expertise of Livermore is in applied science and advanced technology systems. Our vision is that we will be an internationally recognized center for industrial ecology, collaborating nationally and internationally in the integration of energy, materials, technology, scientific, and environmental factors to create the basis for a sustainable global economy. For historic and strategic reasons, our principal areas of research at Livermore are:

- *Global Security,*
- *Global Ecology, and*
- *Bioscience.*

Global Security

While Global Security continues to require expertise and vigilance regarding the residual weapons of the Cold War and international involvement in the control of regional conflicts, security will increasingly involve understanding and mitigation of the underlying ecological sources of conflict, like population instabilities, energy resource limitations, shared water, international air pollution, global climate changes, and major natural calamities. Integration of the concepts and goals of security and sustainability will increase as globalization increases. This trend is an explicit assumption in the National Security Science and Technology Strategy published last year by the US National Science and Technology Council. While these topics are extremely interesting and important, I will focus this summary on issues more relevant to Zero Emissions.

Global Ecology

Our activities in Global Ecology are based on the field of industrial ecology, and focused on primary and secondary energy resources, materials, environmental technology, and global system modeling. I will give examples of some our technical goals in each of these activity areas.

Energy for Transportation

One of the principal emission generators in the wealthy countries of the world is our transportation systems. Several hydrogen, electric, and hybrid alternatives are under development.

If the hydrogen in a gallon of water is separated and then burned back to water, the burning yields the energy equivalent of about a half of a gallon of gasoline. This water to water fuel cycle is zero emission if both the energy needed to separate the hydrogen, and the hydrogen combustion process are clean. The burning of gasoline is, of course, not recyclable; produces CO₂, a greenhouse gas; and produces particulate and gaseous pollutants. Did you realize that 90% of the material used in the life cycle of a car is the non-recyclable burning of gasoline; only the 10% steel and plastic have the possibility of being recycled. Burning methane is better than burning gasoline because it involves burning more hydrogen than carbon, but some CO₂ is still produced. Hydrogen is a good alternative fuel

which can increase the recyclability of transportation by a factor of 10 and decrease the emissions to zero.

Hybrid electric vehicles use the hydrogen energy to generate electricity which is then stored in flywheel or ultra capacitor systems, which in turn power the vehicle through electric motors. The intermediate energy storage allows the vehicle's hydrogen powered electric generator to operate at peak efficiency while the vehicle's power requirements vary. Similarly, the electrolytic production of the hydrogen fuel acts as a load-leveling intermediary for the utility electric source, thus allowing utility power to be used on an as available basis, and absorbing the variability of many renewable primary energy sources.

Another option is the refuelable battery, like our zinc-air battery which can produce five times the energy per unit weight of a lead acid battery and can be "recharged" in 10 minutes, about as long as it takes to fill your gas tank. There are no emissions from this battery and its materials can be recycled and reused, also with zero emissions. The weight of such batteries along with the motors and drive units for a 300-mile-range vehicle weigh slightly more than the gas tank, engine, and transmission for a current technology car of the same range and peak power.

We are developing these technologies in various combinations with the goal of an efficient, safe, low or zero emission vehicle that competes in cost and performance with current gasoline powered cars. Some of this work is being carried out under the Partnership for a New Generation of Vehicles with US auto makers.

Fusion Energy

If hydrogen is burned thermonuclearly in a fusion reaction, rather than chemically in normal combustion, the energy equivalent of the hydrogen, actually deuterium, in a gallon of water is about 500 gallons of gasoline. This burning occurs when the nuclei of the hydrogen atoms collide and fuse to form helium. The inherent fusion energy yield per unit of fuel mass is potentially a million to ten million times greater than the energy yield for chemical combustion.

This process has two remarkable advantages. First, the energy available on Earth from hydrogen fusion is virtually unlimited. After all

this is the same process that drives the sun. And second, the inherent "emissions" or residues are zero, although the design of a practical reactor will involve the generation of some radioactive waste.

Livermore is the world leader of the use of lasers to drive controlled fusion reactions and is in the process of designing and building a system, the National Ignition Facility, which will demonstrate the scientific feasibility of this process by generating more energy from a micro-fusion reaction than is put in by the laser. We are also participants in the international magnetic fusion program and are modeling advanced concepts for machines in which a continuously burning fusion plasma is contained in a magnetic field.

When clean, unlimited fusion, and undoubtedly also advanced nuclear fission, and, hopefully, solar-derived electric energy sources are coupled with hydrogen or battery transportation systems, the essential energy needs of a zero emission sustainable society will be satisfied.

Materials

Turning to materials, let me say that in our advanced technology programs, the performance of materials is always the limiting factor. As a result, we have developed some fairly exotic materials that have application for sustainability. Examples are aerogels, solid materials that are so porous that they are about the same density as air. Depending on the materials from which we make them, aerogels can be either the best thermal and electrical insulators known or able to store electrical energy with extreme density in ultra capacitors. Aerogels have been also demonstrated to purify salty water economically on scales suited to a single traveler or a major city.

Cermet is another example. Cermet is a ceramic-metal alloy, one which is tougher and more durable than steel and as light as aluminum, uncorrodable, non toxic, and superior to glass or metal for many high-volume uses, such as engine parts, although still expensive and difficult to machine. It is the lightness and durability of cermet that could reduce life-cycle materials use; and its inertness that could minimize disposal problems.

Superplastic steel is extremely small grained steel that can be formed to final shape with good enough precision to require no machining, thus,

producing little or no waste. This material was developed in cooperation with industrial partners.

In two weeks, we will hold a working conference at Livermore on the material data base requirements for Design for Environment. The purpose is to eventually make material environmental-life-cycle-load data readily available to designers and manufacturers. The Livermore conference is focused on materials for automotive and electronic manufacturing, but is intended to define the general characteristics needed for the implementation of industrial ecology.

Environmental Technology

Within Livermore Laboratory's own operations, we are committed to the protection of human health and the environment, and the integration of life-cycle environmental quality into all of our activities. We have made many in-house process improvements (described in the Spring 1996 issue of Total Quality Environmental Management) which either recycle troublesome materials or eliminate or greatly reduce their use and wastes, particularly in plating, cleaning, and material test operations. We would be glad to share our experience with anyone engaged on similar activities.

Much of current environmental technology development is focused on the remediation of contaminated sites. However, the sensors for the detection of pollutants and the cleanup techniques are adaptable to material and manufacturing processes, as methods for cleansing and transforming used material for recycle, alternate use, or harmless disposal. For example, microbial destruction of volatile organic compounds (VOCs) can be used to either cleanse reusable liquids or porous materials, or to transform the contaminants into useful materials like alcohol. Sensors developed for detection of pollutants in soil and ground water can also be used on line as process and environmental quality monitors.

Finally, we have developed and are continuing to enhance and increase the linkages between computer models for the global climates, the oceans, and regional atmospheric, surface, and subterranean material flows and pollution effects, from atmospheric CO₂ and the greenhouse effect to hydrocarbon, metal, and brine contamination of soil and water. Our purpose is to provide the tools that are needed to assess the impacts of and define the highest priority responses to human generated emissions.

Bioscience

Our work in bioscience is concentrated on genomics, the decoding and study of the functions of DNA, primarily of humans, but expanding to animals and plants. One of our goals is to understand how environmental insults damage DNA leading to cancer and other health problems. In some cases, DNA is able to repair itself and counter specific environmental threats. We have now mapped human chromosome 19 entirely, and have identified about 500 genes and genetic markers; three of the genes are repair genes. Understanding the fundamental strengths and weaknesses of life forms is essential in establishing environmental priorities.

Another application of genomics is the improvement of human health and the engineering of plants and animals to increase their productivity and environmental performance, that is, their disease and pest resistance with less or no chemical assistance.

Finally, genomics will eventually be the basis for measuring and managing biodiversity. Genetic codes will comprise the catalogue of life forms and functions. The current libraries of genetic fragments and the genome databases are the initial phase of this evolution.

Conclusion

At Livermore our hope and our intention is to make important contributions to global sustainability by basing both our scientific and technological research and our business practices on the principles of industrial ecology. We will:

- Support and develop multi-disciplinary programs which create the scientific basis for environmentally and economically efficient technology.
- Utilize a lifecycle, systems-based approach which integrates environmental considerations and promotes the conservation of natural resources.
- Encourage the development of responsible, technically and scientifically valid, cost-effective environmental laws and practices.

In these ways we share and support the goals of the Zero Emission Research Initiative.

Acknowledgment

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