BREAKING THROUGH EDITORIAL

Chemical Energy Without Carbon Dioxide

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Giant strides that have lifted the standard of living in the twentieth century had to be matched by increasing energy consumption in the form of electricity and the power to drive our means of transportation. Both these energy drains rely heavily on the consumption of fossil fuels. Only a small fraction, foremost hydroelectric power, is renewable and sustainable energy derived from the sun. Hydrocarbon fuels in the ground will run out in a matter of centuries. This may sound like a long period of time. Since our civilization is at stake, it is not too early to think of major innovations in the conquest of solar energy—which is plentiful and for all practical purposes will last forever.

Not only the exhaustion of combustible fuels, but also the pollution of the atmosphere with greenhouse gases provides incentives to aggressively exploit solar energy. About 40% of all the carbon dioxide dumped into the atmosphere derives from thermal power stations which generate electricity. If they could be replaced with solar energy plant, it would be the single most effective measure to counter global warming.

Nuclear fission power is neither renewable nor sustainable. It has other disadvantages concerned with the safety of the population and the long-term storage of highly radioactive spent fuel. Therefore, solar energy has little competition. It is the ideal long-term solution of the ever increasing electricity demand. Even if research and development of the solar solution is scientifically and technologically difficult, requiring R&D funds in the billions of dollars, it should be undertaken. Society is already funding another new energy technology of similar magnitude. This is controlled thermonuclear fusion designed to convert heavy water from the oceans to helium and electrical energy.

Nuclear energy is stored in the bonds between nuclear particles. Hydrocarbon fuels store chemical energy in the bonds between atoms. A popular textbook (*Chemistry*, G.C. Pimental, ed., Freeman & Co., San Francisco, 1963) introduces chemical energy as follows:

> There is present, within the molecule, chemical energy which is related to the forces which hold the atoms together in the molecule. This is referred to as chemical bond energy.

Energy that is related to forces on particles is potential energy. That chemical bond energy is potential energy may seem surprising because the enthalpy of a substance is often described as its heat content. Anyhow, stored potential bond energy is neither heat nor kinetic energy. When heat flows in and out of chemical bonds, as in all thermo-chemistry reactions, it must involve microscopic mechanisms for transforming heat into potential energy, and vice versa.

Above the ignition temperature of the reaction, the important combustion equation of our energy economy is:

$$C + O_2 = CO_2 + \text{Combustion Heat}$$

A carbon atom (C) reacts with an oxygen molecule (O_2) to form a carbon dioxide molecule (CO_2). Air does not spontaneously convert carbon to carbon dioxide. The carbon must be ignited with a match or other small heat source until the ignition temperature is reached. Then the reaction will proceed above the ignition temperature and generate the combustion heat. While a quantity of carbon is burning with the oxygen of the atmosphere, the combustion heat makes the reaction self-sustaining and, indeed, self-intensifying. This is how the flame of a match becomes a roaring forest fire.

The source of the combustion heat is the bond energy in the O_2 molecule. Because of energy conservation, this has to be greater than the bond energy given to the CO_2 molecule. The excess drives our electric power plants and petrol engines. The O_2 molecule acquired its bond energy when two oxygen atoms collided in the atmosphere. Their relative motion stopped and part of their kinetic and structural energy was donated to the O_2 bond, while the remainder was passed on to the environment. It was atmospheric heat which kept the oxygen atoms moving and separated before bonding. This heat was gained primarily from solar energy absorbed in the atmosphere. Hence, combustion energy is derived from solar energy. It is important to realize that this stored energy in the bonds is not the quantity often referred to in textbooks as "latent heat" or "enthalpy of formation or dissociation." These named quantities are all the same amount of energy which is exchanged with the environment on bond making or breaking. The latent heat is higher for CO_2 (1,064 kJ/mol) than for O_2 (498 kJ/mol). Therefore, the stored bond energy describes a different and less well known quantity whose origin is discussed later.

Unfortunately, the carbon of the fossil fuel is preserved in the carbon dioxide molecule where it contributes to the

greenhouse effect and global warming. Even though the combustion process generates electricity with solar heat, the carbon consumption decreases our fossil fuel reserves and increases the CO_2 pollution of the atmosphere.

Many exothermic chemical reactions are known, and many have no doubt been considered for replacing carbon combustion in the energy production business. For economic or technical reasons, it seems, non-carbon exothermic reactions have failed to be competitive with the burning of fossil fuels. There is no reason, however, that the search for an alternative chemical solution to electricity generation, not involving carbon atoms, should be given up.

It is not necessary to rely on a chemical reaction which breaks high energy bonds and creates less energetic bonds, as in the combustion of carbon, and then makes the bond energy difference available for commercial electricity production. As long as a chemical bond is broken or dissolved, its stored potential energy must be set free and may be consumed in an electricity generator. If later the separated atoms are reassembled and re-bonded into identical molecules, with the help of solar energy, the process of bond energy liberation becomes renewable. The bonded substance may then be recycled in another pass through the electricity generator. This possibility has been researched by the author and his colleagues.

Three different chemical bonds have been found which meet this criterion and yield renewable solar energy. They are the diatomic bonds of oxygen (O_2) and nitrogen (N_2) in air and the hydrogen bond between H_2O molecules of liquid water. In all three cases the bonds have been severed by an electric arc. In the air arc, or lightning stroke, the O_2 and N_2 bond energy is first converted to electrical energy, by MHD action, and then to heat. (P. Graneau, N. Graneau, G. Hathaway, "Evidence of Thunder Being a Chemical Explosion of Air," *Journal of Plasma Physics*, 69, 3, 187, 2003). Hydrogen bond breakage of water results in a water droplet (fog) explosion. For electric arcs of similar size and current, water contains many more hydrogen bonds than there are oxygen and nitrogen bonds in atmospheric air. Hence, the water arc explosion is far stronger than the air arc explosion. Therefore, research has been concentrated on water arcs.

The hydrogen bond of water is a chemical bond between a hydrogen atom in one water molecule and an oxygen atom in a neighboring molecule. Therefore the liberation of chemical energy from hydrogen bonds of water does not involve carbon atoms and carbon dioxide, or any other greenhouse gases. It is a totally clean process. This is the reason why we think the hydrogen bond energy liberation from water is a most promising chemical energy development which should be pursued with the utmost vigor by as many laboratories as possible.

Chemical bonding has been the subject of intense research for about one hundred years. This is approximately twice as long as the pursuit of nuclear energy. We have a good understanding of chemical bonding between atoms. There remain, however, some uncertainties. One is the origin of chemical bond energy. Another has to do with the precise mechanism which converts potential bond energy to heat and kinetic energy. Both these uncertainties are related to the reversible transformation of heat to potential bond energy. No new physical chemistry is required to resolve the uncertainties, but treating bonding and un-bonding entirely by thermo-chemistry is misleading.

The chemical bond is the result of attraction between bonded atoms. This attraction is due to the outer electrons of the two atoms. It can be electrostatic attraction between the electrons of one atom and the nucleus of the other. Because of their spins, the electrons of two atoms may also attract each other electrodynamically, as in "spin bonding." Whatever the precise mechanism of the bonding process is, it must be opposed by an equal and opposite atomic repulsion of the two nuclei. Without this repulsion the two atoms would collapse into each other, which they obviously do not. The stored bond energy is the result of all these forces.

The repulsion between atomic nuclei is similar to the expansion force of a compressed spring. Both store potential energy. Spring expansion is usually opposed by mechanical barriers or by the inertia of material objects. In the case of water arc explosions, it is the quantity of energy tied up in the repulsion forces and the size of the resulting droplets which controls the strength of the explosion.

All potential energy is stored energy but the word "stored" is rarely mentioned. Many physical chemists speak, instead, of the "inter-atomic potential." As atoms are very stable particles, the bond energy between atoms can be stored for long periods of time before it is extracted by breaking the bond and disposing of the bond energy as heat or kinetic energy.

There is little discussion in textbooks about the origin of chemical bond energy. Since energy is conserved, it must have resided somewhere else before the bonding took place. Let us now confine the discussion to the collision of a water molecule of the atmosphere with a fog droplet in the clouds. If the molecule sticks to the droplet, at least one hydrogen bond has been formed. It would then seem most likely that the hydrogen bond energy has been created by absorbing the increasing potential energy of attraction as the intervening distance decreases and the electrons reposition themselves into bonding orientations. Similarly, energy is stored by the repulsion of the two positively charged nuclei which are being pushed toward each other. It is possible that the water molecule will simply bounce away from the droplet. However, if during its time of contact with the droplet it is able to transfer some heat energy to the droplet (latent heat of formation) then a stable bond can form. The source of this stored energy must be solar energy, which was initially contained in the widely separated droplets where the energy density (J/m^3) is relatively low.

When two water droplets amalgamate, additional hydrogen bonds are formed by absorbing solar energy. The amalgamation process increases the stored energy density in water and makes the liquid so useful in subsequent energy extraction and conversion to electricity. This resolves the uncertainty of the origin of hydrogen bond energy in water.

The second uncertainty concerns the reverse process of transforming the hydrogen bond energy to kinetic fog energy. To liberate the chemical bond energy stored in the hydrogen bond, we must break or somehow dissolve the bond. This can be done with an electric arc which disrupts the liquid arc column into many small droplets by the electrodynamic force known as Ampere tension. The nuclear repulsion forces across the broken bonds then accelerate the droplets and cause an explosion. The droplets are large clusters of cohering water molecules which collide with individual water molecules and push the latter out of the way. Experiments have shown that the fog droplets move at speeds up to 1,000 m/s or more, in straight lines through the surrounding water. Hence the fog can be said to have

acquired kinetic energy in proportion to the liberated hydrogen bond energy.

If the arc explosion had subdivided the water into individual molecules (steam), the explosion would have produced scattered collisions of randomized molecular motion. This is heat. It is the process of molecular scattering which converts liberated bond energy to heat. Boiling the water has the same effect. When boiling water, energy (the latent heat) is required from a heat source and when combined with the stored repulsive bond energy, it is enough to overcome the forces and energy of attraction and break the bond. No excess energy is gained by boiling water.

To tap the solar energy in hydrogen bonds for electricity generation we must find a way of dismantling the bonds with less energy than the latent heat. The electric water arc achieves precisely this by breaking hydrogen bonds in tension rather than by thermal collision or thermal activation. It can be shown with surface energy and surface tension calculations that splitting water into fog droplets by highly directional tensile forces requires very little energy. The energy liberated from the hydrogen bond can be one hundred times as large as the tension energy expended in breaking the bond. This has been proved with water arc experiments. In this way it has become clear that further research should try and find even more effective ways, than the electric arc, of creating tensile forces for breaking hydrogen bonds in water.

Water cannot be gripped in two places and pulled apart to set up tensile stress along the connecting line between the grips. Water can be disrupted in one place, but this breaks very few hydrogen bonds. An example of this occurs in ultrasonic room humidifiers which eject a stream of cold fog droplets from a point on the internal water surface on which the ultrasonic waves are focused. This experimental fact suggests that the ultrasonic vibrations of water molecules do break hydrogen bonds and the liberated energy then accelerates water droplets. This interesting phenomenon has not been subjected to any further investigation because ultrasonic bond disruption does not appear to be an efficient process of liberating hydrogen bond energy.

In contrast, blowing air over the surface of water accelerates surface molecules by viscous drag and tension. This is how ocean waves are created. The build-up of waves suggests that the water continues to cohere and no hydrogen bonds are broken. Ultimately the crest of a wave will break and a white plume is formed. The white plume seems to consist mainly of films of water which diffract light. Hence, hydrogen bonds must have been broken. Fog will diffract light for the same reason, but it would fly away up into the air. Water film structures in places remain connected with hydrogen bonds to the water surface. The tensile stress required to break hydrogen bonds in the wave crest may be due to molecules actually streaking ahead of the bulk water because of forces of inertia. The same phenomenon seems to occur when a wave breaks on a shore or crashes onto a rocky cliff.

"White caps" on the crests of ocean waves during a storm, therefore, provide evidence of tensile hydrogen bond ruptures. As the wind speed, or the storm force, increases, a point is probably reached when fog droplets are created and separate from the wave crests and are driven up into the atmosphere by bond energy explosions. The action begins to resemble what is happening in a water arc explosion. The fog droplets will ultimately evaporate and increase the humidity of the atmosphere. However, droplet evaporation takes time and further fog explosions at sea level may drive the fog higher and higher up into the atmosphere.

The spray of small water droplets from the crest of breaking ocean waves will be accompanied by the release of hydrogen bond energy. It may well play an important role in the build-up of the mountainous fog wheel which constitutes a hurricane. Without tension breaks of hydrogen bonds, it is quite difficult—if not impossible—to explain how so much fog comes into existence.

There are two ways of converting ocean water into a hurricane cloud. It is commonly believed that the hurricane cloud is formed like any other cloud by condensation of water molecules contained in the atmosphere. This requires the making of bonds and, therefore, redistributes the energy in the storm system without adding to it.

An alternative explanation is the shearing of small water droplets off the ocean surface. It produces tensile fractures of hydrogen bonds and thereby liberates chemical energy that is added to the kinetic energy of the storm. The latter mechanism results in positive feedback of a greater storm force creating more bond ruptures and energy liberation. This could be the principal reason for the self-intensification of hurricanes which has found no easy explanation. In practice, both mechanisms—condensation and tensile bond fracture—may contribute to the complex action of hurricanes.

Kerry Emanuel, in his fascinating book *Divine Wind: The History and Science of Hurricanes* (Oxford, 2005), speculates that the hurricane is nature's steam engine. He frankly admits that problems exist in reconciling the Carnot cycle of a gas heat engine with the fog of the hurricane cloud. One of the difficulties is the phase change from vapor to water droplets of the huge spinning wheel of the storm cloud. If the fog is created by storm winds sweeping over the sea and tearing droplets from the water surface, no phase change occurs. No steam is needed and water is converted to fog by the mechanical shear of hydrogen bonds. Here is not the place to investigate the cause of hurricanes, but the subject certainly deserves further study.

Blowing air over a stationary surface of water is very likely to break hydrogen bonds and liberate the associated chemical bond energy. Unfortunately, the air blowing effort may consume more energy than that given up by the hydrogen bonds. But there is scope for the inventive mind to overcome skepticism. The energy conversion efficiency has been a major problem in bond energy research. Readers of *Infinite Energy* are invited to pitch in their own thoughts and ideas. Gene Mallove would be proud if his journal became a platform of collaboration which resulted in major advances of a new energy technology. We owe it to Gene to try to make this come true. The research on water arc explosions has been in progress for twenty-three years at the Massachusetts Institute of Technology and at Oxford University. Nine peer-reviewed and international conference papers on this subject have been collected in a booklet, titled *Unlimited Renewable Solar Energy from Water*, which can be purchased from the New Energy Foundation, Inc. (See ad on p. 9.)

The first half of our research dealt with the anomalously large forces of water arc explosions which are gainfully employed in production line machinery for metal forming operations. We found that the arc forces are actually due to the explosion of cold fog. Arc researchers had missed the fog explosions for nearly fifty years. These explosions are invisible to the naked eye because of their short duration of a few milli-seconds or less. In 1994 they were photographed for

the first time with a video camera by Richard Hull in his laboratory at Richmond, Virginia. This proved that the anomalous arc forces were actually due to liberated chemical energy from broken bonds between water molecules. Richard Hull is now the Editor of the *Electric Spacecraft Journal*.

Perhaps this is the time to mention a remarkable property of the cold fog jet which was discovered several years ago, but has not been explained, followed up, or exploited. Liquid droplets collide inelastically with metal surfaces. This is to say, instead of bouncing off the solid surface, they are deflected sideways and slide along the surface. The inelastic behavior of all liquids is well understood. It has to do with the fact that a deformed liquid does not exhibit restitution forces which try and restore the original shape of the liquid.

Now if a vertical fog jet, traveling upward, strikes a fixed horizontal metal plate, the fog will be diverted radially outward, in all directions, and slide away from the impact area. The fog seems to stay in contact with the horizontal plate as a thin layer. The surprise is that the horizontally sliding fog appears to travel faster than the vertical fog jet. The first time this was noticed, the visible part of the vertical fog jet had a velocity of approximately 500 m/s while the visible part of the horizontal fog layer traveled at almost 1,000 m/s. If the individual fog droplet in the vertical jet retains its identity in a different shape, it changes direction on impact with the plate. The question is can it continue to move at almost double its original speed and four times its kinetic energy? Perhaps the individual droplet does not survive the impact and subdivides into a number of smaller droplets, liberating more chemical bond energy. Another complication of this experiment is that fog droplets of less than 1 μm in diameter become invisible because of light wave-length considerations. It certainly is a difficult and challenging experimental result and thoughts on it from the *Infinite Energy* readership would be very welcome.

The most convenient form of the new energy is electricity. Chemical energy from fossil fuels is normally liberated as heat, which may then be converted to electricity by a steam turbine which is a heat engine. This engine is subject to the Carnot efficiency, which for steam is at best 35%. Therefore, more than half the chemical energy from fossil fuel combustion is immediately wasted and rejected as low grade heat to the atmosphere, rivers, or oceans. Chemical energy from hydrogen bonds of water emerges as fog kinetic energy. This is not subject to the low Carnot efficiency of the steam cycle. It is a major advantage of fog kinetic energy, which should make it possible to convert chemical energy to electricity with turbo-generators of at least 50% efficiency.

Unfortunately, as it stands today, the water arc technology gives us fog pulses of about 1 gram mass traveling at a speed of the order of 1,000 m/s. Turbines have great difficulties in handling such small masses traveling at so high a velocity. Exploratory experiments have shown that turbo-generators can be driven with this kind of fog pulse and generate electricity, but if this is done without regard to the optimum turbine configuration and running conditions, it will easily result in an efficiency as low as 1%. There are no optimum commercial turbines available for the fast fog pulses. Such turbines remain to be developed. This will take time and a considerable R&D effort.

To avoid the turbine development, a solution would be to convert the kinetic fog energy directly to electricity by MHD action. This has been done in the case of N_2 and O_2 bonds of air arc explosion. The MHD method is described in Appendix 8 of *Unlimited Renewable Solar Energy from Water*.

Briefly, the N and O atoms produced in the air arc explosion are positive ions which travel radially away from the arc column. They intersect the azimuthally encircling magnetic field lines of the arc current. This perpendicular intersection induces an axial electric field which increases the arc current. The resulting MHD energy will be collected in the capacitor bank which is, otherwise, responsible for supplying the arc current.

The discharge circuit is under-damped and therefore the arc current oscillates. If the arc current is electronically interrupted at the end of the first current half-cycle, we find that at this point the capacitor voltage has reversed from a positive to a negative peak. If the negative peak is greater than the original positive peak, then we will have collected liberated hydrogen bond energy in the capacitor bank. This would subsequently be available as electrostatic potential energy. MHD energy gain has been achieved with air arc explosions but not yet with water arc explosions.