

# A STUDY OF THE ENERGY EFFICIENCY OF HADRONIC REACTORS OF MOLECULAR TYPE

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## Abstract

In this paper, we introduce an estimate of the "commercial efficiency" of Santilli's hadronic reactors<sup>TM</sup> of molecular type [1] (Patented and International Patents Pending) which convert a liquid feedstock (such as automotive antifree and oil waste, city or farm liquid waste, crude oil, etc.) into the clean burning magnegas<sup>TM</sup> plus heat acquired by the liquid feedstock. The conversion is done via a new process based on a certain flow of the liquid feedstock through a submerged electric arc between carbon-base electrodes and other features. The "commercial efficiency" is defined as the ratio between the total energy output (energy in magnegas plus heat) and the electric energy used for its production, while the "scientific efficiency" is the usual ratio between the total energy output and the total energy input (the sum of the electric energy plus the energy in the liquid feedstock as well as that in the carbon electrodes). Needless to say, the scientific efficiency is always smaller than one because of the conservation of energy. However, a peculiar features of Santilli's hadronic reactors of molecular type is that their commercial efficiency is considerably

bigger than one, namely, the reactors are capable of tapping energy from the liquid feedstock and the carbon rods. A primary purpose of this paper is to show that conventional thermochemistry does indeed predict a commercial efficiency bigger than one, although their values is considerably smaller than the actual efficiency measured in the reactors, thus indicating the applicability of the covering hadronic chemistry from which the reactors have received their name. Under the conditions that the reactions run at temperature  $T = 25^\circ$  C and pressure  $p = 1$  atm, the chemical composition of the combustible gas is conventional, and all thermochemical calculations processes are conventional, we reach an upper limit of the commercial efficiency of 3.11 for the use of pure water as feedstock, and of 3.11 to 7.5 for a mixture of ethyleneglicole and water with increasing relative consumption of ethyleneglicole with respect to the consumption of carbon rods. The study of the heat produced by the reactions leads to large divergencies between the thermochemical predictions and experimental data of at least a *factor of three*. Such divergencies can only be explained with deviations from quantum chemistry in favor of the covering hadronic chemistry and. In particular, the indicated large divergencies can only be explained with the assumption that the produced combustible gas has the new non-valence chemical structure of Santilli magneucules.

# 1 Introduction

In this paper, we introduce an estimate of the "commercial efficiency" of Santilli's hadronic reactors<sup>TM</sup> of molecular type [1] (Patented and International Patents Pending) which convert a liquid feedstock into the clean burning magnegas<sup>TM</sup> plus heat acquired by the liquid feedstock.

The reactors operate via a new process based on a certain flow of the liquid feedstock through a submerged electric arc between submerged carbon-base electrodes (for which reason the reactors are also called PlasmaArcFlow<sup>TM</sup> reactors) and other features.

The "commercial efficiency" [1] is defined as the ratio between the total energy output (energy in magnegas plus heat) and the electric energy used for its production, while the "scientific efficiency" is the usual ratio between the total energy output and the total energy input (the sum of the electric energy plus the energy in the liquid feedstock as well as that in the carbon electrodes). Unless otherwise specified, the word "efficiency" is referred hereon to the "commercial efficiency." The latter name originates from the fact that liquid wastes carry an income, rather than having a cost and, for this reason, they are not included in commercial calculations of operating costs.

Needless to say, the scientific efficiency is always smaller than one because of the conservation of energy. However, a peculiar feature of Santilli's hadronic reactors of molecular type is that their commercial efficiency is considerably bigger than one, namely, the reactors are capable of tapping energy from the liquid feedstock and the carbon rods.

A primary purpose of this paper is to show that conventional thermochemistry does indeed predicts a commercial efficiency bigger than one, although their values is considerably smaller than the actual efficiency measured in the reactors, thus indicating the applicability of the covering hadronic chemistry from which the reactors have received their name.

By its elementary chemical content, magnegas is similar to the water gas, or synthesis gas, although we should emphasize that magnegas is produced under a DC electric arc, and reveals an unusual chemical structure characterized by the presence of heavy molecular mass clusters, which have not been identified by Gas Chromatography Mass-Spectroscopy and InfraRed spectroscopy (GC-MS/IR) tests among about 135,000 species [1, 2]. This feature may be naturally attributed to the influence of the plasma arc and related

strong external magnetic field which can lead to new couplings of CO and H<sub>2</sub> molecules and other new effects.

In Secs. 2 and 3, we consider in detail conventional chemical reactions in a PlasmaArcFlow reactor operating with pure water or ethyleneglicole and water mixtures as feedstock. We treat the gas produced as a simple mixture of carbon monoxide CO and hydrogen H<sub>2</sub> viewed as ideal gases, to simplify consideration, and calculate its combustion heat.

We estimate the upper theoretical limit of the efficiency of the reactor by using only chemical energy balance equations. The efficiency is defined as a ratio between the total energy release (including combustion heat of magnegas) to the energy input (electricity consumed). Such efficiency is over unity due to the fact that the sum of the combustion heat of the gas and the heat acquired by the liquid is bigger than the electric energy needed for their production. It is therefore evident that, for the case of water as feedstock, the missing energy originates from the combustion of carbon with oxygen originating from the separation of water. This is due to the fact that the original water is reproduced in the combustion and, therefore, cannot contribute to the total efficiency.

Independent experimental tests of the efficiency of the PlasmaArcFlow reactors clearly confirm such a commercial over-unity [1], since the measured value of the over-unity is of about 3 to 5 for antifreeze stock at atmospheric pressure with bigger values for bigger pressures and powers. Our theoretical result is that the upper limit of the commercial over-unity ranges from 3.11 to 7.5, in a remarkable correspondence to the tests.

However, it should be noted that, whenever the study is specified to the heat acquired by the liquid feedstock a discrepancy of a factor of three originates between experimental data and the prediction of thermochemical calculations. An additional discrepancy also of a factor of about three exists between the measured combustion heat of magnegas and its predicted value.

The above discrepancies are of such a magnitude to support the hypothesis that the chemical composition of magnegas is that Santilli's magnecules [1].

It should also be noted that our calculations are based, as usual, on thermochemical values at  $T = 25^{\circ}\text{C}$  and pressure  $p = 1$  atm while the arc plasma (reaction zone) is characterized by much higher temperatures. Therefore, our results are of preliminary character. Also, in the present paper we do not consider issues pertaining to mechanism of the reactions, thermodynamics,

|                        |       |                      |       |
|------------------------|-------|----------------------|-------|
| Diatomic molecules     |       | Diatomic molecules   |       |
| H–H                    | 104.2 | C=O                  | 255.8 |
| O=O                    | 119.1 | N≡N                  | 192.0 |
| Manyatomic molecules   |       | Manyatomic molecules |       |
| C–O                    | 85.5  | O–H                  | 110.6 |
| C=O in CO <sub>2</sub> | 192.0 | O–O                  | 35    |

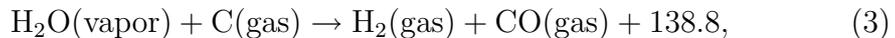
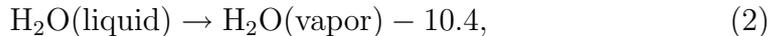
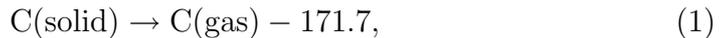
Table 1: Binding energies, kcal/mole.  $T = 25^\circ\text{C}$ .

fluidodynamics, and chemical kinetics.

In Sec. 4 we consider in detail the energy balance for the plasma creation. In Sec. 5 we introduce the heat production coefficient and calculate the heat production. In Sec. 6 we consider the total heat production as a sum of the heat produced and the combustion heat of the gas. In Sec. 7 we outline the results. Numerical data are presented in Appendix.

## 2 Water as a feedstock of PlasmaArcFlow reactors

The main chemical reactions in PlasmaArcFlow reactors are the gasification of carbon (graphite), evaporation of water, and the conversion of water and carbon to hydrogen and carbon monoxide, according to the known reactions



in kcal/mol. Therefore the related the balance reaction, i.e.,



is endothermic. Hereon, we use binding energies represented in Table 1.

The energy input of  $1 \text{ kW}\cdot\text{h} = 860 \text{ kcal}$  produces  $860/43.9 = 19.6$  moles  $= 19.6 \times 22.4 \text{ l} = 439 \text{ l} = 439/28.317 \text{ cf} = 15.5 \text{ cf}$  of  $\text{H}_2$  and the same amount

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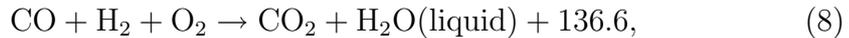
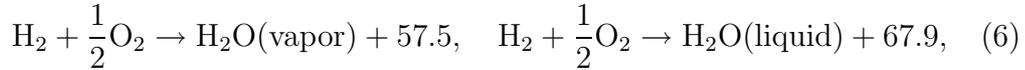
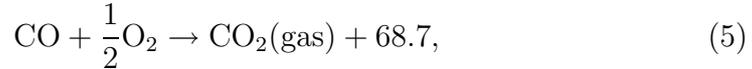
|                  |   |                              |
|------------------|---|------------------------------|
| 1 kcal           | = | 3.9685 BTU                   |
| 1 kcal           | = | $1.1628 \times 10^{-3}$ kW·h |
| 1 BTU            | = | 0.25198 kcal                 |
| 1 BTU            | = | $2.930 \times 10^{-4}$ kW·h  |
| 1 kW·h           | = | 3413.0 BTU                   |
| 1 kW·h           | = | 859.99 kcal                  |
| 1 m <sup>3</sup> | = | 35.314 cf                    |
| 1 cf             | = | 28.317 liters                |

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Table 2: Conversion factors.

of CO, treated here as ideal gases (1 mole = 22.4 l); conversion factors are presented in Table 2.

The combustion of the products is exothermic,



i.e., the 50%-50% mixture of (CO+H<sub>2</sub>) ideal gas has 68.3 kcal/mol = 271.2 BTU/mol = 342.8 BTU/cf content<sup>1</sup>. The total combustion heat is 19.6×126.2 = 2473.5 kcal = 2.88 kW·h (for water vapor) and 19.6×136.6 = 2677.4 kcal = 3.11 kW·h (for water liquid), respectively. Therefore, the theoretical upper limit of the efficiency is 3.11.

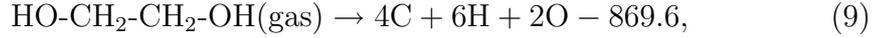
Clearly, only some part  $k$  of the consumed electric energy contributes directly the reaction (4) because some of the electric energy is consumed in the production of heat (dissipation). Consequently, the real efficiency is  $3.11k$ , where  $k < 1$ .

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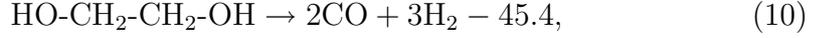
<sup>1</sup>Due to experimental tests magnegas, which consists mainly of CO and H<sub>2</sub> at approximately equal percentages, has about 800 BTU/cf energy content [1].

### 3 Antifreeze as a feedstock of PlasmaArcFlow reactors

We assume that antifreeze consists of ethyleneglicole and water. The complete dissociation of ethyleneglicole (we ignore evaporation heat and solution effects) is characterized by

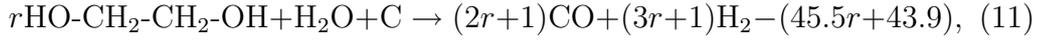


and the subsequent association of CO and H<sub>2</sub>,



produces 2 moles of CO and 3 moles of H<sub>2</sub>.

In PlasmaArcFlow reactors we thus have a pair of chemical reactions, (4) and (10), or



where  $r$  represents the relative consumption of ethyleneglicole with respect to that of carbon rod.

The energy effect of reaction (11) is endothermic,  $-(45.4r + 43.9)$  kcal  $< 0$ . The energy input of 1 kW·h = 680 kcal produces  $(2r + 1)680/(45.4r + 43.9)$  moles of CO and  $(3r + 1)680/(45.4r + 43.9)$  moles of H<sub>2</sub>, with the total combustion energy,

$$\frac{680}{45.4r + 43.9} ((2r + 1)68.7 + (3r + 1)67.9) \text{ kcal}, \quad (12)$$

where we have used Eqs. (5) and (6) Therefore, the upper theoretical limit of the efficiency is given by

$$\frac{1}{45.4r + 43.9} ((2r + 1)68.7 + (3r + 1)67.9). \quad (13)$$

For  $r = 0$ , we recover the value 3.11 obtained in Sec. 2. The efficiency increases from 3.11 to 7.51 with the increase of  $r$  from 0 to infinity. Figures 1 and 2 display efficiency (13) as a function of  $r$ . Only some part  $k$  of the electric energy consumed contributes directly the reaction (11) because, again,

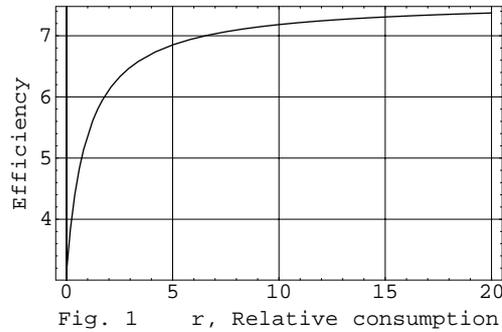


Figure 1: Theoretical efficiency of PlasmaArcFlow reactors as a function of relative consumption  $r$  of ethyleneglicole with respect to carbon rods;  $0 \leq r \leq 20$ .

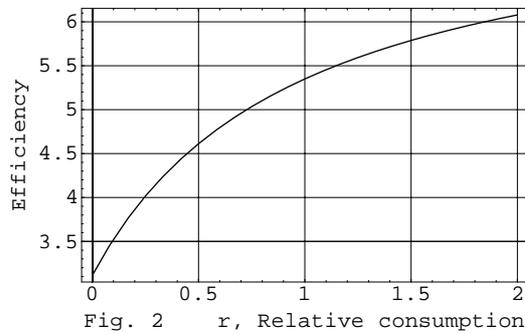


Figure 2: Theoretical efficiency of PlasmaArcFlow reactors as a function of relative consumption  $r$  of ethyleneglicole with respect to carbon rods;  $0 \leq r \leq 2$ .

some electric energy is dissipated into heat. Therefore, the real efficiency of the reactor is less than that given by Eq. (13).

In general, higher consumption rates of ethyleneglicole and carbon rods per 1 kW·h electricity consumed imply bigger real efficiency. This is due to higher values of  $k$ , which depend on design of the reactor. In turn, the consumption rates depend on reaction rates, volume of the reaction zone, rates of the reactants (ethyleneglicole, water, gasified carbon rod) input, rates of the products (CO and H<sub>2</sub>) removal, stoichimetric ratios, etc. The reaction rates depend on temperature and pressure. The volume of the reaction zones depends on size of the plasma arc and on the size of surrounding high-temperature regions. The rates of the reactants inlet and products outlet depend on the rate of the carbon rod gasification, geometry and velocity of the liquid flow, and pressure. Here, it is important to identify a limiting factor (e.g., the slowest rate among the above) in order to better represent the efficiency of the reactor.

## 4 Accounting for plasma creation

We now present calculations of the energy required to convert liquid water and solid graphite into the plasma state so as to identify its possible contribution to the overall efficiency.

### 4.1 Water contribution

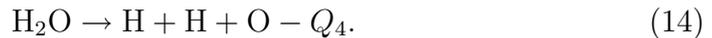
We take 1 mole of liquid water at  $T = 20^\circ\text{C}$  and atmospheric pressure as an initial state.

(1) The energy required to heat up one mole of water from  $T = 20^\circ\text{C}$  to  $T = 100^\circ\text{C}$  is  $Q_1 = 1.4$  kcal.

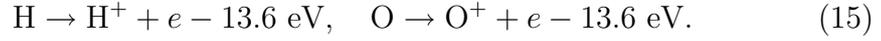
(2) The energy required to evaporate one mole of water is  $Q_2 = 10.4$  kcal.

(3) The energy required to heat up one mole of water vapor from  $T = 100^\circ\text{C}$  to  $T = 3600^\circ\text{C} = 3300\text{K}$  is  $Q_3 = 26$  kcal.

(4) The energy required for total disintegration of one mole of water molecules to individual atoms is  $Q_4 = 221.6$  kcal,



(5) The energy required to ionize all the H and O atoms can be calculated due to the following known values of the first ionization potentials,



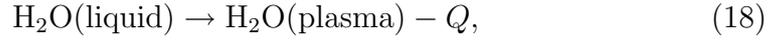
Taking into account that  $1 \text{ eV} = 3.83 \cdot 10^{-23} \text{ kcal}$ , the Avogadro number is  $N = 6 \cdot 10^{23}$  particles per mole, 1 mole of water (i.e.  $N$  molecules of water) gives  $2N$  atoms of the hydrogen and  $N$  atoms of the oxygen (in total  $3N$  atoms), we have

$$Q_5 = 3N13.6 \text{ eV} = 3 \cdot 6 \cdot 10^{23} \cdot 13.6 \text{ eV} = 244.8 \cdot 10^{23} \text{ eV}, \quad (16)$$

i.e.,

$$Q_5 = 244.8 \cdot 10^{23} \cdot (3.83 \cdot 10^{-23}) \text{ kcal} = 937.6 \text{ kcal}. \quad (17)$$

In total we obtain the following energy required to convert 1 mole of liquid water into the pure plasma state,



where

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5, \quad (19)$$

so that by inserting the above values, we finally get the following numerical value:

$$Q = 1.4 + 10.4 + 26 + 221.6 + 937.6 = 1197 \text{ kcal}. \quad (20)$$

## 4.2 Carbon contribution

We assume 1 mole of solid carbon (graphite) at  $T = 20^\circ\text{C}$  and atmospheric pressure as an initial state.

(1) The energy required to heat up one mole of graphite from  $T = 300\text{K}$  to  $T = 3300\text{K}$  is  $E_1 = 6 \text{ kcal}$ ;

(2) The energy required to evaporate one mole of graphite,  $\text{C}(\text{solid}) \rightarrow \text{C}(\text{gas}) - E_2$ , is  $E_2 = 171.7 \text{ kcal}$ ;

(3) The energy required to ionize one mole of graphite can be calculated due to the following known values of the first ionization potential:



One mole contains  $N = 6 \cdot 10^{23}$  atoms, so the require energy is

$$E_3 = 11.3N \text{ eV} = 67.8 \cdot 10^{23} \text{ eV}, \quad (22)$$

or, using  $1 \text{ eV} = 3.83 \cdot 10^{-23} \text{ kcal}$ ,

$$E_3 = 259.7 \text{ kcal}. \quad (23)$$

In total, we obtain the following energy required to convert 1 mole of solid carbon to the pure plasma state,

$$\text{C(solid)} \rightarrow \text{C(plasma)} - E, \quad (24)$$

where

$$E = E_1 + E_2 + E_3, \quad (25)$$

so that by inserting the above values, we finally obtain the following numerical value,

$$E = 437.4 \text{ kcal}. \quad (26)$$

### 4.3 Fully ionized plasma of 2H, O and C

In total, the energy required to convert 1 mole of liquid water and 1 mole of solid carbon to a pure plasma state is the sum of the above two energies,

$$W = Q + E, \quad (27)$$

i.e.,

$$W = 1197 + 437.4 = 1634.4 \text{ kcal}. \quad (28)$$

This energy is required to convert 1 mole the water and 1 mole of carbon to 4 moles of the pure plasma, as a sum of 2 moles of H, 1 mole of O, and 1 mole of C. More precisely, the plasma consists of  $2N$  positive ions  $\text{H}^+$ ,  $N$  positive ions  $\text{O}^+$ ,  $N$  positive ions  $\text{C}^+$ , and  $4N$  electrons.

We can convert moles to cubic foots by assuming that the plasma is an ideal gas. Using the facts that 1 mole of ideal gas is 22.4 liters and 1 cf is 28.3 liters, we obtain that 1 mole of ideal gas is 0.79 cf.

Thus, 4 moles =  $4 \cdot 22.4$  liters = 89.6 liters = 3.16 cf of plasma require 1634.4 kcal energy input due to the above result. So that we obtain the

following estimation of the energy needed to convert 1 mole of H<sub>2</sub>O and 1 mole of C (graphite) to the plasma,

$$1634.4/4 = 408.5 \text{ kcal} \quad (29)$$

per one mole of the 100% ionized 2H,O,C plasma; or

$$1634.4/3.16 = 517 \text{ kcal} \quad (30)$$

per one cubic foot of the 100% ionized 2H,O,C plasma; or, using the relation 1 kWh = 860 kcal,

$$517/860 = 0.6 \text{ kWh} \quad (31)$$

per one cubic foot of the 100% ionized 2H,O,C plasma, or, using the relation 1 kWh = 3413 BTU,

$$3413 \cdot 0.6 = 2052 \text{ BTU} \quad (32)$$

per one cubic foot of the 100% ionized 2H,O,C plasma.

The following remarks are in order. In our study, (i) we do not take into account energies associated to cathode, anode, and in the form of a radiation (DC electric low-voltage high-current discharge in water vapor); (ii) we do not consider fluidodynamics and thermodynamics issues associated to the flow and bubbles in the PAF reactor; (iii) we do not consider mechanism of the reactions and chemical kinetics issue; (iv) we do not consider magnetochemistry (influence of strong external magnetic field on the species and chemical reactions) of the PAF reactor; and (v) we do not consider the creation of clusters containing molecules and atoms.

#### 4.4 No recombination of water

We assume 1 mole of liquid water and 1 mole of solid graphite, at  $T = 300 \text{ K}$ .

Reactions (33) and (35) below are due to the formation of the 2H,O,C plasma, with  $T = 3300 \text{ K}$ , from the above water and graphite. Reaction (37) is ion recombination of 2H; reaction (38) is formation of H<sub>2</sub> gas; reaction (39) is ion recombinations of C and O; and reaction (40) is formation of CO gas; namely,



where

$$Q_{\text{water}} = 1197 \text{ kcal.} \quad (34)$$

$$\text{C(solid, 300K)} \rightarrow \text{C(plasma, 3300K)} - 437.4 \text{ kcal,} \quad (35)$$

where

$$Q_{\text{carbon}} = 437.4 \text{ kcal.} \quad (36)$$

$$2\text{H(plasma, 3300K)} \rightarrow 2\text{H(gas, 300K)} + 625 \text{ kcal,} \quad (37)$$

where  $625 \text{ kcal} = 2N13.6 \text{ eV} = 163.2 \cdot 10^{23} \text{ eV}$  is ion recombination heat of 2 moles of H ( $2\text{H}^+ + 2e \rightarrow 2\text{H}$ );

$$2\text{H(gas, 3300K)} \rightarrow \text{H}_2(\text{gas, 300K}) + 104.2 + 18 \text{ kcal.} \quad (38)$$

Here, 104.2 kcal are released due to recombination heat of  $\text{H}_2$  molecule,  $\text{H} + \text{H} \rightarrow \text{H}_2$ , and 18 kcal are due to cooling down of a diatomic gas from  $T = 3300\text{K}$  to  $T = 300\text{K}$ . Heat capacity of a diatomic gas is about 6 to 7 cal/(mole K), at high and low temperatures.

$$\text{C(plasma, 3300K)} + \text{O(plasma, 3300K)} \rightarrow \text{C(gas, 3300K)} + \quad (39)$$

$$+ \text{O(gas, 3300K)} + 259 + 313 \text{ kcal;}$$

where  $259 \text{ kcal} = N11.26 \text{ eV} = 67.6 \cdot 10^{23} \text{ eV}$  is ion recombination heat of 1 mole of C ( $\text{C}^+ + e \rightarrow \text{C}$ ), and  $313 \text{ kcal} = N13.6 \text{ eV} = 81.6 \cdot 10^{23} \text{ eV}$  is ion recombination heat of 1 mole of O ( $\text{O}^+ + e \rightarrow \text{O}$ );

$$\text{C(gas, 3300K)} + \text{O(gas, 3300K)} \rightarrow \text{CO(gas, 300K)} + 255.8 + 18 \text{ kcal,} \quad (40)$$

where 255.8 is energy released during formation of carbon monoxide CO, and 18 is energy released due to the cooling down of CO from  $T = 3300\text{K}$  to  $T = 300\text{K}$ .

In conclusion,

(i) The creation of 4 moles of fully ionized 2H,O,C plasma ( $T=3300\text{K}$ ) requires

$$Q_{\text{water}} + Q_{\text{carbon}} = 1197 + 437 = 1634 \text{ kcal;} \quad (41)$$

Thus, the energy consumption for the plasma is  $(1/4)1634 \text{ kcal/mol}$ , i.e.

$$408.5 \text{ kcal/mol} = 0.475 \text{ kWh/mol} = 1621\text{BTU/mol} = 515.8 \text{ kcal/cf} = \quad (42)$$

= 0.600 kWh/cf = 2047 BTU/cf of the plasma;

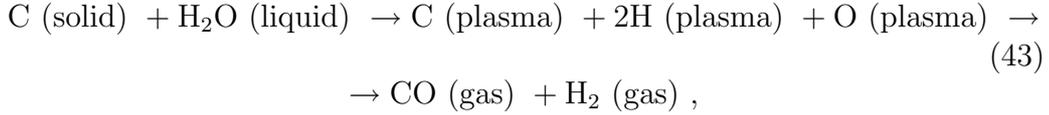
(ii) The formation of 1 mole of H<sub>2</sub>(gas, 300K) releases 625+104.2 + 18 = 747 kcal;

(iii) The formation of 1 mole of CO(gas, 300K) releases 259+313+255.8 + 18 = 846 kcal;

(iv) In total, 747+846= 1593 kcal is released as a heat. Thus, the heat released is (1/4)1593 =398 kcal/mol=1994 BTU/cf of the plasma.

(v) In total, 2 moles of the CO+H<sub>2</sub> (1:1 ratio) gas have been produced from 4 moles of the plasma (more precisely, from 4 moles of the positive ions and 4 moles of electrons);

(vi) As the net result, from (i) and (iv) we obtain 1593-1634 = - 41 kcal per two moles of CO+H<sub>2</sub> gas, i.e. the considered reaction,

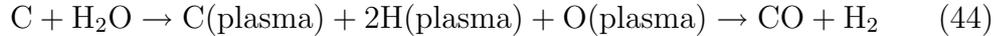


is endothermic. Within the adopted accuracy, this value confirms the value 43.9 kcal of Eq. (4) obtained without consideration of the intermediate plasma state.

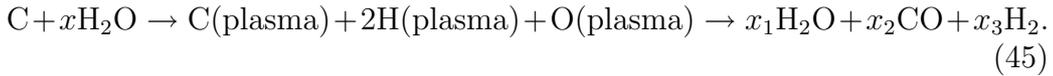
(vii) Since the number of moles of the gas produced is two times less than the number of moles of the plasma we have, in addition to the above results (i) and (iv), the following alternative result. The energy input is 2·2047 = 4094 BTU/cf of the CO+H<sub>2</sub> gas; and the heat produced by the exothermic reactions is 2·1994 BTU/cf = 3988 BTU/cf of the CO+H<sub>2</sub> gas. The total balance is -4094 + 3988 = -108 BTU/cf.

## 4.5 50% recombination of water

The reaction



represents an ideal situation because in reality some atoms may recombine back into the water. Therefore, we should consider the more general case,

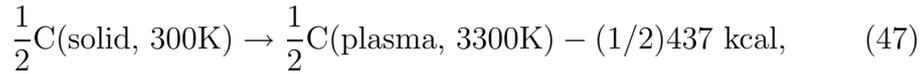


For  $x_1 \neq 0$ , we have lower efficiency of the process since the target products are CO and H<sub>2</sub>.

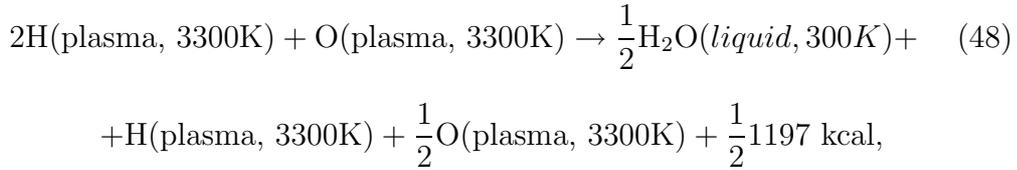
Below, we consider the sequence starting with 1 mole of water and 1/2 mole of graphite; reactions (46) and (47) below are formation of the 2H, O, (1/2)C plasma; reaction (48) is ion recombination of H and (1/2)O, and recombination of liquid (1/2)H<sub>2</sub>O (50% recombination); reaction (49) is ion recombination of the remaining H; reaction (50) is formation of (1/2)H<sub>2</sub>; reaction (51) is ion recombination of (1/2)C and remaining (1/2)O; and reaction (52) is formation of CO; namely,



i.e., the same as the above reaction (33);



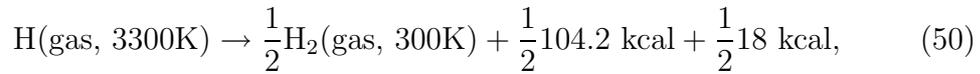
i.e., 218.5 (one-half of the above reaction (35));



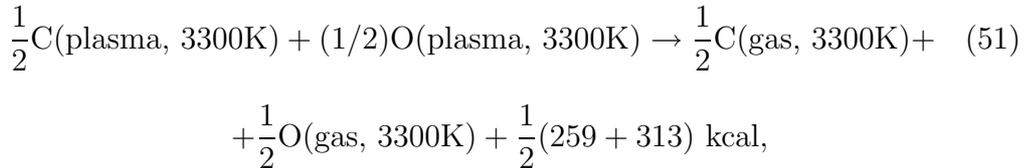
i.e., 598.5 kcal release;



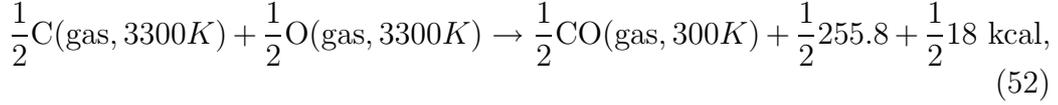
i.e., 312.5 kcal release;



i.e., 52.1+9= 61.1 kcal release;



i.e.,  $129.5+156.5=286$  kcal release.



i.e.,  $128+9=137$  kcal release;

In conclusion,

(i) The formation of 3.5 moles of  $2\text{H}$ ,  $\text{O}$ ,  $\frac{1}{2}\text{C}$  plasma with  $T=3300\text{K}$  from 1 mole of liquid water and  $\frac{1}{2}$  mole of solid graphite ( $T=300\text{K}$ ) requires  $1197+218.5= 1415.5$  kcal. Thus, the energy consumption for the plasma is  $(1/3.5)1415.5$  kcal/mol, i.e.  $404.4$  kcal/mol =  $0.47$  kWh/mol =  $1605$  BTU/mol =  $510.6$  kcal/cf =  $0.594$  kWh/cf =  $2026$  BTU/cf of the plasma;

(ii) 50% recombination of water ( $\frac{1}{2}$  moles of water) releases  $598.5$  kcal;

(iii) The formation of  $\frac{1}{2}$  moles of  $\text{H}_2$  releases  $\frac{1}{2}(625 + 104.2 + 18) = 312.5 + 52.1 + 9 = 373.6$  kcal;

(iv) The formation of  $\frac{1}{2}$  moles of  $\text{CO}$  releases  $\frac{1}{2}(259 + 313 + 255.8 + 18) = 129.5 + 156.5 + 128 + 9 = 423$  kcal;

(v) In total, 1 mole of  $\text{CO}+\text{H}_2$  (1:1) gas and  $\frac{1}{2}$  mole of water has been produced from 3.5 moles of the  $2\text{H}$ ,  $\text{O}$ ,  $\frac{1}{2}\text{C}$  plasma (more precisely, from 3.5 moles of the positive ions and 3.5 moles of electrons);

(vi) In total,  $598.5+373.6+423 = 1395.1$  kcal released as a heat. Thus, the heat released is  $\frac{1}{3.5}1395.1 = 399$  kcal/mol =  $1997$  BTU/cf of the plasma.

(vii) Since the number of moles of the gas produced is 3.5 times less than number of moles of the plasma we alternatively have, in addition to the above results (i) and (vi), that the energy input is  $3.5 \times 2026 = 7091$  BTU/cf of the  $\text{CO}+\text{H}_2$  gas; and the heat produced by the exothermic reactions is  $3.5 \times 1997$  BTU/cf =  $6990$  BTU/cf of the  $\text{CO}+\text{H}_2$  gas.

## 5 Heat production

### 5.1 No heat production

No heat production is here understood in the sense that all the heat produced by the exothermic reactions is used back in the endothermic reactions, and thus helps the formation of the plasma and  $\text{CO}+\text{H}_2$  gas. The energy balance could be calculated as follows:

$$\textit{Energy required to form the plasma} + \textit{Energy released as a heat.} \quad (53)$$

Since the energy input is negative while heat produced is positive we obtain from the above result (vi) of Sec. 4.4 the following energy consumption:

$$-4094 + 3988 = -106 \text{ BTU/cf of the gas;} \quad (54)$$

and from the above result (vii) of Sec. 4.5 (the case of 50% recombination of water):

$$-7091 + 6990 = -101 \text{ BTU/cf of the gas.} \quad (55)$$

Here, minus sign means that energy is required. Hence, about 100 BTU is required to produce 1 cf of the gas, under the assumption that the reactor has ideal 100% efficiency (does not produce any heat but only the gas).

## 5.2 The heat production coefficient

The heat produced by the exothermic reactions (see (vi) of Sec. 4.4 and (vii) of Sec. 4.5) is distributed via two main channels: first, it contributes to the endothermic reactions and, second, it is dissipated into the environment (heat production). If some part  $k$ ,

$$0 < k < 1, \quad (56)$$

of the heat produced by the exothermic reactions is removed due to dissipation (convection, radiation, heat-mass transfer, etc.) to the environment from the region where the endothermic reactions occur, i.e., the "heat production coefficient" is given by

$$k = \frac{\text{Heat transferred to environment}}{\text{Heat produced by exothermic reactions}}. \quad (57)$$

Therefore the remaining part,  $(1 - k)$ , of the heat,

$$1 - k = \frac{\text{Heat transferred to endothermic reactions}}{\text{Heat produced by exothermic reactions}} \quad (58)$$

is used in the endothermic reactions. The latter part of heat cannot be measured directly since it is absorbed by the endothermic reactions thus

helping the formation of the plasma and CO+H<sub>2</sub> gas. Therefore, we could modify the above energy consumptions (54) and (55) as follows:

$$-4094 + (1 - k)3988 \text{ BTU/cf} \quad (59)$$

and

$$-7091 + (1 - k)6990 \text{ BTU/cf} \quad (60)$$

of the gas, with the associated heat produced being

$$k3988 \text{ BTU/cf} \quad (61)$$

and

$$k6990 \text{ BTU/cf} \quad (62)$$

of the gas, respectively. The heat productions (61) and (62) are those corresponding to the measurable heat produced since these heats are absorbed by the environment (surrounding liquid, metal parts of the reactor, etc.).

### 5.3 Example 1: 70% heat production

For  $k=0.7$  (70% of the total heat is dissipated/utilized and 30% is used in the endothermic reactions), we get energy consumptions

$$-4094 + 0.3 \cdot 3988 = -2898 \text{ BTU/cf} \quad (63)$$

and

$$-7091 + 0.3 \cdot 6990 = -4994 \text{ BTU/cf} \quad (64)$$

of the gas, with the associated heat production (i.e. measurable heat produced) being

$$0.7 \cdot 3988 = 2792 \text{ BTU/cf} \quad (65)$$

of the gas and

$$0.7 \cdot 6990 = 4893 \text{ BTU/cf} \quad (66)$$

of the gas, respectively. These heat productions correspond to measurable heats produced.

## 5.4 Example 2: 100% heat production

For  $k=1$  (100% of the heat produced by exothermic reactions is dissipated/utilized), we evidently have the maximal value for the energy consumptions:

$$-4094 \text{ BTU/cf} \quad (67)$$

of the gas; and

$$-7091 \text{ BTU/cf} \quad (68)$$

of the gas, and the associated maximal values of the heat productions:

$$3988 \text{ BTU/cf} \quad (69)$$

of the gas; and

$$6990 \text{ BTU/cf} \quad (70)$$

of the gas, respectively. These heat productions correspond to measurable heats produced.

## 6 Total heat produced

We now add the combustion heat of the produced  $\text{CO}+\text{H}_2$  (1:1) gas (the theoretical value is 315 BTU/cf) to the measurable heat produced by the reactor, in order to estimate the total heat produced. By adding 315 BTU/cf to the heats (59) and (60) we obtain the total measurable heat produced

$$k3988 + 315 \text{ BTU/cf of the CO+H}_2 \text{ gas;} \quad (71)$$

and

$$k6990 + 315 \text{ BTU/cf of the CO+H}_2 \text{ gas,} \quad (72)$$

for the cases of 0% and 50% recombination of water, respectively. Here, the coefficient  $k$  ( $0 < k < 1$ ) is defined by (57) and can be given in some approximate value by studying thermodynamics of a specific reactor. This coefficient accounts for all heat losses, including that at (tungsten) anode.

By assuming that the total heat produced is approximately equal to the energy input (see the energy inputs in (vi) of Sec. 4.4 and (vii) of Sec. 4.5), that is, by assuming the efficiency 1, we have

$$\frac{k3988 + 315 \text{ BTU/cf of the CO+H}_2 \text{ gas}}{4094 \text{ BTU/cf of the CO+H}_2 \text{ gas}} = 1, \quad (73)$$

and

$$\frac{k6990 + 315 \text{ BTU/cf of the } CO + H_2 \text{ gas}}{7091 \text{ BTU/cf of the } CO+H_2 \text{ gas}} = 1. \quad (74)$$

Therefore, we obtain

$$k = 0.948 \quad (75)$$

and

$$k = 0.969, \quad (76)$$

respectively. The measurable total heat produced is

$$4094 \text{ BTU/cf of the } CO+H_2 \text{ gas}; \quad (77)$$

and

$$7091 \text{ BTU/cf of the } CO+H_2 \text{ gas}, \quad (78)$$

which is valid under conditions (73) and (74), i.e., that the total measurable heat produced is equal to the energy input.

The above estimations (75) and (76) mean that about 95% of the (electric) energy input is dissipated into the environment and the remaining 5% contributes to the endothermic chemical reactions.

The following remark is in order. We can account for additional heat production which could not be accounted by the coefficient  $k$  by adding some heat  $Q'$ , so that (77) and (78) become

$$\frac{k3988 + 315 + Q' \text{ BTU/cf of the } CO+H_2 \text{ gas}}{4094 \text{ BTU/cf of the } CO+H_2 \text{ gas}} = A, \quad (79)$$

and

$$\frac{k6990 + 315 + Q' \text{ BTU/cf of the } CO+H_2 \text{ gas}}{7091 \text{ BTU/cf of the } CO+H_2 \text{ gas}} = A, \quad (80)$$

where  $A$  can be taken approximately one, or some other value. However, one can incorporate  $Q'$  into  $k$  by simple redefinition. For instance,  $k3988 + 315 + Q' \rightarrow k3988 + 315 + k'3988 \rightarrow (k + k')3988 + 315 \rightarrow k3988 + 315$ , and we arrive again to the estimation (75), for  $A = 1$ . However, here  $k$  acquires some other meaning which is different than that in Eq. (57).

## 7 Conclusions

In this paper we have studied the upper limit of the "commercial efficiency" [1], simply referred in the text as "efficiency" of Santilli's hadronic reactors of molecular type, also called PlasmaAArcFlow reactors [1].

For the case of pure water we have obtained the upper limit 3.11, while for the mixture of ethyleneglicole and water the efficiency is given by Eq. (13) (see Figs. 1 and 2), and rises from 3.11 to about 7.5, with increase of the relative consumption of ethyleneglicole with respect to that of carbon rods. These results are based on the assumptions that all thermochemical processes are conventional and have been obtained at  $T = 25^\circ\text{C}$  and  $p = 1$  atm.

Similar calculations can be made for different water-based liquid wastes, provided that their main chemical composition is known.

We have accounted for the plasma production, and obtained a more detailed view on the steps of the entire process. This has allowed us to account for the water recombination and the heat production coefficient.

The comparison of the theoretical results with measurements leads to a sharp discrepancy between theoretical predictions and experimental data. In fact, the fitting of the measured commercial over-unity leads to a prediction which is about three times smaller than the measured heat. On the other hand, the fitting of the measured heat production leads to the prediction that the measured commercial over-unity is smaller than that predicted.

The implications of the above calculations are the following. The fact that the heat produced in the PlasmaArcFlow reactors is less than 1/3 the theoretical prediction constitutes clear evidence that magnegas is not composed of conventional  $\text{H}_2$  and  $\text{CO}$  molecules. Alternatively, the indicated evidence prohibits the complete formation of  $\text{H}_2$  and  $\text{CO}$ . It then follows that magnegas is indeed composed of clusters, called Santilli magnecules [1], which are composed of clusters of individual H, C and O atoms, dimers OH, CH or C-O in single bond, and ordinary molecules  $\text{H}_2$  and  $\text{CO}$  under a new attraction between opposite polarities created by magnetic and electric polarizations of the orbitals of individual atoms into toroids.

On the other side, the fact that the heat content of magnegas is about 3 times that predicted is additional strong evidence that magnegas, again, contains non-molecular bonds. In fact, said H, C and O atoms may bond into  $\text{H}_2$  and  $\text{CO}$  at the time of combustion, thus releasing extra energy. As

such the above two large deviations complement each other rather nicely.

It is evident that no additional quantitative study of the commercial efficiency of PlasmaArcFlow reactors can be done without a more accurate knowledge of the new chemical species of magneccules, as well as a reinterpretation of thermochemical processes via the covering hadronic chemistry.

## Appendix

### Hydrogen

Atomic weight: 1 gram/mol;

Ionization potential: 13.6 eV;

Melting point: 13.8 K;

Boiling point: 20.3 K;

Specific heat capacity (300K):  $14.304 \text{ J}/(\text{gram K}) = 3.4 \text{ cal}/(\text{gram K}) = 3.4 \text{ cal}/(\text{mole K})$ ;

Density: 0.09 gram/liter (gas).

To heat 1 mole (i.e. 1 gram) of hydrogen from  $T = 300\text{K}$  to  $T = 3300\text{K}$  it is required  $3.4 \text{ cal}/(\text{mole K}) \cdot (3300 - 300) \text{ K} = 10.2 \text{ kcal}$ .

### Oxygen

Atomic weight: 16 gram/mol; First Ionization potential: 13.6 eV;

Melting point: 54.8 K;

Boiling point: 90.2 K;

Specific heat capacity (300K):  $0.92 \text{ J}/(\text{gram K}) = 0.22 \text{ cal}/(\text{gram K}) = 3.5 \text{ cal}/(\text{mole K})$ .

To heat 1 mole (i.e. 16 grams) of oxygen from  $T = 300\text{K}$  to  $T = 3300\text{K}$  it is required  $3.5 \text{ cal}/(\text{mole K}) \times (3300 - 300) \text{ K} = 10.5 \text{ kcal}$ .

### Carbon

Atomic weight: 12 gram/mol;

First ionization potential: 11.26 eV;

Melting point: 3825 K;

Boiling point: 5100 K;

Specific heat capacity (300K):  $0.709 \text{ J}/(\text{gram K}) = 0.17 \text{ cal}/(\text{gram K}) = 2 \text{ cal}/(\text{mole K})$ ;

Heat of evaporation:  $715 \text{ kJ}/\text{mol} = 171.7 \text{ kcal}/\text{mol}$   $1 \text{ J} = 0.24 \text{ cal}$   $1 \text{ J} = 2.8 \times 10^{-7} \text{ kWh}$   $1 \text{ J} = 10^7 \text{ erg}$ .

To heat 1 mole (i.e., 12 grams) of carbon from  $T = 300\text{K}$  to  $T = 3300\text{K}$  it is required  $2 \text{ cal}/(\text{mole K}) \times (3300 - 300) \text{ K} = 6000 \text{ cal} = 6 \text{ kcal}$ , thus  $E_1 = 6 \text{ kcal}$ .

## Water (liquid)

Molecular weight: 18 gram/mol;

Specific heat capacity (300K):  $4.18 \text{ J}/(\text{gram K}) = 1 \text{ cal}/(\text{gram K}) = 18 \text{ cal}/(\text{mole K})$ .

To heat 1 mole (i.e., 18 grams) of liquid water from  $T = 20\text{C}$  to  $T = 100\text{C}$  it is required  $18 \text{ cal}/(\text{mole K}) \times (100 - 20) \text{ K} = 1440 \text{ cal} = 1.4 \text{ kcal}$ , thus  $Q_1 = 1.4 \text{ kcal}$ .

## Water vapor (ideal gas)

Molecular weight: 18 gram/mol;

For ideal gases the heat capacity is  $Nk/2$  per each degree of freedom of molecule.  $Nk/2 = 4.2 \text{ J}/(\text{mole K}) = 1 \text{ cal}/(\text{mol K})$ .

Water molecule has 3 translational and 3 rotational degrees of freedom. Also, there are 3 vibrational degrees of freedom, at sufficiently high temperatures ( $T > 3000\text{K}$ ). So, in total we have (about) 9 degrees of freedom. Hence, the heat capacity of water vapor at high temperatures is  $9Nk/2 = 9 \text{ cal}/(\text{mol K})$ . The heat required to heat up 1 mole of water vapor from  $T = 100\text{C} = 400\text{K}$  to  $T = 3300\text{K}$  is thus  $9 \text{ cal}/(\text{mole K}) \times (3300 - 400) \text{ K} = 26100 \text{ cal} = 26 \text{ kcal}$ , therefore  $Q_3 = 26 \text{ kcal}$ .

## Conversion factors and constants

$1 \text{ kWh} = 860 \text{ kcal} = 3413 \text{ BTU}$ ;

$1 \text{ kcal} = 3.97 \text{ BTU}$ ;

$1 \text{ eV} = 3.83 \times 10^{-23} \text{ kcal}$ ;

$1 \text{ cal} = 4.18 \text{ J}$ ;

$1 \text{ mole} = 22.4 \text{ liters} = 0.792 \text{ cf}$  (an ideal gas, normal conditions);

1 cf = 28.3 liters;  
1 cf = 1.263 mol (an ideal gas, normal conditions);  
 $N = 6 \times 10^{23} \text{ mol}^{-1}$  (Avogadro number);  
 $Nk/2 = 1 \text{ cal}/(\text{mol K})$ ;  
 $R = 8.314 \text{ J}/(\text{mol K}) = 1.986 \text{ cal}/(\text{mol K})$ .

### Specific heat capacities

$p = 1 \text{ atm}$ ,  $T = 25\text{C}$ .  
 $\text{H}_2$ (gas):  $29.83 \text{ J}/(\text{mol K}) = 7 \text{ cal}/(\text{mol K})$ ;  
 $\text{H}_2\text{O}$  (liquid):  $4.18 \text{ J}/(\text{gram K}) = 1 \text{ cal}/(\text{gram K}) = 18 \text{ cal}/(\text{mol K})$ ;  
C (graphite, solid):  $0.71 \text{ J}/(\text{gram K}) = 0.17 \text{ cal}/(\text{gram K}) = 2 \text{ cal}/(\text{mol K})$ ;  
 $\text{O}_2$  (gas):  $29.36 \text{ J}/(\text{gram K}) = 7 \text{ cal}/(\text{gram K})$ ;  
H (gas):  $14.3 \text{ J}/(\text{gram K}) = 3.42 \text{ cal}/(\text{gram K})$ ;  
O (gas):  $0.92 \text{ J}/(\text{gram K}) = 0.22 \text{ cal}/(\text{gram K})$ ;  
Fe (solid):  $0.45 \text{ J}/(\text{gram K}) = 0.11 \text{ cal}/(\text{gram K}) = 6 \text{ cal}/(\text{mol K})$ .

### Evaporation heats

Water:  $10.4 \text{ kcal}/\text{mol}$ ,  $T = 25\text{C}$ ;  
Graphite:  $171.7 \text{ kcal}/\text{mol}$ ,  $T = 25\text{C}$ .

### First ionization potentials

H:  $13.6 \text{ eV}$ ; O:  $13.6 \text{ eV}$ ; C:  $11.26 \text{ eV}$ .

### Test results for some model of PAF reactor

Measured energy consumption:  $100 \text{ Wh}/\text{cf} = 341.3 \text{ BTU}/\text{cf}$  of magnegas;  
Measured heat production:  $665 \text{ BTU}/\text{cf}$  of magnegas produced;  
Measured combustion heat of magnegas:  $650 \text{ BTU}/\text{cf}$ ;  
Measured commercial over-unity:  $(665+650)/341.3 = 3.85$ ;  
Theoretical combustion heat of  $\text{CO}+\text{H}_2$  (1:1) gas:  $315 \text{ BTU}/\text{cf}$ .

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