

HYDROGEN STRATEGIC COMPLEMENT OF OIL, COAL, GAS AND RENEWABLE ENERGY

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ABSTRACT

Hydrogen Investment is the future business!

Strategies of global energy game should guide the future energy world. These strategies can be realized by managing flexibility price with Real Options Theory and produced quantity by using Nash equilibrium in cooperative industrial systems. We can calculate hydrogen volume that should exist in the global energy marketing in order to keep "petroleum status quo".

Although hydrogen was not properly understood as an alternative energy, it has emerged as strategic complement of oil in recent times. In this sense, we introduce the need for Tobin q^* . It was modified for oil and hydrogen projects. Furthermore, q^* permit us to maximize profitability and minimize risks simultaneously.

Key Words: Oil Real Options, Energy Efficiency, Petroleum Status Quo, Stochastic Calculus, Hydrogen Economy, Sustainability.

1. INTRODUCTION

Is it possible to live in balance or harmony-equilibrium between nature, oil- energy companies, and man, so we share interests and problems, we minimize profound differences expressed in economic utility functions, conflicting values and benefits through implementing a cooperative equilibrium with emphasis on respect for the environment and sustainable energy? Binmore, K. (1992), Fudenberg, D., Tirole, J. (1991), Myerson, R (1991, 1994), Nash (1953), Aumann & Schelling (2005), Ipieca 2013.

The answer is yes, if and only if, we strictly adhere to the objectives of survival, utility, and intrinsic order of each of the three teams of strategic players: nature, humanity, oil-energy companies, here and now present and active. Current trends in alternative energy located in complementarity with oil; therefore, the ideal should be rational use of oil without harming nature, leaving minimal ecological footprint, and transforming the relationship divisive dominant of oil and energy over Humanity and Nature ($P / H / N$) by a multiplicative holistic interaction (PHN). Good practices of Business Intelligence and Corporate Governance have demonstrated need for cooperative work between the actors and makers of oil energy efficiency of clean hydrogen production of petrochemical development in order to ensuring a sustainable future. Energy Intelligence Group (2000), Bockris. John O'M. (2013), Stygar, M (2013), World Oil Outlook 2012.

Any oil or energy project leverages on operational and financial indicators that ultimately define viability. Therefore, new developments in real options theory, oil energy efficiency, and hydrogen clean production allowed us a glimpse of a quantitative way, this new cooperative equilibrium between oil companies, humanity, and nature is represented by PHN. The oil and hydrogen are engines of the world from the perspective of businesses we require flexibility in time and investment arbitration technically known as real options. *Dixit & Pindick (1994), EPPetroecuador (2011), Kagel and Roth (1995)*.

On one hand, hydrogen as an energy carrier understood and not properly as an alternative energy in recent times inevitably has emerged as strategic complement of oil for four main reasons: 1. - The refining and petrochemical industries rely on hydrogen for their processes of hydrotreating, hydrocracking and hydrodesulfurization. 2. - When alternative energies are not consumed immediately and need to be stored or transported are transformed into electricity or converted into hydrogen. 3. - The use of hydrogen in fuel cells to generate electricity is attractive for future of alternative energy. 4. - The abundance of salt water on planet earth and scientific trends of sun water splitting, offers hope to the world through the hydrogen economy. In *Bockris. John O'M. (2013)*, One of founders of Hydrogen Economy, "was able to obtain considerable increases in efficiency of decomposition of water by solar light, and at the time the work was interrupted he had 9.6 percent efficiency for decomposition".

On the other hand, the strategy of global energy game should guide future energy world. It can be done, managing flexibility price with real options and produced quantity using Nash equilibrium in cooperative industrial systems. The calculation of the hydrogen volume should exist in the global energy market in order to maintain "petroleum status quo".

Why we use Game Theory and Nash's equilibrium in this study? Because:

- We apply the Nash equilibrium, in trouble where there is strategic interaction between players, such as oil producers and energy producers. In this sector, every company makes decisions based on their prices and production levels that keep their opponents (competitors) and market. Moreover, alternative energy and hydrogen are especially now a strategic opponent oil. Game theory provides a set of mathematical tools for calculating profits and production volumes in markets including probabilistic environments. Therefore, it is logical for us to use the methodology of game theory to calculate volumes of oil production and hydrogen energy.
- Quantum Game Theory introduces the concept of states of order and minimum entropy, which is an extension of the Nash equilibrium, which best suits the dynamic processes of the oil industry and energy. Moreover, we used equilibrium concepts in a creative and unique, as evidenced in equations 15, 16, 17, 18, 19, 20. Finally, we show that the laws of probability apply dynamic systems completely stochastic environments such as oil and hydrogen.

This research is a response to a major initiative by ARPEL, 11-13 September 2012 in Uruguay. 2012 MEETING OF THE CLIMATE CHANGE AND ENERGY EFFICIENCY, which involved the following oil and energy companies: ANCAP, ECOPETROL, Petroamazonas EP, OCENSA, Pemex, Petrobras, Statoil and EPPETROECUADOR.

In terms of energy efficiency and reduction of greenhouse gases is an important decision ARPEL member countries, to implement ISO 50001, which will reveal the amount of barrels of oil equivalent, which saves on refining plants and crude production when applied industry best practices, properly explained in ISO 50001.

It was gratifying to verify that when we're talking about our destination, many actors involved in the oil and sustainable energy PHN. Although, not all players (oil, humanity, man) have same strategic weight, and same vision, we are expressing us as follows:

N. Nature, manifesting directly and indirectly in the air, sea, land, Earth planet evolution, and climate changes which are even quantified. *See, Rifkin. J(2002).*

H. Humanity. It is let by the scientific community and the policy makers of world energy. *Ipieca (2012), Jiménez, E. H (2012a,b).*

P. Energy and Oil Companies. It is the responsible for world production.

The U.S. Department of Energy, a priory says that by 2030, renewable energy will be 30% of the global energy mix. This percentage of participation will be dynamic. For that reason, arbitration options would allow insider groups make million dollars in profits. *Edward Jiménez, Hedge Funds, (2009).* This new composition of the global energy mix would ensure the reduction of CO2 emissions into the atmosphere, but not a sustainable energy future.

According to Nicholas Stern, "even if the rich world takes full share of responsibility and able to impose absolute emission cuts of up to 60-80% by 2050, the developing countries are not exempt from undertaking measures share equally significant ". Thus all countries are stewards.

- **Industry focus of true complementarily between oil and hydrogen production, oil refining and petrochemicals.**

The dynamics of renewable energy, hydrogen and oil are completely related. Industrial experience shows us that you can generate electricity by burning oil or surplus renewable energy such as solar, wind, geothermal, and so on. Similarly, we can store electrical energy through hydrogen generation, using fuel cells. As the fuel cell can function in reverse, it can generate hydrogen if connect a source of electricity. Thus, we see that there is a causal link between hydrogen and renewable energy. Moreover, in Stygar, M (2013), hydrogen as an energy source and as an energy carrier alone cannot develop to the levels required daily energy demand, projecting in millions of barrels of oil equivalent of 279 MBOED for 2020 and 359 for MBOED 2035.

Hydrogen as strategic complement has intrinsic advantages: the global need for clean energy use that will reduce the rate of global warming and air pollution rate of CO2 emission, using it as raw material and/or process catalyst treatment and refining of oil, coal and gas account for 89.8% of the total energy consumed on the planet (in barrels of oil equivalent), with reference 2010 and 82.26% with reference 2035; World Oil Outlook 2012.

This paper has a lot of information, which should be structured and correlated to be consistent and easy to read. As a result, each of the chapters and subchapters are converged to the same fundamental idea, economic necessity and defense of the environment to introduce in the global energy matrix alternative energy and hydrogen. Furthermore, in the short term is imminent start alternative energy has competitive pricing with oil.

In section 1 INTRODUCTION, we present the state of the art of energy economy and oil. Also, we review some publications suggesting that hydrogen future will be as a complement-operative of industrial processes and petrochemical refining. Finally, we explain how to use game theory in the field of oil and energy.

In section 2 PETROLEUM AND HYDROGEN TRUE STRATEGIC COMPLEMENTS, we teach strategic weight to calculate the global hydrogen, for which we have introduced some concepts such as:

How and when to apply investor's real option concepts in oil and energy.

Energy efficiency and its impact on production costs.

Oil reserves and world energy game in a stochastic environment.

Quantitative evidences of a possible oil crisis.

Game Theory and War of Attrition in petroleum and energy sector.

Simulation and examples.

Hydrogen as catalyst for petroleum status quo.

In section 3, CONCLUSIONS, we recorded all the contributions of this work, a small part of which previously have been presented at international events organized by ARPEL and PEMEX.

2. PETROLEUM AND HYDROGEN TRUE STRATEGIC COMPLEMENTS

In the current situation of energy and petroleum world economy, global strategic teams are humanity, nature, and business. Each of these players is motivated by intrinsic values and common interests such as survival, profit, and order.

From a broader perspective, it could be said that the development models implemented in the oil-producers countries have disproportionately relied on the extraction of non-renewable natural resources in conditions of limited Sustainability and a considerable negative effects on ecosystems. These models have also consolidated a highly unequal social structure and have left unsatisfied basic needs of the majority of the population.

It is a fact that the human mind always justifies by their values, their deepest individual interests, while cooperative goals arise by the overflowing of common problems such as global warming, floods, famine, and so on.

The supremacy or the imposition of a single point of view has obvious risks such as causing falsehoods, partial truths, non-equilibriums, appearances, and, the most painful: the uniformity in searching, information analyzing, and strategic decision making.

Various players in this strategic relationship perceive reality from their present, past, and future. So, they have common points and differences fully marked. Axiomatic objectives of a consensus must, on the one hand, leverage, maximize, and implement coincidences, and, on the other hand, reduce, mitigate, and manage discrepancies.

Axiom Truth is intersection of individual truths of the involved players: nature-humanity-companies.

Axiom Man bases on oil and energy companies which should govern nature. That means its fundamental laws, respect its own dynamics, and live harmoniously with it.

Axiom Oil and energy companies must provide services to humanity, not just maximizing its returns through exploration, exploitation, oil refining or energy production but rather using natural resources most friendly way with nature and man.

Axiom Concept of optimality centralizes holistically fundamentals laws of nature (Principle of Least Action in Physics), economics (Economic Rationality) and Man (Sociological Rationality).

Theorem Self- Organization Equilibrium means Minimum Entropy.Proof See *Jiménez, E (2003c)*.

Let $U_P(P, C) = (P - C)Q$ be a function of utility of oil exploitation process: where: U_P is the function of Utility [\$].

P Crude Price [\$/bls]. Q Total production of crude [bls]. C Operating and financial fixed unit cost [\$/bls]. For arbitration in time the utility function U_P becomes net present value $V(P, C)$

Let $U_R(P_R, C_R) = (P_R - C_R)Q_R$ be a utility function from refining crude oil, where: U_R Utility function [\$].

P_R Barrel price of oil products [\$/bls]. Q_R Total production of derivatives [bls]. C_R fixed operating cost refining unit [\$/ bbl]. For arbitration time, the utility function $U_R(P_R, C_R)$ becomes real option value $V(P_R, C_R)$.

We will understand as energy efficiency e , the value that minimizes production cost or refining cost and, simultaneously, reduces environmental impact represented by the carbon footprint, such that $C = C(e)$, $dC/dt < 0$, $d^2C/dt^2 > 0$. This equation show that utility represented by net present value increases when costs fall. This value is verified both for dynamics profit and for stationary profit (equilibrium).

It is evident that all energy-efficient process may have positive implications not only in operating cost, but also in operating value $Q = Q(e)$. However, we will keep $Q = cte$ at first approximation.

Strategy of global energy game and world oil production can be performed using real options in price variable P and using cooperative Nash equilibrium in quantity variable Q.

2.1 THE INVESTOR'S REAL OPTIONS

On one hand, the strategic investor must make decisions using only reliable and complete information, according to the definitions of Game Theory, so that your projects can:

- Maximize profitability
- Minimize risk and
- Optimize the amount of investment.

The real options approach, meets the requirement of maximizing returns correctly represented by the value of the real option and mathematically written as $F(V)$.

On the other hand, the efficient portfolio approach show that it is equivalent maximizing profitability to minimizing the risk (volatility), we can write mathematically as: $\text{Min}(\sigma) = F(V)$.

Finally, to apply these concepts to oil and energy projects, we introduce the indicator of Tobin q^* , which tells us when we must invest optimally in uncertain environments. That is, maximizing profitability.

$$F(V) = \max E[(V_T - I)e^{-\rho T}]$$

This equation will be explained in this section, according to equations [1],...,[14].

These valuation options allow the investor the easy and quantitative investment decisions. Furthermore, econometric and financial models that are available to an investor of the oil and energy sector, should enable him to make confident decisions in their daily work and in their daily activities. From this perspective, we discuss the real options that are flexible tools from several points of view:

Firstly, it allow us to track and refinement of available information, which, undoubtedly force has restructured a project or investment decision.

Secondly, in business world of oil and energy projects are always competitive when investing, as a result, the time flexibility of investment alternatives can be implemented only under the concept of real options:

- Decision to reduce the current level of investment.
- Decision to close a business, if expected future results are negative.
- Decision to increase investment when increasing demand.
- Decision to replace a project for a more cost-effective.
- Decisions to find accessories and strategic investment. For example hydrogen.

Thirdly, delaying the investment decision until the last moment, in which the probability of success is high and more than 50%.

Fourthly, investment projects make real options relevant for the following reasons:

- High performance and dynamic information.
- The optimal time of investment, is the key variable.
- The geographical location of the oil fields or the location of energy sources are crucial in this business and target market addressed.
- Global Geopolitics depends on international oil producers and energy.

According to a Brownian motion, the basic model assumes that the net present value V evolves motion with slope α and standard deviation σ

$$dV = \alpha V dt + \sigma V dz$$

[1]

where: differential dz is infinitesimal increment of a Wiener process.

The equation [1], indicates that net present value V meets a brownian motion of mean α and standard deviation σ .

Definition Wiener Process: the motion experienced by an econometric variable with Brownian motion during a certain time interval is independent of that experienced in any other interval that is foreign to the first.

The postulates of the Wiener's process can be put in mathematical formalism using independent displacement concept:

1. $(x(t), t \geq 0)$ has independent increments.
2. $\forall t > 0, x(t)$ has normally distribution.
3. $\forall t > 0, E[x(t)] = 0, \text{var}[x(t) - x(s)] = \sigma^2|t - s|$
4. $x(0) = 0$

In Dixit & Pindyck (1994), "If an investor is rational should maximize the following function:

$$F(V) = \max E[(V_T - I)e^{-\rho T}] \quad [2]"$$

Equation [2], attests that the fundamental assumption of microeconomics is fulfilled, i.e. every economic agent maximizes intertemporal utility function.

Where E denotes the expected value; ρ is the discount rate; I the value of the investment or the cost associated with the flexibility of investment in time; and T is the future value and unknown, in which the optimal investment must be made.

In Dixit & Pindyck (1994), "Synthesizing and including an investment term I when $P > C$, the valuation equation of a project is:

$$V(P) = \begin{cases} K_1 P^{\beta_1} & \text{if } P < C \\ B_2 P^{\beta_2} + \frac{P}{\delta} - \frac{C}{r} - I & \text{if } P > C \end{cases} \quad [3]"$$

Equation [3], explicitly presents the evolution of the value of an option, depending on strategic variables such as price P , production cost C , amount of investment I , interest rates r , and volatility σ .

2.1.1 ENERGY EFFICIENCY AND IMPACT ON PRODUCTION COSTS

The utility is represented by the net present value, which is a function that depends on the price and cost of oil and energy. Our interest is to know what happens to the variable $V(P) = B_2 P^{\beta_2} + \frac{P}{\delta} - \frac{C}{r} - I$ when the cost of production or refining of oil increases or decreases and minimization the footprint carbon.

Case $P > C$.

$$\frac{\partial V(P)}{\partial C} = P^{\beta_2} \frac{\partial B_2}{\partial C} - \frac{1}{r} \quad [4]$$

Equation [4], measures the change in value of a real option depending on the variable production cost per unit C .

From equation on SIMULATION PRICE STRATEGY SECTION, we obtain $\frac{\partial B_2}{\partial C}$.

$$\frac{\partial B_2}{\partial C} = \frac{1 - \beta_2}{\beta_1 - \beta_2} \left(\frac{\beta_1}{r} - \frac{\beta_1 - 1}{\delta} \right) C^{-\beta_2} \quad [5]$$

Replacing in $\frac{\partial V(P)}{\partial C} - \rho \beta_1 \frac{\partial B_1}{\partial C} - \frac{1}{r}$ we have:

$$\frac{\partial V(P)}{\partial C} - \frac{1 - \beta_2}{\beta_1 - \beta_2} \left(\frac{\beta_1}{r} - \frac{\beta_1 - 1}{\delta} \right) P^{\beta_2} C^{-\beta_2} - \frac{1}{r} \quad [6]$$

Case $P > C(e)$

$$\begin{aligned} \frac{\partial V(P)}{\partial e} &= \frac{\partial V(P)}{\partial C} \frac{\partial C}{\partial e} \\ \frac{\partial V(P)}{\partial e} &= \left(\frac{1 - \beta_2}{\beta_1 - \beta_2} \left(\frac{\beta_1}{r} - \frac{\beta_1 - 1}{\delta} \right) P^{\beta_2} C^{-\beta_2} - \frac{1}{r} \right) \frac{\partial C}{\partial e} \end{aligned} \quad [7]$$

Equation [7] shows that the value of a real option is a function of the variable called energy efficiency e . Put in another way, philosophical and practical ISO 50001 certification has its econometric demonstration. Equations [5], [6], [7] are intermediate steps necessary to obtain the equation [7]. One explicit functional of $C(e)$ shows that it is entirely related to energy efficiency indicators.

Remark 1.

An immediate application of this work answers the following question, asked from an investor. If I want to invest 1000 million USD in the period 2014 ... 2020, in hydrogen projects, what is the option value and risk, considering that if I invest in oil I have a 15% return with minimal risk.

Remark 2.

Using Tobin's approach we must invest when $q^* = \frac{\beta_1}{\beta_1 - 1} = \frac{r^*}{r} > 1$. In oil and energy projects, investment conditions are more demanding $\frac{r^*}{r} > 1.15$. If we introduce modified q^* Tobin's, then we can get profit maximization and risk minimization, which could be expressed as follows:

$$\frac{V + \Delta V}{I} > 1.15. \quad [8]$$

Writing first-order Taylor's theorem to $V(P)$, when $P > C$, and using the explicit function $V = V(P, \delta, r, C, \sigma, I)$ where $\mathbf{x} = (P, \delta, r, C, \sigma, I)$, we can write $V = V(\mathbf{x})$ to find the value of ΔV .

$$\Delta V = V(\mathbf{x} + \Delta \mathbf{x}) - V(\mathbf{x}) = \sum_{i=1}^7 \Delta x_i \frac{dV}{dx_i} \quad [9]$$

Note that ΔV measure risk σ , and it can have positive and negative values.

$$\frac{V + \Delta V}{I} = \frac{V + \sum_{i=1}^7 \Delta x_i \frac{dV}{dx_i}}{I} > 1.15.$$

This last equation has relation with risk (volatility) in the next manner.

$$\sigma = \Delta V \quad [10]$$

Equations [8], [9] and [10], are a mathematical development to structure explicit form of modified Tobin's q^* , where the variables are: Price P , Cost C , investment I , interest rate r and volatility σ . The calculation of q^* , is the contribution of this paper.

2.2 OIL RESERVES AND WORLD ENERGY GAME

This entry is the stock of proved reserves of crude oil in barrels (bls). Proved reserves R_t are those quantities of petroleum which, by analysis of geological and engineering data, can be estimated with a high degree of confidence to be commercially recoverable from a given date forward, from known reservoirs and under current economic conditions.

The duration span of the oil reserves in a reference time $t = t_0$ noticed by d_{t-t_0} , is calculated by dividing reserves to production, in the same reference time $d_{t_0} = \frac{R_{t_0}}{Q_{t_0}}$. The estimation of reserves changes along time and requires additional study of geology, geophysics, and reservoir for validation. The global reserves have increased at an annual rate of 3.5% in the last decade, as shown in Table1 OIL RESERVES.

Table 1. WORLD OIL RESERVES

PROVEN OIL RESERVES [BILLIONS BARRELS]		
YEAR	END 2002	END 2011
North America	49,90	39,40
S & Central America	98,60	327,00
Africa	77,40	128,60
OEDC Europe	4,84	12,60
Eurasia	92,66	127,00
Middle East	685,60	796,80
Asia Pacific	38,70	50,10
TOTAL	1.047,70	1.481,50
RESERVES ANNUAL GROWTH		3,5%

The reality of oil production determined by technology, investment and current reserves, requires the calculation of dynamics reserves, given by the following equation:

$$d_t = d_{t=t_0} \frac{(1 + y_R)^t}{(1 + y_D)^t} \quad [11]$$

Where y_R is the annual rate of increase in reserves and y_D the annual rate of increment in oil demand.

Equations [11] and [12], indicate the time evolution of the oil reserves based on annual rate of increment in oil demand y_D and annual rate of increase in reserves y_R .

In the case of multi-player international oil market (countries), we have various duration spans of oil reserves given by:

$$d_t^i = d_{t=t_0}^i \frac{(1 + y_R)^t}{(1 + y_D)^t} \quad [12]$$

We can see that the growth rates of reserves and demands remain for all the oil market, with $i = 1, \dots, n$.

Definition static duration, $d_{i=0}^i$: the duration span of the oil reserves in each country is stationary and determines the equilibrium, when supply and demand for oil are equal (i.e. when the rate of discovery of new reserves is equal to the rate of increase in demand for oil in the world) this is $y_R = y_D$.

In the last decade, despite high oil prices $y_R > y_D$, we mention as reference OPEC's data in the medium and long term, $y_R = 3,5\%$ and $y_D = 2\%$. *World Oil Outlook 2012*.

Table 2. STATIC LIFETIME OIL RESERVES

COUNTRY	PROVED OIL RESERVES, CIA, 01/2011 BLS	OIL PRODUCCION 12/2010, CIA. BPD	OIL COMSUMPTIO N, CIA 2011 BPD	STATIC LIFETIME RESERVES YEARS
United Kingdom	2.858.000.000,00	1393000,00	1622000,00	5,62
United States	20.680.000.000,00	9688000,00	19150000,00	5,85
Colombia	1.900.000.000,00	800100,00	296000,00	6,51
European Union	5.544.000.000,00	2263000,00	13680000,00	6,71
Norway	5.670.000.000,00	2134000,00	221300,00	7,28
Argentina	2.505.000.000,00	763600,00	618000,00	8,99
Mexico	10.420.000.000,00	2983000,00	2073000,00	9,57
China	14.800.000.000,00	4073000,00	9400000,00	9,96
Indonesia	3.990.000.000,00	1030000,00	1292000,00	10,61
Angola	9.500.000.000,00	1988000,00	74000,00	13,09
Congo, Republic of the	1.600.000.000,00	302200,00	13000,00	14,51
Brazil	12.860.000.000,00	2301000,00	2029000,00	15,31
Russia	60.000.000.000,00	10270000,00	2199000,00	16,01
Algeria	12.200.000.000,00	2078000,00	312000,00	16,09
India	5.682.000.000,00	954000,00	3182000,00	16,32
Australia	3.318.000.000,00	549200,00	960800,00	16,55
Syria	2.500.000.000,00	401000,00	292000,00	17,08
Oman	5.500.000.000,00	867900,00	142000,00	17,36
Egypt	4.400.000.000,00	662600,00	740000,00	18,19
Azerbaijan	7.000.000.000,00	1041000,00	104000,00	18,42
Malaysia	5.800.000.000,00	716000,00	556000,00	22,19
Gabon	2.000.000.000,00	227900,00	18000,00	24,04
Sudan	5.000.000.000,00	514300,00	98000,00	26,64
Yemen	3.000.000.000,00	258800,00	157000,00	31,76
Ecuador	6.510.000.000,00	500000,00	166300,00	35,67
Nigeria	37.200.000.000,00	2458000,00	279000,00	41,46
Qatar	25.380.000.000,00	1437000,00	166000,00	48,39
Kazakhstan	30.000.000.000,00	1608000,00	218000,00	51,11
Saudi Arabia	262.600.000.000,00	10520000,00	2643000,00	68,39
Libya	46.420.000.000,00	1789000,00	289000,00	71,09
Iran	137.000.000.000,00	4252000,00	1845000,00	88,27
United Arab Emirates	97.800.000.000,00	2813000,00	545000,00	95,25
Kuwait	104.000.000.000,00	2450000,00	354000,00	116,30
Iraq	115.000.000.000,00	2642000,00	694000,00	119,25
Canada	175.200.000.000,00	3483000,00	2209000,00	137,81
Venezuela	211.200.000.000,00	2375000,00	746000,00	243,63
TOTAL	1.457.037.000.000,00	84.586.600,00	69.383.400,00	

In Table 2. STATIC LIFETIME OIL RESERVES, we can see the information of the 38 countries whose reserves and daily production is greater than 95% of world total reserves. Color has been used to indicate duration of their respective static reserves such as red for reserves lasting less than 10 years, orange for a duration between 10 and 20 years, yellow for duration reserves between 20 and 50 years, and green for static reserves exceeding 50 years.

2.3 EVIDENCE OF A POSSIBLE OIL CRISIS

Elements that must determine this new global oil crisis would be: reserves depletion of some oil producer countries, increment in demand for oil in oil producing survivors for each time period, strategic, and unstoppable use of hydrogen as a key element in refining and petrochemicals, and international measures still weak in protecting the environment.

If at the beginning of the analysis period a producer of crude ends its reserves; then, there is a quota to be completed by the survivors. If a country with reserves, increase production $Q_{t0} + \Delta Q$, i.e. running their capabilities, then automatically decreases duration of its reserves as follows $d_t < d_{t0}$.

$$d_t = \frac{R_{t0}}{Q_{t0} + \Delta Q} < \frac{R_{t0}}{Q_{t0}} \quad [13]$$

Equation [13] shows that any variation in the rate of oil production, as a result of increased demand has an impact on the duration of the oil reserves.

Similarly, if increase of production due to necessity in crisis oil market at a determined time t we have:

$$d_t = \frac{R_{t0}}{Q_{t0} + \Delta Q} \frac{(1 + y_R)^t}{(1 + y_D)^t} \quad [14]$$

Equation [14] is an explicit form of the duration of the oil reserves in terms of initial data.

Table 3. DYNAMIC LIFETIME OIL RESERVES.

	INCREASING PRODUCTION YES/NO	STATIC LIFETIME RESERVES (t0-t)	DYNAMIC LIFETIME RESERVES (t1-t)	CHAOTIC LIFETIME RESERVES (t2-t)	AVERAGE RESERVES COUNTRY	UNIFORM OIL CRUSH	POSSIBLE OIL PRODUCTION INCREASING	% CONSUMED RESERVES			
COUNTRY	BPD	YEARS	YEARS	YEARS	%	YEAR	BPD	[0, 10]	[0, 20]	[0, 50]	[0, 243]
United Kingdom	NO	5,62	0,00	0,00	0,2%	2019	0	0,20%	0,20%	0,20%	0,20%
United States	NO	5,85	0,00	0,00	1,4%	2019	0	1,42%	1,42%	1,42%	1,42%
Colombia	SI	6,51	7,21	4,09	0,1%	2020	673728	0,13%	0,13%	0,13%	0,13%
European Union	NO	6,71	7,43	0,4%	0,4%	2020	0	0,38%	0,38%	0,38%	0,38%
Norway	SI	7,28	8,06	5,91	0,4%	2020	908249	0,39%	0,39%	0,39%	0,39%
Argentina	NO	8,99	9,95		0,2%	2022	0	0,17%	0,17%	0,17%	0,17%
Mexico	SI	9,57	10,60	6,77	0,7%	2023	1893181	0,72%	0,72%	0,72%	0,72%
China	NO	9,96	11,03		1,0%	2023	0	1,02%	1,02%	1,02%	1,02%
Indonesia	NO	10,61	11,76		0,3%	2024	0	0,27%	0,27%	0,27%	0,27%
Angola	SI	13,09	14,50	6,61	0,7%	2026	2566427	0,50%	0,50%	0,50%	0,50%
Congo, Republic of the	NO	14,51	16,07		0,1%	2028	0	0,08%	0,11%	0,11%	0,11%
Brazil	NO	15,31	16,96		0,9%	2028	0	0,58%	0,88%	0,88%	0,88%
Russia	SI	16,01	17,73	16,90	4,1%	2029	984896	2,57%	4,12%	4,12%	4,12%
Algeria	SI	16,09	17,82	1,73	0,8%	2029	20323433	0,52%	0,84%	0,84%	0,84%
India	NO	16,32	18,07		0,4%	2029	0	0,24%	0,39%	0,39%	0,39%
Australia	NO	16,55	18,33		0,2%	2030	0	0,14%	0,23%	0,23%	0,23%
Syria	NO	17,08	18,92		0,2%	2030	0	0,10%	0,17%	0,17%	0,17%
Oman	NO	17,36	19,23		0,4%	2030	0	0,22%	0,38%	0,38%	0,38%
Egypt	NO	18,19	20,15		0,3%	2031	0	0,17%	0,30%	0,30%	0,30%
Azerbaijan	NO	18,42	20,40		0,5%	2031	0	0,26%	0,48%	0,48%	0,48%
Malaysia	NO	22,19	24,58		0,4%	2035	0	0,18%	0,30%	0,40%	0,40%
Gabon	NO	24,04	26,63		0,1%	2037	0	0,06%	0,11%	0,14%	0,14%
Sudan	NO	26,64	29,50		0,3%	2040	0	0,13%	0,26%	0,34%	0,34%
Yemen	NO	31,76	35,18		0,2%	2045	0	0,06%	0,13%	0,21%	0,21%
Ecuador	NO	35,67	39,51		0,4%	2049	0	0,13%	0,25%	0,45%	0,45%
Nigeria	SI	41,46	45,93	13,20	2,6%	2054	6479417	0,62%	1,23%	2,55%	2,55%
Qatar	NO	48,39	53,59	1,7%	1,7%	2061	0	0,36%	0,72%	1,74%	1,74%
Kazakhstan	NO	53,11	56,61	2,1%	2,1%	2064	0	0,40%	0,81%	2,01%	2,01%
Saudi Arabia	SI	68,39	75,75	14,14	18,0%	2081	48342468	5,27%	13,18%	18,02%	18,02%
Libya	NO	71,09	78,74		3,2%	2084	0	0,45%	0,90%	2,24%	3,19%
Iran	NO	88,27	97,77		9,4%	2101	0	1,07%	2,13%	5,33%	9,40%
United Arab Emirates	NO	95,25	105,50		6,7%	2108	0	0,70%	1,41%	3,52%	6,71%
Kuwait	NO	116,30	128,81		7,1%	2129	0	0,61%	1,23%	3,07%	7,14%
Iraq	NO	119,25	132,08		7,9%	2132	0	0,66%	1,32%	3,31%	7,89%
Canada	NO	137,81	152,64		12,0%	2151	0	0,87%	1,75%	4,36%	12,02%
Venezuela	NO	243,63	269,85		14,5%	2257	0	0,59%	1,19%	2,97%	14,50%
TOTAL		104,0	115,1	3,7	1,0		82.171.800,00	19,6%	32,3%	59,1%	100,0%

In the Table 3. DYNAMIC LIFETIME OIL RESERVES, it is clear to see the change in the value of duration span of reserves in $t = 7, t = 10$. At $t = 7$, using initial information, where just two countries have almost finished their reserves. Assuming constant growth of the reserves increment and of demand, we calculate duration value that span of reserves for all countries, except for the first two non-survivors. At $t = 10$, we evaluate only those countries that can increase their production according to demand. There are countries that have remaining production, but below market needs.

When supply energy structure is analyzed in general, highlights distribution into four major categories: oil, gas, coal, and (nuclear, hydro, biomass, and other renewable). It is possible that giving another structure to these four strategic areas, some universal invariant appears to show a **conservation of some fundamental variable**. In this study, we demonstrate that by applying game theory and grouping in a specific way the different types of energy appears an equilibrium that consolidates team of green energy: nuclear, hydro, biomass, petrochemical and other renewable which are tacitly manned by hydrogen vector.

Table 4. WORLD ENERGY GAME STRUCTURE

WORLD SUPPLY OF PRIMARY ENERGY									
									MBOE/D
YEAR / TYPE	OIL	COAL	GAS	OTHER RENEWABLES	NUCLEAR	HYDRO	BIOMASS		TOTAL
2009	79	66,3	51	1,6	14,1	5,6	8,2		225,8
2010	81	68,8	53,1	1,8	14,3	5,8	8,5		233,3
2020	89,7	84,3	66,5	3,8	16	7,4	12		279,7
2035	97,8	102,9	94,8	12,5	21,6	10,4	19,3		359,3

WORLD ENERGY GAME STRUCTURE									
									MBOE/D
YEARS / UTILITY	R: REFINING	C: COAL	G: GAS	X: PETROCHEMICALS + NUCLEAR+ HYDRO+ BIOMASS+ OTHERS RENEWABLES	GAME STRUCTURE				TOTAL
YEARS									
2009	70,4	66,3	51	38,1	R >	C >	G >	X	225,8
2010	72,2	68,8	53,1	39,2	R >	C >	G >	X	233,3
2020	79,8	84,3	66,5	49,1	C >	R >	G >	X	279,7
2035	85,9	102,9	94,8	75,7	C >	G >	R >	X	359,3

Let $\Gamma = (I, S, v)$ refers to a game of n – players, where I is the set of players, $i = 1, \dots, n$. The finite S_i cardinal set; $I_i \in N$ is the set of each player's pure strategies, where $i \in I$, $s_{ji} \in S_i$, $j = 1, \dots, I_i$ and $S = \prod_{i \in I} S_i$ represent the set of pure strategy profiles; where $s \in S$ represents an element of that set; $I = I_1, I_2, \dots, I_n$ is S cardinality. The vector function $v : S \rightarrow R^n$ is associated with every profile $s \in S$, where the utility vector $v(s) = (v^1(s), \dots, v^n(s))^T$, and $v^i(s)$ refers to the players' utility i , depending on the profile s . To make the calculus easier to understand, the function $v^i(s)$ is written explicitly as $v^i(s) = v^i(j_1, j_2, \dots, j_n)$. The matrix $v_{n,l}$ represents all points of the Cartesian product $\prod_{i \in I} S_i$. The vector $v^i(s)$ is the i – column of v .

If mixed strategies can be performed, the following results:

$$\Delta(S_i) = \left\{ p^i \in R^{I_i} : \sum_{j_i=1}^{I_i} p_{j_i}^i = 1 \right\}$$

[15]

Equation [15] indicates that the sum of probabilities of each of the strategies chosen by each of the players in the oil market and hydrogen, must be equal to unit 1.

Mixed-player strategy unit simplex $i \in I$, and $p^i = (p_{j_k}^i)$ result in the probability vector. The mixed-strategy profile is the polyhedron Δ with $\Delta = \prod_{i \in I} \Delta(S_i)$, where $p = (p_{j_1}^1, p_{j_2}^2, \dots, p_{j_n}^n)$, $p \in \Delta$, $p^i \in \Delta$ and $p^i = (p_{j_1}^i, p_{j_2}^i, \dots, p_{j_{I_i}}^i)^T$. The following formula can be written, using the Kronecker product ($\otimes$)¹:

¹We use bolt in order to represent vector or matrix.

$$\mathbf{p} = \mathbf{p}^1 \otimes \mathbf{p}^2 \otimes \dots \otimes \mathbf{p}^{i-1} \otimes \mathbf{p}^i \otimes \mathbf{p}^{i+1} \otimes \dots \otimes \mathbf{p}^n$$

$$\mathbf{p}^{(-i)} = \mathbf{p}^1 \otimes \mathbf{p}^2 \otimes \dots \otimes \mathbf{p}^{i-1} \otimes \mathbf{1}^i \otimes \mathbf{p}^{i+1} \otimes \dots \otimes \mathbf{p}^n$$
[16]

Where.

$$\mathbf{1}^i = (1, 1, \dots, 1)^T, [\mathbf{1}^i]_{i,1}$$

$$\mathbf{o}^i = (0, 0, \dots, 0)^T, [\mathbf{o}^i]_{i,1}$$

In equation [16], we can write a law of probability using matrix notation of Quantum Game Theory.

The n -dimensional function $\bar{\mathbf{u}} : \Delta \rightarrow \mathbb{R}^n$ is associated with every mixed-strategy profile and expected utilities vector.

$$\bar{\mathbf{u}}(\mathbf{p}) = (\bar{u}^1(\mathbf{p}, \mathbf{v}(s)), \dots, \bar{u}^n(\mathbf{p}, \mathbf{v}(s)))^T$$
[17]

Equation [17], represents the utility function of a strategic game, with dependent variables: probability $\mathbf{p}$ of the profits of each player u^i .

where $\bar{u}^i(\mathbf{p}, \mathbf{v}(s))$ represents the player's expected utility i . Every $\bar{u}_{ji}^i = \bar{u}_{ji}^i(\mathbf{p}^{(-i)}, \mathbf{v}(s))$ refers to each player's expected utility strategy and vector $\mathbf{u}^i$ is written as $\mathbf{u}^i = (\bar{u}_1^i, \bar{u}_2^i, \dots, \bar{u}_n^i)^T$.

$$\bar{u}_i = \sum_{j=1}^{I_i} \bar{u}_{ji}^i(\mathbf{p}^{(-i)}, \mathbf{v}(s)) p_{ji}^i$$

$$\bar{\mathbf{u}} = \mathbf{v}^T \mathbf{p}$$

$$\mathbf{u}^i = (\mathbf{1}^i \otimes \mathbf{v}^i) \mathbf{p}^{(-i)}$$
[18]

Equation [18], represents the utility function of a strategic game, using the Kronecker matrix product, widely known.

The three elements $(\mathcal{I}, \Delta, \mathbf{u}(\mathbf{p}))$ refer to the game Γ of mixed strategies. Nash's equilibrium results (the utility maximization), if and only if, for all $i, \mathbf{p}$, the inequality $\bar{u}^i(\mathbf{p}^*) \geq \bar{u}^i((\mathbf{p}^i)^*, \mathbf{p}^{(-i)})$ holds. Another way to calculate the Nash's equilibrium, *Rasmusen, E. (1989), Myerson, R. (1991, pg 96-104)*, is equal to the values of the expected utilities of each strategy when it is possible.

$\bar{u}_1^k(\mathbf{p}^{(-k)}, \mathbf{v}(s)) = \bar{u}_2^k(\mathbf{p}^{(-k)}, \mathbf{v}(s)) = \dots = \bar{u}_{j_k}^k(\mathbf{p}^{(-k)}, \mathbf{v}(s))$
$\sum_{j_k=1}^{I_k} p_{j_k}^k = 1 \quad \forall k = 1, \dots, n$
$\sigma_k^2 = \sum_{j_k=1}^{I_k} \left(\bar{u}_{j_k}^k(\mathbf{p}^{(-k)}, \mathbf{v}(s)) - \bar{u}^k \right)^2 p_{j_k}^k = 0$

[19]

Equation [19] indicates the value of the standard deviation of utility, in a game of n players.

If the resulting system of equations doesn't have solution $(\mathbf{p}^{(-k)})^*$ then we propose the *Minimum Entropy Theorem*. This method is expressed as $\text{Min}_{\mathbf{p}}(\sum_k H_k(\mathbf{p}))$, where $\sigma_k^2(\mathbf{p}^*)$ standard deviation and $H_k(\mathbf{p}^*)$ entropy of each player k .

$$\sigma_k^2(\mathbf{p}^*) \leq \sigma_k^2((\mathbf{p}^k)^*, \mathbf{p}^{(-k)}) \text{ or }$$

$$H_k(\mathbf{p}^*) \leq H_k((\mathbf{p}^k)^*, \mathbf{p}^{(-k)})$$
[20]

Theorem (Minimum Entropy Theorem) and the game entropy is minimum only in mixed strategy Nash's

equilibrium. See proof in Jiménez, E (2003c).

Equation [20] shows the linkage of Nash Equilibrium, or Maximum Profit with Minimal Entropy equivalent duly demonstrated in the paper by this author.

2.4 WAR OF ATTRITION

In the biological literature, this game is referred to Hawk-Dove. In Hawk-Dove game is typically taught and discussed with the payoffs in terms of benefits and costs, the solutions hold true for any matrix with the payoffs in next game, where R: refinery, C: coal, G: gas and X: nuclear, hydro, biomass, other renewable and petrochemical, in order to get Nash equilibrium it is necessary that $R > C > G > X$.

	Hawk	Dove
Hawk	X,X	R,G
Dove	G,R	C,C

The utility function in hawk-dove game is easily calculated, despite it, we will write utilities of player 1 (hydrogen) and player 2 (oil) as an example.

$$\begin{aligned}u_1 &= pqX + p(1-q)R + (1-p)qG + (1-p)(1-q)C \\u_2 &= pqX + p(1-q)G + (1-p)qR + (1-p)(1-q)C\end{aligned}$$

[21]

Equation [21], is a concrete application of game theory to global oil production. That is, one of the key parts of this paper.

Definition The potential of hydrogen in the global energy equilibrium for each of the players and in equilibrium $(X;X)$ is given by u_1, u_2 . The minimum content of hydrogen is given by pqX .

EVIDENCE OF A POSSIBLE OIL CRISIS
WAR OF ATTRITION
SIMULATION

2.5 SIMULATION

2.5.1 PRODUCTION STRATEGY

- Establishment of production levels and prices of hydrogen as a function of traditional energy in 2020 and 2035 that are the reference times of world energy.
- Understanding the Nash equilibrium and their application to evolution of hydrogen demand in the global reference years

The solution game for table WORLD SUPPLY OF PRIMARY ENERGY -OPEC 2012 gives us an equilibrium utility function for each year of interest: 2009, 2010, 2020, 2035, for each player, based on the four strategic energy sectors: R, C, G, X. As an example and for year 2020, we will calculate utility function for player 1 with equilibrium probability values ($p = 0.81; q = 0.67$).

$$u_1 = 0.5427X + 0.2673R + 0.1273G + 0.0627C$$

Respective values in 2020 are: $X = 49.1, R = 79.8, G = 66.5, C = 84.3$.

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MBOE/D									
SECTOR/ YEARS	R: REFINING	C: COAL	G: GAS	X: PETROCHEMICALS + NUCLEAR+ HYDRO+ BIOMASS+ OTHERS RENEWABLES	TOTAL	WORLD H2 PRODUCTION	SIMULATION: MINIMUM H2 PRODUCTION	SIMULATION: MAXIMUM H2 PRODUCTION	NASH
YEARS									p q
2009	70,4	66,3	51	38,1	225,8	3,20	22,50	49,86	0,83 0,71
2010	72,2	68,8	53,1	39,2	233,3	3,22	22,61	51,71	0,82 0,70
2020	79,8	84,3	66,5	49,1	279,7	3,80	26,69	62,85	0,81 0,67
2035	85,9	102,9	94,8	75,7	359,3	7,06	49,66	80,66	0,90 0,73

3 CONCLUSIONS.

- We introduce q^* Tobin's modified in order to implement best practices to oil and energy projects, in which we need to maximize profitability and to minimize risk. See the next equation:

$$q^* = \frac{V_0 \sum_{i=1}^7 \Delta x_i \frac{dV}{dx_i}}{I} > 1.15.$$

- We understand as energy efficiency e , a value that minimizes costs of crude oil production or crude oil refining and, simultaneously, maximize firm utility.
- We verified Nash equilibrium of global energy game where entropy value of each player decreases from a baseline in 2009 to their lowest level in 2035. Player 1 (high presence of hydrogen and alternative energy) has an entropy value of $0,321 < 0,462$, Player 2 (lower presence of hydrogen and higher oil presence) has an entropy value of $0,586 < 0,598$.
- Game Theory permits to calculate hydrogen potential volume in global energy equilibrium (quantity of hydrogen atoms) and for each one of the players, **Table 6**. Equilibrium $(X; X)$ is better understood by using u_1, u_2 . Moreover, minimum content of hydrogen is given by pqX , and maximum content of hydrogen is given by $pqX + p(1-q)R + (1-p)qG + (1-p)(1-q)C$.
- Dynamics of renewable energy demonstrates that hydrogen and oil are linked, so that at level of energy vector in the oil industry, they are mutually interdependent. In other sectors, industrial experience shows that it could be generated electricity by burning oil or using surplus of renewable energy such as solar, wind, geothermal. In the same way we can store electricity through production of hydrogen fuel cells because fuel cell can operates conversely to generate hydrogen if we apply in electrical source. Thus, we see that there is causality between one and other. Hydrogen as an energy source and as an energy carrier cannot develop itself to the levels of energy required daily. Hydrogen as strategic complement has intrinsic advantages: it can support global need for clean energy used to reduce rate of global warming and air pollution due to CO2 emission, and it can be used as raw material and / or as a catalyst for treatment processes and oil refining, coal and gas that represent 89.8% of the total energy consumed on our planet (in barrels of oil equivalent), with reference 2010 and 82.26% in reference 2035.
- Assessment of oil and hydrogen answers a financial strategy and policy based on traditional and modern approaches. Modern approaches prioritize commodity assessment in continuous time and including decisions in optimum time. Traditional assessments do statically, just standing at the present and estimated future as if it were a repeated picture of a window in the time. The dynamic proposal presents guidelines grounded in stochastic calculus and flexibility in decision making from new projects or energy trends, facilitating management action of economic policy, businessmen and research center. It should be determined technology strategy forward facing new joint ventures in alternative energy or oil.
- Business economic decisions are made in environments of risk and uncertainty; nothing is determined by 100% certain, there is always a margin of randomness in the estimation of oil and hydrogen prices, volumes of oil and hydrogen produced, and reserves duration. In this sense, we proved that good practices in investment decisions are based on real oil options, alternative energy in special hydrogen.
- Real options show that there is one possibility of arbitration in projects with flexible decision in time. If we introduce real options of conventional or alternative energy; then, results and power of

this method are superior to classical ones. It was demonstrated in section SIMULATION.

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