Wet Combustion and Water Vapor Pump-cycle Efficiency

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By

Rémi Guillet

Cambridge Scholars Publishing

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THE AUTHOR

Rémi Guillet was born on an island (Noirmoutier) and from his youth he has been aware of the beauty of nature. But he also had an early admiration for fuel power, convinced of the necessity to save this natural resource! Knowing the pollution caused by diesel engine fumes on fishing boats, he has been simultaneously concerned by environmental protection...

(In the photo, Rémi is attending a meeting on the fuel energy strategy held in Paris in 2001)

Rémi Guillet was born in 1943. He is an Engineer (Ecole Centrale de Nantes) and a Doctor in Mechanics (University of Lorraine). He was in charge of innovations in the field of combustion efficiency for more than 35 years in the Gaz de France Company.

Besides this, he also graduated in economics (DEA at Paris 13 University).

Since 2003, he has been retired from Gaz de France, but he continues to write articles on combustion efficiency and for more equity in the company.

His more remarkable results:

- in the field of **thermodynamics**, the so-called “Water Vapor Pump" cycle (in French: “Cycle PAVE”). In 2002, he presented a thesis on “La combustion par voie humide et ses performances” and received in the same year a Mongolfier Prize for Chemical Arts for his work in the combustion field.

In 2018, "Techniques de l’Ingénieur” published his article “Combustion par voie humide et cycle de la pompe à vapeur d’eau”.

- in the field of economics, a model of “fair" remuneration, based on the negotiation of “insiders/outsiders” in the company, was presented in a book entitled “Pour plus de solidarité entre le capital et le travail ou de nouvelles chances pour l’emploi" by l’Harmattan edition (2004).

*

A short story about combustion and water…

Of course we cannot omit here that water in large quantity allows the extinction by asphyxia of flames and fires ...

Beside this…

In the past, water has been used as an anti-knock agent or as an “additive” component to improve combustion efficiency, to boost engine power. Today, in a context of severe environmental requirements, of energy saving responsibility, the good use of water continues to offer many possibilities to serve both environmental and energy savings targets. And many works were dedicated to improving combustion quality in reciprocating engines by using water as an additive.

Early in the Seventies, in France and in the new context of natural gas uses in district heating plants, the humidity of fumes and the correlative high risks of condensation at the chimney output, were considered by architects as a disadvantage for the new forms of energy. At the same time, and to reverse the disadvantage into an advantage, the engineers’ target was marked by a greater interest in condensing in the development of boilers, by recovering the latent heat in the boilers and retaining the water in the liquid phase at the boiler level. It was the first challenge for Rémi Guillet, a young researcher working as a pioneer on the topic at the Gaz de France company.

Of course, the interest in condensing boilers was reinforced after the first oil crisis (1973). It is in this frame that engineering researchers launched new studies to find a way to enlarge the area of interest in condensing boilers towards a higher “condensing temperature” …

Thus, to reply to the challenge, the water vapor pump-cycle was invented in 1979 by Rémi Guillet who has always been rightly concerned by innovations to reduce the impact of combustion on our environment and energy savings.

In 2002, Rémi Guillet introduced the Humid Combustion concept…

ACKNOWLEDGEMENTS

This book is an English version of the most original parts of my thesis presented at the Nancy 1 University on October 15, 2002 [*] .

It also gives me a new opportunity to thank students in France, Germany, Italy, other European countries, and North America, and all who had an early belief in the concept and assisted me in the development of the water vapor pump-cycle without forgetting industrial partners, mainly the Seccacier company with Jean Verrier and Gerard Brunel who have worked on this innovation since the early 1980s.

I would also like to thank again my main scholarly sustainers, Professors Claude Thenard and Lionel Estel from Rouen University and Michel Feidt from Nancy 1 University. But also Jean-Pierre Hébert for his implication in the “CHD” software development, Gilles Cabot and Sébastien Caillat for their works on the wet combustion of methane, Marie-Sophie Cabot for her very fruitful literature research, Françoise Jonon for her contribution to feeding the contents of the introduction and Jacques Lombart who is always ready to promote this new technology.

REMERCIEMENTS

Ce livre est une version anglaise des parties les plus originales de ma thèse présentée à l'université de Nancy, le 15 octobre 2002.

Cela me donne également une nouvelle opportunité de remercier des étudiants en France mais aussi en Allemagne, en Italie et dans d'autres pays européens, en Amérique du Nord qui ont travaillé sur le concept les partenaires industriels principalement la société Seccacier avec Jean Verrier et Gérard Brunel qui ont développé cette innovation depuis le début des années 80.

Je voudrais aussi remercier mes supporters universitaires, professeurs et chercheurs comme Claude Thérard et Lionel Estel de l'Université de Rouen, Michel Feidt de l'Université Nancy 1. Mais aussi Jean-Pierre Hébert pour son implication dans le développement du logiciel "CHD", Gilles Cabot et Sébastien Caillat pour leurs travaux sur la combustion humide du méthane, Marie-Sophie Cabot pour sa recherche documentaire fructueuse, Françoise Jonon pour sa contribution à l'introduction de ce livre et Jacques Lombart toujours disponible pour soutenir et promouvoir le projet.

ABSTRACT

For millennia, and especially since the discovery of fire and its ability to improve our well-being, humanity has based part of its development on its ability to improve fire control and to extend its applications. And it is precisely with the discovery of systems capable of directly transforming fire into work that a socio-economic revolution has taken place, a revolution accelerated by discoveries relating to the possibilities offered by the use of fossil energies (coal, oil, natural gas, etc.)
In the context created after the 1973 oil crisis and more recently by environmental issues, the author, with his double training in the physical sciences on the one hand and in economics on the other, proposes a long introduction presenting the global "fossil energy challenge" before developing a very technical text on the topic he has called since the early 2000s, the "wet way combustion" (or humid combustion) and presenting a large development concerning his own invention called the "water vapor pump-cycle".

In the technical part of the text, the author reminds us that water has been used for a long time as a useful additive component to improve combustion quality, as a booster for power engines, as an anti-knock agent and, more recently, in the case of clean fuel (methane, bio-fuels, hydrogen…) as a nitrogen oxides inhibitor. Today we are stressed by a double challenge, always energy savings but, before all, environmental protection. The addition of water at the combustion level may be an outstanding way towards the double goal.

Using a *wet combustion technique*, gas turbine efficiency can be increased substantially. As examples, the steam in the gas turbine-cycle (STIG) and the humidified air turbine-cycle (HAT), are good illustrations of the turbine cycle possibilities by using water as an additive component besides air and fuel, to compete with the combined cycles.

Furthermore, the water vapor pump-cycle, which preheats and humidifies the combustion air by recycling all the sensible and latent heat still contained in the flue gases leaving the process, offers outstanding global energy efficiency, focusing on the fuel's gross calorific value recovery.

Elsewhere, the direct injection of additive water in combustion chambers and the use of a water/fuel mixture are well-known ways to reduce NO_x formation in engines because of the stoichiometric combustion temperature and the oxygen concentration in the combustion mixture decreasing.

In the case of cogeneration processes we can often benefit from all the advantages offered by wet combustion techniques, to focus on a very high global efficiency process with the benefit of very clean combustion.

More particularly, wet combustion techniques underline the advantages of high-efficiency processes from the energy and ecology points of view, as for example:

- boilers;
- direct contact heaters;
- direct contact dryers with latent heat recovery;
- regenerative turbines in a cogeneration context;
- clean incineration plant with energy recovery, etc.

In wet combustion, three fluids are supplied to the process: the fuel, the oxidizing agent and the additive water.

To analyse the wet combustion processes, the *Combustion Hygrometric Diagram* method, using the wet bulb temperature as a major parameter, has been developed, and is presented in detail with many useful diagrams. The CHD method can be recommended for:

- studies of processes, such as efficiency analysis, efficiency prediction, improvement, and optimization;
- predictive monitoring;
- plume anticipation; and
- two-phase exchanger sizing.

But the CHD method also offers metrological advantages to acquire more accurate and cheaper knowledge of the efficiency of combustion processes, such as condensing boiler efficiency.
Much information on the influence of water on the behavior of combustion processes is also given in this thesis.

Keywords: *combustion, humidity, hygrometry, environment, efficiency, energy, thermal processes, nitrogen oxides, protection*

RESUME

Depuis des millénaires, et surtout depuis la découverte du feu et sa capacité à produire de l'énergie qui améliore notre bien-être, l'humanité a basé en partie son développement sur sa capacité à améliorer le contrôle du feu. Et élargir ses applications. Et c'est précisément avec la découverte de systèmes capables de transformer directement le feu en force de travail qu'une révolution socio-économique a eu lieu, une révolution accélérée par des découvertes sur les possibilités offertes par l'utilisation de sources d'énergies fossiles (charbon, pétrole, gaz naturel, etc.).

Dans le contexte issu de la crise pétrolière de 1973 et plus récemment par les questions environnementales, avec sa double formation en sciences physiques d'une part, en sciences économiques d'autre part, l'auteur propose une longue introduction pour présenter le défi global associé à l'utilisation des énergies fossiles avant de développer un texte très technique sur ce qu'il a appelé depuis le début des années 2000 la combustion humique, puis présenter sa propre invention appelée le "cycle pompe à vapeur d'eau".

Concernant l'aspect technique de ce texte, l'auteur rappelle que l'eau a déjà été utilisée comme additif pour améliorer la combustion, la puissance des machines, voire comme antidétonant puis, plus récemment, avec les hydrocarbures réputés propres (gaz naturel, bio-fuels, hydrogène…) comme inerte permettant la réduction de la formation des oxydes d'azote. Aujourd'hui le défi à relever est plus contraignant que jamais. Il concerne l'économie de la ressource mais, prioritairement, la protection de l'environnement. L'addition d'eau au niveau de la combustion est une bonne voie pour répondre au défi d'aujourd'hui.

Avec la combustion humide, les performances des turbines à gaz terrestres peuvent être améliorées de façon très significative. Ainsi, les cycles à injection de vapeur (STIG), les cycles régénératifs à air humidifié (HAT), peuvent approcher les performances des cycles combinés.

De son côté, le cycle de pompe à vapeur d'eau qui recycle les chaleurs ultimes, sensible et latente, habituellement rejetées à la cheminée, sous forme d'air de combustion préchauffé et humidifié, permet à de nombreux procédés d'approcher le rendement maximal de combustion de 100% du pouvoir calorifique supérieur du combustible.

Sous toutes ses formes, l'introduction d'eau dans les chambres de combustion est également connue pour réduire la formation des NO_x: injection directe, en émulsion avec le combustible, sous forme vapeur générée par un récupérateur, une pompe à vapeur d'eau…
Alors, des performances énergétiques et écologiques remarquables sont possibles, particulièrement pour les procédés qui valorisent la récupération de chaleur latente. Parmi les procédés les plus susceptibles de bénéficier des avantages de la combustion humide, on cite:

- les chaudières
- les générateurs à contact direct
- les séchoirs *en direct* avec récupération d'énergie
- les turbines régénératives en cogénération
- les procédés d'incinération propres avec récupération d'énergie

Etc.

En combustion humide, trois fluides sont introduits dans la chambre de combustion : le combustible, l'air de combustion et l'eau additionnelle…

Pour analyser ces procédés, nous avons développé une méthode d'analyse utilisant la température humide comme paramètre principal, dite *Diagramme Hygrométrique de Combustion.* Cette méthode, présentée en détail ainsi que de nombreux diagrammes qui en sont issus, est à recommander pour :

- l'analyse, la prévision, l'amélioration, l'optimisation des rendements de combustion
- la commande prédictive
- la prévision de la condensation
- le dimensionnement des échangeurs biphasiques.

Mais la méthode peut également être utilisée dans le cas de procédés traditionnels comme les chaudières et générateurs à condensation pour offrir des perspectives d'accès au rendement avec plus de précision et au moindre coût.

D’autres informations sur les modifications dues à la présence d’eau additionnelle dans les procédés thermiques avec combustion sont également fournies.

INTRODUCTION

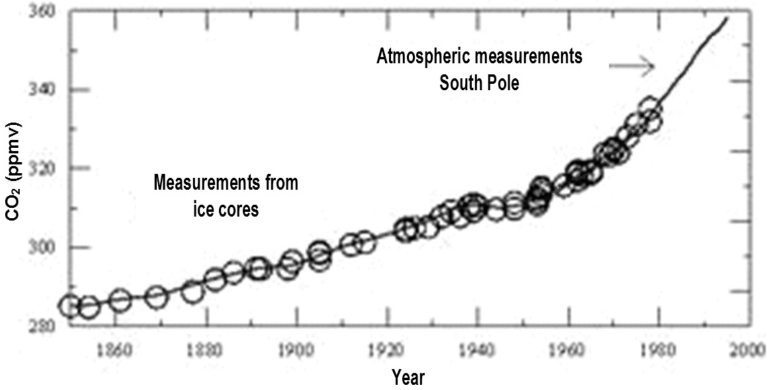
OR THE FOSSIL ENERGY CHALLENGE

Correlation between fossil energy consumption and economic development

For millennia, in addition to the strength of the wind and gravitational force, and especially since the discovery of fire and its contribution to improve the human condition, humanity has based a great part of its development on more efficient fire uses. And it is precisely with the discovery of systems capable of directly transforming fire into a work force that a socio-economic revolution has taken place.

This revolution has been accelerated by discoveries relating to the possibilities offered by the use of stored fossil energy such as coal, oil, natural gas, etc., ignoring the long-term future of the combustion impact on the atmosphere.

Using the CO_2 concentration in the atmosphere as a witness of human activities, we observe a long period of low and stable emissions and an outstanding take off when the industrial era appears. Stable at 280 ppmv, the CO_2 concentration value takes off at the beginning of the industrial era (about 1850; see Figure 0.1 for the strong correlation between energy consumption and GDP at world level).



Curve of evolution of CO_2 since 1850 from analysis of Antarctic ice cores

Adapted from Etheridge et al., 1996, J.G.R.
Source: document transmitted by Jean Marc Barnola,
Laboratoire CNRS de Glaciologie, Université Joseph Fourier, Grenoble

Fig. 0.1

The following curves (Fig. 0.2) underline the correlation between energy consumption and economic growth since 1970…

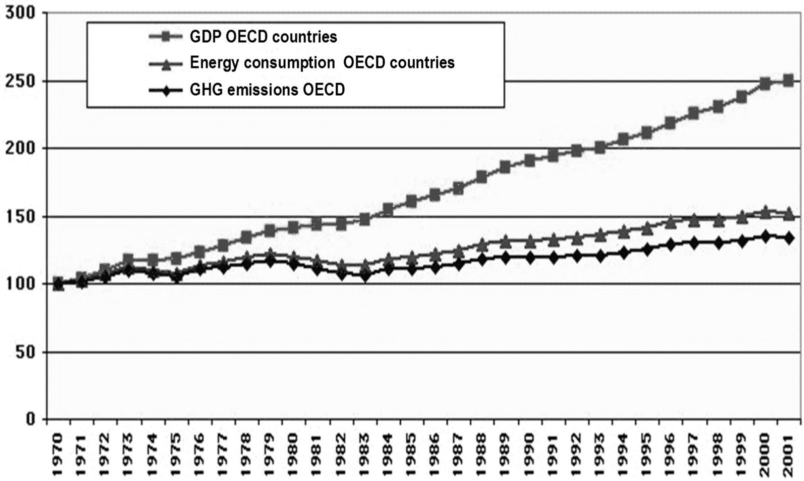


Fig. 0.2

And since the first oil shock (1973), which was to sow doubt about the "actual availability" of oil resources, and later with the massive awareness of environmental problems caused by its use that the Kyoto agreement underlined in 1997, noticeable efforts have been made by engineers and scientists to improve the efficiency of fossil fuels, especially oil when it came to fuel, in order to go in the direction of the economy of the primary resource and of the corresponding reduction of atmospheric emissions.

Unfortunately, during the same time there has been an ever-greater enthusiasm for the public exhibition of the futility of "heavy" symbols of a certain level of wealth and other social success: the advent of 4x4s and other large sedans “just for fun”, the development of low-cost airlines, air-conditioning and heating equipment for living spaces that became more spacious, etc. Besides, there was demand for these technologies in the emerging countries on the one hand and more generally the world population was growing exponentially on the other hand. In short, the efforts of some have been thwarted by the behavior of others...

Now, and firstly because of the planet’s climate drift, we are living with a real and strong dilemma which shakes the western growth paradigm that has been practically followed everywhere in the world since the fall of the Berlin wall in 1989.

The stability of fossil fuels’ place in the world

The place of fossil fuels in the world between 1980 and 2005 was maintained at a very high level (96%, wood not considered, about 10% of total; see Table 01).

Data in %	1980	1985	1990	1995	2000	2005
Coal	34	37	36	34	32	34
Oil	42	37	37	38	38	37
Natural gas	20	22	23	24	25	25
Total “fossil energies”	**96**	**96**	**96**	**96**	**95**	**96**
Nuclear	0.8	1.5	1.8	2	2.3	1.94
Hydro	2	2.1	2.1	2.3	2.1	2.15
Other renewables	0.04	0.06	0.13	0.17	0.21	0.26

Table 0.1

Combustion, pollution and health

The main emissions in atmospheric air coming from the combustion of fossil fuels or even biomass or organic wastes are sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), and greenhouse gases such as carbon dioxide (CO_2). Depending on the type and quality of fuel used, mainly for fuels derived from waste and solid fuels, other substances, including heavy metals (mercury, arsenic, cadmium, vanadium, nickel, etc.), halide compounds (including hydrogen fluoride), unburned hydrocarbons and other volatile organic compounds (VOCs) may be emitted in smaller quantities, but they may have a significant impact on the environment due to their toxicity and/or persistence. Sulfur dioxide and nitrogen oxide also contribute to acidic deposition that covers long distances and can cross national boundaries. The magnitude and nature of air emissions are dependent on factors such as fuel (e.g., coal, fuel oil, natural gas, or biomass fuel), the type and design of the combustion unit (e.g., alternative engines, gas turbines or boilers), the modes of operation, the measurements taken to control emissions (e.g., primary control of combustion, secondary treatment of flue gases), and the overall efficiency of the system.

Sulfur dioxide (SO_2)

Sulfur is very often a natural component of coal and crude oil, even natural gases at their "natural state". Sulfur has the property of combining with oxygen during the combustion process. Thus, it generates sulfur dioxide (SO_2), a harmful gas, and partly in the presence of water, at the base of "smog" and acid rain. More than 85% of it comes from the use of fossil fuel.

For human health, it causes inflammation of the bronchi that causes coughing and shortness of breath and is considered to be involved in many respiratory and cardiac diseases.

Eventually, atmospheric emissions of SO_2 must be eliminated and many processes (including flue gas cleaning) exist. But the removal of sulfur from the fuel before combustion has to be reinforced by increasingly strict legislation on fuel cleaning.

- The case of motor fuels

Engines are particularly sensitive to sulfur. Intensive testing in the United States has shown that a decrease in sulfur content from 100 to 30 ppm reduces harmful emissions by 15 to 30% (2).

- The case of maritime transport

It provides that according to a law of 17 August 2015: The thresholds are set at 0.1% by mass in the sulfur emission control zones and 1.5% outside these zones until 31 December 2019 for passenger ships and 3.5% for other vessels, then 0.5% thereafter for all vessels. Ships at shore for more than two consecutive hours shall use marine fuels with a sulfur content of 0.10% or less by mass.

- The case of thermal power plants

Optimizing energy efficiency in the context of the generational process depends on many factors, including the nature and quality of the fuel, and the thermodynamic cycle. As elsewhere, natural gas is preferable to hydrocarbons and coal. Local legislation can be useful to help a bad situation.

Nitrogen oxides (NO_x)

The nitrogen oxides have essentially the form of nitric oxide (NO) and nitrogen dioxide (NO_2), more rarely protoxide (N_2O). For the former, they are the result of the combination of nitrogen and oxygen in the air at high temperature (1800 K). 95% of nitrogen oxides are due to the use of fossil fuels, especially in thermal engines and it is estimated that 59% are due to road traffic.

Pollution by nitrogen oxides takes various forms:

- NO_x are responsible for low-level ozone formation, particularly in smog. They also have a great responsibility in the formation of acid rain, here due to nitric acid which would represent 30% of the acidity at the origin of the decline of certain forests.

- In the upper atmosphere, nitrogen oxides are half responsible for the destruction of the ozone layer. The NO and NO_2 produced on the ground have a life span that is insufficient to reach altitude, the NO_x complained about here come from aircraft engines or the N_2O produced on the ground, this form of nitrous oxide having a sufficient life to reach the upper atmosphere.

It is an irritating gas for the bronchi, particularly harmful for people with asthma and for children in whom it can promote lung infections. NO becomes dangerous when the content exceeds 25 ppm. NO_2 becomes dangerous above 5 ppm.

Carbon monoxide (CO)

This gas is the result of incomplete combustion. It appears mainly in the exhaust of alternative engines so, is largely due to road traffic (59% of emissions in France) and then in the combustion gases of heating boilers (if the unit emission is low, it must be remembered that one-third of the global energy consumption of a country like France is for space heating to reach 21% of CO emissions). In the atmosphere, it participates in the formation of tropospheric ozone.

We underline the CO responsibility in a large number of asphyxias. It binds to red blood cells to cause, in high doses, fatal respiratory disorders. At low doses, it causes headaches, dizziness, nausea and heart problems.

The particles

The particles are the witness of bad combustion, of a bad efficiency of the machine, that one often observes visually in diesel cars when the motor regime changes. The finer they are, the more they stay suspended in the air and the longer they stay in the lungs. At less than 3 microns, they reach the pulmonary alveoli and can enter the blood. They also have an indirect effect as they support the transport of other elements such as heavy metals and hydrocarbons. Their interaction with pollens to increase sensitivity to allergens is also shown.

Volatile organic compounds (VOCs)

These are mainly hydrocarbons from the use of paint, varnish, and glue or evaporation from hydrocarbon storage. With NO and CO, VOCs contribute to the formation of the tropospheric ozone.

In monocyclic aromatic form they are found in fuels, thus in the exhaust gas and the evaporation of storage. Polycyclic aromatics, we find in a form associated with particles. They come from the incomplete combustion of coal and fuel oil, especially in diesel engines.

Ozone

It is a major secondary pollutant that forms on the ground by the action of ultraviolet rays of the sun on primary pollutants such as NO_x, VOCs and CO.

On the ground, ozone is a very irritating gas that reduces respiratory function. It creates irritation of the eyes, throat and bronchi and aggravates asthmatic diseases.

Heavy metals

They include all metals that pose a threat to public health and the environment. They come from the combustion of coal, oil, and garbage and more generally from industrial processes. We can mention lead, mercury, cadmium, nickel, and zinc. They come from coal, oil used in industrial processes and waste incineration.

Hydrochloric acid

This pollutant participates in the formation of acid rains. It comes mainly from the incineration of PVC.

Global pollution or the peril of planet temperature elevation

After being denied by most political leaders, or even the majority of scientists, global warming with its devastating consequences, is now undisputed. Known as the greenhouse effect, the phenomenon is mainly attributed to CO_2, CH_4, N_2O and water vapor emission in the atmosphere.

The production of carbon dioxide (and water) is inevitably linked to the combustion of hydrocarbons. CO_2 is the main cause of the increase in the greenhouse effect.

The United Nations Convention on Climate Change, signed in 1992, and the Kyoto Conference in December 1997, marked the first steps towards an international commitment to limit the discharge of these gases.
The French Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique (CITEPA) published the following table in 1993 (Table 0.2):

	CO_2	SO_2	NO_x	Particles
Solid fuels	4100	30	11	4,2
Heavy fuel oils	3500	10 à 80	7,5	1,6
Light fuel oils	3400	5	4	0,2
Natural gases	2600	0	3	0

Table 0.2: Average pollutant emission factors according to fuels used in boilers and out of the centralized production of electricity and excluding (post) reduction devices, expressed in kg/tep

Now, we know the peril to the multiple faces as collateral to global warming and whose control escapes us. Our development model is now challenged ... But, in spite of this we do not see the emergence of effective alternatives!

In the context of growing energy demand, what about other energy sources…?

Nuclear power

One seldom speaks of uranium reserves: 100 years or 1000 years? According to the French Society of Nuclear Energy "used in current reactors, the uranium resource can be compared with the oil reserve". However, thanks to fast neutron reactors, it could meet our needs across several millennia. Here are no GHGs, but we cannot ignore the potential dangers associated with nuclear power – one thinks of the accidents and the issue of waste management in the long term.

Methane hydrates

Methane hydrates (6-7 water molecules that, under certain conditions of temperature and pressure, can trap a molecule of methane) are less well-known. However, even around 2000 it was being said at the *California Scripps Institute of Oceanography* (La Jolla) that there were 3000 years of reserves of methane hydrates in deep sub-marine resources. From our point of view, if it should occur, this form of energy should be exploited (converted to electricity) *in situ*.

Renewables

Today, the order of 4% of total renewable energy sources will ensure the future coverage of virtually all our energy needs! But apart from residential hot water and space heating (through solar panels, heat pumps, and geothermal), these renewable energies will be primarily for electricity generation. Electricity is often very costly! (See Table 0.5.)

Hydropower

The best sites for traditional hydropower are now in use (at least in the West). Among the major new unknowns to consider now, we will discuss the uncertainty of climatic changes and their impact on hydrology and the ability to obtain acceptance (by democratic means) for the destruction of natural sites. For example, in France, all that remains is micro hydropower or turbines over water. But again, there are voices warning about the consequences on the surrounding environment.

Photovoltaics

This technique of producing electricity is 12-36 times more expensive than conventional hydraulic or nuclear power. It requires a large footprint and may be in conflict with farming. As often happens with renewable energy, electricity production is discontinuous, even random, and the application of photovoltaics poses the problem of storing the energy produced. Now, high expectations are based on the technology of lithium batteries and through this, photovoltaic and electric cars have linked destinies, but with the risk that their development is hampered by the relative rarity of lithium.

Wind and tide

In this case, the production of electricity is 2.5 to 3.7 times more expensive than hydropower or nuclear power. Furthermore, we begin to understand that the noise pollution of onshore wind turbines, has an impact on sea species living around the offshore wind turbines. In the case of submerged tide or stream technology, it is likely that local marine ecosystems are disrupted. So, the two technologies are already highly controversial.

Biomass

Even if wood is not the only "biomass" resource, trees and forests are the first representation, with a double challenge. Indeed, as a source of energy (and materials), trees are the "terrestrial carbon dioxide sinks", the most important after the oceans. It is important to remember that a felled mature tree will be replaced in terms of its photosynthetic capacity and absorption of CO_2 after several decades. And this remark is of utmost importance when we are told that we have more than 15 years to respond to and limit global warming to some degree (there is little that is specific about the number!). So, the reasonable supposition might be that, from today, there must be a global moratorium of at least 15 years on deforestation.

Biofuels

Biofuels are also expensive to produce. To launch them (make them more competitive), many states are ready to de-tax them (see the further development on taxes, and then we will have some idea of the average cost of production compared to fossil fuel). Moreover, strictly referring to energy, the carbon balance of "Operation biofuel" is very controversial in many parts of the world! Thus, after the cereals pathway and its impact on the food issue, after the “jatropha” pathway which is more acceptable as it plants semi-arid regions, we now turn to the (micro) algae and the "algocarburant" opens (already!) the third generation of biofuel. In reality, for its use as fuel, the pathways that substitute oil all remain problematic. And the geo-strategic issue here is considerable when we know what the Western economic development of the twentieth century owes to oil and to its use as fuel.

About the comparison of electricity production costs

The cost comparisons below do not include externalities or indirect costs such as nuisances. They are therefore interesting for comparative values. The ranges are often very open due to the variety of sites, and infrastructure costs (construction and operation).

Table 03 was compiled based on data from the United Nations Program for Development (UNDP), and those of the Management of Energy and Raw Materials in France (DGEMP) (evaluation at the beginning of the 21th century).

RL = the value relative to the lowest of "ranges lows"
RP = the ratio of the lowest value of "ranges peaks”

	Costs 1995/2000 (HT*)	/bottom range of RL	/bottom range of RP
Hydraulic	2 to 10 (2 = RL)	RL	2.86 x RP
Photovoltaic	25 to 125	12.5 x RL	35.7 x RP
Wind-Tide	5 to 13	2.5 x RL	3.7 x RP
Biomass	5 to 15	2.5 x RL	4.3 x RP
Coal	3.7 to 4	1.85 x RL	1.14 x RP
Gas (combined cycles)	3.3 to 4.3	1.65 x RL	1.23 x RP
Nuclear	3.2 to 3.5 (3.5 = RP)	1.6 x RL	RP

Table 0.3

And now, what are we going (need to) to do? Anticipating the future…

The scenario of the World Energy Council (WWC)

This scenario extrapolates on the basis of the known by integrating the demographic forecasts (see Table 0.4).

En Mtep	1985	2020	2060
Petrol.	2820	2560	2500
Coal	2140	4300	6930
Gas	1360	2670	3760
Total fossil.	6320	9530	13190
Nuclear	330	1710	2910
Hydraul.	450	965	2080
Other renewables	580	1790	3490
Total without fossil.	1030	2755	5570
Total	7680	13995	21670

Table 0.4: The WWC scenario up to 2060

The New Energies Options (NOE)

This scenario is characterized by a very important and continuous effort to increase the energy efficiency of the industrialized countries. It is also based on the provision and rapid learning of the countries of the South. It should be noted that it is part of a nuclear disappearance at maturity in 2100 (see Table 0.5).

Mtep	1985	2020	2060
Petrol.	2820	2600	1700
Coal	2140	2100	1800
Gas	1360	2200	2000
Total fossil.	6320	6900	5500
Nuclear	330	450	250
Hydraul.	450	1000	800
Other renewables	580	1750	3950
Total without fossil.	1030	2750	5750
Total	7680	10100	11500

Table 0.5: the NEO scenario up to 2060

Today it is difficult to imagine new sources of energy that are capable of upsetting the current situation. And if for some the long-term remains unpredictable, with the improvement of energy efficiency in the transformation of primary fossil energies into active energy, useful is hopeful. This hope is increased if energy efficiency doubles as an intrinsic ecological efficiency to the systems that will be developed to produce, transport, and use energy ...

In this context, wet combustion offers a path that has not been explored until now, but is promising in order to meet the energy challenge facing the new century.