"Engineering and the future energy scenario"

"Predicting the future is a hopeless, thankless task, with ridicule to begin with and, all too often, scorn to end with." Isaac Asimov. Science Digest, 1965

I will present an overview of the technological aspects of the energy sector, not referring in depth to issues beyond my specific field, as I have no valuable contributions to make, nor to issues within my specific field whose details are not relevant to the objective of my presentation.

The objective of my presentation is to identify the opportunities offered by engineering to contribute to the design of a viable and consistent energy scenario with the adequate supply and demand and other proper features to face the threat of climate change.

Two powerful technical drivers will be responsible for the profound changes in the energy scenario that the world will face in the middle of the twenty-first century.

In both cases, we have witnessed a long dispute of opposing views in the scientific community.

The first of these drivers refers to the exhaustion of fossil fuels. The discussion has been centered in the decision about the peak oil date, that is, the moment when the production will reach its maximum, to then begin the process of decline.

The positions of the experts about the peak date differ, even for a lapse of 50 years. The experts don't agree either on the shape of the decline curve from the inflection point.

I agree with the group of experts who state that this decline is temporarily very far away. As the reasons for this are beyond the objective of this conference, I will only use a repeated statement to summarize them: the same will happen with the "fossil fuels age” as with the "stone age", which finished before the stones were exhausted.

The second driver is the climate change caused by the accumulation of greenhouse gases generated by human activities. This is, from my point of view, the real transformation driver.

In this case, the long controversy seems to have been settled as stated by the "Intergovernmental Panel on Climate Change" in its publication of February 2, 2001.

According to this report of the United Nations, "the scientific evidence about climate change is unequivocal and conclusive. The global average surface warming is likely to be around 3ºC, if greenhouse emissions continue increasing at the current rate. An increase of 3ºC would translate into a severe shortage of water, lower crop yields and a severe impact on global economic and social progress." This report has been drafted by 800 authors and 2,500 scientific reviewers of 130 countries, which would grant it high endorsement and credibility. With no intention of controversy, we believe reasonable to take these assertions as a work hypothesis.

The mathematical simulation models on which the "Intergovernmental Panel on Climate Change" is based would indicate, on the one hand, that the tolerable maximum for the increase in average atmospheric temperature would be 2ºC, and on the other hand, that this increase would be caused by the increase to 450 p. p. m. (expressed in CO2 equivalent) of atmospheric greenhouse gases.

However, everybody knows that the complexity of these mathematical models could increase as more computational processing capacity becomes available, and that the current magic numbers of a 2ºC increase with an average concentration of greenhouse gases of 450 p.p.m. could be subject to changes in the future.

Faced with these forecasts, there are two ways to proceed to achieve the objective of stopping global warming: a strategy to provoke the opposite effect technically, or a strategy to mitigate global warming through the creation and use of technologies that reduce or eliminate greenhouse gas emissions.

There are many proposals for the former; let me mention only two examples. One proposal consists in spreading aerosols in the high atmosphere, being inspired by the case of Titan, the larger satellite of Saturn, whose high atmosphere contains a fog of molecules that is quite opaque to the entrance of solar radiation and very transparent to the infrared radiation reflected from the surface, a mechanism that is symmetrical to the one produced by greenhouse gases.

Another proposal is that of high technology sunshades, presented at the NASA Institute for Advanced Concepts by astronomer and opticist expert Roger Angel, of the University of Arizona.

Professor Angel proposes a giant sunshade that might reduce the solar energy entering the atmosphere by 1.8%. This sunshade would be located near the Lagrange L1 point, about 1,8 million kilometers from the Earth, where the gravity of the Earth and the Sun are balanced, thus enabling the stationary maintenance of the sunshade.

This sunshade would be composed of a cloud of 16 trillion disks flying freely and reflecting the sunlight off into space. Each circular refractor would have a diameter of 0.6 m, a width of 5 microns and a weight of 1.2 grams. These refractors would be launched in stacks and then unfolded upon arriving at the above-mentioned point.

The launch of these disks into orbit presents tremendous difficulties, and Dr. Angel has proposed the required high technology solutions that should be implemented. In a first phase, the stacks of refractors would be launched until they reach the velocity required to escape Earth's gravity with an electromagnetic tube, and then they would be propelled to Lagrange L1 point with argon ion thrusters. But more high technology is required. Once in the above-mentioned point, each disk would locate its position using hyper-miniature cameras that would sense the Sun and the Earth by means of thin adjustable tabs that would use the pressure of solar radiation to maintain the correct orientation. The disks should not have a reflective surface, as they would be pushed toward the Earth by solar radiation. They should be designed to refract light. According to Angel, the disks would remain in orbit at least 50 years, until their solar cells degrade and they cannot maintain their position by themselves.

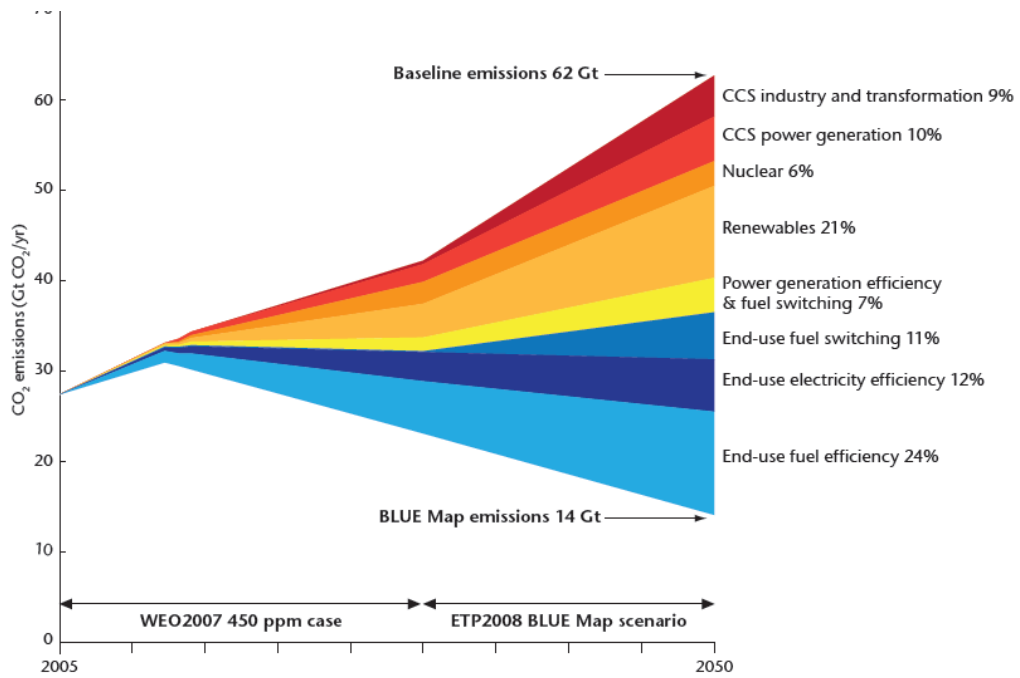
Although Dr. Angel has managed to build a prototype optical element with adequate refractive qualities and research on aerosols with properties to create anti-greenhouse effects has advanced, these solutions to stop global warming are still at the level of science fiction, if we may say so. The time for implementation is incompatible with the urgent actions that, according to the scientific community, are required to stop global warming.

Notwithstanding these enormous technical difficulties and the long time required for their development, we believe that the research done to find these proactive solutions offers an exciting challenge for the future generations of engineers.

The second strategy is mitigation. Conceptually, this means to reduce the CO2 emissions generated in the production of energy. This is achieved, from the supply viewpoint, through the introduction of alternative technologies, and from the demand viewpoint, through an improvement of efficiency and through innovative technologies.

It is estimated that the size of the global economy will be multiplied by 4 by 2050, but in developing countries as China and India, it could be even multiplied by 10. Their energy requirements would multiply accordingly.

CONTRIBUTIONS OF TECHNOLOGIES IN THE BLUE SCENARIO



Source: International Energy Agency, *Energy Technology Perspectives* (2008)

If the current energy scheme continues, emissions will have increased 130% by 2050. The Intergovernmental Panel on Climate Change states that, if this happens, the global average temperature would increase 6ºC, and as a consequence, there would be an important and irreversible change in the natural environment.

This trend could be reverted through a global revolution in energy supply and demand methods.

We will use the scenarios methodology that the International Energy Agency uses in its "Energy Technology Perspectives" publication to order, calibrate and analyze the magnitude of that technological change and the economic effort required to implement this revolution.

ACT Scenario: The ACT Scenario aims to bring back CO2 emissions to 2005 levels by 2050 using the current technologies or technologies in an advanced phase of development.

Depending on the combination of technologies and the velocity of their implementation, in the ACT Scenario emissions would continue to grow until 2020-2030, and would then decline to reach 2005 levels by 2050.

The ACT Scenario implies the adoption of a wide variety of technologies with marginal costs of up to USD 50 per ton of CO2 saved.

What does this mean? This would mean, for example, the cost of generation of a coal power station not equipped with CO2 capture and storage system would double.

It is already difficult and costly to comply with the objectives of ACT Scenarios. The additional investments in the energy sector would be equivalent to 0.5% of the world GDP every year until 2050.

BLUE Scenario: In this scenario, emissions are reduced to 50% of the 2005 level by 2050, using new technologies.

The Intergovernmental Panel on Climate Change has recently concluded that maybe it is not enough to reduce emissions to the 2005 level, but they should be reduced to 50% of the 2005 level to deter global warming from 2ºC to 2.4 ºC.

The 50% reduction of emissions was already a global objective in the 2007 G8 leaders summit.

This scenario not only implies much higher costs, but also more uncertain costs, as it requires technologies that are still under development and whose progress and final success are difficult to predict.

In the so-called "technological optimism" hypothesis, the implementation of new technologies could cost up to USD 200 per ton of CO2 saved.

But if the progress of new technologies does not meet the expectations ("technological pessimism" hypothesis), the costs of saving the emission of a ton of CO2 would increase to USD 500.

The needs for additional investments in RD&D of technologies that are still not competitive would account for 1.1% of the world GDP each year to 2050.

What are we doing in the technical and scientific community about research, development and demonstration regarding the technologies required to reach the emissions objectives of the BLUE scenarios?

Very illustrative of this is the magnificent work prepared by the International Energy Agency for the "Major Economies Forum on Energy and Climate" launched by President Obama on March 28, 2009, as a preparatory stage of the United Nations Framework Convention on Climate Change that was held in Copenhagen in December 2009.

This work analyzes categories of technologies and/or low carbon energy practices stating the research field and the potential maximum and minimum budgetary requirements. Let me quickly refer to the activities in course in these ten sectors.

Advanced technology vehicles. The main areas are energy efficiency in transportation, electric plug-in vehicles and hydrogen powered vehicles.

Some of the research, development and demonstration priorities regarding sectoral decarbonization are the following: storage of energy (batteries), new light materials, technologies for efficient combustion, low carbon fuels and fuel cell propulsion systems.

Bioenergies. Research efforts are focused on second generation biofuels, such as conversion of cellulose to ethanol, to mention the most notorious example, and in the substitution of some current processes that seem to ignore the first principle of thermodynamics.

CO2 capture and storage. This issue is very important because it will be determining in the transition stage between the fossil fuels times and the new sources of energy. Several technologies at different stages of development are competing to become the solution of lower cost for each stage of the chain of the CO2 capture and storage process.

Energy efficiency in buildings. Approximately one third of the consumption of energy in developed countries occurs in residential, commercial and public buildings.

Several technologies have been recently developed. For example, high performance windows and high yield reversible heat pumps, when combined with a passive solar design, may reduce energy consumption by 80%. This reduction may be even higher if intelligent control systems are used in buildings.

Energy efficiency in the industry. The industry accounts for about a third of the final global energy and is responsible for almost 40% of the total energy-related CO2 emissions.

Five sectors, iron and steel, cement, chemicals and petrochemicals, wood pulp and paper, and aluminum are responsible for 75% of the direct CO2 emissions of the industry.

Some of the RD&D priorities for this sector are advanced chemical and mechanical heat pumps, heat exchangers, ceramic recuperators, advanced industrial combustion systems, new cogeneration technologies, intelligent process sensors and controls, etc.

Technologies to burn coal with high efficiency and low emissions. Large emerging economies, such as the BRIC economies, are increasingly using coal-based generation.

Though carbon credits might be an incentive to decrease the use of coal, the real complementary and effective method is to decrease emissions with the use of clean technologies.

We refer, for example, to gasified coal, combined cycles and fundamentally, to complementing this generation with CO2 capture and storage facilities. This, together with gasification technologies, solid to liquid processes and fluid bed combustion, are some of the technologies that still require research, development and demonstration in order to make coal usable according to the BLUE scenarios strategy.

Solar energy. The two main areas where research, development and demonstration regarding solar energy are focused are photovoltaic energy and concentrated thermal energy.

The photovoltaic systems commercially available may be classified into two categories: the classic crystalline silicon wafer systems and the thin film systems, which include amorphous silicon, copper indium galium selenide or sulfide and cadmium telluride.

In both cases, research is aimed at improving step by step the percentage of energy converted and the efficiency of manufacturing processes at industrial scale in order to lower costs.

In the concentrated thermal energy systems, the available technologies may be classified into four categories: the plants using parabolic cylinder (mature technology), linear Fresnel reflectors, central receptor systems (towers) and parabolic dishes.

In general, these solar systems may dispatch energy when combined with backup storage facilities or with generation based on fossil fuels, working as real hybrid processes.

Research and development priorities focus on increasing thermal efficiency, trying to reach the highest possible temperature and using Rankine or Brayton cycles together with combined cycles. Research is also done on advanced automation operations.

<u>Wind energy</u>. Onshore power generation facilities using wind energy have proved to be a commercially valid option, with important installed capacity, while the offshore option is still an emerging technology. Research is focused on making additional progress in cost reduction, a better evaluation of wind resources, the construction and operation of offshore facilities and the

development of technologies to anticipate wind changes and for the intelligent integration of these facilities with the transportation and distribution networks. We should not forget that the safe integration of wind power to the networks is one of the greatest challenges to the stability of these networks working with distributed generation.

Smart Grids. One of the new and most important instruments for the future of low carbon energy is the use of smart grids.

These networks integrate transport and storage solutions that enable the efficient and reliable delivery of energy.

They allow easier integration to existing networks, distributed generation and the use of electric vehicles as sources of energy accumulation. In addition, these technologies enable the interaction of consumers with the network, in order to get the best conditions as regards prices and real time responses.

The RD&D priorities are focused, in this case, on the integration and application of many mature technologies used for information management.

This is a typical case of application of ICTs that may radically change the nature and efficiency of a specific sector.

Nucleus-electric energy. In the different BLUE scenarios, nucleus-electric energy takes a very important fraction. This is the energy based in the fission of heavy atomic nuclei, the only energy currently available for the generation of electric power with reasonably mature technologies and at sufficiently advanced stages.

The latest technological developments of the last generation reactors are mainly aimed at security, management and waste minimization. These developments will advantageously replace old reactors that are ending their useful life and will encourage an increase in this energy in the future matrix.

It is well known that research and technological development of this form of energy have their own ways, and the respective investments in RD&D are not covered by the International Agency estimates that we will analyze below.

This brief reference to quality of research, development and demonstration of low carbon technologies tells us very little about the potential work and its difficulties, if we do not have some measure of its cost.

For this purpose, in my opinion, the task of search and evaluation made by the International Energy Agency is very important.

RD & D GAP ANALYSIS OVERVIEW
(MILLIONS USD / YEAR)

	ANNUAL NEEDS	ANNUAL SPENDING	ANNUAL GAPS
ADVANCED VEHICLES	24.900	1.543	23.357
BIOENERGY	705	590	115
CARBON CAPTURE AND STORAGE	8.250	884	7.366
ENERGY EFFICIENCY (INDUSTRY)	6.750	411	6.339
HIGHER EFFICIENCY COAL	2.250	544	1.706
SMART GRIDS	8.330	420	7.910
SOLAR	2.460	665	1.795
WIND ENERGY	1.950	186	1.764
TOTALS	**55.595**	**5.243**	**50.352**

Note: Values represent 80% attributes to MEF contries.

Source: International Energy Agency (2009)

In this exercise, the Agency has attempted to estimate the current levels of investment in research, technology development and demonstration of low carbon energy, and what the level of investments required to reduce emissions from 2050 to 50% of 2005 emissions should be, according to the BLUE map.

Everybody is aware of the difficulties in making these estimates, and that is the reason why the Agency makes a minimum and a maximum estimate. For simplicity of this presentation, this chart represents the average value, giving the same probability of certainty to both estimates.

Since the "Major Economies" are generating about 80% of greenhouse gas emissions, the Agency also attributes responsibility for 80% of the cost of investment in RD&D.

As a first conclusion to be drawn from these assessments of the International Energy Agency, it is clear that the large deficit lies in the transportation sector and specifically in the technology of advanced design vehicles.

One of the greatest opportunities for engineering is in this sector. This is where more efforts are needed and where relatively less research and development than required is being made.

Secondly, there has been little progress in carbon capture and storage, which every day become more critical as a consequence of the massive installation of coal-based generation plants. The challenge here is more focused on storage and less on capture. The solutions proposed so far are extremely expensive and the alternatives are of questionable safety.

In a similar situation in terms of amount of investment required and the gap with real spending are smart grids. Although we said that ICTs to implement in the field were mostly mature technologies, there remains a tremendous work of integration and implementation to the specific case of electricity networks. Graphically speaking, electricity distribution networks are currently living in the era before the PC appeared in computer networks.

Slightly lower -though not much- are the investment requirements in developing technologies to improve energy efficiency and emission control in the industry, mainly iron and steel, cement and aluminum, to name the most important.

In summary, we can conclude that major economies are investing only 10% of the requirements for RD&D to meet the needs of the BLUE scenario.

The smallest gaps are in the sectors of bioenergy, wind and solar energy. These, of the new technologies, are the ones usually mentioned in the information to the public. However, it is clear, as we have seen, that renewable energies by themselves only solve 20% of the emission reduction claimed by the BLUE scenario. This reduction can only be achieved with significant advances in other sectors.

<u>What are we doing directly in the "World Petroleum Council" for the decarbonization of energy supply?</u>

In December 2007, we decided in Punta del Este, Uruguay, to hold the 20th World Petroleum Congress in the first week of December 2011 in the city of Doha, Qatar. In this Congress, which takes place every three years, the latest technology in their R&D phase, among other topics, and in the accompanying industrial exhibition, cutting-edge products in their demonstration phase are presented. This is the major event of the oil and natural gas industry in the world.

Why Qatar? Among the many reasons to choose this venue is that by the date of this Congress, Qatar will be the first global producer and exporter of liquefied natural gas, with the largest and most modern fleet of cryogenic vessels in the world.

And why natural gas? Because, as its carbon-hydrogen relation is much lower than that of other hydrocarbons, it is the transition fuel and the most available of all current fossil sources (coal and oil) and future fossil sources.

And why liquefied natural gas? Until a few years ago, the natural gas market was little globalized by the simple reason that suppliers and consumers were linked through a pipeline, or pipeline networks, which could only operate within the continents, with only a few exceptions. Liquefied natural gas, on the contrary, can be transported by sea between continents and extends the geographical scope of continental networks.

This intercontinental trade is globalizing by means of forward contracts and specific contracts that optimize trade flows and prices based on seasonal changes.

The use of this energy is being promoted by the high thermal yields of combined cycles in the generation of electricity.

Given this potential of natural gas as transition energy, we have planned for this Congress a block of forums called "Natural Gas: the energy that makes the difference".

Some of the most prominent and more technologically-focused forums in this block are the following:

Forum 1: LNG producers: Latest technological developments in liquefaction and transportation

This session will explore the opportunities for innovation in liquefaction technologies offshore, where there are enormous potential reserves. This session will also explore the latest innovations in loading and unloading terminals.

Forum 3: Improving efficiency, safety and economics for GTL

The great technological stretch to reach substitute energy vectors in transportation, such as electricity and hydrogen, must be temporarily filled with high-quality liquids as those obtained from natural gas through synthesis processes. This session will review the status of research and development programs and the progression of GTL technology towards higher efficiencies and lower capital costs.

Forum 5: Non conventional gas resources

In a world with an energy transition based mostly on natural gas, research and development of exploration and production technologies for non conventional natural gas supplies found in nature becomes essential.

The amount of non conventional reserves and their geographical distribution will radically change the economic and geopolitical map of natural gas.

This session will analyze technologies to exploit potential reserves of all natural gas supplies: coal bed methane, gas shales, tight gas, underground coal gasification and methane hydrates. These are crystalline solids formed by gas and water, stable in adequate thermobaric conditions, high pressure and low temperature, which are found in nature in permafrost soils, such as the Arctic, and offshore sedimentary basins.

The methods for production of this gas from methane hydrates are based on displacing hydrate stability conditions regarding pressure and temperature. The difficulty is to perform this destabilization under controlled conditions. Precisely, one of the effects that might accelerate climate change would be the destabilization by warming of the Arctic permafrost, with the resulting release of methane, a gas with a very high greenhouse effect.

Final conclusions.

The continuous improvement of simulation models to study climate change, the extraordinary increments in computing processing capacity and the development of methods and remote measuring instruments of emissions (beyond the recent failure of the launch of the Orbiting Carbon Observatory), will provide more variables to consider for the models and more certainty in the results.

However, I believe that a reversion of tendencies is very unlikely, so it is reasonable to maintain the current work hypotheses, focusing efforts on RD&D of mitigation technologies.

The results of the COP 15 held last December in Copenhagen should not be surprising if we consider the huge gap between the investment in research and development needed to fulfill the commitments required and the real investment made in research and development, which does not reach 10% of the investment necessary to have the appropriate technologies available and to achieve the mitigation of emissions. This adds to the huge expenses to install these technologies, once they have been demonstrated.

Although the agreement of Copenhagen does not provide for any expected results, it does provide a guide on the steps to take towards a legally binding agreement among the parties, and this will be, in my opinion, the focus of the agenda for the COP 16 to be held in Cancun, Mexico, at the end of this year.

While proactive solutions to prevent global warming, such as Professor Angel's refractors, or the use of anti-greenhouse aerosols in the higher atmosphere continue to be at the edge of science fiction, and civil technologies for the fusion of light nuclei fails to definitively solve the problems of plasma contention and fusion reaction control, there is no alternative at sight but to use the mitigation technologies that I just summarized.

Significant qualitative changes in technology occur suddenly, unlike the continuous evolution in the development phase. A radical technological change can always occur to modify radically our views about the future energy scenario. This possibility makes us remember, in this type of forecasts, the famous phrase of Professor Asimov that I quoted at the beginning of my presentation.

Do we have the required engineers, in terms of quality and number, to face this task? I don't know.

Do we have the resources to recruit them and face the RD&D that we are currently not carrying out? I believe we do, if the cap and trade mechanism of the Kyoto Protocol is universalized, or if a tax on CO2 emissions is agreed upon. However, here is once again the ancient Aristotelian dilemma of "the chicken or the egg": what will happen first, the availability of economic resources or the will of governments to achieve a binding agreement?

Albert Einstein said: *"We can't solve problems by using the same kind of thinking we used when we created them"*.

Are we using a different kind of thinking from the one we used when we created the problem of greenhouse gas emissions? I believe we are, and therefore, according to the statement I quoted, we are optimistic that we will have the chance to solve this problem.

Thank you for your attention.