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Essay

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An overview of Total's activities on alternative energies, advanced biofuels and bioproducts for energy efficiency and environmental acceptability

Abstract: Total, as well as most major energy players, faces a double challenge: plateauing production of hydrocarbons while the global demand for energy needs continues to grow, and global warming due to the greenhouse effect. In this context, novel approaches have to be developed in order to meet the energy demand while reducing CO_2 emissions. Based on reports published by energy agencies and analyses by our own strategists, the evolution of global energy demand and supply between 2010 and 2030 was estimated. Total has recently launched a series of strategic actions in the fields of energy diversification, energy conservation, and a reduction of the environmental footprint of its operations and products. Some examples of these developments are presented in detail in this paper: new products and new forms of energy, in addition to the traditional oil business: biofuels, dimethylether, photovoltaic, etc., as well as helping our customers to reduce their energy consumption through the use of eco-efficient products and services.

Keywords: biomass; biotechnologies; eco-efficient products and services; fossil fuels; renewable energies.

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1 Total at a glance

Total is a leading multinational energy company with 96,000 employees and operations in more than 130 countries, and engages in all aspects of the petroleum industry, including upstream operations (oil and gas exploration, development and production, liquefied natural gas) and downstream operations (refining, marketing, trading and shipping of crude oil and petroleum products). Total is also a major actor in chemicals (base and specialty chemicals, polymers). In addition, Total has interests in the coal mining and power generation sectors and is developing complementary next generation energy activities (solar and biomass). We strongly believe that all energy sources will be necessary to meet growing global energy demand. Still very abundant, oil and gas resources are essential to ensure a smooth transition to a lower carbon energy mix, while limiting the price pressure and guaranteeing a secure supply. Significant investments need to be made to optimize and diversify our production, to prepare for tomorrow's energy mix, particularly by enhancing energy efficiency and developing alternative and renewable energies.

2 Tomorrow's energy mix

2.1 Factors to be taken into account

Our industry is geared to the long-term: the work we do today concerns projects that will come on stream 10 or 20 years down the road. It is important to consider what the energy context will be at that time. Within what constraints will it operate? What opportunities will it bring? According to the International Energy Agency's (IEA) New Policies Scenario [1], the global energy demand will increase by 40% between 2009 and 2035: 65% in non-organization for economic co-operation and development (OECD) countries compared to 8% for OECD countries over the same period. The increase will be driven by:

- population growth, with an additional 1.7 billion people by 2035;
- rapid economic development in emerging economies, where GDP will grow by an annual average of 4.9% between now and 2035;
- new energy needs associated with population growth and growing affluence, resulting in a significant increase in demand for transportation fuel and electricity.

Two of the greatest challenges facing the world today and tomorrow are energy supply and environmental protection. The responsibility of Total, as an energy producer, is to meet both of these challenges as best we can and in a sustainable way. In practical terms, that means managing both our operations and energy use and offering our customers ways to do the same.

More importantly, it also means developing an energy model that combines fossil fuels with low-carbon energy sources, to satisfy energy demand without interruption, while at the same time protecting the environment.

The availability of primary energy, in terms of the amount of fossil fuel reserves, the technical maturity of renewable energies, as well as the potential of nuclear power, will be critical issues in this decade:

- oil and gas reserves – particularly unconventional reserves – are still abundant, but require increasingly complex technology to produce;
- hydropower has just about reached its maximum potential, with very few major waterways still available;
- wind, solar and modern biomass technologies are being developed. However, technical improvements are necessary for the widespread deployment of new technologies and this requires time – several decades – and considerable financial investment [2];
- solutions, for example in the areas of power storage and smart grids, need to be found to overcome the intermittence issues associated with renewable energies;
- nuclear power depends on the availability of a safe, socially acceptable installed base of plants, together with reliable solutions for plant decommissioning and storage of nuclear waste. Total believes that nuclear energy is one response to the world's energy and climate challenges, since it is a mature, long-established technology, emits almost no greenhouse gases, and makes bulk power generation possible. Although Total is a newcomer to the field, we plan to acquire the skills and expertise that will eventually allow us to operate plants in line with the expectations and concerns of all stakeholders. We have a number of assets we can build on to gradually become a major nuclear operator. However, Total is closely monitoring the impact that the serious situation in Japan may have on the development of certain nuclear projects worldwide.

Improvement in energy efficiency, by using less energy to achieve the same performance during production and consumption, depends largely on energy policies and trends in consumer behavior, which vary significantly between countries. Total is deploying an overarching strategy to manage and mitigate our greenhouse gas emissions, based on four strategically related approaches: enhancing the energy efficiency of our facilities, products and services; reducing the flaring of associated gas from our oil production; developing carbon capture and storage; and energies that emit less CO_2.

Together, we expect these measures to reduce the greenhouse gas emissions of our operated activities by around 15% in 2015 from 2008 levels.

By 2050, carbon capture and storage (CCS) could account for nearly 20% of the reductions in global carbon emissions generated by energy combustion deemed necessary by the Intergovernmental Panel on Climate Change (IPCC). Total is involved in a number of R&D and demonstration projects worldwide, to help make CCS viable and gain proficiency in this technology. We are exploring all options to help bring the most efficient, sustainable processes to commercial maturity and are already studying the feasibility of their implementation in growth projects, for example, oil sands development, liquefied natural gas production and developing sour gas fields.

Since early 2010, we have been testing a commercial-scale integrated CO_2 capture and storage process at our Lacq complex in southwestern France. The process spans extraction, treatment and oxy-fuel combustion of natural gas, capture, treatment and transport of the carbon, then storage at a depth of more than 4000 m in a depleted gas reservoir. This demonstrator unit, one of the very first of its type in the world, has captured and stored around 100,000 metric tons of carbon in 2010–2012.

2.2 Scenarios 2010–2030

In the IEA's New Policies Scenario, global CO_2 emissions would be 21% higher in 2030 than in 2008, a forecast that puts greenhouse gas emissions on track to cause a global temperature rise of 3°C by 2100. This is the most realistic vision and calls for significant energy efficiency efforts in all of the world's big energy consuming countries and regions, including Europe, China, India and North America. This scenario could evolve post-2030, with larger reductions in emissions, once further progress has been made in technologies like CCS.

We have developed our own vision of tomorrow's energy mix that differs somewhat from existing scenarios. In our opinion, fossil fuels will represent 76% of the energy mix in 2030 (Figure 1 and Table 1). Although abundant, oil resources are becoming increasingly difficult to access. This will limit oil production, which we believe will plateau at 95 million to 97 million barrels per day around 2020, stabilizing thereafter. Accounting for an estimated

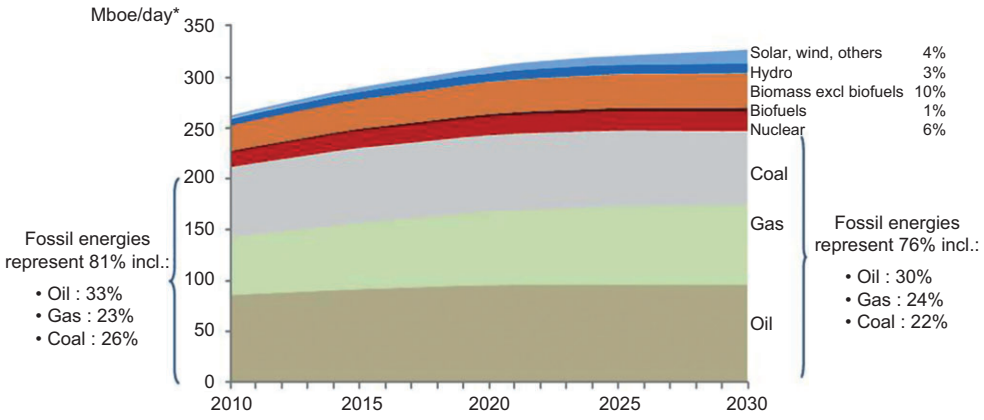

Figure 1 Evolution of world energy supply 2010–2030. Source: Total estimates after the Fukushima accident.

24% of the energy mix, natural gas will become the second largest energy source in 2030, overtaking coal, which generates twice as many greenhouse gas emissions.

The contribution made to the energy mix by oil and gas will undoubtedly decline gradually after 2030. However, it is important that we continue to produce these resources, because it is the only way of ensuring a smooth transition to a lower carbon energy mix, while allowing the balanced development of emerging economies and without putting too much financial strain on consumers.

3 Renewable energies

The non-fossil forms of energy (nuclear power, hydroelectricity, biomass, and "new" renewable energies such as solar, wind, geothermal and marine energies) are slated for steady growth. These resources will account for a quarter of the energy supply by 2030.

Despite the robust growth forecast for biofuels, solar, wind, geothermal and marine energies, they will continue to represent only a modest share of 5% of the energy mix 20 years from now (Figure 1). The transition to a new and more diversified energy model is on the march, but it will take time.

Energy type (%)	IEA	Total S.A.
Oil	28	30
Coal	25	22
Gas	23	24
Nuclear	7	6
Biomass	11(of which 1% is agro-fuels)	11(of which 1% is agro-fuels)
Renewables	6(of which 3% is hydropower)	7(of which 3% is hydropower)

Table 1 The energy mix in 2030, according to the IEA and Total. Source: International Energy Agency and Total.

The estimated 2010–2030 growth rates of four renewable energy sources, i.e., hydroelectricity, wind, biomass, and solar, are reported in Table 2, together with their main perceived advantages and drawbacks. The main on-going developments on renewable energies are summarized in the following sections.

3.1 Biofuels and biopolymers

Global biofuels supply reached 0.7 million b/day in 2007, yet still accounted for only 1.5% of the total road-transport fuel. This supply will climb to 1.6 million b/day in 2015 and 2.7 million b/day in 2030, meeting then 5% of the total world road-transport energy demand, up from about 2% today.

Total believes that wider-scale development of biomass hinges on four conditions. First, it must not compete directly with food. Second, it must deliver a real gain in terms of greenhouse gas emissions avoided from field to wheel. Third, farming and operational practices must accord with our ethical principles. Lastly, it must provide a reasonable return on investment.

To meet these conditions, we have broadened our R&D to include processes that utilize the non-edible parts of plants as well. Total is the leading biofuel distributor in Europe [3] and devotes considerable R&D resources to the development of second generation biofuel technologies, through large-scale demonstration projects for conversion of biomass to fuels which have been recently launched.

3.1.1 Thermochemical routes

The 7-year BioTfueL project will develop a completely integrated industrial process chain including biomass drying and crushing, torrefaction, gasification, purification of

Energy type	Annual growth rate 2010–2030 (%)	Benefits	Drawbacks
Biomass	5.4	Low CO_2 intensity expected from second generation biofuels	Competition with food security for first generation biofuels, costs, global analysis (water, land-use change, etc.)
Solar	21.6	Unlimited supply, strong potential for efficiency and cost improvement, access to electricity in remote areas	High costs in early stages, variable peak rates
Hydroelectricity	2.2	Low CO_2 intensity	Limited potential, environmental impact, population displacement
Wind	10.0	Low CO_2 intensity	Limited technological progress, high costs, acceptability, variable peak rate

Table 2 2010–2030 growth rates and benefits/drawbacks of biomass, solar, hydroelectricity, and wind.
Source: TOTAL S.A. estimates.

the synthesis gas and its ultimate conversion to second-generation biofuels using Fischer-Tropsch synthesis [4]. The flexibility of the process chain allows co-feeding various types of biomass and fossil resources, in both the liquid and solid form, to produce high-quality renewable fuels.

The UPM Stracel BTL Project, partly funded by the EU's NER300 funding program, one of the world's largest funding programs for innovative low carbon energy commercial demonstration projects [5], concerns the construction and operation of a second-generation Biomass-to-Liquid (BtL) plant in cooperation with Total, on the Strasbourg (France) site of the UPM Group, which already owns and operates a paper mill on the same site (Stracel). The project is based on a prototype developed in cooperation with the technology provider using novel pressurized oxygen blown biomass gasification technology. The BtL plant will be integrated into the paper and pulp production line, enabling exchanges of energy and products. The plant will use about 1 million tonnes of woody biomass and will have an annual output of 105,000 tonnes of biofuel. Using mainly wood feedstock, the project aims to produce and sell biodiesel (80%) and bionaphtha (20%). The proposed technical solution is based on the following main components: feedstock handling, gasification, raw gas cleaning, gas-to-liquid conversion, liquid treatment and storage, and power generation.

Total is also involved in the development of bio-dimethyl ether (DME) produced from black liquor, a byproduct of pulp manufacturing. The pilot plant is located in Piteå (Sweden), where the large pulp industry creates very attractive conditions for bioDME production. Initiated by Volvo, the EU FP7 bioDME project covers the entire DME chain, from biomass gasification, to the development of dedicated additives and lubricants to experiments using bioDME as a fuel in a fleet of 14 trucks under customer driving conditions.

Often described as "diesel LPG", DME offers a solution for the future as an automotive fuel, notably in corporate and municipal fleets thanks to its high cetane number and environmental benefits (no soot, no sulfur emission...) [6, 7]. In addition, few engine modifications are required to use DME. However, widespread use will not be possible in the short-term, as distribution networks will need to be created or adapted.

3.1.2 Fermentation and biotechnology routes/ biopolymers

Launched in 2008, the 8-year Futurol project will develop and validate a "second-generation" bioprocess for ethanol production by using lignocellulosic feedstocks [8]. Its main targets are to develop cellulose extraction technologies, to select cost-effective enzymes and yeasts, and to develop the most appropriate hydrolysis and fermentation processes, with the best possible energy and greenhouse gas balances. The industrial-scale pilot unit (180,000 l/year) (Figure 2) was inaugurated on October 10, 2011 on the Pomacle-Bazancourt agro-industrial complex near Reims (France).

Total has also partnered with several US biotech companies to get access to advanced biofuels and speciality chemicals derived from biomass. A case in point is the partnership concluded in June 2010 with the US startup Amyris, specializing in white biotechnology. Together, Total and Amyris R&D teams work at the cutting edge of the technology to design and develop biotechnological routes to produce molecules of interest for Total.

Founded in 2003, based on research from the University of California at Berkeley, Amyris is among the leaders in synthetic biology, with two R&D centers located in Emeryville (California, USA) and Campinas (Sao Paulo, Brazil). Their laboratories at the forefront of technology

Figure 2 The Futurol project (Pomacle-Bazancourt, France): ethanol distillation tower (left side) and enzyme production (right side).

enable them to keep a significant lead over other players in the field of biotechnology. Through high-throughput screening platforms and development of novel methods for automated engineering of strains, Amyris can produce up to 2000 modified strains (instead of only 250 with conventional technologies), at a cost which is lower by a factor of 50 to 100. By controlling their metabolic pathways, Amyris is able to design microorganisms, primarily yeasts, and use them as living factories in established fermentation processes, to convert plant-sourced sugars such as those from sugarcane or sweet sorghum into target molecules such as farnesene, being used to make diesel fuel for buses in Brazil.

Amyris is now close to industrial maturity, having already proven in the laboratory and on a first semi-industrial pilot in Brazil, its ability to produce biodiesel from sugarcane juice. Amyris No Compromise renewable fuels are designed to be optimal transportation fuels which are drop-in replacements for petroleum-derived fuels. They perform comparably to, or better than petroleum fuels and they are cost competitive and compatible with existing engines. Amyris renewable diesel meets ASTM D975 standards and solves the stability and cold flow problems associated with conventional biodiesels. Molecules for renewable jet fuel are being developed, to be commercialized with Total.

The fully-integrated demonstration-scale facility, Lighthouse, located in Madison, Pennsylvania, USA, represents the successful scale-up of Coskata's feedstock flexible technology based on biological conversion of syngas into ethanol [9]. Coskata's microorganisms convert nearly all of the chemical energy of the syngas into the desired end product, leading to high yields. The fermentation process operates at low pressures and temperatures, delivering cost and energy advantages over thermochemical pathways. Finally, commercially available distillation and dehydration technologies are used to efficiently separate the final product from the water stream exiting the bioreactor. As one of the largest syngas fermentation facilities in the world, based on production capacity, Lighthouse has accumulated more than 15,000 operating hours and has produced ethanol from natural gas, wood chips, and simulated waste materials (Figure 3).

Futerro, a joint venture between Galactic – the world's second-largest producer of polylactic acid (PLA) – and Total Petrochemicals, started its bioplastics demonstration unit at Escanaffles in Belgium in October 2009. PLA is a polymer derived from lactic acid, which in turn is produced by fermentation of renewable resources such as sugar or starch. The aim of this demonstration plant producing 1500 tonnes of PLA per year, is to validate an innovative, competitive and clean manufacturing technology. The unit comprises two main sections: a monomer process that transforms lactic acid into lactide (the monomer), and then a polymerization process that transforms the lactide into PLA (Figure 4).

Figure 3 Coskata's Lighthouse demonstration-scale facility (Madison, Pennsylvania, USA).

This first-generation PLA will be used mainly in consumer applications, such as packaging, but Futerro is also devoting considerable efforts to developing a second-generation PLA, suitable for long-term applications.

In addition, PLA opens up new possibilities for end-of-life solutions compared to plastics derived from petrochemicals. Heat-recovery recycling is possible with PLA, but due to its specific structure, PLA can also be composted in compliance with the European standard EN 13432 (industrial composting). In addition, used PLA can be recycled by depolymerization by the "LOOPLA" process, including also collection and transport of used PLA products.

3.1.3 Shortening the biofuel production process

We are applying our expertise in engineering and community development, to study the potential transformation of various plants to automotive and other fuels via shortened systems. The initiative has two advantages:

Figure 4 Polylactic acid granules.

utilizing bioresources close to the fields and plantations on which they grow, and maximizing the economic and environmental benefits in developing countries for the communities involved.

An experiment along these lines is being conducted in Mali with non-governmental organizations (NGOs) and specialized partners. It aims to replace the diesel fuel used to run the generators in a few villages, with the oil from an inedible succulent called jatropha.

3.2 Solar energy

Total has been present in the solar energy sector since 1983. In June 2011, Total became the majority shareholder of SunPower, a US company which is the number three worldwide solar power supplier. SunPower is present on the entire chain, from production of cells to the design of large solar power plants, with a 1300 MWp/year production capacity of cells. Technologically, SunPower has a technological edge over its competitors, producing cells with the highest yield in the market, with an average of 22.4% against 16–17% for its competitors.

Its activities have strengthened since its merger in January 2012 with Tenesol, a French company owned by Total, and one of the leading industry players of solar energy in Europe. Tenesol is leader in the French market for large industrial and commercial photovoltaic rooftop solutions. Third panel assembly unit, SunPower Manufacturing De Vernejoul, was opened in May 2012 in Moselle (France). Covering an area of 3300 m^2, the factory has a production line with a capacity of 44 MWp and will produce about 150,000 high-performance solar panels per year. These panels will be powered by Maxeon solar cells developed by SunPower,

which offer the most advanced commercial technology with yields above 20%.

Our expertise as an equipment maker, combined with our knowledge of user expectations, gives us an even broader overview of the photovoltaic sector. They also provide a springboard for working more closely with electric utilities and for spurring sales of solar solutions around the world. Some 1.5 billion people still do not have access to electric power: solar power is an obvious way to bring a decisive and sustainable improvement in the living standards of people in numerous underdeveloped countries, by give them access to a water supply and purification, lighting, refrigeration, telecoms and power for basic electrical appliances.

Total, via its local subsidiaries, has for many years been promoting the use of photovoltaic systems for decentralized rural electrification programs, in countries such as South Africa, Morocco, Venezuela, Yemen and Indonesia. The management of these programs is adapted to the local context and they are always based on the active involvement of the local population.

Photovoltaic solar power is not just clean energy; it is also produced in a sustainable way. The components used in photovoltaic modules – silicon wafers, aluminum frames, glass covers and the cables that link up the module – are to a large extent, recyclable. In Europe, the photovoltaic segment is moving to set up its own collection and recycling system for end-of-life modules, called PV Cycle, in preparation for the waste problem expected to begin around 2015.

4 Eco-efficient products and services

Total interacts also with its clients, both professional and private, encouraging them to save energy (e.g., energy savings certificates, awareness raising actions) by offering assistance or concrete solutions such as energy saving products for transportation and housing, etc., under the Total Ecosolutions label [10]. Some examples of these solutions are a combination of solar and gas or fuel boilers for hot water and heating, new Eco Fuel engine lubricants for vehicles, thinner but more resistant plastics used for various applications like food packaging, etc.

As of May 2012, 33 products and services have earned this label, complying with the ISO 14020 and 14021 standards that regulate environmental declarations and guarantee their accuracy. According to our estimates, based on a comparison with reference products and services available in the European market and offering an equivalent outcome for the customer, the use of all of the products and services in the Total Ecosolutions lineup would avoid the emission of nearly 800,000 tonnes of CO_2 equivalent per year, which is the amount emitted by approximately 80,000 European Union residents in 1 year.

Total has a comprehensive line of biodegradable lubricants, made partly from renewable resources. They have been designed to meet the specific requirements of operating machinery such as chain saws and tractors in sensitive environments – mountains, forests, farming and fishing – and to prevent pollution caused by accidental spills of hydraulic fluids. This product line has been awarded a European Union ecolabel in recognition of their environmental friendliness.

5 Conclusions

Meeting the future growing energy demands in the decades ahead whilst minimizing our environmental footprint starts with being smarter and more frugal energy users. Total acting on this will enable our customers to do the same. It also entails working to add competitive energy solutions with lower environmental impacts to our fossil fuel offering. We are focusing on three promising pathways: solar energy, biomass and carbon chemistry, combined with CO_2 capture and storage, and, in the longer term, nuclear power. Our goal is to become a leader in these sectors within the decade, by shepherding them to commercial maturity.

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