Energy as a driver for European agriculture and forest, bioenergy and bioproducts

Yves SCHENKEL
Agricultural Research Centre – Wallonia

1. Introduction : Energy in Europe today

The total energy consumption of the EU-25 amounted to 1 654 Mtoe in 2000 and has been estimated to totalise 1 743 Mtoe in 2005, representing a 5.4 % increase. The different sources of energy and their relative importance are listed in table 1.

Table 1 : EU 25 gross inland consumption in 2000 and 2005 (estimates) by energy source (after Mantzos and Capros, 2006).

	2000		**2005 (estimates)**	
	Mtoe	**%**	**Mtoe**	**%**
Solids	306.5	18.5	305.0	17.5
Oil	634.7	38.4	649.2	37.2
Natural gas	376.3	22.8	422.7	24.2
Nuclear	237.7	14.4	251.3	14.4
Electricity (imports)	2.1	0.1	2.5	0.1
Renewables	96.5	5.8	112.7	6.5
Total	**1 653.8**		**1 173.4**	

The European energy scene is dominated by oil although proportionally in diminution between 2000 and 2005. However, the quantities of oil consumed in Europe continue to increase (from 635 to about 650 Mt). As the European production of oil decreases (from 164 Mt in 2000 to 134 Mt in 2005), this means that the European dependency on imported oil has raised by 15 Mt corresponding to 1.3 % of our 2005 gross inland energy consumption.

Natural gas is becoming more and more important in the EU25; its consumption increased by 46.4 Mtoe between 2000 and 2005, a jump of 12.3 %. Natural gas reinforces its second place in the European energy sources portfolio. Solid fuels, such as coal and lignite, are decreasing while nuclear power quantitatively increases but keeps its percentage at 14.4 % of EU25 gross inland energy consumption.

Renewable energy sources have also raised between 2000 and 2005, by 16.2 Mtoe equivalent to 16.8 %. In 2005, biomass and waste are the major renewable energy source (64.4 %), followed by hydro (25.6 %), wind (5.8 %), geothermal (3.3 %), solar and others (0.9 %).

To complete the scene, table 2 gives data on the final energy demand for each sector in the EU25.

Table 2 : Final energy demand by sector for the EU25 in 2000 and 2005 (after Mantzos and Capros, 2006).

	2000		**2005 (estimates)**	
	Mtoe	**%**	**Mtoe**	**%**
Industry	302.2	27.6	311.4	26.7
Residential	273.3	25.0	294.6	25.2
Tertiary	159.0	14.5	173.7	14.9
Transport	333.0	30.4	360.6	30.9
Agriculture	27.8	2.5	27.8	2.4
Total	**1 095.3**		**1 168.1**	

The major sector regarding energy demand in the EU25 is transport, with more than 30 %, followed by industry (27 %), residential (25 %) and services (14.5 %). Agriculture is a very small direct consumer of energy. However, table 2 does not allocate the energy used for the production of fertilizers, pesticides, etc, to agriculture but to industry, hence the actual energy linked to agricultural activities could be higher. As a consequence, we may say that we should look to the relation between energy and agriculture not for its "energy use" part but rather for its "energy production" component.

This paper describes the evolution of the energy sector following three axes - transport, electricity and heat – at the horizon of 2030. The implications of this evolution on agriculture are discussed, regarding energy production as well as bioproducts and biomaterials. The impact of climate change on agriculture and economy is not discussed here.

2. A snapshot on energy strategies of China, India, Russia, Brazil and USA

2.1. China

Energy security is the corner stone for China to achieve its goal of quadrupling its gross domestic product (GDP) between 2000 and 2020. At the current exchange rate, China's GDP will total $3.2 trillion by 2010, this is to say $2,400 per capita GDP. China is the world's most populous country, willing to maintain a 8 % annual growth between now and 2015 and then slow to 6.5 % from 2016 to 2020. China mainly relies on domestic supply to satisfy its energy demand : 90 % of the latter is met with domestic energy sources (this is projected to be near 80 % by 2020), but China is also the second world's largest oil importer. China's dependence on imported energy sources is increasing, exposing the country to considerable risks of global and regional energy supply disruptions.

Consequently, China's willingness is to achieve its goal of economic development while reducing the energy use per unit of GDP by 20% by 2010 through energy conservation and efficiency.

It is estimated that China's oil consumption grew about 6 % and reached 177 million tons in 2005 at an annual increase of 9 million tons. The oil demand reached 6.8 million barrels per day (bpd) in 2005, with China importing about 40% of its oil needs (2.46 bpd). Rising prices of oil have not dramatically reversed the economic growth. It is important to bear in mind that oil price is partially controlled by the Chinese government, who keeps it much lower than that of the international market. China is expected to be able to increase its national oil production, maintaining its imports to the level of 40 %. Analysts predict that China's share of world oil consumption would double to 14 % over the next decade.

In the framework of its environmental policy, the Chinese government has encouraged the use of natural gas instead of coal. The present share of natural gas is 3 % of total Chinese needs, but the target is to reach 8 % by 2010. This can only be achieved through imported natural gas, which would account for 40 % of China's total gas needs by 2025.

Considering oil and natural gas supply constraints, China has shifted its efforts to more dependence on coal. By 2030, coal is expected to provide 62 %, oil 18 %, natural gas 8 %, hydropower 9 %, nuclear power 3 % of China's energy consumption.

Deterioration of environment (SO_2, greenhouses gases, NO_x) and low energy efficiency are key characteristics of the energy scene in China. The Chinese government is working on plans to remedy this situation (Clean Air Programme, ten programmes announced to improve energy efficiency in buildings and industries), but analysts are dubious on the actual results of these programmes.

Energy security is considered as a key strategic issue of China's economic development, social stability and national security. China's energy security strategy is built on five pillars :

- Intensify domestic energy exploration and production.
- Develop new alternative energy sources.
- Optimise energy consumption structure
- Improve energy efficiency
- Establish strategic petroleum reserves

China will try to meet its energy demand mainly with domestic sources (cf supra), utilizing **coal as its main source of energy**. China's proven reserves amount to 114.5 billion tonnes, but the Chinese government looks also to huge reserves in the western regions of Inner Mongolia and Shaanxi which may contribute to 235.2 and 166.3 billion tonnes. Water resources are also considered as a major source of energy especially in southwest China. Oil and natural gas reserves are also mainly located in western regions (25 to 30 %), with a total onshore reserves of 82 billion tonnes of oil and 39 trillion cubic meters of natural gas. Solar energy installed capacity should reach 10 GW by 2020.

China has implemented an important research programme on **coal gasification technologies** (Coal To Liquid) targeting a price of $25 per barrel of CTL. It is estimated that China could make up to 1.2 million bpd of CTL in ten years, equivalent to more than a sixth of current demand.

China is also emulating Brazil's experience in **bioethanol production**. China has started a bioethanol programme with a present capacity of a million tonnes per year which it plans to double by 2010. Biodiesel is also considered as a potential transport fuel in China. The target is to substitute biofuels for 10 million tonnes by 2020.

By 2010, nuclear power, hydropower, solar power, tidal power, geothermal power and biopower will have risen from 5 percent in 1990 to 10 percent of China's power resources.

The share of renewable energy in the total Chinese energy supply should increase to 15 % from the current 7 % over the next 15 years thanks to an investment of $180 billion. The development of biomass should allow China to substitute renewable energy for 10 million tonnes of petroleum annually.

China is also **strengthening international cooperation** in the field of energy in order to diversify its energy supply. Specific relations are developed with Russia, Central Asia, Iran, Saudi Arabia, Africa, Canada, India.

2.2. India

In 2004, the total primary energy supply amounted to 573 Mtoe. The share of each fuel was as follows :

- coal : 196 Mtoe (34 %)
- oil : 127 Mtoe (22 %)
- gas : 23 Mtoe (4 %)
- nuclear : 4 Mtoe (1 %)
- hydro : 7 Mtoe (1 %)
- biomass and waste : 214 Mtoe (37 %)
- other renewables : 0 Mtoe (0 %)

Biomass and waste are the major energy resource of India (37 %), followed by coal (34 %) and oil (22 %). Although oil represents only 22 % of India's primary energy consumption, India is now importing 70 % of its oil (national oil reserves : 5.6 billion barrels). Over the last 20 years, India's domestic production of oil has stagnated while its consumption of petroleum products has almost trebled. It is considered that India is too big and too late in the game to develop an oil-based energy economy. Hence India must emphasize to use energy efficiently and increase energy independence by developing alternative energies.

India's energy strategy includes 4 main measures.

1. **Provide clean and affordable energy to all** : this measure is mainly articulated around access to energy for everybody in India, through a.o. instruments such as the promotion of decentralized energy, micro-credit, differentiated energy services.
2. **Ensure security and energy supply** : energy sources and technologies mapping, encouragement of private sector investment in energy systems and technology research, preparation to emergency situations.
3. **Improve the efficiency of the energy system** : open up energy markets, adequately empower independent regulatory authorities, uniform pricing principles, internalizing environmental costs, promoting energy efficiency.
4. **Reduce the adverse environmental impacts of energy use** : accelerate the development and market adoption of environment friendly technologies and environmental standards, exploit opportunities arising out of international agreements such as climate change and WTO.

To meet its accelerating energy demands, India is very keen to secure overseas energy sources. In the next ten years, even if the latest domestic oil exploration discoveries are fully exploited, India will still struggle to keep its imports down at currents levels. Domestic demand for petroleum products is increasing by 5 % per year. Meanwhile, the demand for natural gas is also rising at high speed : the consumption was 3.4 billion m^3 in 2002 and is expected to reach 6 billion m^3 in 2015. Despite the increased reserves discovered by recent exploration (present reserves : 850 billion m^3), India will have to import one-third of its projected needs in natural gas.

Consequently, India has developed a very active energy diplomacy. India's Oil and Gas Corporation has bought equity stakes in oil fields in Iraq, Sudan, Libya, Angola, Burma, Russia (Sakhalin), Vietnam, Iran and Syria, while the Gas Authority of India Limited (GAIL) has invested in liquefied natural gas plants in Oman and >Iran and is pursuing plans for direct pipelines from neighbouring countries such as Bangladesh, Iran, Burma and even Pakistan. However, India is facing fierce competition from other major players on the international energy markets, such as China and EU, which have pushed Indian companies further towards the global oil market, in Ecuador and Ivory Coast for example. Furthermore, even if its neighbouring countries possess the resources to meet India's energy shortages, Delhi's diplomatic relations with them have traditionally been difficult. Also, the Indian public-energy sector is plagued by a lack of organisation and coordination.

2.3. Russia

In 2004, the total primary energy supply amounted to 640 Mtoe. The share of each fuel was as follows :

- coal : 104 Mtoe (16 %)
- oil : 130 Mtoe (20 %)
- gas : 345 Mtoe (54 %)
- nuclear : 38 Mtoe (6 %)
- hydro : 15 Mtoe (2 %)
- biomass and waste : 7 Mtoe (1 %)
- other renewables : 0 Mtoe (0 %)

The Russian energy supply is primarily based on natural gas (about 55 %), followed by oil and coal. Russia possesses great energy resources : one-third of the world natural gas reserves, one-tenth of oil reserves, one-fifth of coal reserves and 14 % of uranium reserves. Consequently, the Russian government sees the "fuel and energy complex" as the instrument of carrying its internal and external policies.

The energy strategy of Russia is based on energy safety, energy effectiveness, budget effectiveness and ecological energy security for economic growth and improvement of life quality. This energy strategy is implemented in two phases The first phase, which should end in 2010, will see the reforming of the energy sector completed including :

- a legislative base allowing a transparent competitive energy market;
- realization of the export potential of oil and gas;
- transition to a Russian "fuel and energy complex" as an effective and stable supplier of fuel and energy resources;
- transforming adjacent economic sectors to energy effectiveness.

The second phase aims at :

- further growth of openness and competitiveness of energy markets;

- implementation of prospective projects in existing energy sectors (nuclear, coal, hydro, petroleum and gas chemistry) to develop new regions of Russia;
- increased contribution of science and technology to Russian energy sector;
- development of renewable energies.

EU officials are not pleased with Russia's ongoing energy strategy. Andris Piebalgs, EC Commissioner for Energy, said that "The energy strategy of Russia is not fully aimed to transport energy resources to meet the growing consumption. The monopolistic situation of major Russian energy companies is also questioned.

Russian energy safety is under threat : shortage or misallocation of energy investments, absence of competition between fuels, lack of scientific and technological energy know-how, absence of developed and stable legislation, great dependence on world energy market conditions. The answer of the Russian government to these energy safety threats is vague.

The energy sector has caused important damages to the environment in Russia. The aim of the **environmental policy** is to gradually limit the stress on environment caused by the fuel and energy complex and to come closer to the European environmental standards. The mechanisms of this policy include : economic stimulation of environmental friendly technologies, control strengthening. According to the estimates, by the year 2010, the GHG emissions will make up 75 to 80 % of the 1990 level, and even in 2020 that level will not be reached which will help Russia to fulfil its obligations.

Today, **the economy of Russia is wasteful in energy**. The power intensity of Russian GDP is 2.3 times more of that of the world and 3.1 times more than in EU countries. Climate and territorial factors do no explain alone this situation : the structure of industrial production, the lack of technological development of power-consuming branches of industry, low prices of energy (natural gas), are major factors explaining the poor efficiency of the Russian energy economy. The aim of the state policy is to decrease the power intensity of GDP by 26-27 % by 2010, and from 45 to 55 % by 2020. Measures to reach this goal are not well defined : structural rebuilding of economy in favour of low energy consumption industries, housing, services; use of the potential in the field of technological energy saving. A complete system of legal, administrative and economic measures which stimulate the effective use of energy is to be implemented, including : new norms, rules and regulations; energy audits of industries, economic incentives, public sensitization.

The energy sector in Russia is characterized by complex and different relation with the state budget, being at the same time the main source for filling its profitable part (half of federal budget income) and the recipient of the state funds. A budget effective policy is built on stable prospects of energy budget incomes, equilibrated budget effectiveness, good budget management practices.

The Russian energy policy is to be directed on the change from the role of supplier of raw resources to the role of substantive member of the **world energy market**. The market of Central and Western Europe remains the greatest market in the forthcoming 20 years. USA can become the long-term market of sale of oil industry production. The US capital can become the source of investments in the development of industry and export trends of Russian oil transport and a market for LNG. The part of Asia Pacific Region – countries in the export of Russian oil will rise from 3 to 30 %, of Russian gas up to 25 % in 2020. China, Korea, Japan, India will remain major partners of Russia's economic co-operation.

The main expected results of the realization of the Energy Strategy are :

- reduction of the specific energy capacity of GDP with the correspondent growth of energy effectiveness of economy, from 22 % in 2000 to 13-15 % in 2020;
- moderate growth of fuel and energy supply expenses of population in 2000-2020 (2.3-2.4 times mores) with the increase of real population income (3.4-3.7 times more);
- annual income from the fuel and energy complex activity will increase 1.5 time more by 2010 with the lowering of fuel energy complex part in the industrial production from 30 % nowadays to 25-26 % in 2010 and 18-20 % in 2020 with the growth of scientific and remaking sectors with low energy capacity;
- export of energy resources can grow on 45-46 % by 2020, which corresponds to the payment balance of the country.

The whole volume of capital investment in the reconstruction and development of the energy sector is estimated at $260 to $300 billion in the period 2000-2010 and at $400 to $510 billion in the period 2010-2020.

2.4. Brazil

In 2004, the total primary energy supply amounted to 200 Mtoe. The share of each fuel was as follows :

- coal : 14 Mtoe (7 %)
- oil : 85 Mtoe (43 %)
- gas : 16 Mtoe (8 %)
- nuclear : 3 Mtoe (2 %)
- hydro : 28 Mtoe (14 %)
- biomass and waste : 54 Mtoe (27 %)
- other renewables : 0 Mtoe (0 %)

Brazil’s economy is largely dependent on oil for its primary energy supply. However, renewable energies (hydro and biomass) have also a considerable share of the Brazilian energy mix with more than 41 %. Energy intensity, measured by the ratio of energy demand to GDP, has declined over the past 30 years. But the share of fossil fuels in the primary mix has increased and growth in CO_2 emissions has been on a par with growth in energy demand.

Brazil has a very dynamic energy sector. Energy efficiency in the residential and industrial sectors has considerably improved. Non-hydro renewable energy (biomass) has also deeply penetrated the power generation supply. Production of crude oil in deep and ultra deep water and od ethanol from sugar cane has beneficiated from important technological advances. Brazil is today the second world’s largest bioethanol producer (after the USA) and the first largest ethanol exporter. Brazil has vast oil proven reserves amounting at 11.2 billion barrels as well as 306 billion cubic meters of natural gas reserves. In April 2006, Brazil achieved self-sufficiency in crude oil consumption, largely as a result of investments in exploration and production. Rising domestic ethanol production and consumption, combined with a slow down in energy demand in the transport sector, has also helped to free up oil for export.

Brazil has a **considerable potential in renewable energy resources**. Not only biomass and biofuels are key energy sources, but the technical potential of hydropower totals 260 GW while the technical wind potential is estimated at 143 GW.

But Brazil faces several **energy and environmental challenges**. Natural gas demand has increased considerably over the last few years, as part of a governmental policy to diversify fuels supply. But Brazil dependence on Bolivia for its natural gas supply is huge : in 2004, 43 % of its gas came from Bolivia. With the Bolivian policy of nationalization of gas production, Brazil's supply in gas is potentially in danger. In the near future, Brazil will have to address environmental concerns related to the gas transportation and distribution infrastructure, the building of new large hydropower plants (together with financial obstacles). The sustainability of its bioethanol production is also frequently questioned.

2.5. USA

In 2004, the total primary energy supply amounted to 2 324 Mtoe. The share of each fuel was as follows :

- coal : 545 Mtoe (23 %)
- oil : 946 Mtoe (41 %)
- gas : 515 Mtoe (22 %)
- nuclear : 212 Mtoe (9 %)
- hydro : 23 Mtoe (1 %)
- biomass and waste : 71 Mtoe (3 %)
- other renewables : 11 Mtoe (0.5 %)

The US energy strategy lies on energy security. This strategy consists of three elements : the Energy Policy Act of 2005 (EPAct), the American Competitiveness Initiative (ACI) and the Advanced Energy Initiative (AEI).

EPAct majors points are :
- to diversify US energy supply and to reduce its dependence on foreign sources of energy;
- to increase energy efficiency and conservation in homes and businesses;
- to improve energy efficiency of vehicles;
- to modernize national energy infrastructure.

ACI proposes to double the federal commitment for research programmes in the physical sciences over the next ten years. **AEI** proposes to increase the US investment in alternative fuel and clean energy technologies.

To diversify US energy supply, EPAct contains several measures. A first important one is the promotion of <u>alternative and renewable sources of energy</u>. USA will fund demonstration projects of biorefineries for the production of biofuels, bioproducts and biomass-based heat and power. The Department of Energy (DOE) announced a $50 million funding for these demonstrations projects in 2006. 50 letters of intent to participate have been received with three expected awards. The projected three year biorefinery programme amounts to $160 million. DOE established a Loan Guarantee Programme providing backing for up to $ 2 billion of loans to finance new energy projects. By sharing some of the financial risks associated with new energy technologies, DOE hopes to spur industry to invest in new technologies. EPAct provides for an extension of federal tax credits for renewable energy production that reduce the cost of green electricity. For example, 27 new ethanol plants have broken ground since the enactment of EPAct. It is expected that more than 8.33 billion litres of new production capacity will be in operation in the next 18 months, bringing the US production capacity to 30 billion litres by the end of 2007.

Another measure is to encourage the expansion of nuclear energy in a safe and secure manner. It is important to note that USA has not licensed a new nuclear plant in over 30 years. This expansion will be encouraged through :

- building advanced nuclear power facilities (six new nuclear power plants are planned);
- establishing the Global Nuclear Energy Partnership (GNEP), which seeks to develop worldwide consensus on enabling expanded use of safe, economical, emissions-free nuclear energy to meet electricity demands;
- funding research to support advanced reactor technologies.

Increasing domestic production of conventional fuels is also an important measure of the EPAct. Key implementation actions include :

- creating an adequate Liquefied Natural Gas (LNG) infrastructure : LNG imports are anticipated to increase from 17 trillion litres per year to 125 trillion litres per year;
- expanding the availability of power from clean coal technologies, to dramatically reduce emissions of pollutants such as SO_2, NO_x, Hg and to improve the coal-to-product efficiency for all types of coal by 2020;
- enhancing oil and natural gas production through CO_2 injection and increasing the sequestration of CO_2;
- accelerating the commercial development of oil shale and oil sands;
- advancing methane hydrate research; methane hydrate reserves are estimated at about 5.663 trillion m^3 and could provide a large new source of natural gas by 2020.

The science and technology measure targets the hydrogen economy and biofuels research. DOE will spend $250 million to fund the creation and operation of two new Bioenergy Research Centres to accelerate basic research on lignocellulosic bioethanol and other biofuels. Harnessing the potential of fusion energy is also targeted.

To increase energy efficiency and conservation in homes and businesses is a second pillar of EPAct. DOE will publish new or amended appliance standards for 23 different products including residential furnaces and boilers, air conditioners, etc. over the next five years, in order to improve the energy efficiency of consumer products. New tax incentives have been established for consumers who buy “ENERGY STAR” products, businesses and manufacturers who use efficient building products and practices. Furthermore, EPAct calls on federal agencies to lead by example and improve their energy efficiency. Industries consuming significant amounts of energy may enter voluntary agreements to reduce their consumption.

Improving the efficiency of vehicles and encouraging the development and use of alternative fuels is another important dimension of US energy strategy. EPAct requires that by 2012, at least 210 billion litres per year of renewable fuels be blended into fossil fuels supply. Capital to build biofuel facilities is available. In 2006, 170 billion litres of ethanol will be used in the USA.

Country	Strengths	Weaknesses
China	Considerable domestic energy sources (oil, gas, coal, hydro, biomass)	Energy efficiency Environmental challenges Artificial energy economy
India	Renewable sources potential Technological capability and dynamics	Foreign dependence Economic disparity Relations with neighbouring countries
Russia	Huge energy reserves (oil, gas, coal, uranium)	Energy efficiency Environmental challenges Policies transparency and stability
Brazil	Dynamic energy sector Renewable sources potential	Environmental challenges Financial capacity
USA	Scientific and technological excellence Important domestic resources (coal, biomass) Financial capacity	Energy efficiency Environmental concern Political arrogance
EU	Scientific and technological capability Energy efficiency Imagination	Foreign dependence Political dispersion Land availability (except in Central Europe)

3. Energy in general : Projection to 2030

Petroleum and other fossil energies have already start to disappear little by little. Today, the estimation of the conventional petroleum reserves is about 40 years to the current level of consumption, as well as the gas reserves (Riedacker & al., 2006). Therefore, nowadays, to be sure to have sufficient energy resources for a long time, we have to transform the way we use energy, to power a cleaner future, to promote research and development, to finance the transition to cleaner energy, to manage the impact of climate change and to tackle illegal logging (Mandil, 2005). There are only some countries which are aware of the problem but to progress, a sudden awareness by all countries is really necessary. Fortunately, progresses concerning the exploitation and the prospecting of new petroleum fields are also conceivable in a near future what will increase the extraction capacities in the known deposits and so, the energy reserves (Riedacker & al., 2006).

In 2030, the resources will be constituted by discoveries of oil and gas reserves which have fallen in these recent years mainly because exploration has shifted to less prospective regions, by fossil fuels accounting for almost 90% of the growth in energy demand between now and 2030 and by the increase in world primary energy production by regions occurring mainly outside the OECD, mainly in developing countries (Van Hulst, 2005). Indeed, two-thirds of the increase in world primary energy demand between 2002 and 2030 comes from developing countries, especially in Asia (Kobayashi, 2005).

Even if the resources are not infinite and are decreasing strongly, the energy demand doesn’t stop to increase! According to the G8, the strong global growth has boosted energy demand and, together with capacity constraints and supply uncertainties, has led to high and volatile oil prices. It is sure that significant investments will be needed, in the short-, medium-, and long-terms, in exploration, production, and energy infrastructure to meet the needs of a growing global economy (Mandil, 2005).

A few years ago, an analysis revealed that the energy future of the European Community would be determined by a number of key long-term trends. Energy growth would be modest. There would be a growing consumer dependence on network-delivered energy and import dependency rises in all scenarios. There was also the possibility of renewables strong penetration and yet, despite improved technology and increased energy efficiency, energy demand growth remains a strong function of overall economic growth (DGE, 1996).

Developments in the European Candidate and Neighbouring Countries (CCN) will influence energy developments in the wider European energy system even if, concerning their energy and transport outlook to 2030, overall primary energy production will peak in 2010 and decline thereafter (Mantzos et al., 2003).

Concerning the final energy demand in EU-25, it is projected to increase by 29.3% between 2000 and 2030, well above that projected for primary energy needs (+19,3%). In the Baseline scenario, this demand grows by 63% in 2000-2030, while CCN primary energy needs grow by 51% in the same period. This differential reflects the significant improvements in conversion efficiency for power generation projected to occur in the CNN energy system (Mantzos et al., 2003).

With a growing energy demand and decreasing reserves, prices are continuously increasing in such a way that measures have to be taken such as increasing the energy efficiency, identifying measures to reduce demand from transport sector, promoting the development and the deployment of technology (Mandil, 2005).

In 2030, oil remains the dominant fuel around the world even if gas grows the fastest in absolute terms and non-hydro renewables the fastest in % terms. In every region of the world, oil demand grows but faster in developing countries. This growing will principally be for the transport sector (around three-quarters of the increase in demand) (Birol, 2004). And during the period 2003-2030, power sector will absorb 62% of global energy investment (Kobayashi, 2005).

Concerning the primary energy needs, they are projected to grow by 0.6% pa in 2000-2030 compared to annual GDP growth of 2.4% pa. The total indigenous production of primary energy is projected to decline continuously over the projection period (-1% pa in 2000-2030). The decline is more pronounced in fossil fuels production while renewable energy forms are expected to grow over the projection period. Indigenous production of solid fuels declines by some -50% between 2000 and 2030 (-54% for coal, -43% for lignite) driven by the increasing competitiveness of imported coal and natural gas. Crude oil and natural gas production also experiences a significant decline (-47% and -40% respectively from 2000 levels by 2030) due to the exhaustion of currently exploited reserves and the limited scope for the exploitation of new, more costly ones (Mantzos et al., 2003).

Under Baseline assumptions, the EU-25 energy system is projected to become increasingly dependent on fossil fuels. Indeed, fossil fuels account for almost 90% of the growth in energy demand between now and 2030 (Kobayashi, 2005). And as there is an increasing primary energy demand for fossil fuels, the primary production declines generating a significant growth of import dependency for the EU-25 energy system from 47.1% in 2000 up to 67.5% in 2030, an increase of more than 20 percentage points (Mantzos et al., 2003).

The share of solid fuels is projected to decline until 2015, regaining some market share thereafter. Liquid fuels are also projected to exhibit a modest decline with their market share reaching 34.8% in 2030 compared to 38.4% in 2000. On the contrary, natural gas, spurred by its rapid penetration both on the demand and the supply sides, accounts by 2030 for 32% of primary energy needs. Overall, in the Baseline case, the share of fossil fuels is projected to reach 81.8% of primary energy demand in the EU-25 energy system by 2030 compared to 79.6% in 2000 (Mantzos et al., 2003).

4. Transport fuels

The transport sector accounts for more than 30 % of the total energy consumption in the EU. It is 98 % dependent on fossil fuels with a high share of imports and thus extremely vulnerable to any market disturbance.

4.1. Fossil fuels

Liquid fuels are projected to remain the main energy carrier in the EU-25 energy demand sectors over the projection period, but growing at rates well below average, constantly losing market share. By 2030, some 80% of liquid fuels demand is projected to arise from the transport sector compared to 70% in 2000. And in the CCN energy demand sectors too, liquid fuels remain the main energy carrier over the projection period (Mantzos et al., 2003).

Oil will remain the world’s leading energy source (Van Hulst, 2005).

Most of the increase in oil demand comes from the transport sector, especially in OECD countries. In the non OECD countries, there is a more important increase in oil demand for the industry compared to the OECD countries. Demand will rise from 79 mb/d in 2003 to 121 mb/d in 2030 (Van Hulst, 2005). The global oil demand for transport increases very closely in line with GDP (Kobayashi, 2005).

The market share of the Organisation of the Petroleum Exporting Countries (OPEC) will recover strongly, exceeding 50% by 2030. They will meet most of the demand increase. But in the long term, higher oil prices would significantly reduce demand and OPEC revenues (Van Hulst, 2005).

Under Baseline assumptions, the CCN energy system becomes increasingly dependent on fossil fuels over the next 30 years. A higher use of fossil fuels, and the fall in CCN primary energy production after 2010, leads towards much higher energy import dependence (Mantzos et al.., 2003).

Concerning the oil resources, in 2020, it will remain 1/3 of the existing capacities compared to the resources of 2005 and there will also be new resources such as new discoveries, non-conventional oil, enhanced oil recovery, development of existing reserves. So, the reserve will meet demand to 2020 and moreover, we can say that the Earth's oil resources are also adequate until 2030 and beyond. And conventional production will not peak before 2030, assuming more oil is "proved up". The world's remaining proven oil reserves, between 57% and 65%, are in the Middle East while North Sea production is declining. The access to much of these world's reserves is restricted.

The Middle East strengthens its position as the World's largest oil exporter. And concerning the oil import dependence, Asia sees the biggest jump in import dependence, while the Organization for Economic Co-operation and Development (OECD) imports also continue to rise, especially in Europe (Birol, 2004). By 2030, more than 88% of primary energy needs for oil, excluding requirements for marine bunkers, will be satisfied by imports compared to 76.5% in 2000 (Mantzos et al., 2003).

Nowadays, the main investment concerning oil is made for the exploration and development. Less investment is made for non-conventional and refining (Van Hulst, 2005). But in recent years, the prospects for a major expansion in non-conventional oil production have increased. These non-conventional oil resources are found in countries outside of the Middle East. It is sure that the development of those resources will have significant implications for global oil markets. But concerning the constraints to non-conventional oil production, this production is rising sharply and yet some important issues still need to be addressed such as environment, social, technological… And the commitment of both the private sector and governments will be necessary and international oil prices will be an important factor (Birol, 2004).

Based on its 2001 forecasts, the European Commission expects road transport fuel consumption to reach 325 Mt by 2020. There should be significant differences with the period 1985-2000 : demand for gasoline should increase slightly (+ 0.6 %/year) and demand for diesel fuel should grow at a substantial rate (+ 1.1 %/year). Truck consumption will increase by nearly 80 % and road traffic by 2.4 %/year between now and 2030. In its Green Book on security and energy supply, the European Commission set an objective to replace 23 % of conventional motor fuels with alternative fuels (liquid biofuels, natural gas and hydrogen) by 2020.

Beside oil, natural gas could also become an important transport fuel (10 % of total road fuels by 2020 for the European Commission). However, the major uses of natural gas will remain for power and heat production (see here below).

High oil prices in the future will make coal-to-liquids (CTL) economic. The production of synfuels from coal is expected to grow (in the OECD countries mainly, it would reach 1800 Mtoe of coal by 2050). Concerning coal, reserves are huge when measured against the current consumption rate. However, CTL remains a fossil carbon fuel and will have to face important fossil carbon taxes.

Under the pressure of citizens, governments will have to set up policies to encourage energy changes, including emissions trading, taxes on energy and energy-related emissions or externalities (like CO2 taxes), imposed either on fuels use or on energy consumption. Such policies are already in place in some industrialized countries.

Remaining subsidies on coal or other fossil fuels should be progressively removed, with more targeted support systems taking care of the social consequences in these sectors. These policies to induce a shift of the fuel mix from fossils to alternative fuels should be complemented by policies to improve the efficiency of energy systems.

In power generation, the mix of fuels will gradually shift towards fuels with a lower or zero carbon content (away from coal and towards more gas and more renewables). However, fossil fuel resources (in particular coal and gas) will still continue to be used for power generation. While their use will significantly improve in terms of efficiency, CO2 emissions from the power sector will still be increasing at the global level. Coal will remain important only in steel and metallurgical industries. However, increasing interest, in some countries, will be paid to capture and storage of pollutants from coal burning.

In brief, coal will remain a major source of energy for power production especially in countries having access to important reserves (China, Australia, USA, Russia). However, considerable research efforts are still needed to develop CO_2 capture, storage and recycling technologies in order to make coal a neutral CO_2 fuel as much as possible. Regarding CTL, they will be considered like other oil-based transport fuels and will be heavily charged with environmental taxes. Nevertheless, they should be seen, like biofuels, as a part of the solution of the transport fuels equation : indeed, their physical and chemical composition, almost identical to present transport fuels, makes them very attractive for the motor industry and car users who do not like to change their driving habits (hydrogen for cars will face this problem).

4.2. Renewables for transport

Liquid biofuels market share is also increasing, thanks to the EU 2003 directives[1] : this share should reach 5.75 % (18 Mtoe) of the total transport fuels by 2010. To give an indication of the size of the task, biofuels accounted for only 0.45 % (about 2 Mtoe) of EU road transport energy consumption in 2002. However, although absolute levels are low, the production of liquid biofuels is increasing rapidly. Studies indicate that biofuel crops would take up between 4 and 13 % of the total agricultural area in the EU25, depending on the choice and technological development, if the 5.75 % target is to be fully met and all crops are home grown (Kavalov, 2004; EEA, 2004; Francis, 2006). The lowest land use would come from an equal mix of sugar beet and woody biomass, while the most land intensive single crop is rapeseed and the most land intensive combination is the one containing wheat. Biodiesel from rapeseed predominates with a production of 2 Mt in 2004, mainly in Germany, France and Italy. Ethanol is mainly produced from wheat, and to a lesser extent sugar beet, in France, Spain and Sweden, with a total of almost 500,000 tonnes in 2004.

[1] Promotion of biofuels for transport applications by replacing diesel and petrol to the level of 5.75 % by 2010 (Directive 2003/30/EC) accompanied by detaxation of biofuels (within Directive 2003/96/EC).

Regarding bioethanol, it is true that the energy efficiency of bioethanol production from corn, wheat or sugar beet is significantly lower compared with sugar cane. The use of sugar cane bagasse as a fuel for the distillery make this route very efficient and we should certainly not dismiss bioethanol import from tropical countries as a part of the solution to solve our future transport fuels problems in Europe. Two remarks :

1. Energy efficiency should not be considered only at the level of the bioethanol production plant. The whole chain, from sugar cane cropping (including fertilizers) to bioethanol transport from tropical countries to Europe, must be analysed. In particular, the environmental and socio-economic impacts of intensive sugar cane cropping for bioethanol must be analysed, converted in money value and their cost must be included in the price of imported bioethanol. (ex : the bioethanol programme in Brazil has lead to terrible damages on soil conditions, biodiversity and social condition of Brazilian farmers).
2. The production efficiency of bioethanol from wheat and sugar beet can definitely be improved through the concept of biorefinery. This is the case of a new bioethanol plant that is under construction in Belgium (BioWanze) : this plant will produce bioethanol from sugar beet surpluses during a couple of month and from wheat during the major part of the year. Wheat bran will be burned in a boiler to produce heat and electricity for the sugar mill and the distillery which will be operated all year round. The electricity surpluses will be sold to the grid as green electricity benefiting from green certificates. This will not increase sugar beet and wheat crop yields, but will significantly improve the bioethanol production efficiency of the plant.

Regarding biodiesel, as mentioned here above, the motor industry and car users do not like to change their driving habits and the car industry will make everything possible to keep diesel engine type vehicles. The second generation biofuels like DME or synfuels from biogas (diesel like transport fuels) benefit from considerable research efforts, supported by the car industry.

Will this have a significant impact on small farmers in Europe ? Will these small farmers start to produce bioethanol or biodiesel in “home” distilleries or oil mills in case of transport fuels high taxation or erratic prices ? Some will do it definitely, but they will be only few of them. Indeed, technology level, fuel quality requirements, investment costs will be major obstacles. However, there is a strong need for farmers involvement in the biofuels processing chains : the added value is not gained at the crop production level but at the transformation level (currently, the ratio is about 1:50). Farmers must thus become stakeholders of future biorefineries - biofuels processing units. In Europe, these biorefineries will not be “petrol like biorefineries” but rather rural industries of a smaller size.

Taking into account the need to increase the production of other energy crops in order to meet the renewables targets referred to above, the total area needed for energy crops is estimated to be of the order of 11-28 % of current agricultural area in the EU25.

Liquid biofuels may provide a solution to transport and to greenhouse gases mitigation. Estimating the net impact of liquid biofuels on oil use for transport and on GHG emissions is a complex issue. One way to estimate this is can be achieved through the assessment of the full fuel cycle or “well-to-wheels” greenhouse gas emissions. Table 3 gives some values available in the literature for various liquid biofuels.

Liquid biofuels can contribute significantly in the reduction of greenhouse gas emissions compared to gasoline and diesel fuels on a “well-to-wheels” basis. Furthermore, recent studies tend to make estimates towards the higher reduction end of the range, reflecting efficiency improvements over time in both crop production and ethanol conversion. From the already commercially available processes, ethanol from sugar cane shows considerable reductions in GHG emissions; however, few studies are available on estimates for ethanol from sugar cane. In the future, ethanol from wood (enzymatic hydrolysis) and biodiesel from wood (gasification) might be the most attractive processes regarding GHG emissions.

Liquid biofuels contribute not only to GHG emissions reduction but can also play a major role in a low-carbon economy. As emphasized by the Stern Review, the transition to a low-carbon economy will bring challenges for competitiveness but also opportunities for growth. The Stern Review estimates that markets for low-carbon energy products are likely to be worth at least $500 billion per year by 2050. Liquid biofuels (as well as other biofuels), with their neutral carbon cycle, should be positioned to take advantage of these opportunities.

Table 3 : Well-to-wheels GHG emissions compared to base (gasoline for ethanol, diesel for biodiesel) vehicle per km travelled for different liquid biofuels (after IEA, 2004).

Liquid biofuel	**Well-to-wheels GHG emissions (percent reduction)**
Commercial liquid biofuels processes	
Ethanol from corn	21 to 38 %
Ethanol from wheat	19 to 47 %
Ethanol from sugar beet	35 to 56 %
Ethanol from sugar cane	About 90 %
Biodiesel from oil-seed crops	44 to 66 %
Advanced liquid biofuels systems	
Ethanol from cellulosic feedstock	57 to 107 %
Ethanol from wood (enzymatic hydrolysis)	101 to 112 %
HTU biocrude	60 %
Biodiesel from wood (gasification/Fischer Tropsch)	108 %
DME from wood (gasification/DME conversion)	89 %
Hydrogen from wood (gasification)	95 %

5. Electricity and heat production

An overview of the present electricity generation in the EU25 is given in table 4.

Table 4 : Electricity generation in the EU25 in 2000 and 2005 (after Mantzos and Capros, 2006).

	2000		**2005 (estimates)**	
	GWh_e	**%**	**GWh_e**	**%**
Nuclear	921 193	32	974 239	31
Hydro and Wind	359 249	12	412 484	13
Thermal (incl. Biomass)	1 620 392	56	1 790 623	56
Total	**2 900 835**		**3 177 346**	

The status of electricity generation in the EU25 has not evolved between 2000 and 2005. The major source of electricity is thermal generation, using more and more natural gas and biomass and less and less coal. These sources represent in total more than 50 % of electricity production, even if in some European countries, like Lithuania, France, Slovakia or Belgium, nuclear is the major source of power generation. Hydro and wind have slightly increased their market share, as a result of the significant effort made by many EU State Members to increase the production of electricity from renewable sources, such as wind, hydro and biomass, following the impulsion of the European Commission[2].

Electricity generation in the EU25 will considerably increase by the year 2030. Indeed, the potential for electricity imports from outside the EU is very limited; hence, the soaring electricity demand will require a considerable growth in power production in the EU. According to Mantzos and Capros (2006), IEA (2006), this will be conducted through a considerable change in the sources of power production : natural gas and renewables will significantly increase while nuclear and coal will lose market shares. Furthermore, a increase in CHP capacities is also foreseen.

Natural gas, spurred by its rapid penetration both on the demand and the supply sides, accounts by 2030 for 32% of primary energy needs even if in the long run, demand growth for natural gas decelerates due to limitations in infrastructure but also to technological factors (Mantzos et al.., 2003). Most of the increase in gas demand comes from the power sector, especially in OECD countries (Kobayashi, 2005).

Concerning the proven natural gas reserves, the ultimate remaining resources are an estimated 453-527 thousands cubic meters (Birol, 2004). These gas reserves, concentrated in the Middle East and the transition economies, are equal to 66 years of current production (Kobayashi, 2005).

The increasing dependence of the EU-25 energy system on energy imports (more than two thirds of primary energy needs in 2030) raises significant concerns as regards the security of supply in the long run. This is especially the case for natural gas given the increasing dependence upon gas imports from a limited number of suppliers and the need for long distance transport infrastructure, as well as the increasing natural gas demand in other world regions. Indeed, this dependence is projected to increase sharply, reaching 81.4% by 2030 compared to 49.5% in 2000 (Mantzos et al., 2003).

The world coal market remains well diversified with abundant supplies (Mantzos et al.., 2003). Coal will continue to play a key role in the world energy mix-virtually and all the increase in demand will be for power generation. Fortunately, Australia has the potential to greatly increase its exports to overcome the steady increase in coal trade due to the industrialisation of developing Asia and the decline of coal mining in Europe (Kobayashi, 2005).

Up to 2030, nuclear capacity increases in absolute terms but its share of the generation mix falls as new capacity is offset by retirements (Kobayashi, 2005)

Renewable systems forms are projected to remain one of the fastest growing fuels in the EU-25 energy system with natural gas, growing at rates 3 times faster than overall energy needs over the projection period (+1.7% pa for natural gas, +1.9% pa for renewable). Renewable energy forms, such as solar energy used in water heaters, grow also quite rapidly

[2] Promotion of renewable energy-based electricity generation from 14.0 % in 1997 to 21.0 % in 2010 for the EU25 (Directive 2001/77/EC). Promotion of cogeneration of heat and electricity (Directive 2004/8/EC).

(5.7% pa in 2000-2030) but they remain insignificant proportionally to the overall final consumption (Mantzos et al., 2003). In 2001, total biomass use for energy purposes was 56 Mtoe. It was estimated that, to achieve the 2010 RES 12 % target, an additional 74 Mtoe biomass would be required, with the split between sectors as follows : electricity 32 Mtoe, heat 24 Mtoe, liquid biofuels 18 Mtoe. Total biomass use for energy would therefore be 130 Mtoe by 2010.

Concerning the non-hydro renewables, they have yet to gain a significant share in the power-generation fuel mix in OECD countries but their share will increase substantially through 2030, especially in OECD Europe (Kobayashi, 2005).

6. Disruption scenario

Petroleum reserves on earth are not unlimited. But it has always been very difficult to determine with accuracy the time of their end. Indeed, the figures on petroleum reserves are enormous. Furthermore, petroleum reserves constitute a subjective notion : it is a simple declaration made by a petrol company corresponding to what this company is sure to extract from the substratum according to the present geological, technical and economic information it has. Petroleum reserves vary according to their definition ("proven", "uncertain", "conventional" or "non conventional"), itself varying from one country to another. They vary also according to the extraction level planned by the company, which depends on the technologies used and on the crude oil price. The reserves vary also according to the declarations of the producing countries and petrol companies following their strategies and of the geopolitical context of the world. As an example, the major OPEC countries have seen their reserves growing between 1985 and 1990 from 169 to 258 billion barrels for Saudi Arabia, from 30 to 92 billion barrels for Abu Dhabi, from 48 to 92 billion barrels for Iran, from 44 to 100 billion barrels for Iraq. The problem is that not any new significant oil reserve has been found in these countries during this period ! Some experts estimate that about 50 % of the oil reserves of the major OPEC countries are dubious or false.

The world oil reserves are estimated at 1 188.6 billion barrels; the daily world consumption is in average 86.96 million barrels. If oil is used at the same rate (no increase, no decrease), the existing reserves will be exhausted by the year 2043. But this calculation is too simple :

A. The Association for the Study of the Peak Oil (a group of scientists and petrol companies retired managers) estimates the actual reserves amount to 777 billion barrels; these reserves would be exhausted by the year 2031 if we consume oil at the same rate as today.

B. The world economic growth, and especially the development of China and India, would require a doubling of the world oil consumption. The end of the oil reserves could thus come sooner than 2031 or 2043.

C. There has been no major oil reserve discovered recently : we live today with the reserves discovered 30 years ago. Presently, one discover 1 new barrel for 4 to 6 consumed.

As a consequence, in a near future, the supply and demand law of petrol will be influenced not only by political strategies but also by geological issues. Before reaching the end of petrol reserves, we will face a period of regular increase of petrol prices. The French bank Ixix CIB (Caisse d'Epargne) thinks that it is not unreasonable that the price of one oil barrel could reach US$ 380 by the year 2016. With such high prices, oil will be no more a traditional fuel but a precious substance devoted to high value or vital conversion processes.

Increasing oil prices and the end of oil reserves will also have a direct impact on other fossil fuels such as natural gas, coal and uranium, which will also become more expensive. The global economy depends entirely on a cheap energy. If this latter changes, the economy changes and the society too : proximity values will replace mobility values.

In brief, the questions in front of us at the horizon 2030 are :

- There is no more oil on earth or oil is unaffordable as a transport fuel : on which fuel are we going to run our cars and trucks ? How will developing countries (and industrialized countries too) sustain their economic development ? Which substances will replace petroleum for the production of materials and chemicals (plastics, textiles, solvents, resins, etc.) ?

- With soaring prices of other fossil fuels, with uranium facing severe people oppositions, how shall we produce the electricity and heat that our economies (both industrialized and developing countries) badly need in order to continue to grow ?

As the EU25 are by far not self-sufficient regarding energy and fossil resources supply, they need to import a lot of them; if nothing changes within the next 15 years, Europe will be caught in a trap by 2030. The rational use of energy (building thermal insulation, increased use of public transport, combined heat and power, etc.) or nuclear electricity will not make the EU25 capable to face the energy situation, not to speak about material and chemical resources. Consequently, in order to decrease the EU25 dependency on energy and industrial resources imports while sustaining economic, environmental and social development, these questions have direct implications on agriculture and forestry : agriculture and forest will become the new major sources of energy and substances.

7. Implications on agriculture and forestry research

7.1. Biomass production

Biomass resources consist of residual biomasses (straw, forest residues, manure, organic industrial residues, wood industry residues, etc.) and dedicated crops (short rotation coppice, miscanthus, non food-rapeseed, -sugar beet, -cereals, etc). These two groups of biomass resources require different research strategies.

In the first case, we are in the presence of existing organic components and of raw material whose composition is not flexible. At this level, research and development should be focused on the identification of the outlets and the improvement of the processes (old or new) likely to generate a sufficient added value and profitability to justify their transformation. In this case, the raw material nature conditions the processes.

In the second case, we can focus on the development of applications and new products in relation with the market demands. Their characteristics and their manufacturing processes will condition the nature of the raw materials used and thus the nature of the biomass required. That is important to notice that the downstream part of the production chain (market, technical requirements of the processing industry...) conditions its upstream part (the sector of raw materials production).

A. Residual biomass

Residual biomasses can be used for a wider variety of applications including bioproducts (pulp and paper, boards, animal food, …) and bioenergy (heat and/or electricity, transport fuel). The final objectives of interdisciplinary research in this area are mainly :

- the supply of quality biomass feedstock tailored to specific applications;
- the reduction of supply costs;
- the public acceptance of residual biomass use for products and energy, and their relative socio-economic and environmental impacts.

To achieve these final objectives, research must be carried out in three major fields :

- to increase the knowledge on the quantities and the physico-chemical characterisation of actually available residual biomasses;
- to improve the logistics (harvesting, storage, transport) and the pre-treatment of biomass feedstocks (cost reduction, energy and physical density increase, moisture content reduction, efficient recovery, reduced environmental impact, increased added value);
- to develop a comprehensive understanding of socio-economic and environmental impacts.

Table 5 : Indicative research areas for residual biomass.

<table>
<tr><th>SHORT TERM</th><th>MID TERM</th><th>LONG TERM</th></tr>
<tr><td>Develop a methodology for permanent survey (total + available) of residual biomasses, including organic waste</td><td></td><td></td></tr>
<tr><td colspan="3">Conduct a permanent survey + physico-chemical characterization of residual biomasses, including organic waste</td></tr>
<tr><td>Identify new solutions for organic industrial waste (dairy, green)</td><td>Test and demonstrate new solutions for organic industrial waste, increasing quality</td><td></td></tr>
<tr><td>Perform research in harvesting costs reduction</td><td rowspan="3">Test and implement new systems of storage, mechanical harvesting, pre-treatment</td><td rowspan="3">Disseminate harvesting, storage, pre-treatment and transport systems that reduce products costs by 30 (?), 40 (?), 50 (?) %</td></tr>
<tr><td>Improve storage systems to increase storage life, reduce costs while keeping quality of feedstocks</td></tr>
<tr><td>Perform research in pre-treatment technologies (drying, size reduction, energy density, enzymatic,…)</td></tr>
</table>

Identify low cost/low emissions transport systems		
Perform research in MSW organic fraction sorting	Test and demonstrate sorting systems of the organic fraction of MSW	
Develop a calculation methodology of biomass logistics socio-economic impacts		
Assess the socio-economic and environmental impacts of the new logistics systems		

A first priority is to install a monitoring system to follow the quantities, the availability and the characteristics of residual biomasses including organic waste. This monitoring is essential for industries and market development (which quality biomass resource is available and where).

B. <u>Dedicated crops</u>

As for residual biomasses, dedicated crops (or non food chains) can be used for a wider variety of applications including bioproducts (pulp and paper, boards, animal food, green chemistry…) and bioenergy (heat and/or electricity, transport fuel). The final objectives of interdisciplinary research in this area are mainly :

- the economic viability of the non food chain;
- a reasonable profit for farmers;
- the public acceptance of dedicated crops use for products and energy, and their relative socio-economic and environmental impacts.

In this sector, the top short term priority is to reduce the cost of raw materials (carbohydrates, starch, oils, lignocelluloses) supplied to industries. In the short term, cultivated biomass for non food applications (bioproducts and bioenergy) will be mainly traditional agricultural crops such as sugar beet, cereals, oil plants. But in a more longer term, biomass resources will come from other crops, dedicated to non food applications. These crops will include oil, sugar and cellulose/hemicellulose-producing crops that can provide high energy content and/or usable plant components. To achieve the final objectives for dedicated crops, research must be carried out in three major fields :

- to improve the knowledge in crops biochemistry and genetics in order to increase the yield, the energy content and the valuable components of the crops;
- to improve the agronomic practices, including soil protection, reduction of environmental impacts, farmers profit,…;
- to develop a comprehensive understanding of socio-economic and environmental impacts.

Table 6 : Indicative research areas for dedicated crops.

SHORT TERM	MID TERM	LONG TERM
Perform economic studies on biomass cost vs petrol, viability of food agriculture vs non food agriculture, land availability including surfaces of contaminated soils, use of subsidies in agriculture	Perform eco-political studies to develop instruments to measure the effect of political decisions (CAP) on non food agricultural productions and on land availability	
Perform research on specific crops for bioremediation, including specific agronomic practices	Test and demonstrate specific crops for bioremediation Perform research on “contaminated crops” pre-processing for components and energy extraction	Test and demonstrate “contaminated crops” pre-processing for components and energy extraction
Perform research on impacts of non food single crop farming on pests and diseases	Test and demonstrate improved agronomic practices with low environmental impact and enhanced production	Disseminate improved agronomic practices with low environmental impact and enhanced production
Develop best practices for non food crops farming (soil protection, water use, water treatment, pesticides, fertilizers)		
Perform research on pre-treatment methods to increase chemical and energy densities	Test and demonstrate pre-treatment methods to increase chemical and energy densities	Disseminate pre-treatment methods to increase chemical and energy densities
Perform research on plant biochemistry, molecular biology and genetics to increase non food crops, including trees, total biomass yield, biomass quality, high energy content, high value molecules yield (bioactive molecules, proteins, fatty acids, etc.)	Test and demonstrate non food crops, including trees, with increased total biomass yield, biomass quality, high energy content, high value molecules yield (bioactive molecules, proteins, fatty acids, etc.)	Disseminate non food crops, including trees, with increased total biomass yield, biomass quality, high energy content, high value molecules yield (bioactive molecules, proteins, fatty acids, etc.)
Perform research on identification and selection of new crops for non food applications		Test and demonstrate new crops for non food applications
Assess socio-economic and environmental impacts (especially vs petrol and petrol products)		
Translate fundamental knowledge gained from model organisms to non food crops, including trees		

Both biomass resources (residual biomass and dedicated crops) are not “dense”. Transporting them on long distances can be very expensive. Pre-treatment processing close to biomass production sites is essential to reduce raw material costs at conversion plant gate. Pre-treatment technologies must be identified and further improved according to bioprocesses and bioenergy technologies needs. Pre-treatment technologies research must focus on :

- upgrading agricultural and forest lignocellulose co-products (straw, wood, …) – hydrolysis, other splitting up processes;
- plant oil refining through enzymatic processes;
- increasing storage period of biomass raw materials.

In addition, techno-economic models must be developed to price transport, pre-treatment and storage constraints and to optimise any biomass chain concept (to find a compromise between the scale effect for the conversion unit and the distance for raw material supply).

7.2. Transport fuels

The current production of liquid biofuels in the EU25 is about 2 Mtoe, which is less than 1 % of the market of transport fuels. Although there have been marked increases in production and use in recent years, the market share is at risk of failing the EU policy target for 2010 of 18 Mtoe used in the transport sector. Between 2000 and 2030, energy demand for passenger transport will increase by 14 %, whereas freight transport will increase by 74 % (Mantzos et al., 2003). Based on this growth, a strong increase in the need for middle distillate fuels for transportation is expected, diesel fuel mainly for transport, kerosene for aviation. The demand for diesel fuel is expected to grow by 51 % from 2000 to 2030, due to the strongly growing need for freight transport services and an increasing number of diesel passenger cars. Gasoline consumption, on the other hand, is forecast to even shrink in the last decade of the time period. For kerosene, an increase of nearly 60 % has to be expected.

Table 7 : Projected transport fuel requirements for EU25 (after EMCC, 2004).

(in billion litres)	**1990**	**2000**	**2010**	**2020**	**2030**
Gasoline	132.1	129.8	142.1	145.4	141.6
Kerosene	29.2	45.1	53.0	63.3	72.0
Diesel oil	103.0	147.7	182.1	207.6	223.6
Total	**264.3**	**322.6**	**377.2**	**416.3**	**437.2**

If we consider present scenarios or visions built by the European Commission or the International Agency (BRAC, 2006; IEA, 2004), we have an idea of the quantities of liquid biofuels to be produced (table 7).

Table 8 : Production of liquid biofuels and cropland requirements according to present scenarios and existing fuels (bioethanol from sugar or starch, biodiesel from vegetable oil).

	2010		2020	
	Ethanol	Biodiesel	Ethanol	Biodiesel
Displacement of conventional fuel (% energy basis)	5	5	10	10
Biofuels production				
- Total gasoline/diesel use (billion litres)	157.8	178.7	164.4	206.3
- Required biofuel production (billion litres)	11.4	10.2	23.2	23.3
Cropland requirements and availability				
- Average biofuels production yields (l/ha)	4,800	1,400	5,900	1,600
- Cropland area needed for production of biofuels (million ha)	2	7	4	15
- Total cropland area (million ha)	49	49	49	49
- Percentage of total cropland area needed to produce biofuels for each fuel	5 %	15 %	8 %	30 %
- Percentage of total cropland area needed to produce crops for both fuels	20 %		38 %	

The message is this table is that, in order to substitute 20 % of the fossil transport fuels by bioethanol and biodiesel in the year 2020, the EU25 should allocate 38 % of its cropland to grow sugar beet, cereals and rapeseed for liquid biofuel production. The economic, energy and environmental results of the 1^{st} generation liquid biofuels are not decisive and cannot make them a real alternative to fossil transport fuels (IEA, 2004; Sourie et al., 2005). If the target is to substitute 50 % of fossil transport fuels, the EU25 needs 95 % of its agricultural surface for production of liquid biofuels, not to speak about a situation where we should replace 100 % of fossil transport fuels. This is unfeasible and totally incompatible with the production of food, which remains the major role of agriculture. Of course, one solution is to import massively liquid biofuels from tropical countries where the crops productivity (sugar cane, palm oil) is higher than in Europe. But, is this compatible with climate change, preservation of biodiversity and environment ?

Consequently, we should look to the present liquid biofuels (bioethanol from sugar and starch, biodiesel from oil plants) only as preliminary solutions to open the market of biofuels. To be ready in 2020, the research programmes administrators and policy makers should seriously consider here and now how to effectively support the development of the liquid biofuels of the second generation, such as bioethanol from lignocellulosic biomass or DME (dimethyl ether) from synthesis gas. These 2nd generation liquid biofuels will be able to limit the needs in croplands, will have higher energy yield and will be cheaper. Ideally, that should be as similar as possible to present transport fuels, in order to avoid any big "technological jump" for the car users.

The characteristics of lignocellulosic biomass are different from those of grain and sugar crops, and so the technologies for converting them to biofuels must be modified appropriately. The sugars and starch from sugar/grain crops are relatively easy to ferment into ethanol, and the oils from oil-seed crops are easily converted to biodiesel. By comparison, the major building blocks of lignocellulosic biomass are more difficult to convert to liquid biofuels. The major building blocks of lignocellulosic feedstocks are 6-carbon sugars stored as cellulose, 5-carbon sugars stored as hemicellulose, and lignin, a complex phenolic material. Technologies must be able to effectively utilize these components for efficient biofuels production.

A. Ethanol from lignocellulosic feedstocks

The focus of research is to produce fermentable 5- and 6-carbon sugars that can subsequently be converted to ethanol. Basic processing steps include pretreatment that both disrupts the structure of the woody biomass and releases 5-carbon sugars from hemicellulose, hydrolysis of the cellulose to form 6-carbon sugars, and the fermentation of the sugars to ethanol.

The pretreatment step, while relatively well understood, remains a significant technical challenge due to the heterogeneous nature of lignocellulosic feedstocks. Several different types of processes, including steam explosion, ammonia steam explosion, dilute acid and concentrated acid treatments, have been studied extensively for application to agricultural residues, but these are less well understood when applied to forest residues. The forest materials typically have lignin contents that inhibit subsequent hydrolysis. To provide better conversion of these feedstocks, newer pretreatment approaches including enzymatic pretreatment and others must be examined.

The fermentation step for lignocellulosic biomass also faces unique challenges. While the 6-carbon sugars are readily fermentable by commercially available microorganisms, these organisms typically do not convert 5-carbon sugars. R&D activities have created organisms capable of generating ethanol from either the 5-carbon or 6-carbon sugars. However, the lignocellulosic materials contain a greater range of sugars and other products, some of which can inhibit the fermentation reaction.

At various stages throughout the process, fractionation or separation of the chemical components of lignocellulosics is important. Improvements in separation processes and product recovery are helping to improve process efficiencies. Improved fractionation technology will provide industry with the ability to utilize more variable biomass sources of lignocellulosics, including urban waste, agricultural and mill residues, as well as traditional agriculture and forest crops and residues.

Additional RD&D activities must be conducted to develop bio-based products from ethanol-based processes. Bio-based products provide additional revenue streams to help support biorefineries economically. Like the grain-based facilities of today, the lignocellulosic-based facilities of the future will also require a variety of products to provide adequate economic return.

Successful implementation of the advanced technologies is expected to lead to significant reductions in the cost of producing ethanol. The National Renewable Energy Laboratory estimates that the selling price of ethanol from lignocellulosic biomass could be reduced to less than $0.25/litre with appropriate technical progress. As a result of the RD&D progress over the past several years, a number of pilot- or demonstration-scale facilities are being planned or built by industry. These initial facilities are typically utilizing agricultural biomass resources.

In addition to the interest in biological conversion of lignocellulosic biomass, there is also substantial current interest in the thermal conversion of this resource to ethanol or methanol. Thermal conversion technologies offer the potential of high conversion efficiencies because they utilize all the major components of the lignocellulosic resource. In the thermochemical conversion process, biomass would be gasified to form a synthesis gas composed primarily of carbon monoxide and hydrogen. The synthesis gas produced by biomass gasification would subsequently be used to produce ethanol or methanol, using either a catalytic or biological process, or a combination of both. The catalytic process would be similar to those used in the petrochemical industry to produce chemicals such as methanol. As an alternative, the synthesis gas could potentially be converted to ethanol using micro-organisms.

B. Biodiesel

Biomass-based diesel can also potentially be produced by the thermochemical conversion of biomass utilizing gasification technologies. As discribed above, the biomass feedstock would be gasified to produce a synthesis gas composed primarily of hydrogen and carbon monoxide. The synthesis gas would then be converted to hydrocarbon products in the diesel range using catalysts based on the existing Fischer-Tropsch process. The product, while different from that made from vegetable oils, would directly replace petroleum diesel.

C. Other biofuels

The shift to lignocellulosic biomass feedstocks and more efficient conversion pathways provides the opportunity to consider ‘next-generation’ biofuels. These fuels would be produced by efficient processes that could be based on biological or thermochemical pathways, or a combination of both. Highly efficient processes would produce more biofuel per quantity of biomass resource, therefore reducing the land area requirements for these fuels. Such fuels might include methanol, dimethyl ether (DME), methyl-tetrahydrofuran (MTHF), fuels based on biomass pyrolysis, or others. Methanol is of interest because of its potential for powering fuel cells, and DME production has recently been evaluated in Europe.

Biomass is a potential source of hydrogen for fuel-cell powered vehicles. Hydrogen is viewed by many as an important transportation fuel in the future, and biomass resources provide a renewable feedstock for its production. Biomass provides the flexibility to address both the near term needs of the transportation sector and the longer-term opportunities for new fuels.

7.3. Electricity and heat

Technologies to produce heat and/or electricity from biomass are fully commercially proven today. In the short term, these technologies, such as combustion or anaerobic digestion, will enjoy efficiency improvements, advanced reactor design and a better understanding of their socio-economic benefits thanks to a wider implementation.

However, new technologies such as advanced combustion, thermal gasification, pyrolysis, still need a lot of research support to become mature and reach the stage of full commercial competitiveness. Research targets include thermal gas cleaning (tar), bio-oil refining, aerosols limitation. Standardisation of solid biofuels will be also a key component for commercial development of these technologies (see here above biomass production).

7.4. Bioproducts and green chemistry

In the vision of a sustainable knowledge-based society, green chemistry and white biotechnology will play a major role beside bioenergy. As pointed out by Europabio (2005), green chemistry and white biotechnology will not only reduce our dependence on – or replace fossil resources, they will also reduce the use of hazardous substances, minimise energy consumption and waste generation. Guillou (2006) insists on the fact that the development of white biotechnology should also broaden the changeability of bioproducts : control of the length of fatty acids chains, lignin, starch and proteins structure. Adaptation of plants to their final use, including splitting, as well as the development of catalytic conversion systems will make biotechnology processes more specific, more efficient and even more environmental friendly.

Nine research areas have been defined for industrial biotechnology on a European level:

- Novel enzymes and micro-organisms
- Fermentation science and engineering
- Metabolic engineering and modelling
- Biocatalyst function and optimisation
- Microbial genomics and bioinformatics
- Innovative down-stream processing
- Bio-based performance and nanocomposite materials
- Biocatalytic process design
- Integrated biorefineries

A. <u>Novel enzymes and micro-organisms</u>

Industrial biotechnologists are continuously looking for novel microorganisms and enzymes. Finding the most appropriate microorganisms and enzymes are key points for the economic viability of new bioprocesses and bioproducts. The screening is, by nature, an essential step that requires an important investment. Not only the maintenance and build-up of the culture collection should therefore be supported, but also the screening from the environment should be encouraged. Particularly, research should be directed towards extremophiles and the use of metagenomics for screening.

B. <u>Fermentation Science and Engineering</u>

Fermentation science and engineering constitutes the workhorse of most bioprocess industries as well as of those industrial sectors making use of one or a few bioprocessing steps in their flow-sheets. This discipline is at the cross-section of life sciences, chemistry and chemical engineering and has, as its focus, the implementation of a cellular (prokaryotic or eukaryotic) culture within a bioreactor system on a production scale. Although mature in comparison with emerging biotechnological fields such as genomics and metabolic engineering, fermentation science and engineering is profiting from advances in specific areas, including computerassisted scale-up, process modelling and control. The need for flexibility within established bioprocess industries (brewing, antibiotic fermentations or food fermentations) dictates fairly standard bioreactor design (primarily stirred tanks and, to a lesser extent, bubble columns or airlift vessels) and mode of operation (mostly batch or cyclic fed-batch), whereas new and upcoming applications (biopharmaceuticals from animal cells, biotreatment of toxic wastes) may require innovative reactor design and operating regime (continuous perfusion, fed-batch with adaptive profile feeding). The case of animal cell technology is of special interest because the high unit price of the end product (therapeutic antibody, cytokine, etc.) could well justify the development of unconventional bioreactors and sophisticated process control schemes.

Since the modern tools of bioinformatics and genome research will lead to more and more optimised high-performance strains of micro-organisms fermentation engineering has to keep pace with this development. Although there has been quite some success in modelling fermentation processes on different scales, much more effort is needed until these tools may be applicable for routine process development. Shortening of process development time is required. This includes, besides a knowledge-based approach, the development of highly parallel cultivation systems in order to be able to converge the development process rapidly into an optimised solution. This also means that highly parallel cultivation systems on small scale would have to be undertaken under conditions met in industrial fermenters. The engineering of micro-reactors is entering biotechnology. This includes the development of low-cost fermenters, alternative novel reactor concepts and the development of simulation tools for modelling fermentation processes on different scales. Further improvements may result from developing processes working at low pH and high temperature. The application of specific stresses may sometimes be beneficial. Particular attention should be paid studying the physiology of micro-organisms under conditions of extremely slow growth, because the normal fermentation process should yield a maximum of product and not of microbial biomass. The engineering tools should be used for designing strategies for process intensification.

C. Metabolic engineering and modelling

Metabolic engineering is the improvement of cellular activities by manipulation of enzymatic transports and regulatory functions of the cell, typically using recombinant DNA technology. However, the most common approach for optimisation of microbial metabolism is to make an educated guess based on biochemical knowledge of the synthesis pathway(s) in order to find a modification that might improve or redirect the metabolic flux to a particular compound. This then has to be put to practice by genetically modifying the micro-organism after which the assumption has to be checked experimentally. Unfortunately, this can only be done after the time-consuming process of genetic modification of the production strain. Furthermore, one is often exposed to the unpleasant phenomenon that the complex cell metabolism is designed to prevent overproduction, which often leads to unexpected and counterintuitive findings when applying the modifications in practice. Consequently, in most cases a relatively large number of modifications at different sites in the cell's metabolism are required to obtain a good result. At present, it typically takes about 5 or more years to obtain a microbial production strain that performs more or less satisfactorily...

Mathematical models of microbial metabolism can be a great help to underpin the effects of single modifications as it helps to understand the metabolic interactions and the regulatory mechanisms in the complex metabolic network.

For an optimal application of the industrial potential of micro organisms the combination of genomics techniques with evolutionary engineering (selection of mutants equipped with new better and more enzymes) is needed. The link between genomics, proteomics and metabolomics is obvious because these disciplines strongly interact with each other. Integration of these different fields is therefore of prime importance to completely unravel and, eventually, predict microbial metabolism.
High throughput screening of mutants, is required to shorten the development phase of a new process or product.

D. Biocatalyst function and optimisation

Nature has made enzymes into catalysts that supersede chemical catalysts by far in terms of higher reaction rates, milder reaction conditions, and greater reaction specificities resulting in less unwanted side products. Moreover, the catalytic activity of an enzyme is mostly regulated by factors associated with parts of the polypeptide chain outside that of the active site. All these features are the result of a process of natural evolution and selection dictated by the needs of cells and organisms to survive in their environment. Man has now developed methodological tools, however, that may speed up a further evolution of enzymes into still more specific biocatalysts with still higher catalytic efficiencies and greater stability. Since many of the thousands of enzymes catalyse the formation of chemical products considered to the beneficial to man, it is evident that 'directed evolution' alone and/or in combination with techniques of protein engineering through which specific amino acids can be replaced by more suitable ones, will be one of the central issues in the setting up of bioprocesses and the production of bioproducts suitable for man. Molecular biology methods have become very significant for biocatalyst discovery (i.e. metagenome approach) and improvement (i.e. directed evolution).

E. Microbial genomics and bio-informatics

The explosion of microbial sequencing projects is opening up a huge reservoir of novel catalysts as well as a unique *in silico* resource of studying the genetic fundamentals of strain design and evolutionary history. This resource provides direct access to multiple variants of already identified functions that can serve as input for shuffling experiments, as functional equivalents under different conditions (such as genes from hyperthermophiles), or as input for the design of multi-domain enzymes.

Acquiring genes for combinatorial biocatalysis or pathway design will become a matter of simply selecting appropriate algorithms to search a permanently expanding genomic space. Combined with our concomitantly improving ability to synthesize artificial genes for ever larger DNA-segments, the assembly of artificial but suitably designed pathways for the selected production host will be dramatically facilitated.

Next, we are also able to rationally and efficiently study the function of genes of so far unknown function in targeted and system-level gene disruption and over-expression studies, which should rapidly lead to a much more complete understanding of the available white biotechnology model organisms. This will also require novel methods to assess the behaviour of the resulting mutant strains beyond the digital statement of growth/no growth.

Furthermore, advancing our ability to integrate the context of a given DNA segment, inspired by a wealth of possible ways of realization from the already sampled genomic space, into the annotation of genes will also improve the functional assignments. Beyond the gene-level, drafting from a large genomic space will also allow to much more profoundly delineate the structure of more complex traits that are important to industrial biotechnology, such as flavour formation and the involved pathways, stress responses, natural product synthetic routes, etc.

Finally, advances in comparative genomics will reveal the molecular mechanisms of how evolution led to novel enzymes, cluster, and even strain architectures and this will instruct us on the basic principles that we need to consider when designing suitable strains for biotechnological processes.

Bioinformatics is already the working horse of systems biology, covering activities from automated genome annotations to the integration of disparate datasets from different system level activities. These activities will have to be extended and intensified, as the rate of data generation has increased to unprecedented levels (compare for example the organized archiving of metagenomic sequencing projects). Even more important than established primary repositories of (annotated) information (eg sequence databases), are secondary databases where the information is organized into some kind of knowledge aiming at understanding functions and utilities at the molecular, cellular, and organism level (eg KEGG). It is obvious, that in the same context that system-level questions will become crucial questions for future biocatalyst design, bioinformatics will be of central importance to white biotechnology.

F. Innovative down-stream processing

Historically, there has been a lack of interest in downstream processing in comparison to upstream technologies in Industrial Biotechnology. This lack of interest has resulted in a technology bottleneck in more traditional processes through a deficiency of specialized, high throughput apparatus and automation systems. However, because typically 50-70% of the total production cost in technological processes can be attributed to the downstream processing, it is a very important part of the overall process. Designing an economically competitive and environmentally sustainable technological process means considering the downstream separation needed to capture the final product during the initial process design. It is key to take into account the overall processing requirements as early as possible in the development of a new industrial biotechnology process. The specific requirements to obtain a workable and effective industrial process have to be included in the research program.

Particularly for biotechnological processes which move more and more into lower-value higher-volume chemicals (the so-called commodity bioprocesses), it becomes necessary to maximize efficiency, and minimize costs and waste by-products to compete effectively against traditional options. Achieving these goals means approaching the design of the bioprocess and downstream separations as a single, integrated process. In this approach, the bioreactor is regarded as an integrated unit operation with both upstream and downstream unit operations.

Industrial biotechnology must also focus on improving the competence of downstream processing to reduce downstream processing costs significantly. Innovative downstream processing (using for instance membrane technology, supercritical fluid technology or chromatographic techniques) must be developed to process new biotechnological products.

This requires, however, extensive knowledge of these innovative separation and purification processes. Therefore, specific research programs on innovative downstream processing are very important and will contribute to the overall success of biotechnological processes.

G. Bio-based performance and nanocomposite materials

Bio-based performance and nanocomposite materials are polymeric materials which are produced by/from plants, micro-organisms or other bioprocesses, and which are featured by specific functionality based on the micro/nanostructure of the material, derived from self-organisation. Concerning the basic research, studied should be devoted to:

- The basis of molecular assembly in living systems. The biological cell functions because of self-organisation, but what is the molecular mechanism? For instance, what is the exact nature of the interactions between proteins and membranes? This should lead to molecular understanding at such a level that accurate predictions can be made concerning the manner of self-assembly of biomolecules, and the magnitude of their interactions.
- The basis of molecular recognition in living systems. If we understand how Nature's receptors function, we can design and produce them ourselves and use them to make advanced sensors, for instance for the prevention and timely detection of serious diseases, the detection of toxic agents and biohazards at low concentrations, etc.

Using the knowledge obtained in the basic studies, it will be possible to develop bio-based materials for the following applications:

- Controlled release of drugs and nutrients. Bio-based materials are more biocompatible and therefore they are ideal carriers that can be administered to human beings.
- Smart materials (*e.g.* membranes, adsorbants) for separations of (bio)molecules. They can be used for desalination or removal of pollutants from water, or the removal of malodours from foodstuffs.
- Smart surfaces and matrices for the immobilisation of enzymes and receptors.

Enzymes are the 'workhorses' of industrial biotechnology and for various reasons it is important to immobilise them to a solid support. At present enzyme immobilisation is a more or less random process; it would be advantageous to have surfaces and matrices which interact with the enzyme in such a way that the non-catalytic part of the enzyme is bound to the surface, leaving the catalytic site open to the solution, in order to ensure optimum activity.

H. Biocatalytic process design

Optimal bio-catalytic process design will offer large efficiency gains in the production of major chemicals such as pharmaceuticals, food additives or antibiotics, as well as in the treatment of industrial and domestic emissions. Today, new designs result mainly from case based reasoning. That is why promising process interactions are rarely discovered and exploited in industrial practice. Therefore, there is a strong need for systematic design technology for a quick and reliable selection of high-performance process configuration. Biological processes, which work well in the laboratory, need careful scale-up if they are to be equally effective on an industrial level. Good process engineering knowledge and skills are essential to achieve these goals.

Multienzyme systems, using multistep reactions catalyzed by cascades of enzymes, will address the preparation of biosensors for analysis and diagnostic kits, process monitoring, and cell-free protein synthesis. Multi-enzyme analytical reactors are prepared for automated online monitoring of nutrients and metabolites in cell cultures and process streams using optical and electrochemical detection systems. The modelling of these analytical bioreactors is addressed in order to optimise their performance and to readily provide the analyte concentration as function of the detector response.

It is also foreseen to address micro/nanofluidics for the design and operation of micro-enzyme reactors. Multi-step enzyme processes will also be investigated by spatially positioning or mixing together different enzymes within the reactors, as this methodology enables multi-step reactions to be conducted in such a way that it is not necessary to isolate intermediates.

I. Integrated biorefineries

Bio-refineries are small or large industrial factory complexes, in which agricultural feedstocks are processed, fractionated into intermediate basic products and converted into final products. These products often have little in common with the original plant feedstock. Bio-refineries use physical, chemical, and biotechnological processes, whereby particularly fermentation technology and biocatalysis play a major role. This technology uses micro-organisms and their enzymes to convert basic resources such as sugars and oleo-chemicals to products that often having nothing in common with the feedstock. By simply using another production organism, the same renewable raw material can be converted into totally different products. The organisational structure of these large factory complexes is comparable with that of the chemical industry. They are also often connected to a closely located integrated petroleum refinery. The fundamental difference is that bio-refineries use renewable agricultural feedstock, whereas petroleum refineries and the conventional chemical industry start from fossil feedstock such as crude oil and natural gas.

Research should be directed towards the efficient integration of the different processing steps of biorefineries, the utilisation of (waste) biomass feedstocks, and the minimisation of the ecological footprint of biorefineries. Such research should be typically performed in “mixed” joint programs, in which universities and research institutes will develop the basic technology, followed by demonstration projects in collaboration with the bio-industry to address the practical scale-up issues.

8. Availability of agricultural lands for non food chains

8.1. General considerations

Thanks to the food self-sufficiency which figures amongst the strategic objectives that have priority for the states because it is responsible of the vital interests of the Nations, a remarkable progress in reducing the problem of undernourishment (food energy deficiency, hunger) has been made over the past several decades (IFPRI, 2005).

But currently, with the announcement of a population increase, we wonder if the biosphere will have enough land and water for feeding everyone because such an increase means an increase of needs which means more competition for land use (Griffon). Fortunately, as we know, the world population will go on rising but less rapidly compared with the past 30 years (FAO, 2002). According to Downey (2005), the projected population growth is around 2-3 billion what will lead to a probable increasing of crops and livestock production of the order of 40%. But on the other hand, according to United Nations, the mean figures of population will increase by 4.7 billion inhabitants in 2050 (Dameron & al., 2005).

According to FAO (2002), even if a detailed analysis shows that, globally, there is enough land, soil and water, and enough potential for further growth in yields to make the necessary production feasible, food insecurity will persist because in some regions and areas, there are already serious shortages and these may worsen.

As there are lands which cannot be cultivated, the major share of future increases in food production must come in part from new productivity increases on existing land. But the additional quantity of food needed to be produced every year for the next twenty-five years is higher than ever. So, failure to achieve productivity increases on existing lands will result in farmers and governments pushing agriculture into lands that are less suited for the purpose, including forested areas. The result will be rapidly increasing land degradation and deforestation (OCDE, 1998).

Due to the increasing population, more production is certainly required, which is possible by increasing the efficiencies and the number of harvesting per year on a same surface in addition to increase the area. The area increase should count for 20% in the increase of future harvestings. According to FAO, for 1.4 billion hectares of currently cropped lands (11% of land area on the earth), there is still 2.8 billion hectares which could be more or less qualified for rain cultivated lands. Nevertheless, 45% of these are currently covered by forests, 12% are protected areas and 3% are used by humans. For industrialised countries, for which the population growth will be low and for which the calorie intake is already high, principally due to meat, the food needs won't increase and even could decrease. Because of the important production costs, their agricultural surfaces would decrease thanks to a light improvement of the efficiencies and to the import of products (Dameron & al., 2005).

But currently, there is a problem with the land resources required for food production. Indeed, the lands are clearly under stress; 16% of arable land is degraded and the percentage is increasing. The main reason for this situation is the increasing demands placed on land by the unprecedented rate of population growth and the effects it induces (FAO, 2001).

The food production depends on physical constraints relative to the availability of the crop lands and water. Many factors are determining such as water resources, potential of irrigated lands, water efficiency, pollution and climatic change and also durable development (IFRI, 2002). To increase this production, three main sources are necessary: expansion of arable land, increase in cropping intensity and improvement in yield (FAO, 2002).

With an increasing production, food has also known a deep change in its composition. The main explication resides in the change of food of the world population (IFRI, 2002). The cereal supply and demand will continue to increase but at the same time, meat and dairy products will provide a growing share of the human diet, with the poultry sector expanding most rapidly (Downey, 2005). Concerning the livestock production, it currently accounts for some 40% of the gross value of world agriculture production, and its share is rising. It is the world's largest user of agricultural land, directly as pasture and indirectly through the production of fodder crops and other feedstuffs (FAO, 2002).

In industrialised countries, there is one risk factor associated with consumer preference changes, this is the movement towards increasing food safety and consuming organic foods produced without the use of chemical inputs such as fertilisers, pesticides and herbicides. Related to this movement is the possibility of rapid increases in the desire for purely vegetarian diets, instead of a mixed diet consisting of vegetables and foods of animal origin. In the short run, such a movement would result in sharp reductions in agricultural productivity and food production (OCDE, 1998).

At present, in addition to provide for food needs, the rural areas of Europe vary also greatly in terms of the nature of the challenges they face in their efforts to achieve sustainable development. Rural areas must negotiate transformation of farming from predominantly tradition-oriented family-run businesses to a professionally run, science-based competitive enterprise. Deep structural changes will also occur over the next few decades due to demographic movements, pressure from the WTO and CAP reform. The challenge is how to manage this transition so as to preserve the balance between the needs of society, the environment and the economy (EU Commission, 2004).

There are a few factors that cause major uncertainty and risk in long-term projections of food supply. The first factor is the government action, including policies and legislative government behaviour which can have many effects. The second one is the extent of investment in agricultural research aimed at the production of appropriate technology for farmers in both developing and industrialised nations because the future food needs cannot be met with existing technology. The third one is the availability and the use of natural land synthetic resources in agriculture, and the productivity effect of natural resource management. Concerning the land use, long-term projections for food supply are based on certain assumptions regarding the future use of land, not only for food production but also for alternative uses (urban development, roads and other infrastructure, non-food agricultural commodities, etc.). However, efforts to bring additional land under agricultural cultivation would, in most cases, imply large economic and environmental costs. The fourth factor concerns the changes in domestic agricultural markets and the fifth one the productivity and sustainability impact of climatic changes. But while the trend of global warming is becoming increasingly clear, there is still a great deal of uncertainty about the effect of that warming of food supplies (OCDE, 1998).

A problem which could be harmful for a sufficient food production is the pressure put on rural areas considered as attractive places to live by the town dwellers. There are also other factors which can harm these areas such as the conversion to urban uses, the land degradation, etc. Those sites are also appreciated by industrial or commercial activity. Currently, the changes occurring in this kind of regions are abandonment and intensification of agricultural activity, decline of rural populations and competition for housing in peri-urban areas, as well as the decline of rural economies and increased rural unemployment. Therefore, today, such regions must balance the needs of people with the need to preserve biodiversity and natural landscapes (EU Commission, 2004).

According to FAO (2002) and assuming a requirement for housing and other infrastructure of 40 ha per 1000 people, the world population growth between 1995 and 2030 implies the need for an additional 100 million ha of non-agricultural land (FAO, 2002).

There are also changes occurring in the structure of agricultural activity such as intensification, extensification or abandonment. The organisation of European agricultural production is undergoing a process of radical change. Concerning the future of Agriculture in Europe, it is no longer reasonable to base policy for the agricultural development on considerations of production alone. Moreover, competitive production is only sustainable when it is embedded in an efficient system of services such as harvesting, storage, distribution, packing and processing (EU Commission, 2004).

The innovations in food production and processing may be accelerated by advances in biotechnology, genomics and other new technologies, especially in relation to human diet and food hygiene (Downey, 2005).

Over the coming decades, agricultural production as an industry sector will provide employment for a decreasing share of the population. Rural areas with competitive agricultural production can pursue strategies to develop competitive world-class industries based on the production of food, energy and other industrial crops (EU Commission, 2004).

According to FAO (2002), trade has a big role to play to improve the food security and to stimulate the agriculture. Two main trends will determine in part the characteristics of food trade of the 21^{st} century. Those trends are the liberalisation movement of the agricultural exchanges and also the growing of food dependency towards imports which can affect an increasing number of countries (IFRI, 2002).

8.2. Non food chains

The concept of using plants as non-food feedstocks is not new, but, despite considerable investment in research and development, little progress has been made on the introduction of such products into the commercial marketplace. The IENICA consortium carried out an estimation of the potential of plants to produce non-food crops and according to them, the potential was enormous, but the markets disorganised and frequently uninformed (OCDE, 2005).

As the petroleum reserves are not infinite, to reduce or to limit the consumptions of fossil products, agriculture is directly requested to produce non food biomass in large numbers, but while knowing that the global food needs increase, it exists new biomass needs for energy, the usable agricultural area doesn’t stop to decrease and we have to attend to the preservation of agricultural ecosystems and to the physical, chemical and biological quality of soils which are the essential and non renewable supports to the phytomass production. But this request does not have to live down the essential role of agriculture which is food. The production and value perspectives of biomass for energy and bio-products are very important. In France, 2 million hectares of agricultural land could be consecrated to the energy production as early as 2010. The biofuel production could increase its contribution from 3 to 4 Mtep in five years (Riedacker & al., 2006).

To obtain permanent and sustainable channels for non food vegetable, it is necessary to control and to limit the environmental and sanitary impacts, to have an optimisation of the cultivation practices and to have a guarantee and a quality supply (Riedacker & al., 2006).

By 2025, the extra area to consecrate to biomass production would achieve around 83 million hectares, admitting an important effort of research to increase the plant productivities. In 2030, it can be 100 million hectares of agricultural lands which could be used for a non agricultural purpose. But previously, Johansson & al. thought that in 2050, it would be possible to consecrate 429 million hectares of agricultural lands for the production of biomass for energy purpose in order to prevent the climate change. By this period, between 50 and 200 million hectares should be found in Latin America, a few million to 50 million hectares in Africa considering a lower growth of the energy demand, between a few to 50 million hectares for Asia and North America and at last, around a few million hectares in Europe. Fisher & al. estimate that more than 2.3 billion hectares could be planted in 2050 but taking into account the possibility to afforest very damaged lands with a low potential of production. In 2100, this extra area would be around 572 million hectares, that is to say around 12% of cropped and grazing lands (Dameron & al., 2005).

Agriculture will have to increase the global production of phytomass to satisfy the food and the new energy needs and will also have to reduce its greenhouse gas emissions and its energy consumption without penalising the production (Riedacker & al., 2006).

The renewable materials are already used on varying scales worldwide. The main categories include crops for energy and fuels, oils crops, fibre crops, carbohydrate crops and speciality crops.

Concerning the crops for energy, the EU is aiming to substantially increase the production of energy from biomass to contribute to reductions in carbon emissions. Annual biomass production for energy purposes in the EU currently amounts to 56 Mtoe per annum, including around 32.7 Mtoe per annum from agricultural residues produced as a co-product of crop production (OCDE, 2005).

There are also crops which are used to provide energy. The major liquid biofuels at present are biodiesel and bioethanol. In the longer term, biomass may be an important source of transport fuels and form feedstocks for production of synthetic hydrocarbons or for the “hydrogen economy” (OCDE, 2005). The advantage of such crops is that they are renewed endlessly. Moreover, the biomass use doesn’t contribute to the increase of greenhouse effect. This double environmental advantage of vegetable justifies its development under many forms such as bio-fuels and bio-products (Riedacker & al., 2006).

About the oil crops, there are the food and feed markets which are the largest consumers of vegetable oils whilst biodiesel dominates industrial markets. However, oil crops have a wide range of other non-food applications. The main industrial applications for vegetable oils are surfactants, detergents, soaps, lubricants, paints and surface coatings, solvents, polymers, linoleum (OCDE, 2005).

The fibre crops are interesting because of the natural fibres. This kind of crops is increasing because of environmental legislation and concerns as well as technical performance advantages in composites and insulation products (OCDE, 2005).

Concerning the carbohydrate crops, there is a particular interest for industrial applications. There are two markets which currently dominate the non-food sector: paper and board manufacture and organic chemicals (OCDE, 2005).

And about the speciality crops, there is a wide range growing in EU, usually on a small scale for niche products. There are five key market sectors for speciality crops such as essential oils, medicinal, perfumes and cosmetics, speciality chemicals and novel products (OCDE, 2005).

But it is important to remember that the first mission of agriculture remains and will remain the feeding for the worldwide population (Riedacker & al., 2006).

8.3. Aforestation of agricultural land

In 2000, the world had some 3 870 million ha of forests, covering 30% of its land area. Altogether, 51% of global forests are available for wood supply. Some 12% of forests are in legally protected areas, while the remaining 37% are physically inaccessible or otherwise uneconomic for wood supply (FAO, 2002).

Establishing forest plantations on agricultural land may become available up to 2050. But the results will depend significantly upon land availability for aforestation of agricultural land (cropland and grassland), upon the type of forest considered and on the final demand of harvestable wood (Riedacker & al., 2005).

The aforestation of agricultural land has many advantages such as the reduction of emissions from fossil fuel, the carbon storage… But finding agricultural lands becoming technically available for aforestation depends on many things: population growth and food demand, improvement in efficiency of land use, and also diet and technology transfer. But before using all the available agricultural lands, it is important to preserve enough lands because up to 2050, there will be an increase of food demand in various part of the world. This increase takes into account the expected population growth, ageing, and basic calorific food requirements per capita (Riedacker & al., 2005). Moreover, an agricultural land can only be considered as available for forest plantations only if it doesn't compete with another use of this land by humans. Two kinds of agricultural lands can satisfy to this criterion: the lands abandoned by agriculture and herbaceous area not used by agriculture (Dameron & al., 2005).

Currently, with the insufficient local demand of wood just for heat and power production, about half of the land becoming available would remain unplanted because wood still cannot be converted in a competitive manner into liquid biofuel (Riedacker & al., 2005).

In brief, the competition between land for food and land for non-food is first of all a political issue. How this issue will be managed depends on several factors : the place of bioenergy and liquid biofuels in our future energy scene, the development and acceptance of GMOs, food consumption behaviour in 30 years etc. Today, the major need in terms of research is the development of decision-making tools that would help public authorities to conduct their land management policies in an integrated manner, combining all decisive drivers such as climate change, energy, food, environment, economic and social development, technology innovation.

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