Science, Technology and Innovation Drivers

Short Report to the SCAR Expert Working Group/ EU Comission

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1. Introduction

This short report is a summary and selection of science, technology and innovation topics that can be major drivers or at least driving forces for the developments in agriculture during the next 10 to 20 years. This was the task given to the SCAR expert group. The author is aware that in the limited time given, only an overview can be provided and single items, technologies or innovations may be missing because they do not fulfil the criteria given or were not mentioned in the foresight surveys or technology platforms that were the major sources of search (see below).

Accordingly, the criteria for the selection of the science, technology and innovation topics as "Major Driving Forces" were:

1. The theme is assessed as relevant (importance).
2. The topic is realistic.
3. The theme might be realised or used during the next 10 to 20 years.
4. The topic is related to agriculture (including forestry) and is assumed to have an impact on agriculture.

Sources for the selection were national and sub-national foresight activities performed during the last five years, especially the Japanese 8th Delphi survey (NISTEP 2005), the EU Technology Platforms and the strategies formulated there, as well as an analysis of different foresight activities performed for the Fraunhofer Society in an internal paper. The background sources are mentioned below. The topics identified as driving forces are generally mentioned in more than one of the sources as relevant. Direct citations are given in the text. For better reading, the general sources (examples) for the whole topic as such are given at the end of the section.

The paper first describes the Major Driving Forces for Agriculture in the order of importance as rated according to the different importance criteria in the sources mentioned. To complete, some important developments that are related to agriculture but do not have the scope of being a "major" driver, are listed in an annex. Two very obvious "wild cards" are also mentioned.

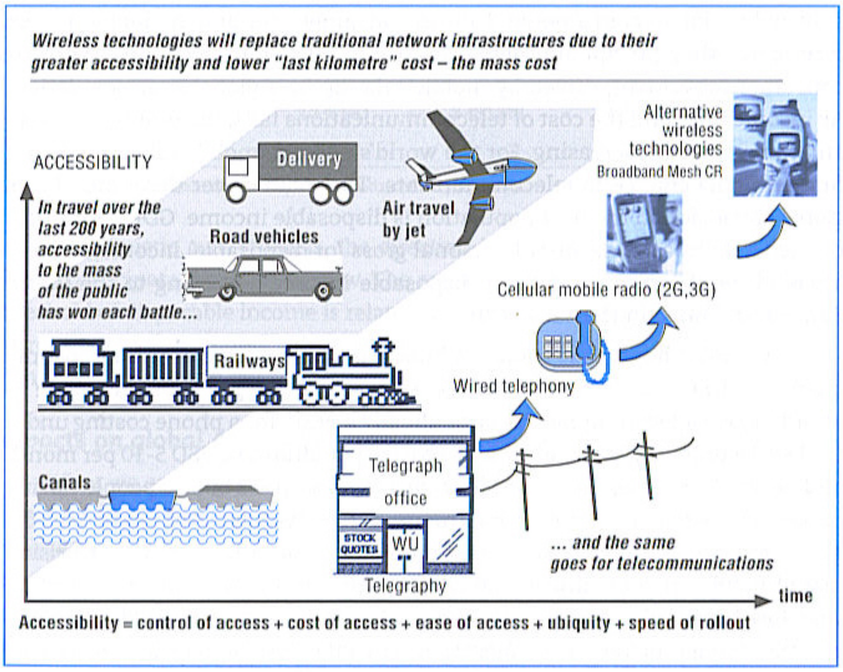
Attention: The driving forces from science, technology and innovation (ST&I) have to be considered with caution, e.g. when building scenarios, because ST&I is on the one hand a certain driver for developments but on the other hand, developments in ST&I are necessary to develop agriculture further. This means, ST&I is both, a driver and a solution. This makes it difficult to differentiate.

2. Major Driving Forces from Science, Technology And Innovation

2.1 Information and Communication Technologies

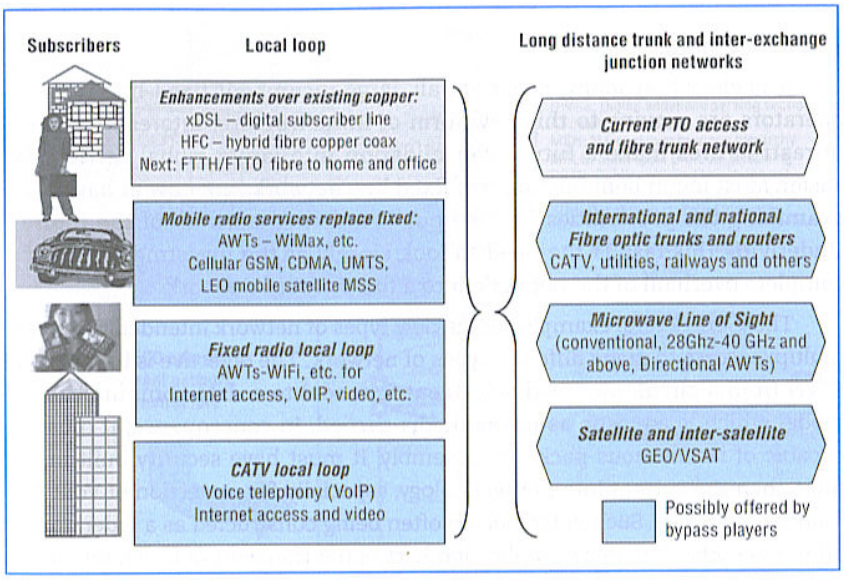
Information and Communication Technologies (ICT) will play a part in all fields of science and technology and are mentioned in every foresight of the last 15 years. But as Major Driving Force, only the interplay and interconnection of different technologies will have a real impact on other sectors (see figure 1 and 2). In the case of agriculture, especially the new ways of providing images and their wireless transmission as well as the availability of real-time data wherever needed (hardware like PDA or "wearables" as well as software are necessary) makes imaging systems a real driving force. "Embedded Systems with nomadic environments" and the "100% available factory" are similar visions in this context. The second topic discussed in ICT is Radio Frequency Identification which will have an impact on logistics but also the identification of cattle or control of plant quality. The third topic is simulation.

Figure 1: Accessibility and telecoms development



source: OECD 2006, p. 79

Figure 2: Low cost infrastructures - a mix of competing infrastructures, technologies and operators



source: OECD 2006, p.93

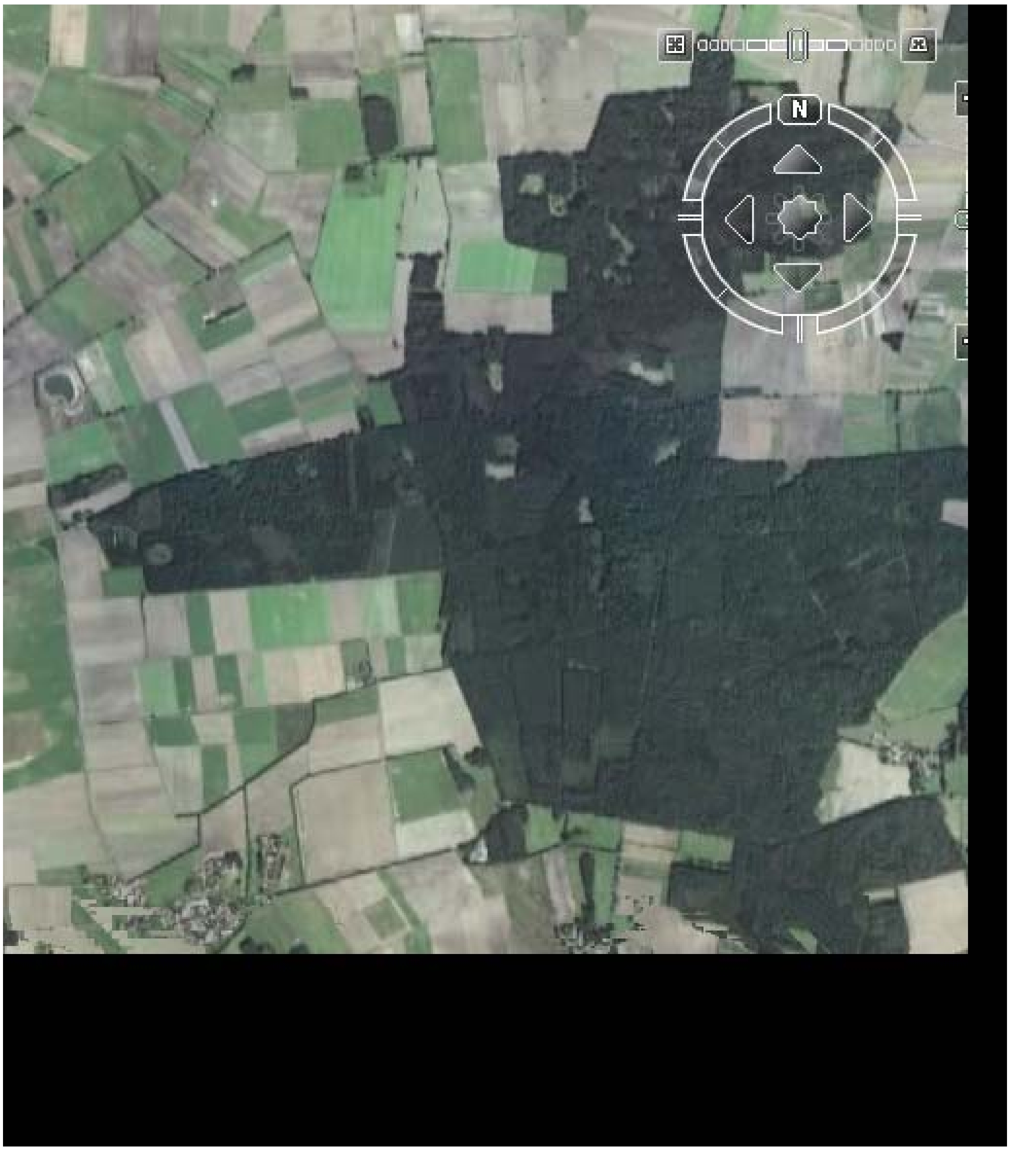
2.1.1 Imaging, wireless transmission, software and hardware for precision farming

Imaging will be available very soon (NISTEP 2005 Report 97, p. 156 and NISTEP 2005 Report 99, p. 150). The first maps from e.g. Google Earth are already online. They are not very precise and not timely but in the future, precise pictures in real time can be available from every place of the world. This will contribute to so-called "Precision Farming" (for the concept see Clavero et al. 2004) and make agriculture more efficient, especially in managing the resources and land. Technically: With the help of bord computers images from the air and from satellites are provided, can be combined with sensor data, different data from the earth so that data about potential harvests can be calculated and planned. Seeds, fertilizers and pesticides can better be managed in amount, which can make a better estimation on logistics possible. On the one hand, this will be economically more efficient, on the other hand support a kind of sustainable agriculture (IÖW 2005).

New software for large-area management combined with imaging will make the control of the land easier and more economic.

Real time imaging via satellites, broadband access, software and hardware combinations are a relatively realistic development which may be available soon. The questions for images are still the real-time availability and the solution provided. A high solution is necessary for agricultural control systems. This is not only a technical question but also a question of regulation. Is it allowed to zoom into the neighbour's garden?

Figure 3: Example of an Image from Google maps



(General sources: NISTEP 2005, Tafazolli/ Saarnio 2005, NEM 2006 (www.nem-initiative.org); Danish Foresight http://www.teknologiskfremsyn.dk/site/doc.php?id=476; IÖW 2005, Fraunhofer 2004, Google Maps; Baczynski 2006; BMBF 2006)

2.1.2 RFID

Radio Frequency Identification (RFID) are active or passive tags on all kinds of products. Even plants or animals can wear them. RFID will – when realised as an innovative infrastructure – be applied for logistics, animal markers (transponders are already standard in new melking machines), plant markers, product markers, control of agriculture in general, supermarkets, control of all products and their ways and and and… This innovation will replace the common barcodes and have a huge impact on agriculture and marketing of products. It is expected that the infrastructure will be build very soon and relatively quickly because of high interests in the industry.

(General sources: Fraunhofer 2005 and 2004, Fraunhofer 2003:
http://www.fraunhofer.de/fhg/Images/28_37_Twelve_tcm6-9805.pdf;
Futur: http://www.bmbf.de/de/6490.php;
http://www.foresight.gov.uk/Intelligent_Infrastructure_Systems/Reports_and_Publications/Intelligent_Infrastructure_Futures/Smart_ProtocolsIntelligentCharging.pdf
EPoSS Working Group Logistics/RFID 2006; European Commission 2004b; BMBF 2006)

2.1.3 Simulations

Simulations for weather forecasts are available and will be improved (precision, timeliness etc.) successively. For strong rain, landslides, for earthquakes, volcano eruptions etc. simulations will also be available. This is not (yet) a major topic in Europe but in other countries like Japan. Nevertheless, also here in Europe, for several reasons (e.g. climate change, changes in wind intensity…) they have a growing importance in risk assessment. And if these simulations are available with the function of predicting an earthquake and avoiding disasters (also crop losses in agriculture), they can be regarded as a major driver in agriculture although these kinds of systems will only be used frequently. Risk management in general, e.g. for harmful chemicals (endocrine disruptors, heavy metals and others are discussed at present) and a better understanding of the risk potentials are another application. The data for simulations have to be generated, assessed and selected, which are often gained via sensors (see below).

But simulations can also be used in agriculture directly, e.g. to simulate when crops are ripe and harvests are due. The "virtual plant" as a computer model is another endeavour. This will have a huge impact on the design of plants and the management of farming.

(General sources: Fraunhofer 2004, NISTEP 2005; European Commission 2004b; BMBF 2006)

2.2 Nanotechnology

Nanotechnology is a topic in nearly every foresight with different assumptions, different aims, applications and time horizons. For agriculture, mainly new materials, packaging, new food ingredients (e.g. for taste or better health), sensors and actuators, and NEMS seem to be of relevance in the time frame until 2020. Also new fertilizers, herbicides and pesticides are discussed if these are not produced in the "classical" chemical way but by manipulating different atoms and molecules, or by a more efficient and safe administration, means pesticides, herbicides and fertilizers are controlled precisely when and where they are released (Kuzma/ VerHage 2006).

"Tomorrow we will design food by shaping molecules and atoms. Nanoscale biotech and nano-bio-info will have big impacts on the food and food-processing industries. The future belongs to new products, new processes with the goal to customize and personalize the products. Improving the safety and quality of food will be the first step. More than 180 applications are in different developing stages and a few of them are on the market already. The nanofood market is expected to surge from 2.6 bn. US dollars today to 7.0 bn. US dollars in 2006 and to 20.4 bn. US dollars in 2010. More than 200 Companies around the world are today active in research and development. USA is the leader followed by Japan and China. By 2010 Asian with more than 50 percent of the worldpopulation will be the biggest market for Nanofood with the leading of China." (Helmut Kaiser Consultancy 2006: http://www.hkc22.com/nanofood.html). A recently started data base on food and agriculture nanotechnolgy "contained already 160 projects, 146 of which were clearly connected to food and agriculture applications of nanotechnology and 14 that had enough connections to warrant their inclusion…" (Kuzma/ VerHage 2006, p. 18).

(General sources: Beyond the Horizon, nearly every Foresight, e.g. Danish Foresight http://www.teknologiskfremsyn.dk/site/doc.php?id=403; NISTEP 2005; Chinese Foresight, or Hauptmann/ Sharan 2005 (www.nano2life.org), Hintze/ Gaisser 2003; Kuzma/ VerHage 2006; European Commission 2004b; BMBF 2006)

2.2.1 New Materials for machinery, colours

The first applications of nanotechnology are different materials, especially for surfaces (some are already available). They are expected to be developed continuously, first ones will be on the market relatively soon. Their application ranges from surfaces on machinery that do not have to be cleaned and have antibiotic effects to colours on machines, equipment, buildings and even plants. New materials will be a continuous development, important but not revolutionary for agriculture until 2020.

2.2.2 Sensors

Sensors are already available but will be more and more widespread over time. Especially new bio-sensors will have their use in agriculture. Sensors for smell, taste but also for bio-chemical detection or to detect single molecules are developed. Even for the machinery and robots in agriculture, sensors sometimes in combination with actuators are a must (navigation, optimization of the machines, adaptation to the soil..). Other projects are concerned e.g. with growable sensors and motors (muscles, supportive tissues, receptor surfaces etc. (Billard et al. 2004).

The different sensors will in the future be able to communicate directly which will be interesting again for ubiquitious services in ubiquitious networks (1. man to man, 2. machine to man, 3. machine to machine). Therefore, they can also be a part of the precision farming vision and may play a role in artificial life (e.g. life-like perception systems, ftp://ftp.cordis.europa.eu/pub/ist/docs/fet/fetbi-17.pdf). Here, dosage control for pesticides, herbicides, fertilizers but also in lifestock raising will play a large role (Kuzma/ VerHage 2006).

Sensors will be developed continuously. They are a more invisible small driver and may be regarded (together with actuators) as a part of the nano electro-mechanical systems (NEMS, see next section).

2.2.3 NEMS (nano electro-mechanical systems)

In nano electro-mechanical systems (the previous ones were the micro electro-mechanical systems (MEMS)) mechatronic devices and optical devices can be combined on a small scale. Applications are e.g. in energy scavenging systems and radio frequency interfaces (see above RFID). First, NEMS will be used in health, security and transport systems but later also in agriculture, especially in the part of mobility and transport, and for the machinery. Especially the easy access to everything on board of tractors (ENIAC Strategic Research Agenda) will profit from NEMS application. But as in MEMS, the development will take time and is expected to be one step after the other. The impact on agriculture will not be visible – like the NEMS are invisible – but will be existent.

(General sources: www.ertrac.org, ENIAC: http://cordis.europa.eu/ist/eniac/; ARTEMIS: http://cordis.europa.eu/technology-platforms/individual_en.html; NEM: www.nem-initiative.org van Hove 2006; BMBF 2006)

2.2.4 New Fertilizers, herbicides and Pesticides

New fertilizers, herbicides and pesticides produced on molecular bases via nanotechnology (and not classical chemistry) are expected to enter the markets. The alternatives are biological pesticides and natural enemies in agriculture. It will depend very much on the type of plant when a realisation might become true. Expert opinions differ here between short and long term so that taking into account the acceptance and risk debate as well as application procedures, it will rather be longer term. New fertilizers and pesticides on the basis of nanotechnology will have their markets and change agriculture to a certain extent but can only be regarded as a small driver.

(Sources: Kuzma/ VerHage 2006)

2.3 Biotechnology

Biotechnology is and will be the major driver for agriculture, be it in plant breeding, farming or food processing. The general aim of biotechnology is to make use of a biological system (e.g. cells, tissues…) to produce something or degenerate products. It is more than genetic engineering or DNA technology. Biotechnology also plays a role in the health debate. In biotechnology, there is a lot of old culture available (joghurt, beer, cheese, wine…) which is directly linked to agriculture and improved successively.

Designing plants for the future and a fusion of green (agro) and red (medical) biotechnology will bring a new step in biotechnology. Biotechnology will transform agriculture into a knowledge-based business (knowledge-based bio-economy). Without knowledge, farmers cannot survive, anymore. From the technology side, "tool-kits" for biotechnology and for genetic engineering are expected to be available, soon.

Nevertheless, like in genomics, the major question in biotechnology is perception and acceptance by the consumers and in agriculture in general. In some countries of the EU, new research programmes just started (e.g. in Germany, 200 mio Euro more for smaller, and new companies, see press release 177/2006).

(General sources: www.epsoweb.org, http://cordis.europa.eu/technology-platforms/individual_en.html see also etp.ciaa.be; www.biomatnet.org; Hüsing et al. 2000; Danish Foresight http://www.teknologiskfremsyn.dk/site/doc.php?id=406, NISTEP 2005; European Commission 2004b; BMBF 2000 and http://www.bmbf.de/de/1024.php; BMBF 2006; www.fabretp.org)

2.3.1 Genetics (in general)

Genetics will lead to the design of new plants and modified plants (for better harvests, resistance against enemies, drought resistence, salt resistence and so on) in a much faster way than the evolutionary biotechnologies or breeding techniques were able to. This is one of the major drivers for agriculture but will still take time. Until now, only some sorts of crops are really genetically modified, tested and on the market. The acceptance by the consumers ("mixed feelings") is one of the questions and a hindrance in some regions. From the scientific side, modelling for genetic and metabolic engineering as well as improved mathematical models are mentioned as the major challenges. Proteomics are the second major field that will follow and is similar to genomics.

What should not be ignored is that other new breeding and reproduction technologies (www.fabretp.org) have advanced during the last years, too, and this still has potential. There are new plants, better selections for professional agriculture, in forestry as well as for horticulture and amateur gardening that are not based on genomics. Until now, genetic engineering plays a minor role in aquaculture (unpublished FAO sources), but this may also change.

In general, also stem cell research and cloning have to be mentioned here. But as long as the processes of aging and why animal clones die early and develop specific illnesses are not clarified, cloning will not be applied in agriculture in larger scale. As this is a longer term endeavour, it is not expected to be realised before 2020 and therefore not a major driver in earlier scenarios.

(General sources: www.epsoweb.org; www.biomatnet.org; all foresights with a section on Life Sciences, Agriculture or Health; European Commission 2004b; BMBF 2006)

2.3.2 Functional Food

Functional food is food or ingredients of food with special functions and an additional value for the consumer, mainly for a higher quality of life and health or a reduced risk of nutrition-based illnesses. The impacts of functional food are caused by (a higher amount of) certain ingredients in food. Also food with reduced potentially harmful parts (e.g. allergens) are called functional food. The definitions vary.

Until now, a few medicals and vitamines can already be integrated in plants or are planned to be introduced (also genetically engineered plants). Some specifically produced food enriched with vitamines etc. is available now, and some amino acids, neuro transmitters, alcaloids and biogene amines are known for their impact on health and will in the future be more and more integrated in food. In a study by Menrad et al. 2000, the perspectives of functional food are described. Functional food is available, will be developed further and is also dependent on the acceptance by the consumers. More and more, the borders between food and pharmaceuticals are diminishing (nutraceuticals).

(Sources: Menrad et al. 2000)

2.3.3 2nd, 3rd generation transgene plants including Molecular Farming

The definition of the 2^{nd} and 3^{rd} generation of transgene plants is not very clear until now. In general, the second generation are those in the "pipeline", means in the industrial development and shortly before the approval. The third generation are those in research and early development. A list of them and their applicability is found in Sauter/Hüsing 2006. These new plants will have an impact on different areas of agriculture, e.g. direct food production, whereas the plant-made pharmaceuticals will have a low impact because they will be the subject of industry more than of agriculture. Plant-made industrials, e.g. oil design, production of enzymes, bio polymers, which all involve the large scale use of plants may be interesting for agriculture and have a certain impact.

The "green gene technology" will in general have an enormous impact on agriculture and will develop successively - also according to acceptance. In the long-term future, bioprocessing will be the key for an integration of "white", "green" and "blue" biotechnology.

(General sources: Sauter/Hüsing 2006; www.epsoweb.org; www.biomatnet.org)

2.4 Internet of Things

The model of the internet of things means that physical transport is possible like data transfer in the internet.

Logistics and management are facilitated when technology for quick and "intelligent" transport, even in different ways are developed. The concept is like in internet: E-Mails are also sent in different packages on different paths but the parts are delivered at the same time at the right place. RFID (see above) may play a role in this concept. The internet of things might bring advantages to rural areas and agriculture to bring the crops, fruits and other agricultural products quickly to the markets. With the Internet of Things, single farmers may be able to deliver the crops directly to the consumers not only in a small region like in direct marketing or shops but in a wider area. This will change the whole supply chain which is mainly in the hand of large companies, now, but can change to a more direct, shorter chain. Therefore, the technology has the potential to develop new markets (see also figure 1). The time frame is medium-term. For the direct marketing of agricultural products this can be a large driving force.

(Source: Fraunhofer 2004 and 2005; www.ertrac.org; BMBF 2006)

2.5 Pharmaceuticals, e.g. against Viruses

Drugs will continue to play a large role in agriculture, for plants and for animals. If pharmaceuticals against certain illnesses like BSE, SARs, Avian 'Flu, Foot and Mouth Disease etc. are available that will have no impact on the animal products directly but a huge impact on the safety in agriculture and on food safety, and therefore the whole sector. Currently, there is unsafety in all poultry facilities, many even give up bird raising. The same can be said for BSE and cows. If here a general breakthrough in prevention or curing is possible (expected in the next 5 years, but experts are unsure), this will have a huge impact on all animal farming facilities, on food safety and on the avoidance of a human pandemic. Anti-infectious management and disease management are an issue that will also be improved but cannot have the same impact as the more direct avoidance of illnesses.

(General Sources: NISTEP 2005, Fraunhofer 2004; BMBF 2006)

2.6 Robotics, Machinery and AI

2.6.1 Service Machines or Robots

Service machines or robots, even cognitive robots or humanoids, are supposed to be used for seeding, harvesting, selecting plants and crops, sorting and distributing the products of agriculture (especially foreseen in the Japanese Delphi surveys). They will be a help in areas with simple work and where human beings are too expensive. Therefore, some of them might replace the jobs of the cheap labour from esp. East European countries migrating to e.g. Germany in harvest times (asparagus, wine, tobacco…). From the technology point of view, mechatronics, machinery processing, and Artificial Intelligence for language input, learning and self-repair are the challenges. Also language processing (understanding common languages and dialects out of direct content) will be combined in robots and machines. This is a continuous development. In the long run, even tractors without drivers seem to be possible.

Like the first Major Driver "Imaging", machines and robots may also play a part in the precision farming concept. Systems that are computer-controlled can for example treat plants (and save pesticides) or exactly spray pesticides in the right dosis. Other examples integrated in precision farming are intelligent "barnstables", intelligent milking machines or robots (some already existing) and intelligent plugs. But even artificial animals are projected, e.g. an artificial mouse (http://cordis.europa.eu/ist/fet/ni-sy.htm) as well as diverse biomimetic robots (ibid).

New small machines and service robots are also interesting for horticulture and "gardening" in private gardens. The prices will fall and as assumed in former times, service robots could be rental ones (e.g. for the weekend, Cuhls/Blind/Grupp 1998). But it is even more probable that the current trend is going on and even private people want to own their machines to have them on hand whenever they want to. In regions with enough capital money for consumption, this will be a source for making money. In other regions, the rental solution might be more interesting.

(General sources: http://cordis.europa.eu/ist/so/advanced-robotics/home.html;
http://teknologiskfremsyn.dk/download/195.pdf, NISTEP 2005)

2.7. Energy

There are many new technical solutions in the pipeline that may have an impact on agriculture but they are mainly dealt with in the paper about Energy (see Expert paper Yves Schenkel). Here, only a few examples that will have a direct impact on agriculture and the rural society are mentioned. They are selected from the science, technology and innovation perspective.

2.7.1 Biofuels

There are attempts to develop biofuels from different plants with different technological approaches. Until now, already some biofuels are standard, e.g. for bioethanol it is sugar, and in the future cellulosic, fibre, wood and waste biomass may be transferred into fermentable sugars, which are reliable, cheap sources for an efficient fermentation process. New biorefinery concepts for plant breeding, harvesting, storage, the optimisation of biomass and feedstocks for biorefinery systems for biofuels are developed. They may change agriculture to a limited extent.

If in the future, a biofuel is developed that is a real substitute for conventional oil products, this will have an enormous impact on agriculture and can be regarded as a major driving force. But the probability is unknown. The other and more realistic assumption is that there will be different biofuels from different plants, which are produced with different technologies applied for the different purposes. Even for driving cars, various biofuels might be possible. In Canada, a plant for producing gazoline, hydrogene and methanol from wood is just being built (Wirtschaftswoche 2006).

In this field, there is still room for a lot of research on the one hand. On the other hand, if a breakthrough in technology occurs, a single biofuel might lead to large production and turn out to be a major driver for agriculture. The danger of a monoculture and competition for land might exist, then.

(General sources: http://en.wikipedia.org/wiki/Biofuel, www.biomatnet.org; NISTEP 2005; Schöpe 2006, Schmitz 2006; Wirtschaftswoche 2006 and 2006b special)

2.7.2 Photovoltaics in combination with Hydrogen/ Fuel Cells

Photovoltaics (energy generation) are interesting for agriculture, or better: the rural society, because in agriculture, the buildings/ roofs are available in a sufficient size to install the systems, and even for larger scale photovoltaics, the space is available in some rural areas. The problem with photovoltaic systems is not only the high costs but the unstable power generation over time. Therefore, the combination with fuel cells or large-scale accumulators (MIT Review 2006) is expected to be one of the solutions: The photovoltaic system produces electricity when the sun is shining. Some energy is used directly. The energy that is not needed at that point in time is "stored" by producing hydrogene which can be re-transferred by fuel cells (into energy and water) or in large-scale accumulators that are currently developed in the USA. This is especially interesting for sunny rural areas with a less developed infrastructure, or for houses in more lonesome areas. It will have its impact but it will not be a major force because harvesting energy is different from harvesting crops. Nevertheless, if largely developed, it can be a second income for agriculture.

(General sources: NISTEP 2005, Fraunhofer 2004,
http://www.foresight.gov.uk/Energy/Energy.html; Cuhls/Blind/Grupp 1998, nearly all foresights that have a section on energy)

2.8 Ecological Systems Research

For years, research to understand biological and agricultural systems is going on. This is a rather complex and long-term scientific endeavour. If the thinking in systems is really possible and the systems are understood well, new bio agricultural approaches might be possible. Fertilizers and pesticides (if used at all, then) can be optimised. Here is still room for much research, basic sciences and applied technology (e.g. for simulations). The complexity of systems is generally a hindrance. The probability for a breakthrough in this understanding is relatively low, but the development will go on. Therefore, the power of this driver might be medium to small. This is also connected to simulations which often cannot be conducted effectively until the systems are understood.

The understanding of a relationship between animals and human beings in agriculture belongs to the understanding of systems. Cognitive sciences (see below) may contribute to this understanding for a better symbiosis. This might lead to better raising of cattle. Often, the focus is on genetic engineering and breeding but the best DNA for lifestock is of no use if the circumstances for raising, e.g. environment, feeding etc., are not optimised or taken into account at all. And this implies the unterstanding of the system from the science and technology perspective. In many cases, not all components of the system are thought through (for instance because of complexity).

Ecological systems research in general can also contribute to "organic farming" and their concepts. Often, organic farming is influenced by conventional approaches (seeds, pesticides, herbicides are introduced just via the air or water). And new approaches can be planned when the systems as such are understood in more detail (from understanding the effects of biological enemies to the effects of bio-fertilizing, the rearrangement of plants so that they have a positive effect on each other etc.).

(General sources: www.futur.de internal paper and discussions, Alcamo, J. et al. 2005 a and b)

2.9 Cognitive Sciences and Cognitive Systems

Under cognitive sciences and cognitive systems, there is a lot of research going on. Brain research is the base and is supported by nearly every government at the moment, although the topic as such is not new (Cuhls/Breiner/Grupp 1995; European Commission 2004b, BMBF 2006). In foresights, the topic is always on the agenda (e.g. in Futur – the German Research Dialogue, it was a lead vision, also the UK Foresight, the Japanese Foresight etc.). And although different facets of the topic are discussed that range from ethical issues over the question how the brain is able to learn, to steer, to feel, the major issue is making use of brain research for computing and for extracting information to develop "intelligent computers" or "intelligent" databases. Therefore, the first small driver mentioned here is the idea of the "intelligent" database that plays also a role for the development of agriculture. The second, more diffuse aspect is the understanding of the brain and its functions.

2.9.1 Availability of "Intelligent" Databases

User-friendly databases or information systems that "understand" usual questions and are via artificial intelligence able to make knowledge out of information so that farmers can make use of them quickly in case of questions (even with language input and output) and for management purposes, this will be one of the drivers towards a knowledge-based economy. Nevertheless, for the next years to come, any (therefore often called "expert") database will still need a lot of user knowledge, means for the "extraction of meaning" the user has to be intelligent, because the database is not. Therefore, the databases are only a very small driver in the short and medium term (www.cordis.lu/ist/fet/bioit.htm, Billard et al. 2004).

Databases are also discussed in connection with genetics and especially with cloning. Currently, a platform to collect characteristic EST (expressed sequence tags) from plants (agriculture and forestry) is to be developed so that these tags are available for tailor-made DNA chips. Databases for providing information are a must in agriculture, no driver (www.cordis.lu/ist/fet/bioit.htm; BMBF 2006).

(General sources: www.cordis.lu/ist/fet/bioit.htm; BMBF 2006; Billard et al. 2004; Fraunhofer 2004; NISTEP 2005)

2.9.2 Brain Research

There are several European websites (e.g. http://cordis.europa.eu/ist/fet/bioit.htm or ftp://ftp.cordis.europa.eu/pub/ist/docs/fet/fetbi-17.pdf), describing the initiatives in brain research. Most of them have aims like: "to build systems that exhibit flexible, autonomous, goal-directed behaviour in response to changes in internal and external conditions" (http://cordis.europa.eu/ist/fet/bioit.htm). If these systems are really understood and can be applied, it will also have an influence in agriculture, not only for data bases, robots, machines and their control but in the long run also for the stimuli of animals and plants (and even human beings). The same is true for the attempt "to create integrated perception-response systems that are inspired by the sophistication of solutions adopted by living systems. “Perception” is meant to include sensorial, cognitive, and control aspects, whether it refers to vision or hearing, or to any other element of interaction with the environment by a biological organism. Such systems would extend the capabilities of machines or be used to augment the human senses." (ftp://ftp.cordis.europa.eu/pub/ist/docs/fet/fetbi-17.pdf).

If human senses can be augmented, in the future also the senses of animals can be augmented, controlled, stimulated etc. Other projects concern the functional organisation of evolving and developing biological and artificial nervous systems, with respect to intelligent behaviour, e.g. the development of peripheral and central nervous systems; autonomic nervous systems; hierarchical structure; modularity vs. full connectivity; self-organising maps for "graphical" primitives from sensor image in robot head (architectures forcombination of orientation, colour, movement sketches), and the development of sensori-motor abilities by operational architectures modelled on cortex (e.g. the self-organization of orientation columns in visual cortex, a possible blackboard architecture in sensory cortex which combine multimodal primitives into objects), or even systems that develop complex motor skills by learning to combine existing motor primitives in novel ways (Billard et al. 2004). All these scientific approaches are closely connected to the topics of robotics, sensors, NEMS etc., see above. Pattern and language recognition contribute to these approaches (Cuhls/Breiner/Grupp 1995; Cuhls/Blind/Grupp 1998; NISTEP 2005).

But in most foresight activities, in which experts had to judge on topics like these concerning brain functions and emotions, education etc, they are estimated to be realised rather in the long term (see Cuhls/Blind/Grupp 1998, von Oertzen/Cuhls/Kimpeler 2006) and evoke philosophical, ethical, religious and other questions (impacts, risks…). Applications of brain research and understanding the functions of the human brain in agriculture can be:

- education: better learning of human beings (maybe also of cattle?) because of the understanding of learning mechanisms (for an overview see http://www.sedl.org/scimath/compass/v03n02/brain.html)
- better capability of memorizing, management etc.,

- human motivation, e.g. to work in agriculture, to behave in a certain way, to eat proper food…., and
- behaviour towards food and other agricultural products (e.g. diets).

For agriculture, also the understanding of animal brains may be interesting for raising animals, understanding their need or even for communication with animals (this is a topic in the 8th Japanese Foresight, NISTEP 2005) and a better symbiosis of human beings with their environment, plants and animals in general.

Nevertheless, currently neuroinformatics (http://cordis.europa.eu/life/src/neuro.htm) are the major approach in research (also BMBF 2006, UK Foresight). A part of it can be found in neuroinformatics for "living" artefacts (NI) a proactive initiative (http://cordis.europa.eu/ist/fet/ni.htm) to foster the field.

"The Life-like perception systems (LPS, see above) initiative focuses on perception-response systems that are inspired by the sophistication of solutions adopted by living systems... It also addresses the process through which sensor signals are integrated to form internal representations of the sensory world. "Life-like" means that the systems should be motivated by and following principles of biological systems. In this context, models and results from neuroethological and behavioural studies, cognitive science, including cognitive psychology, artificial intelligence and philosophy, are expected to contribute important design aspects. "Perception" is clearly more than mere "sensing". It can be defined as the process through which sensor signals are integrated to form internal representations of the sensory world. In addition to visual and auditory perception research work also includes other senses including non-human biological senses such as ultrasound, vibration and mechanoreceptive senses. For the action component, work is not limited to robots. Other types of actuators are conceivable as appropriate system components, as long as they interact with the process of perception. A further important area of interest are systems that interface with biology in providing stimulation to nerves, as required in the design of sensory implants." (http://cordis.europa.eu/ist/fet/bi.htm).

All these developments are rather long-term. Until now, only a small part of the brain functions are really understood (a lot of work is performed e.g. by Berthoz, see Berthoz et al. 1995 or Singer 2002). Nevertheless, as many investments are taken here (nearly all industrial nations have a kind of brain research programme), the development will be accelerated and have its impacts on every field of human life. Major ethical problems will occur, e.g. how much influence on the human (or animal) brain is allowed, or where is the border between a machine and a man?…

(General sources: NISTEP 2005; Hüsing et al. 2006; http://cordis.europa.eu/ist/fet/bi.htm; http://cordis.europa.eu/ist/fet/bi.htm; http://www.sedl.org/scimath/compass/v03n02/brain.html; http://cordis.europa.eu/life/src/neuro.htm; http://teknologiskfremsyn.dk/download/195.pdf; http://www.foresight.gov.uk/Previous_Projects/Cognitive_Systems/Defining_the_Project/Cognitiv e_Systems_A_Summary/Cognitive_Systems_A_Summary.html; www.futur.de Lead Vision "Understanding Thinking"; http://www.bmbf.de/de/4203.php; BMBF 2006)

4. Wild Cards

4.1 Nanotechnology Assembling

If nano materials are developed in such a way that they are self replicant, if assemblers and nanobots are possible and can be used to develop and produce whatever people want (like in Eric Drexlers vision from 15 years ago, Drexler/ Peterson/ Pergamit 1991), if this is really accepted by the people, then this is a real wild card. In this case, the whole sector of agriculture can be diminished or has to be re-defined (e.g. for the protection or conservation of landscapes…) because food production and fuels or materials will not be based on plants and animals, anymore, but will be a product of industry. This wild card has a very long-term time horizon (definitely longer than 2030) and has a low probability but it has to be taken into account when discussing agriculture.

4.2 Artificial Meat

The second wild card is "artificial meat" (Economist 2006). The technology is not really a wild card because the development is rather feasible and has its potential especially as acceptance seems to be no problem. But for agriculture, it is a wild card because if artificial meat is on the market in a larger scale, it will destroy classical animal raising and therefore be disruptive for agriculture.

Artificial food and artificial meat already exist, of course, but what is meant here, is more than Hamburgers from soybean etc. it is meat that cannot be identified as artificial, anymore. The idea is that "meat grown in vats, rather than in the form of animals, could soon be on the menu" (Economist 2006) and might be healthier and even accepted by some vegetarians because no animals have to be slaughtered, anymore. The major reason for the assumption that artificial meet will be accepted is hygiene. Cultured meat grown in sterile conditions can avoid nasty things like Salmonella, E. coly, Campylobacter and others. It can also be made healthier by adjusting its composition - introducing better fats etc. In the USA, this seems to be discussed widely (e.g. within the list of the Millennium project some hints were circulated, Sandhana 2006).

Growing muscle cells in a nutrient broth seems to be possible. It is more difficult to persuade cells to form "meat". One approach for this is stretching the cells with mechanical anchors to arrange something that looks similar to a muscle. Another approach with tissue from fish uses a functioning system of blood vessels to deliver nutrients. At Utrecht University, it is tried to make minced pork from cultured stem cells (Economist 2006).

If artificial meat (same consistency as meat from animals, same taste, smell…) is on the market and is bought by the consumers in larger amounts, food production is industry, not agriculture, anymore, and the landscape will be changed. To raise cattle in large numbers and large varieties is not necessary, anymore. On the other hand, this contributes to the reduction of methane (climate problems).

5. Some Observations

The task given to the author of this paper was to go through different foresight and other studies to identify the major drivers from STI that are relevant for (future) agriculture and agricultural research. When performing this task, some observations were made that might be of relevance for the further work of SCAR and the SCAR working group:

- Agricultural research is found in different disciplines. The new developments mainly occur at the borderlines of agricultural research. Therefore, already now but even more in the future, interdisciplinary research is needed.
- Many new developments that are major drivers stem from completely different disciplines, natural sciences, engineering and sometimes even the social sciences. The timelag for adaptation is often longer for agriculture and agricultural research than for other sectors (e.g. health sector). A very simple conclusion is that agriculture should look much more and much earlier to what is happening elsewhere and that it should open up to other disciplines.
- The costs of introducing a new technology are sometimes immense. But counted over time, facing a lot of challenges from globalisation to energy shortage or climate change, the costs sometimes have to be considered already now because the investments will amortise over time (the whole "Stern Report", 2006, is about this). In the long run, they sometimes make sense (e.g. photovoltaics…) on the economic side. On the other hand, in some of these cases, incentives from policy are needed.
- Here, the author identified the *driving forces* in STI. That does not mean that on the need-side (demand-side) other technologies or innovation have to be disregarded. On the contrary, between the real demand, even more the demand of the future, and what is provided nowadays, there is still a gap that has to be filled.
- Science and Technology did not turn out to be *the* major driving force in and for agriculture. It is one among others. Science, Technology and Innovation can also be an answer to some of the questions. But in most cases, it will be a combination of science, technology and other factors like regulation, infrastructure, costs because of the climate change or rising prices for energy, organisational factors etc. that turns it into a driver (see the IT example in this paper).
- It was a bit difficult to identify STI drivers, because the future picture of agriculture or however it will be called in the future (the picture, even more a clear vision or targets) seems to be unclear. It would be a nice idea to develop a future picture be it as a target to achieve or a benchmark. Like a scenario that needs to be long-term, changeable but consistent and "ideal". It does not mean that the future will exactly look like this.

- We do not know the future. If we knew it, life would be boring. But we can shape it to a certain extent. Foresight helps with this endeavour – and in most cases, it tells you more about the present than about the future. Please keep this in mind when reading the paper because it is about drivers – from the present to the futures.

Annex: Minor Drivers and Single Items that may have an impact

When identifying the major drivers for agriculture and agricultural research during the years to come, also some minor drivers and single items were put on the list of the important developments rated as probable during the next 20 years and maybe playing a role in agriculture or the future biosociety. They should not be ignored, forgotten or overlooked. Therefore, the following is a list (collection of items, technologies, innovations, mainly based on NISTEP 2005, Fraunhofer 2004) of new technologies or innovations that may play a large role in the future but do not have the scope or the importance to be called "Major Driving Force" for agriculture:

Materials

- Bio-lubricants can be a large research area that plays a role in forestry as soon as lubricants from wood can be used in industrial production processes in a larger scale, some programmes seem to be available, e.g. from the German BMELV "Nachwachsende Rohstoffe" because "lubricants made from vegetable oils are not only biodegradable and CO_2-neutral, they are advantageous in quality, too. Technically, they are equivalent to mineral oils. Due to their better durabilty they do even have the edge on them in some fields of application. Biolubricants are best to be applied to usages, where one has to go easy on the environment, so where lubricants can get in contact with soil, water and air. Although 450 different biolubricants are available right now, they are just a niche so far. That is because they are still too expensive compared with mineral oils. This disadvantage in the market competition is because of the relatively little demand and accordingly low production" (www.bioschmierstoffe.info; also NISTEP 2005)
- new wood products and production processes (www.forestplatform.org)
- functional packaging: wood and fibre for "green specialty chemicals" and a new generation of composites (NISTEP 2005)
- "green" fibres (NISTEP 2005)
- epoxy resins, they are similar to petroleum-derived resins and less toxic than synthetic resins, potential use in electric appliances, which means a large demand (NISTEP 2005)
- oil: novel oils from plants, calendula oil, oil from crambe and flax (NISTEP 2005)
- biomaterials, novel biopolymers, especially bioplastics: they will be an industry product and applied in production processes but stem from agriculture. They can develop a large market as soon they are used in packaging or in cables etc. (NISTEP 2005, Fraunhofer 2004, already in Cuhls/Blind/Grupp 1998)

Production:

- biocatalysts: biocatalysts are a substance, especially an enzyme, that initiates or modifies the rate of a chemical reaction in a living body; a biochemical catalyst. New biocatalysts on the basis of screening nature's biodiversity, target-oriented screening methods, new screening tools, new catalysts for specific applications, the understanding and improvement of existing biocatalysts are the challenges (NISTEP 2005; Hüsing et al. 2000)
- novel and robust production microorganisms (NISTEP 2005)
- bioreactors in general and new types of micro-bioreactors: A bioreactor may refer to any device or system that supports a biologically active environment. In one case, a bioreactor is a vessel in which is carried out a chemical process which involves organisms or biochemically active substances derived from such organisms. This process can either be aerobic or anaerobic. These bioreactors are commonly cylindrical, ranging in size from some liter to cube meters, and are often made of stainless steel. A bioreactor may also refer to a device or system meant to grow cells or tissues in the context of cell culture. These devices are being developed for use in tissue engineering. Industrial bioreactors usually employ bacteria or other simple organisms that can withstand the forces of agitation. They are also simple to sustain, requiring only simple nutrient solutions and can grow at astounding rates. In bioreactors where the goal is to grow cells or tissues for experimental or therapeutic purposes, the design is significantly different from industrial bioreactors. Many cells and tissues, especially mammalian, must have a surface or other structural support in order to grow, and agitated environments are often destructive to these cell types and tissues. Higher organisms also need more complex growth medium (http://en.wikipedia.org/wiki/Biochemical_engineering). This is an industrial approach but if large-scale application is intended, maybe agriculture can play a role (NISTEP 2005).

Drugs, medicine etc.:

- Metabolomics (especially mentioned in NISTEP 2005): is the "systematic study of the unique chemical fingerprints that specific cellular processes leave behind" - specifically, the study of their small-molecule metabolite profiles. The metabolome represents the collection of all metabolites in a biological organism, which are the end products of its gene expression. Thus, while mRNA gene expression data and proteomic analyses do not tell the whole story of what might be happening in a cell, metabolic profiling can give an instantaneous 'snapshot' of the physiology of that cell. One of the challenges of systems biology is to integrate proteomics, transcriptomics, and metabolomics information to give a more complete picture of living organisms (Wikipedia, see also Tomita/ Nishioka 2005). This understanding may be of use in agriculture.

- metabonomics: detection of changes in endogenous cellular metabolism of a cell or organism. The word metabonomics is often used in the same sense as metabolomics, particularly in the context of drug toxicity assessment. There is some disagreement over the exact differences between 'metabolomics' and 'metabonomics'; in general, the term 'metabolomics' is more commonly used. The difference between the two terms is not related to the choice of the analytical platform: although metabonomics is more associated with NMR spectroscopy and metabolomics with mass spectrometry-based techniques, this is simply because of usages amongst different groups that have popularized the different terms. While there is still no absolute agreement, there is a growing consensus that the difference resides in the fact that 'metabolomics' places a greater emphasis on comprehensive metabolic profiling, while 'metabonomics' is used to describe multiple (but not necessarily comprehensive) metabolic changes caused by a biological perturbation. (Wikipedia)
- antibodies from plants: if used for pharmaceuticals, or if included in the normal food, large amounts are necessary, that can be a niche, and provide new products for agriculture (NISTEP 2005)
- toxicogenomics: detecting drug induced changes in gene expression in cells can contribute to food safety and therefore to agriculture (NISTEP 2005)
- methods to overcome drug resistance in infections (animals and plants) (NISTEP 2005; nearly all foresights that have a section on health)
- hormone therapy: is interesting for human beings but also for animals, even for plants. If applied in larger scale and if the hormone cycles are understood better, this knowledge can be used in agriculture, too (NISTEP 2005)
- xenotransplantation: the transplantation of tissue or organs raised in animals from the animals to human beings, these special animals can be raised in agriculture. This topic is rather long-term and faces a lot of technological and ethical challenges (Hüsing 2004, NISTEP 2005)
- stem cell transplantation: if stem cell research is fruitful (mainly from adult cells), a lot of applications can be imagined, some also in agriculture, some for artificial meat, see above (NISTEP 2005)
- early warning systems for human and lifestock infections as well as for environmental effects of an accident (NISTEP 2005)

Crops:

- toxicoproteomics: detection of abnormal patterns in proteins can be used for industry on the one hand but also different instruments can be developed to detect these things on the spot where needed, e.g. in agriculture. (NISTEP 2005, Fraunhofer 2004)

- biomass for energy, after 2015 interesting (see energy paper, but also interesting from the technology point of view because a lot of research is involved, currently mainly biogas facilities spread rapidly) (NISTEP 2005, nearly all foresights that have a section on energy)
- biological crop protection (phage, plant activators, natural enemies, pheromones, allelopathy…): this would save pesticides, herbicides, but on the other hand still a lot of research about the whole environmental system is needed in order not to have counter-effects (NISTEP 2005)

Animals:

- communication technology between human beings and lifestock utilizing sensing of the neurotransmission in the brain (very long-term) (NISTEP 2005)
- biological clock research: there are different approaches concerning biological clock research especially on animals and their behaviour but also with conclusions for human beings and their health (http://www.hhmi.org/biointeractive/clocks/whoswho.html; NISTEP 2005)

Climate, water, environment:

- algae's mechanisms of CO_2 absorption and concentration (in order to ban/ store CO_2 in marine areas under the sea), to breed certain algae can be a task in aquaculture as well as the use of algae not only for food like in Japan, but also for pharmaceuticals (NISTEP 2005)
- technology to assess the impacts of global climate and environmental change (see other papers on climate and environment), this is closely connected to simulations, see above (NISTEP 2005)
- technologies for saving water in agriculture (NISTEP 2005)
- technology for efficient revegetation in deserts (NISTEP 2005)
- water treatment technologies are also important but in Europe, there is not such a severe shortage of water (also not predicted) as in other countries, where these technologies will be a major driver (Vidal 2006)

Soft Sciences:

- Under the heading of "soft sciences" often economics, business administration, management, even humanities (from philosophy to cultural studies) are subsumed. They will all play a role in shaping the future of agriculture. Especially political and policy sciences with regard to new governance can play a larger role. Nevertheless, they will not be major drivers from the scientific side even if some applications might have their impacts.

Other basic research:

- microwave-assisted organic synthesis (NISTEP 2005)
- proteomics, which is often mentioned as the next step after genomics. It may have an impact on agriculture, but mainly on production and health issues (Fraunhofer 2004, NISTEP 2005)
- carbohydrates (NISTEP 2005)

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