RFID Resource Network Report

RFID Technology Roadmap

Wireless Smart Systems and RFID

Project acronym: *RFID-RNET*

Project full title: RFID Resource Network

Executive Summary

This report is part of the activities carried out by the RFID Resource network in identifying the main developments at the national level based on the requirements of the Norwegian industry, public sector, and the research and academic communities and the trends at the global level and the research needs in the area of future digital environments, technologies for digital ecosystems based on RFID and wireless smart systems that will form one of the main technologies for the future “Internet of Things” vision.

The document aims to establish the base for providing the detail roadmap of industrial requirements for the uptake of RFID technology in different sectors and defining the RFID technology and development research challenges at the national level in the view of global development.

The report aims to identify the future needs, challenges and solutions and estimate how the RFID technology will develop in the next 10-15 years and in particular how it may influence the society as a whole. This will be the basis for the Norwegian Research Council ICT programmes for extending the existing research areas and defining new areas that will address the RFID technologies.

Parts of the reports are input to the EC final report “Internet of Things in 2020” – INFSO/D.4 NETWORKED ENTERPRISE & RFID” on the results of the Joint EC/EPoSS Expert Workshop, Beyond RFID - The Internet of Things, Brussels, Belgium, 11 - 12 February 2008.

The “Internet of Things” is a network of billions (or trillions) of machines communicating with one another. It is a major or dominant theme for the evolution of information and communications over the next few decades, and is in its simplest form already here. The idea has grown from advanced concepts from the last twenty years:

- Ubiquitous communications
- Pervasive computing
- Ambient intelligence

In the future digital environments the miniaturisation and new communication capabilities will make possible to equip physical objects with RFID tags having sensors and processing power and connect them to ubiquitous (RFID), sensor networks. It may prove feasible to interact with objects and environments through communication via RFID tags including sensors and control functions in, for example, clothes, walls, furniture, tools and machines.

The report presents the main activities related to identification, RFID and wireless technologies where the Norwegian companies are involved and aims to be a bridge between the strategic research agendas for European Technology Platforms (focus on EPoSS, ENIAC, ARTEMIS and eMobility), the joint undertaking initiatives and the national research programmes. The report will be updated annually.

Finally, the report identifies the main RFID technology drivers and the research priorities for the next years and the implications of RFID technology on personal privacy and security, as well as to overall societal issues relating to the situation when people may be “always connected” via different types of equipment to an ubiquitous (RFID) network.

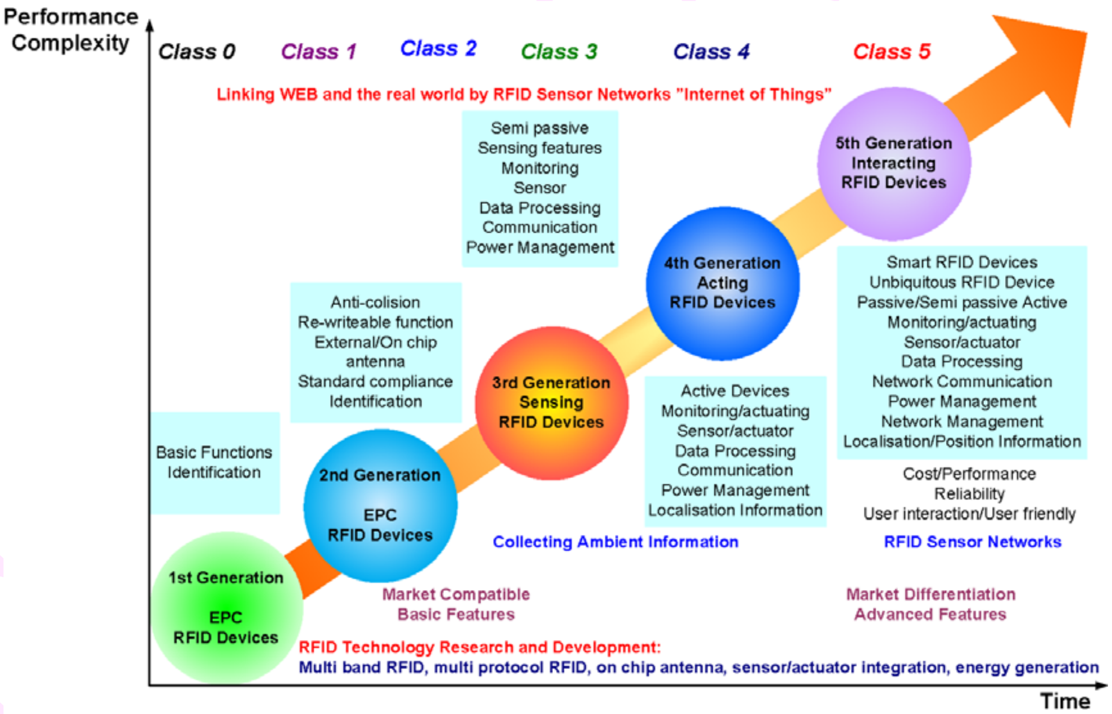
RFID and Wireless Smart Systems

The new information age, has introduced exciting new capabilities, distributed decision and control processes including unprecedented awareness at the consumer level. There is a hunger for faster responses to needs, for greater security, for instantaneous access to information.
Everyone and everything connected to the network. Eventually every person on the planet will be connected to the network. So will virtually every “thing” with a digital and electrical capability and RFID tags on them connected to the “Internet of Things”. The resulting network traffic will require highly scalable, reliable systems.
Logistics and communication are key elements in our globalized society. Identifying, tracking and monitoring objects are becoming important in many industrial sectors. This has also given rise to interesting industrial development in Norway via for instance these companies:

- Tomra (RFID in recycling)
- Titech Visionsort (recycling of textiles, RFID in food industry)
- Idex ASA (biometric identification)
- Sonitor (Real Time Localization Systems in Healthcare)
- Q-Free (Road-user charging).

1.1 Vision

Ambient Intelligence is the vision of the future information technology society. Wireless connectivity is one of the key enabling technologies.
In the “Ambience Intelligence” and the “Ubiquitous Information” society, information technology (IT) enables everyone to enjoy daily life without awareness of IT itself. This will be made possible by the “Invisible Smart Systems” that resides within almost everything in the society, to sense, analyze, and control ourselves and our environment.



The key technology for local connectivity is radio frequency identification (RFID) which makes massive, low cost tagging of objects feasible. RFID is rapidly progressing especially in logistics/chain management and is reaching the consumer markets. RFID chips used in integration with sensor technology are examples of “Invisible Smart Systems” that in this context can provide information about the quality or other features of the goods throughout a logistic chain.

The growing data needs and higher data transfers will require stronger security models employing context security to empower the citizen to secure and build trust by focusing on risk reduction and not on over identification and surveillance. RFID technology can be seen very intrusive for privacy, and, as the advantages are not often clear, the research community must develop security and privacy mechanisms and establish security guidelines for RFID developers and operators of RFID systems.

The future “Internet of Things” will be pervasive, and ubiquitous: wireless smart devices, embedded in smart materials, will work in synergy to make information available anywhere at any time by relying on connectivity and communications, using hybrid networks of devices and sensors/actuators to meet the ‘anywhere’ requirement in order to improve the life quality and reduce the negative impact on the environment.

Considering the functionality and identity as the basic features the “Internet of Things” could be defined as “things/objects having identities, virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate with user, social and environmental contexts”. In this context, mobile robots and wireless smart devices will be able to seamlessly interact and communicate with the environment, thereby contributing to the efficient, secure and inclusive nature of European society.

Example RFID Applications (with reference to Norwegian research, development and innovation activities)

- Tracking and surveillance of consumer and retail products, such as food products
- Reading and storing biometric information for access control where the main application areas are:
  - PC / network security
  - Wireless (cell phones)
  - Physical access control)
- Real-time location systems for healthcare and medical applications (such as keeping track of patient records and medicine). Here different approaches to achieve room-level accuracy have emerged in the market (Sonitor ASA):
  - Hybrid solutions combining RF systems for coarse positioning with other technologies giving more local location information (example: infrared, near field RF etc.)
  - Ultra wide band RF system that use specially shaped radio pulses and a relatively dense receiver network to obtain approximately 50 cm accuracy under optimal conditions
  - Ultrasound location technology that uses the favourable properties of sound, such as confinement by walls and ceilings and the slow propagation of ultrasound waves (one million times slower than RF waves) to obtain precise and scalable location information (down to 1 cm).
- Providing instruction for assembly and disassembly of complex products.
- SIM cards with embedded RFID capabilities developed by Telenor. The goal is to merge the GSM and RFID services and offer an alternative for the contact less card infrastructure being installed in different parts of the world (with the first beneficiary being contactless ticketing).
- RFID in waste management and recycling. Bergen Interkommunale Renholdsselskap (BIR) has an ongoing pilot where they have tagged 200.000 waste bins and equipped their trucks with weights, readers and mobile transmitters which will send information to back-end systems.
- Smart systems for electronic tolling used in the Intelligent Transport System sector by providing communications, transaction technology and products to safeguard transport operators’ cash flow for Road User Charging segment (Q-Free).

- RFID used in the food industry value-chain, enhanced food safety and quality control. LMD (Landbruks og Matdepartementet) has launched a major national project for food safety and quality control: ”På sporet. Viktige prinsipper for utveksling av informasjon i matkjeden”.
- Intelligent biometric identification systems based on SmartFinger® technology (IDEX ASA).
- RFID for recycling instructions for larger, composite objects or modules that require more detailed information (Tomra Systems ASA).
- RFID used for Recycling of textiles. Considering the diversity of fibrous waste and structures, many technologies must work in concert in an integrated industry in order to increase the rate of recycling. One of these technologies could be insertion of RFID tags in textiles which will ease the end of life sorting in different fractions. The logistics from production to the point of sales can also utilize all information coded (Titech Visionsort).

1.2 Rationale and objectives

According to research by IDTechEX, the market for RFID tags and systems will approach $ 24.50 billion by 2015. The growth will occur as a result of consumer demand and new regulations. The major applications that utilize RFID include access cards across industries, libraries, healthcare, etc. By 2008, item level tagging will consume around 6.8 billion tags. EPC readers will account for a sale of $ 1.14 billion dollars in 2008 whereas other readers such as Near Field Communication readers will account for sales worth $ 0.75 billion.

Approximately 10 trillion barcodes are printed every year. Even by the most optimistic estimate, RFID tags cannot touch these numbers before 2020. For “low complexity” RFID tags to touch these numbers they will have to sell at less than one cent per tag and should be printed (“chip-less” tags using polymer transistor circuits and Surface Acoustic Wave (SAW) techniques). The main markets for one-cent chip-less tags include Consumer Packaged Goods (CPG) with a market for trillions of tags, postal departments with a potential for around 650 billion tags and books with a requirement of around 50 billion tags annually.

Smart tags will require memory, sensing capabilities, privacy and security features. For most new technologies or products, security is generally an afterthought. Sustainable RFID tags that can be recycled and/or avoid polluting recycled material fractions should be preferred. The price and functionality of the RFID tags will decide the extent of their application.
RFID are going to be pervasive. Applications will range from logistics to defence. RFID will be used throughout the manufacturing and logistic supply chain to provide traceability.

1.3 Business development drivers

There are a number of factors creating a new demand for RFID technology:

- Strong demand for tracking, locating and monitoring of objects with a focus on increased security, safety, cost savings, and customer satisfaction resulting in higher enterprise security.
- Reduction in cost, size and power consumption of RFID tags and systems.
- The availability of open RFID standards (ISO 18000, EPC Global and IEEE 802.15.4).
- Mobile commerce applications.
- New product developments based on emerging sensor networks and communication technologies.
- Growing demand from the physical access control market
- With increased competitive pressures and customer expectations, businesses need better actionable information on which to make decisions that can impact successful operations in real time.

Thee different business models are envisioned for RFID during the last few years that have the potential to succeed in the future.

- Developing and disseminating ultra low cost tags with very limited features (only EPC code of products stored in the tag memory) and to centralize the information on data servers managed by service operators. Here the value resides in the data management. In this model major actors from distributed computing networks and servers will play a central role.

- Another possibility is to put more functions into the tags bringing local services and added value to the tag itself. This is illustrated by developments of sensing RFID devices.
- The third model that has emerged recently considers distributing the information both on centralized data servers and on the intelligent sensing RFID tags and develop the network infrastructure for communication.

1.4 Technology development drivers

1.4.1 Energy

The development of new batteries (fuel cells, printed/polymer batteries etc.), new energy generation devices using coupling energy transmission methods or energy harvesting using the energy conversion together with compact energy storage devices will be the key factors for implementing autonomous wireless smart systems.

1.4.2 Intelligence

Development of ultra low power processors/microcontrollers cores designed specifically for mobile IoT devices (MIoTDs) and a new class of simple and affordable IoT-centric smart systems will be a priority. The solutions in this respect will range from the use of hard wired or micro programmed finite state machines to the use of microcontrollers. The choice is a trade off between flexibility, programmability, silicon area and power consumption. The devices require some form of non-volatile storage (EEPROM/FRAM/Polymer), whether laser trimmed at the time of manufacture, one time programmable, or electrically rewritable. Rewritable non-volatile memory is clearly preferred for achieving high throughput during production test, and concurrently offers the benefit of user memory, programmability and storage for sensing data. Research topics are: life data retention, read/write capability cycle and embedded memory capacity.

1.4.3 Communication

New, smart beam steer able phased array antennas and multi frequency band antennas, integrated on chip made of new materials are the communication means that will enable new devices to communicate. On chip antennas (OCA), coil on chip, printed antennas, embedded antennas and multiple antenna using different substrates and 3D structures will be optimised for size, cost and efficiency. Modulation schemes, multi frequency energy efficient communication protocols, transmission rates, and transmission speed are also technology drivers. The communication protocols will be designed for Web oriented architectures of the Internet of Things platform where all objects, wireless devices, cameras, PCs etc. are combined to analyze location, intent and even emotions over a network. New methods of effectively managing power consumption at different levels of the network design, from network routing down to the architecture of individual devices.

1.4.4 Integration

The use of integration of chips and antennas into non-standard substrates like textiles and paper, and the development of new substrates, conducting paths and bonding materials adequate for harsh environments and for ecologically sound disposal will continue. System-in-Package (SiP) technology allows flexible and 3D integration of different elements such as antennas, sensors, active and passive components into the packaging, improving performance and reducing RFID tag cost. RFID inlays with a strap coupling structure are used to connect the IC chip and antenna in order to produce a variety of shapes and sizes of labels, instead of direct mounting.

1.4.5 Interoperability

The future standards must ensure that RFID tags and readers work globally. Future tags must integrate different communication standards and protocols that operate at different frequencies and allow different architectures, centralised or distributed, being able to communicate with other networks.

1.4.6 Standards

Royalty-free open standards that allow tags to be read seamlessly across different countries are key enablers for the success of RFID technology, for Machine2Machine communication. In order for RFID to successfully penetrate into large open systems, RFID interoperability is a necessity. Standards evolution and interoperability will influence the RFID deployments in the near future. Sustainable fully global, energy efficient communication standards that are security and privacy centred and are using compatible or identical protocols at different frequencies are needed. The interest at the European level is the near future will be:

- To align RFID standards development globally
- To create a number of liaison activities to disseminate information about the importance of global standards
- To put in place the 'Global RFID Interoperability forum for Standards' (GRIFS) comprising global stakeholders
- To ensure continuous close collaboration between standards activities

1.4.7 Manufacturing

Reducing manufacturing cost is key to RFID push through and the introduction of manufacturing methods for low cost RFID (IC, antenna, gravure printing and etching, assembly) is a priority for the future. Costs must be lowered to less than one cent per tag, and production must reach extremely high volumes, while the whole production process must have a very limited impact on the environment.

In the future the RFID technology should be transparent to the end user, which will concentrate mainly on how to use RFID, identify their target application with a clear objective and a defined medium that has to be tagged and monitored.

In this context the RFID research priorities include elements that are essential for the future development of the RFID technologies. In Europe the RFID technology is addressed in the agendas of the European Technology Platforms ENIAC (Nanoelectronics), EPoSS (Smart Systems Integration), and ARTEMIS (Embedded Systems).

Looking at the major technological developments, the timeframe for industrial innovation's maturity rate is 20-25 years. RFID technology development will span over such a period with the tag prices going down, the infrastructure that will use the information being implemented, and the appropriate business processes applied. Around 2010, a variety of attributes such as temperature, velocity and pressure will become the subject of sensing via RFID sensor networks and possibly the new "Internet of Things" infrastructure.

1.5 Security and privacy

For humans, whenever we interact with other people we give them some form of information which may or may not (directly or indirectly) identify us. This choice has to be implemented in the future IoT devices as well. For some applications and some devices there will be no anonymity at all, a state called verinymity, and for other applications and devices there will be total anonymity or unlink able anonymity. In between these two levels different degrees of anonymity such as persistent pseudonymity and linkable anonymity could be defined by standards and regulation for specific applications and devices.

Development of hybrid security mechanisms that for example combines hardware security with key diversification, therefore delivering superior security solution that makes attacks significantly more difficult or even impossible. The selection of security features and mechanisms will continue to be determined by the impact on business processes and trade-offs will be made between chip size, cost, functionality, interoperability, security, and privacy.

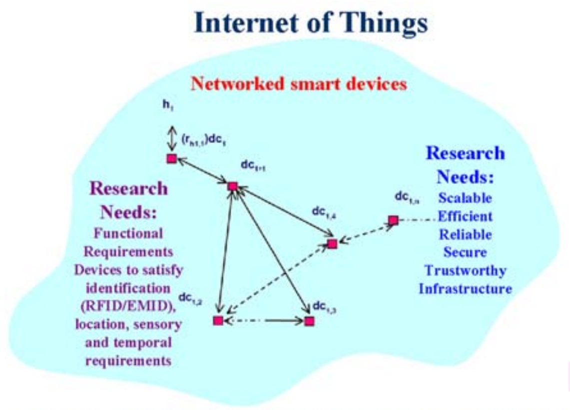
Many of the security and privacy issue will be addressed by the RFID standards which will define different security features that provide confidentiality, integrity, or availability services.

1.6 Research priorities

During the next years, technologies to achieve the ubiquitous network society are expected to enter the stage of practical use. RFID technology will be implemented in the retail industry before 2010. When this scenario is realized, a system will emerge in which a vast amount of objects are connected to IP networks in the first "Internet of Things" system. There will be two major challenges at the network level seamless use of these systems: the first issue relates to the fact that various networks are separated (mobile phone networks, fixed telephone networks, broadcasting networks, closed IP data networks for each carrier (broadband, public wireless LAN, etc.) and the Internet) and the other issue involves that the IT industry has no experience in developing a system in which hundreds of millions of objects are connected to IP networks by means of IPv6. IPv6 can assign more than 4.3 billion unique worldwide IP addresses on a network unit and offer additional functions to facilitate object to object communications that include automatic address setup, security functions such as authentication and encryption, QoS (quality of service) functions to guarantee the quality of communications and multicast functions to deliver voice and video signals efficiently.

The next generation networks used for the "Internet of Things", in addition to fixed telephone networks, mobile phone networks and broadcasting networks will be integrated into closed IP data networks for each carrier and will be used for services requiring high reliability in terms of quality of service (QoS) and security from among data communications services. Most devices such as RFID readers, devices consisting of sensor networks and mobile and fix robots will support IPv6, and a full scale shift from IPv4 to IPv6 will be implemented which will form the backbone of the new "Internet of Things" infrastructure.

Another major point of discussion is the quantity of "intelligence" that the "things" in the IoT will need to have and how this intelligence is distributed. The answer to this question will be given by the requirements from different applications and industries. Retail and logistics require ultra low cost tags with limited features (bearing an ID number and some extra user memory area) and limited security and privacy functions. The information is centralized on data servers managed by service operators and the value resides in the data management. Other applications and industries will require tags that will host a much higher quantity of data and more intelligent services.



Research Collaboration on components and network devices for a truly global 'Internet of Things'

These types of tags will have features ranging from sensing and acting capabilities to interacting with the environment in which they are placed. One such example could be an interacting RFID device placed in the human body with the scope of delivering the right medicine at the right place at the right time. In this context of greater "wireless", "mobility", "portability" and "intelligence" two trends will influence the future development of RFID systems: increasing use of "embedded intelligence" and networking of embedded intelligence. All these will require finding answers and solutions to the following challenges:

- Paradigm shift from identification of objects at a distance to "communication between objects" and "distributed embedded intelligence"
- Intelligence rules whereby linked objects can react
- Available and affordable software and hardware components for network and reacting objects
- Sets of rules and protocols to govern interactions at required speeds and quality while respecting security and privacy
- Application challenges

Intelligent RFID nodes will be integrated in hybrid wireless networks and used in applications like ambient monitoring in buildings, environmental monitoring, home automation, personalization, localisation, positioning. In this category are included as well the Real Time Locating Systems (RTLS) using active RFID.

In the next decade, most of the active RFID market will be in the automotive, transportation (aeronautics, automotive, etc.,), logistics, healthcare and military sectors.
. In the same line, RFID devices will be used for "greening" the environment, recycling, and object life cycle monitoring and disposal management.

To create the RFID future devices the research will focus on antennas that will be realised on chip (on chip antenna) or coil on chip antennas. New technologies and methods are needed for implementing printed antennas using conductive inks, embedded antennas in different materials, multiple antenna substrates and 3D structures.

The processing part of the RFID devices requires new integrated circuits based on novel micro/nanoelectronics/polymer devices and using reconfigurable RF front ends for multiple frequencies (HF/UHF/MW).

Intelligent RFID devices will require more memory and the research topics related to EEPROM/FRAM/Polymer memories will cover areas like life data retention, read/write capability cycle and embedded memory capacity. For devices with networking embedded intelligence new research areas will emerge addressing the application aware storage, autonomic storage, pervasive storage and self configuring, self healing and self protecting intelligent RFID devices.

Multi communication, security and privacy centric ultra low power protocols that are compatible over different frequencies and functional scalable for different applications will be a research priority in the future in order to implement a fully global and interoperable IoT platform.

The research need to concentrate to the sensing and actuating elements that will be embedded together with the intelligent RFID devices. The focus will be on very low power bi-stable, flexible, transparent displays, MEMS/NEMS sensors, sensors on chip and molecular sensors.

Future autonomous smart objects will harvest the energy from the environment in which they operate. The research will focus on wireless power generation, power harvesting (vibration, temp, etc.), new types of batteries (printed/polymer), fuel cells and supper energy storage devices.
Future developments will be seen in the area of software platforms for service oriented applications including micro operating systems and middleware to connect to backend processing systems.

New research areas will combine mobile micro robots with wireless sensor networks and RFID ubiquitous networks. At the same time new multi standard mobile and miniaturised RFID readers will emerge.
Future mobile robots/micro robots and sensor networks using RFID technology will be used to develop efficient, robust and versatile hybrid/heterogeneous networked systems that can be deployed in inaccessible, or remote spaces (oil platforms, mines, forest for fire protection, tunnels, pipes, etc.) or in cases of emergencies or hazardous situations (earthquakes, fire, floods, radiation areas, etc.,).

The research areas will focus on cost and functionality with activities concentrated on “one cent” RFID device based on paper/polymer materials and “smart/intelligent” RFID devices based on silicon. Heterogeneous system integration using different technologies will be used for specific optimised RFID solutions required by specific applications and industries.

The top research priorities within RFID and smart systems in logistics will be:

- System-in-Package (SiP) technology that allows flexible integration of different elements such as antennas, sensors, active and passive components into the packaging, improving performance and reducing RFID tag cost based on ultra thin silicon chips, flexible and multi-layer substrates and integrated devices.
- Integrated micro sensors and actuators based on micro electro-mechanical systems (MEMS) technology.
- Smart RFID tags and mobile readers enabling wireless access and facilitating intelligent networking bringing innovation in smart systems integration by miniaturisation, increased functionality and memory, higher speed, low power, shorter time-to-market.
- Energy supply is a great challenge for smart RFID tags with additional sensors and computing capabilities as well as for mobile readers. Research topics include integrated foil batteries, energy saving algorithms, energy harvesting and an energy saving power management of all tag components, also included printed batteries and miniature fuel cells.
- Antenna design based on dipole, micro strip, slot, fractal, PIFA and coil antenna designs, also including materials that can be recycled.

- Radiofrequency technology in the high frequency (HF), ultra high frequency (UHF) and microwave (MW) bands.
- Bi-stable flexible displays including electronic paper ensuring paper rewrite ability of information and electrophoretic display technology.
- Polymer electronics suitable for disposable, non-polluting and low-cost tags. Research will include organic thin film transistors, non-volatile memories based on semiconducting and ferroelectric organic/polymer materials, solar cells and light-emitting devices based on organic materials. Research will also include novel functionalities such as light emission, chemical/biological sensitivity and energy generation devices for RFID tags.
- The RFID life-cycle including disposability, degradability and recyclability of the materials used in the RFID. Biodegradable materials for RFID sensors may provide one solution.
- RFID tags as electronic waste raises new concerns in recycling. A typical RFID tag may contain as much as 15 different materials (plastics, paper, metals, silicon and adhesives). The copper antenna pollutes steel fractions, silicon is not suited in a glass melt and some of the components are not suited for incineration (energy recycling).
- RFID tags may contain dismantling instructions for composite products enabling a more efficient disassembly of clean material fractions and reuse of parts.
- Security and privacy in RFID tags to avoid unethical and misuse of RFID tag information based on cryptography and untamperable electronic locks including read-only-once technology to ensure privacy in the ubiquitous information society. Secure communication standards between RFID tags and read-out devices will also be important.
- Mobile commerce applications based on RFID tags.
- ICT architectures suitable for RFID information, including development of infrastructure and database capable of storing and tracking information available from billions of tags. One future scenario is the “internet of things” that holds information about every tagged object accessible through RFID tags in a multiplicity of environments.

For smart systems in biometrics, research emphasis in the following areas is indicated:

- Smaller, low cost, low power sensors
- Development of new sensor production technology
- A higher level of integration with electronics
- More efficient implementation of algorithms for image reconstruction and authentication
- Mobile commerce applications
- Development of extremely low cost sensors
- Including pointing and navigation functionality
- Physical access control
- Development of technology for highly robust low cost sensor, coating and packaging technology.

Future Outlook

		Before 2010	2010-2015	2015-2020	Beyond 2020
	Vision	• Connecting objects • Pervasive RFID	• Communicating objects • Socially acceptable RFID	• Interacting objects • Ubiquitous society	• Personalised objects • Next level
	Society	• "Internet of Things" concept debated • Consumer concerns (privacy) • Develop security and privacy mechanisms and establish security guidelines for RFID developers and operators of RFID systems • Realising benefits (food safety, anti counterfeit, pharmacy) • Changing ways to work • Cultural barriers • Data explosion • Business process innovation	• "Internet of Things" defined • New business paradigms • Ambient Intelligence Society • Changing business (processes, models, ways to work) • Distributed power grids • Debate on authentication, trust and verification • Environmental benefits • Energy conservation • Access rights issues	• Interacting retail and logistics • Ambient assisted living • Energy efficient ambient living automation • Interacting and smart transportation • Public awareness of data ownership and management • Expend the ID concept (more than ID number) • EMID (ElectroMagnetic Identification)	• Self aware physical world • Personalised tags, the needed information companion everywhere, every time • ID, sense, interact, track and trace anything, everywhere, anytime, while respecting privacy, security and business rules. • Search the physical world as a commodity • Wireless power grids • Data and storage grids • "Feelings" grids • Master the continuum of people, computers and things
	Politics	• De-facto governance • Privacy legislation • Energy consumption concerns • Standardisation • Energy and environment	• Frequency Spectrum Governance • Unified open interoperability • EU governance • Energy policy	• Debate on data storage, privacy, security and ownership Global governance	• Data governance • Regulation with no jurisdiction • Law beyond acts in the electronic era
Development	**Standards**	• Standardization efforts for RFID security • Creating a Gen2 standard of HF • Extend the UHF Gen2 capabilities (security features) • Standardization of passive RFID tags with expanded memory and read/write capability for product serial numbers, repair and warranty information. • Radio regulation change to	• Privacy and security cantered standards • Adoption of standards for "intelligent" IoT devices • RFID global technology standards for product lifecycle tracking and monitoring (cradle to grave tracking/monitoring) • Adoption of standards for different industries	• Dynamic standards • Adoption of standards for interacting devices	• Evolutionary standards • Adoption of standards for personalised devices

		eliminate the listen before talk (LBT) requirement for improvement of dense reader mode RFID systems. • Proposal for non-EPCglobal RFID standard (uID)			
	IT Systems and Services	• Service oriented architectures • Grid computing	• IoT Browser and search engine • Self management and control	• On demand service discovery/integration • Autonomous computing • Tera scale computing	Autonomous systems for non stop information technology service
	Infrastructure	• Broadband	• Grid network	• Service based network	• Need based network
	Network Technology	• Photonic • Wireless • IPv4	• Hybrid • IPv6	• Ultra high speed	• Network that connect people, things and services
	Business Impact	• Globalization is a primary driver for RFID • In US mandates from the U.S. Department of Defense (DOD) and Wal-Mart • RFID adoption in logistics and retail • Pharmaceutical • Aeronautics and aerospace industry mandate to RFID tag all product shipments by 2010. • Military mandate. • Consolidation of providers in both the hardware and software markets. • Industry specific solutions and expertise will continue to grow • RFID market in exploration phase	• RFID market in addoption phase • Aeronautics • Automotive • Healthcare	• Services • Industrial Applications	• Integrated industries

Outlook Research Needs

		Before 2010	2010-2015	2015-2020	Beyond 2020
Research Needs	**Functionalities Features and Applications**	• Low cost crypto primitives – hash functions, random number generators, etc. • Low cost hardware implementation without computational loss • Smaller and cheaper tags • Higher frequency tags • RFID tags for RF-unfriendly environments (i.e water and metal) • 3-D localistion	• Adaptation of symmetric encryption and public key algorithms from active tags into passive tags • Protocols that make tags resilient to power interruption and fault induction. • Power loss graceful recovery of tags • More memory • Less energy consumption • Protocols for interoperability • 3-D real time location/position embedded systems	• Code in tags to be executed in the tag or in trusted readers. • Global applications • Adaptive coverage	• Intelligent and collaborative functions
	Ubiquitous Sensor Robotic Networks	• Different networks (sensors, mobile phone, etc.,) • Interoperability framework (protocols and frequencies) • Network security (e.g. access authorization, data encryption, standards etc.)	• Hybrid networks • Ad hoc network formation • Multi authentification • Long range tags (higher frequencies –tenth of GHz) • Networked RFID-based systems – interface with other networks – hybrid systems	• Integrated authentification • On chip networks and multi standard RF architectures • Plug and play tags • Self repairing tags	• Internet of Things • Robust security based on a combination of ID metrics
	Power Generation	• Thin batteries • Energy management • RF • Thermal • Solar	• Printed batteries • Photovoltaic cells • Super capacitors • Energy conversion devices • Grid power generation • Multiple power sources	• Paper based batteries • Wireless power everywhere, anytime. • Power generation for harsh environments	• Biodegradable batteries
	Systems, Circuits and Architectures	• Integration of hybrid technologies sensor, actuator, display, memory • Power optimised hardware-software design • Power control of system on chip (SoC) • Development of high performance, small size, low cost passive functions e.g. high-Q inductors, tight tolerance	• Multi protocol front ends • Multi standard mobile readers • Extended range of tags and readers • Transmission speed • Distributed control and databases • Multi-band, multi-mode wireless sensor architectures • Smart systems on tags with sensing and actuating capabilities (temperature, pressure, humidity, display, keypads, actuators, etc.)	• Adaptive architectures • Reconfigurable wireless systems • Changing and adapting functionalities to the environments • Micro readers with multi standard protocols for reading sensor and actuator data	• Heterogeneous architectures. • "Fluid" systems, continuously changing and adapting.

		capacitors, high density capacitors, low loss switches, RF filters, tuneable capacitors • Mobile RFID readers with increased functionality and computing power while reducing the size and cost • Miniaturised and embedded readers (SiP)	• Ultra low power chip sets to increase operational range (passive tags) and increased energy life (semi passive, active tags).	• Distributed memory and processing	
	Devices	• MEMS • Low power circuits • Silicon devices • Smart multi band antennas • Beam steerable phased array antennas • Low power chip sets • Low cost tags • Small size, low cost passive functions • High-Q inductors • High density capacitors, tuneable capacitors • Low loss switches • RF filters	• Paper thin electronic display with RFID • Ultra low power EPROM/FRAM • NEMS • Polymer electronics tags • Antennas on chip • Coil on chip • Ultra low power circuits • Electronic paper • Harsh environments devices (extreme temperature variation, vibration and shocks conditions and contact with different chemical substances) • Nano power processing units	• Polymer based memory • Molecular sensors • Autonomous circuits. • Transparent displays • Interacting tags • Collaborative tags • Heterogeneous integration	• Biodegradable antennas • Autonomous "bee" type devices
	Materials and Processes	• Polymer • Silicon, Cu, Al Metalisation • 3D processes • Assembly and packaging techniques for RFID tags (protection against high/low temperature, mechanical, chemical substances, etc)	• Carbon • Polymer • Silicon • Conductive ink • Improved/new semiconductor manufacturing processes/technologies for higher temperature ranges • Flexible substrates	• Carbon nanotube	•
	Environment Manufacturing	• Vacuum plasma spray (VPS)	• Industrial ecosystems	• Energy recycling	• Eco-friendly production • Biodegradable devices