Semiconductor Technologies for Smart Cities

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Contents

1 Abstract

By 2050, 70 percent of the world's population will live in cities. And, as cities grow and expand their services, the management, operations and governance across the city becomes increasingly complex. To manage this increasing complexity, it becomes necessary to make cities »smart«. Smart Cities have been defined as cities that use information and communications technology to make its critical infrastructure and its components and utilities more interactive and efficient. Smart cities are built on 'smart' and 'intelligent' solutions and technologies that will lead to the adoption of at least 5 of the 8 following smart parameters—smart energy, smart building, smart mobility, smart healthcare, smart infrastructure, smart technology, smart governance and smart education, smart citizen.

Goal of this study, which was performed by a working group of the CATRENE Scientific Committee, was to analyze the requirement a smart city will have with respect to micro-/ nanoelectronics and smart systems for smart cities can be regarded as part of the "Internet of Things" (IoT). In this domain a huge increase in markets is expected for the next years ("The Trillion Sensor Vision").

Within this study the key areas of interest

- Urban Processes
- ICT
- Safety / Security
- Energy
- Buildings
- Mobility, and
- Production & Logistic

have been analyzed. Future key products and roadmaps have been identified; the necessary research topics and their strategic impact have been derived.

Surprisingly, it was a major outcome of this study that the expected application pull does not yet exist. There is not yet a continuous semiconductor value chain. Whereas smart city planners and operators think and act mainly on a conceptional level and utilize microelectronics off the shelves only, technological opportunities, although available and offered, are not really recognized by the smart city people. In addition, Smart Cities Applications today are more or less singular application solutions, because no unified Smart City approach exists yet.

To overcome this situation some topics have been identified which might be future business cases for industry and are regarded as worthwhile to be looked at in more detail.

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Berlin, November 2014

2 Megatrend »Smart Cities«

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2.1 What will turn a city into a »Smart City«?

By 2050, 70 percent of the world's population will live in cities. And, as cities grow and expand their services, the management, operations and governance across the city becomes increasingly complex. To manage this increasing complexity, it becomes necessary to make cities »smart«[1]. Technological, organizational and systemic innovation is required to deal with the most urgent questions. Goal is to overcome the discrepancies between individual and societal needs for mobility, consumption and quality of life on one hand, and resource conservation, climate protection and sustainability on the other.[2] In addition, there are also shrinking cities. Making cities smart might be an opportunity to make such shrinking cities more attractive for people.

Traditionally, a Smart City has been defined as a city that uses information and communications technology to make its critical infrastructure and its components and utilities more interactive and efficient, and making citizens more aware of them[3]. Following an analysis of Frost & Sullivan[4], smart cities are cities built on 'smart' and 'intelligent' solutions and technologies that will lead to the adoption of at least 5 of the 8 following smart parameters—smart energy, smart building, smart mobility, smart healthcare, smart infrastructure, smart technology, smart governance and smart education, smart citizen

The IBM [5] is treating a smart city as a multipart eco system, where management, operations and governance across the city becomes increasingly complex. At IBM, three major areas have been defined: planning and management, infrastructure and humans which comprise government & administration, smart building & urban planning, environmental aspects, energy & water, transportation, education, healthcare, social programs, and public safety.

The German BMBF is just working on a new concept (»Nationale Plattform Zukunftsstadt«) focusing on renewable energies, efficient distribution and use of energy & resources, energy-efficient mobility, innovative mobility technologies, adaptability of urban systems, security & resilience, urban production, and digital city models, as well as the necessary application-oriented technologies.[6] An interdisciplinary approach and an interconnection of the city sectors are required to deal with these challenges and to ensure a socially acceptable transformation: Representatives of cities, civil society, industry, research are involved.

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[1] http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview/
[2] Tobias Hegmanns in Bosshard et al, Sehnsuchtsstädte, transcript Verlag, Bielefeld, 2013
[3] SMART CITIES STUDY: International study on the situation of ICT, innovation and Knowledge in cities; The Committee of Digital and Knowledge-based Cities of UCLG
[4] Strategic Opportunity Analysis of the Global Smart City Market, Frost & Sullivan, August 2013
[5] http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview/
[6] Tobias Hegmanns in Bosshard et al, Sehnsuchtsstädte, transcript Verlag, Bielefeld, 2013

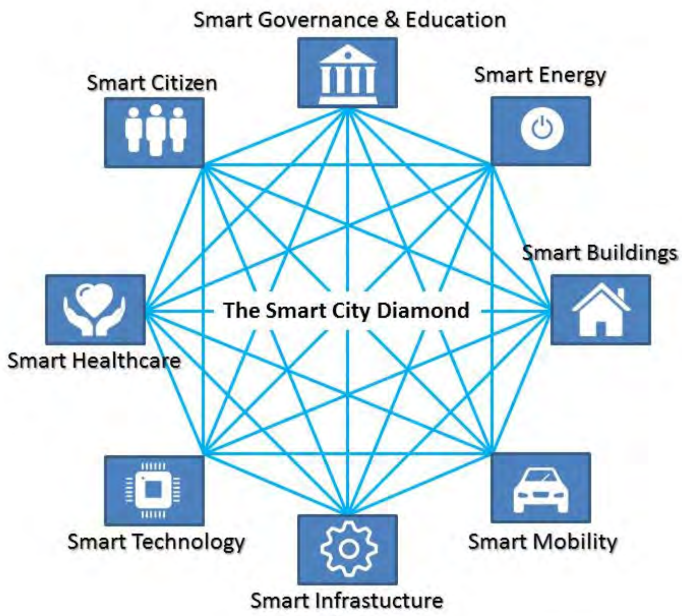

Figure 1: Key Areas to define Smart Cities (adopted from: Frost & Sullivan[4], Icons by Freepik http://www.flaticon.com)

Fraunhofer defines the key elements of a Smart City in its »Morgenstadt« concept[7] as: urban processes & organization, energy for cities of the future, buildings, production & logistics, mobility & traffic, information & communication, and safety & security.

Despite of a different wording and a different granularity, all those studies and concepts are focusing on more or less the same building blocks. All of these building blocks will require application-specific and user-centric technologies. In addition, intuitive human-machine-interfaces in combination with sufficient information and education will be the basis for a broad acceptance of new technologies, applications and appliances.

Using the Fraunhofer »Morgenstadt« concept, the structure of this study is following these seven challenges:

Urban Processes & Organization

Urban governance and planning evolved last decades in the direction of a) a more business-like and b) participatory oriented "urban management" approach. The new model strengthens the role of the responsible citizen and media. Modern urban governance and planning

[7] http://www.morgenstadt.de/de/Forschungsfelder.html

furthermore addresses c) an integrated cross-sectorial view. d) Its priorities are based on "sustainable development" - it reflects environmental aspects. e) ICT-technologies have substantially contributed to modernisation of the public sector and support to integrate and visualize formerly separated planning areas, into a context-sensitive view.
Urban planning is managed in terms of "processes".

Within the new model of public governance structured in urban processes ICT leads towards a structural change. Urban planning obligations are formulated in "implementation plans" and are oriented at Key Performance Indicators (KPI). KPIs are matched to relevant plan objectives manifested in the implementation plan of the city. The activity of continuously keeping the implementation plan under review is a core urban management process and can be supported by ICT and all kind of sensed, analysed and visualized data. Stakeholder/citizen involvement in this kind of processes (in the definition of the implementation plan as well as in the definition of the KPIs) is a basic concept for the modern urban process.

Information & Communication

Information and Communication Technologies are key to nearly all other technology areas relevant for smart cities. Exchange of data is essential everywhere and for everything even today. Its importance will further grow. In future, highly effective, fast and reliable information and communication networks are required not only for media supply and communication but also for energy supply, mobility and public safety/security. Smart cities will become part and will make intensive use of the Internet-of-Things. Communication is no longer restricted to people but will link people, buildings, vehicles, machines, devices and nearly every object of daily life.

Safe and Secure Cities

Urban systems are dynamic systems. The close interleaving of different domains like traffic, energy and buildings, makes such a system operational, but also vulnerable. The challenge today is, to increase resilience without limiting dynamics. Existing infrastructures have to be adapted to climate and demographic changes, for example.

The level of risk in cities and regions is increasing rapidly, particularly in developing countries, where town development often takes place in areas that are open to disasters. Half the world's population lives in cities, which concentrate all kinds of human activities. Therefore, they are more vulnerable to terrorism, crime and natural disasters.

Local authorities can improve security using ICT systems and, consequently, make their cities safer, more sustainable and prosperous. To gain the necessary experience, it is crucial that experts from different disciplines work closely together and in conjunction with relevant partners.[8]

An important issue is the alignment of technical and societal infrastructures (energy, water, traffic, health, …) with the technological development and the societal and environmental changes. The breakdown of critical infrastructures has to be avoided. Modeling of cities as complex systems might be an approach to predict and optimize the system behavior.

Taking into account the ever increasing amount of data being processed in such a complex system, data security is another crucial issue with respect to safety and security. Data must be protected against manipulation, information networks must be protected against any kind of "cyber-attack".

Energy

Cities of today are both, reason for energy wasting and approach towards a sustainable society. 80% of the worldwide CO_2 emissions are generated in cities. Thus, efficient use of energy in cities will be most effective in terms of resource and climate protection. To achieve optimal benefit, a holistic approach in cities is necessary. Optimized flows of energy, goods, materials etc. will significantly contribute to energy saving. The importance of decentralized and local energy systems will grow and will change the cityscape significantly.

Future energy supply will include "smart" production, storage, distribution and use of renewable energies. For increased efficiency the conventional energy grids have to be changed into "smart" grids. They will merge with information networks to exchange information between power plants, storage systems and users to keep the system efficient and manageable. An integrated approach is needed which includes regional, urban and local energy supply (sub-)systems and bridges the gap between renewable and conventional energies.

In addition, consumers today have tremendous expectations for future energy services. However, they are largely unaware that they need to take a more active role in managing energy decisions for their visions to become reality. The "smart grid" needs to improve information transfer also to consumers to build broader acceptance. In the awareness of consumers, gaining more control over energy use, improving environmental impacts and managing costs have been firmly associated with the term "smart grid".[9]

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[8] SMART CITIES STUDY: International study on the situation of ICT, innovation and Knowledge in cities; The Committee of Digital and Knowledge-based Cities of UCLG

[9] Knowledge is power, IBM Institute for Business Value, January 2012

Buildings

40 % total energy consumption is used for construction, operation and destruction of buildings.[10] Today, reconstruction of buildings with respect to cooling and heating, integration of renewable energies and/or power-heat-coupling is in the focus of European countries and will have a significant impact on energy savings. Primary energy consumption will be reduced by 80% till 2050.[11] Other regions like China are able to go even a step further. There, completely new cities are being designed and build, taking into account most innovative technologies.

Beside energy efficiency, which will lead to the "plus-energy" house, with a "negative" energy consumption, wellness and comfort aspects are playing an increasing role, especially in the western hemisphere. This will require "smart buildings", monitored by smart metering and controlled by ICT, integrating most advanced technologies like solid-state lighting.[12]

Mobility

Today's efforts are aiming at reducing the number of vehicles with combustion engines within cities. The European Commission is planning for halving the number till 2030 and achieving an emission-free mobility till 2050.[13]

Electro mobility, car-sharing, and mobility on demand might be solutions to achieve these goals in cities. However, taking into account the traffic density of today, it will require also extensive traffic management using car-2-car and car-2-environment communication as well as new solutions for transport logistics. Attractiveness of public transport will be strongly influenced by speed, comfort, safety and security, and costs.

At the end, avoiding traffic instead of only reducing it will be in the focus. This will result in an increasing "virtual mobility", i.e. an increase in communication (video phones) and new concepts to re-integrate living, shopping and working.

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[10] M. Barthauer in Ökologische Nachhaltigkeit von Büroimmobilien, Jones Lang LaSalle, 2008

[11] Erster Monitoring Bericht Energie der Zukunft, BMWi/BMU, Berlin 2012

[12] E. Hertzsch, M. Buttler in Sehnsuchtsstädte, transcript Verlag, Bielefeld, 2013

[13] http://www.cep.eu/fileadmin/user_upload/Kurzanalysen/Weissbuch_Verkehr/KOM_2011__144_de.pdf

Production & Logistics

Skilled worker shortage, compatibility of family and career, and increasing environmental compatibility of production technologies will change the production environment. A close neighborhood of production facilities, living and services will become possible again and will take some pressure off the mobility challenges.

In synergistic coexistence of production and living, production facilities may supply (waste) heat,and excess energy. Raw materials can be easily recycled (urban mining). Workers will live within short distance from the production sites.

From a logistics' point of view, the mobility issues have to be extended towards all flows of goods & materials, including energy, water, food, and information. Today, the individual delivery of food, goods etc. is one of the major source of noise and air pollution, and a burden for mobility.

Distribution of goods, energy, water and information has to be reorganized and adapted to the increasing importance of the e-commerce and internet based consumption and service offers. At the end, urban infrastructures have to be re-invented to become effective, energy efficient, fast and reliable.

2.2 »Smart Cities«: Vision and Stories[14,15]

A few years ago future cities were hardly a matter of broad discussion. This changed in 2007, when the United Nations illuminated the fact that 50% of the human population (3.3 billion people) already lived in cities. According to the prognosis, in 2030 over 5 billion people will be city inhabitants. This development is not exemplary for all nations - many of the highly industrialized countries experience decreasing population statistics, due to shrinking birth rates, aging of the population, and demographic change.

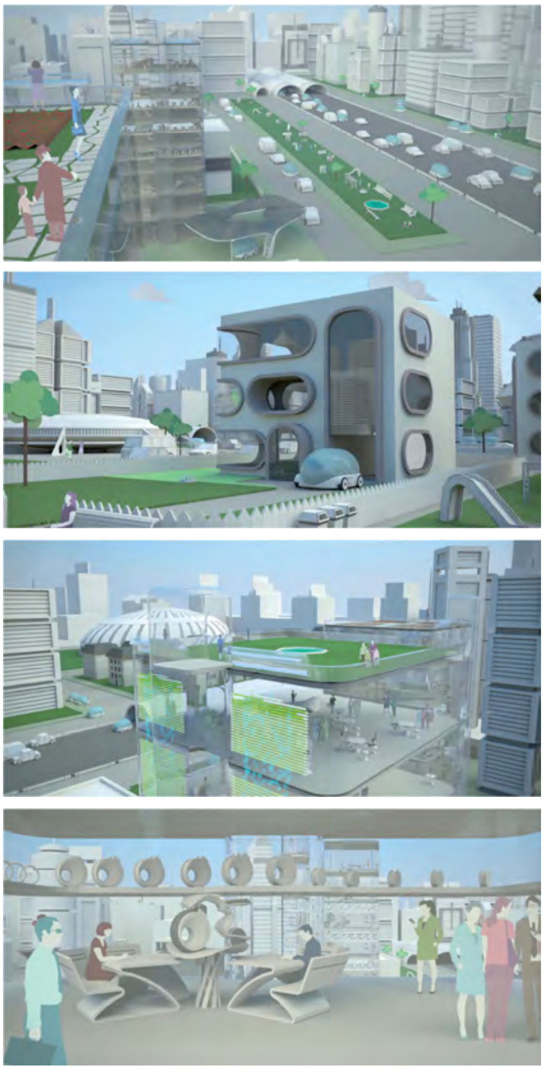

Figure 2: What may »Morgenstadt« look like? (Source: Fraunhofer IAO/FBB)

The cities of tomorrow will differ essentially from today‘s city principles. However, this transformation will slowly happen over the upcoming decades, so that we will hardly be able to detect obvious change as contemporary witnesses. Current future topics, such as electric mobility, industry 4.0, shared economy, energy transition and the internet of things will gradually change our societies by altering value creation as well as living and working processes. The city itself will be the central point of action and testing field of our time. This is the place where people, organization forms, space and technology converge and develop in dependence on each other.

For the first time in human history, mankind is challenged to actively master urbanization worldwide by using the right solutions for a sustainable development. Sustainability goals are necessary for the cities of the future, but have to be complemented by additional dimensions like resilience and the ability to innovate. An increase in extreme situations and changing framework conditions require new approaches, strategies and infrastructures. What will the city look like, in which we want to spend our future in? Which products and solutions will we need to achieve this vision?

After concluding the first phase of the project “Morgenstadt: City Insights” the following most pressing topics have been identified for further research

[14] Visionen zur Morgenstadt – Leitgedanken für Forschung und Entwicklung von Systeminnovationen für nachhaltige und lebenswerte Städte der Zukunft, Fraunhofer Gesellschaft, Stuttgart, 2012
[15] Innovation Network Morgenstadt: City Insights Phase 1, Executive Summary, München 2014

- The bottom line for urban sustainability needs to be redefined.
- Resilience has to be an integral part of sustainable development.
- Cities need individual long-term visions as guideline for socio-economic, spatial and technical development.
- Sustainability is the goal, maximizing fitness is the way

Cities need to know which goal represents their individual ideal situation. This vision has to be simple, clear and highly ambitious, representing the ideal stadium of a sustainable city. A »Morgenstadt« vision is suggested that builds upon four main development goals:

- 0% Waste
- 100% Resilience
- 100% Livability
- 100% Innovation Excellence

2.2.1 Urban processes and Organization

The core concept of Smart Cities is based upon the efficient exploitation of data and data collections. Increasing amounts of digital information are expected. The data is supposed to be about almost every measurable phenomenon, for example about economical, demographic and ecological conditions, about the amount and types of cars moving at crossings, energy consumption, water flows, and the health situation of the inhabitants. Sensors are collecting more data on urban environments than ever before. Information technology with its high-performance database systems, data analytics tools and information systems integrates, analyzes, visualizes and manages that data from different sources. This provides an innovative and needful overall view to the city governance and supports them in understanding how Smart Cities are functioning as complex systems. The activities of the city governance in city operations, planning, and development are performed as a sustainable urban processes.

The “Urban Processes” chapter below describes the modern urban process, how it is generally composed, the goals it is oriented at and its technological backbone.

The chapter intends to indicate future development needs and requirements for the semiconductor industry. Since urban processes and required data are manifold, we exemplarily limit the further exposure of the chapter in its second part to the application area “air”. We describe a sensing scenario that concentrates on measurement and monitoring of air quality in an urban area. From that the respective requirements to the sensors needed are derived.

Selection of key action fields

- Smart Cities Management Process: - Integrated strategies development
- Citizen/Stakeholder Involvement in Urban Processes - eParticipation
- Implementation Plan and Key Performance Indicators
- Business Analytics for Urban Process Management
- Smart Cities Architectures
- Smart City Cockpits, Visualization, open 3-D-City Models (Open Data, Open Source)

- environmental data to be sensable in real-time

2.2.2 Information and Communications Technologies (ICT)

In the City of the Future, every person, each component und all systems will be provided with all necessary information according to need, interest, or authorization – no unnecessary or obsolete information will be distributed. The user will get relevant and requested information only. It is guaranteed that important information will reach its destination in time; a prerequisite to better solve or even avoid critical situations.

Highly flexible communication and information networks are the basement. They allow for innovative solutions for mobility, administration and public security. Citizens, enterprises, institutions and administration are linked; quality of work and life is improved by an efficient and integrated information flow. The City of the Future has become a service provider for citizens and enterprises, relieving them by seamless and transparent processes. This optimal city network will also provide for ecological and sustainable solutions. By ICT, the City of the Future is networked and informed. The City has become mobile, secure and sustainable.

Information and communication are key to a “smart city”. All core issues of the City of the Future will build on latest information, communication data exchange and networking: energy supply, mobility, and public safety and security. Communication technologies are no longer limited to conventional telephone networks, mobile phones and internet. Communication networks have become seamless and ubiquitous. They integrate everything from sensor networks to internet, including all kinds of mobile communication.

New actors will be added. Beside smart phones and all kinds of computers, vehicles, streets buildings and household appliances have become part of a comprehensive communication infrastructure. The focus is no longer on the direct communication between people or devices but on linking countless users, devices and systems with each other.

Not only infrastructure will change but also information content and service offers. Today, commercial “apps” are aimed mainly on consumption or entertainment. In the City of the Future, all public services and information are available via “apps”. Information on traffic situation, environmental data, air and water pollution and pollen count as well as the quick information exchange among government agencies will open up a wide area of ease in daily life.

The city of tomorrow will be data driven and thus, it needs to adapt to this trend by analyzing the various existing data sets with urban context and using the gained knowledge in order to optimize municipal processes. Thus, ICT solutions contribute to the sustainability development across sectors. This overlap occurs due to efficiency, promising opportunities of new technologies and emerging demands. ICT solutions can mostly be considered transferrable, although dependent on basic societal approval and financial resources. Successful ICT solutions need, amongst others:

- Jointly developed ICT strategies.
- (Big) Data analysis with high performance analysis tools.
- Defined transfer of knowledge processes.
- Dissemination processes for public information.

Selection of Key Action Fields:

- Open data systems.
- Urban Big Data systems.
- Intelligent traffic management based on real-time information.
- Interoperable electronic ticketing systems in public transport.
- Digital self-helping structures.

2.2.3 Safety, Security and Resilience

Safety and security has become self-evident in daily life. This results in an absolute freedom. Children can play everywhere, airports and stations have become multi-function buildings of public life and parks and foot paths are crowded even in darkness. Public safety and security is not guaranteed by security guards alone, every citizen has become part of a comprehensive resilience concept ("sustainable security").

This resilience concept allows also for an integrated risk management. The city is prepared to handle dangerous situations. Real time information is analyzed by complex simulation tools, which displays an image of the current danger potential and of possible consequences for infrastructure and people.

Ubiquitous embedded and autonomously operating wireless sensors are part of this concept and monitor buildings and infrastructures. They detect damage and wear-out and support rescue teams be locating helpless persons. Sensor networks also make the working environment safe. A smart health system has become part of the overall resilience concept. In addition, smart network structures make the ICT infrastructure less vulnerable.

Thus, urban systems will be facing two major challenges in the 21st century: First, the absolute and relative number of severe shocks and stress fractures (either man-made or naturally-caused) is going to rise. Second, our daily life is increasingly relying on ICT. Interconnected infrastructures and social networks need to be able to rapidly absorb such disturbances without jeopardizing or surrendering the sustainability imperative. Still, pay-off for investments in security and resilience is seen as low, since the occurrence of so-called low-probability high-impact events is rare.

Future resilient urban systems and their individual components will need good design and construction, good management and good governance.

Selection of Key Action Fields:

- Resilience-by-Design Approaches.
- Network Security Solutions.

- Business Continuity Management and Planning.
- Flood Protection.
- Integrated Risk Management.

2.2.4 Energy and Resources

Today, heating of buildings in Germany is responsible for nearly half of the CO_2 emissions. Buildings of the City of the Future will no longer emit any carbon dioxide at all. They are zero or even plus energy buildings which will generate at least as much energy as they consume. They will be equipped with solar panels. Old buildings are completely refurbished and have significantly reduced energy consumption by using innovative insulating materials. Cogeneration of heat and power is used, often in combination with thermal heat pumps and/or fuel cells.

Energy systems for heating/cooling and electrical energy have been combined into a “smart grid” which allows for an optimized and interleaved operation. Electrical cars and hydrogen powered vehicles have become part of this smart grid. Electrical energy is generated locally from renewable sources only. Energy providers have merged to regional service providers, which provide energy, and operate grids, storage systems and control centers.

Energy systems have developed into “multi-energy-smart-grids” which integrate generation of power and heat and energy storage systems. Smart buildings equipped with innovative facility engineering systems are part of the smart grid. Smart sensors control the operation of air conditioning and lighting. Variations in electricity tariffs are taken into account automatically by the energy management systems to reduce costs and to preserve energy without diminishing quality of life.

Sustainable cycles of materials have become part of daily life. Heat is recovered from waste water; digester gas from clarification plants is converted into electricity. Energy, waste, water, and sewage flows are analyzed systematically and are recycled. Big gardens have been built into fresh air swaths between the city quarters and are watered with recycled “grey” water. Green houses on top of the roofs and shared cars help further to preserve resources and to improve quality of life.

Today, energy production and consumption of urban processes account still for a great deal of resource use and emissions. Indicators not only reflect the level of efficiency, they are also influenced by the climatic conditions and the size and type and industry located in a city.

In general three types of energy-related projects can be distinguished today:

- Citizen oriented projects, where a high acceptance and interest of the citizens is necessary to implement projects. The availability of private funding is also crucial for such projects.
- Technically oriented projects, which improve the energy system‘s efficiency as well as the share of renewable energy, without involving the energy user to a great extent.

- Research oriented energy projects, which are aiming at identifying possibilities to increase the sustainability of the energy system. A public-private partnership is an important impact factor, since pilot installations are usually realized in cooperation between cities and industry.

Selection of Key Action Fields:

- High-efficient centralized energy supply.
- Promotion of renewable energies.
- Communal energy management.
- Use of smart grid technologies.

2.2.5 Buildings

The City of the Future is an organically grown complex consisting from interacting buildings and infrastructures. The concept is designed for autarkic energy supply by solar energy and a complete use of building envelopes for energy generation. Disposal of access heat is achieved by high energy efficiency in combination with wind inflow, use of daylight and waste water systems, heat islands within metropolitan areas no longer exist. Optimized aerodynamics is used for ventilation. The building envelope is used as a sink for emissions which are collected and disposed by natural process (e.g. moss). Energy is not only consumed by buildings; buildings are also an important resource for urban energy generation, for energy storage. Buildings are part of the smart girds for electrical and thermal energies.

Sustainability roadmap concepts or regulations for cities are necessary, and role models for sustainable buildings are important for raising awareness and garnering wide acceptance for innovative solutions from all city stakeholders. Acceptance can also be improved by lessening the time and effort necessary for building applications, e.g. by simplified and alternative approaches within a city's regulatory structures. Furthermore, passive consumers (e.g. building occupants) need to be integrated more strongly in the future.

Selection of Key Action Fields:

- Regulation for construction processes and building activities.
- Prefabrication of buildings for efficient city transformation and use of resources.
- Energetic retrofit.
- Increased energy building standards for new construction and building retrofit.
- Sustainable certification.
- Material flows.
- Socially acceptable rent levels.

2.2.6 Mobility and Transport

Nobody can imagine any longer the solid lines of cars in a traffic jam of today which produced a lot of harmful exhaust. Traffic in the city of the future is completely aligned with the needs of the population. It is highly efficient in terms of sustainability and quality of life.

Traffic management means no longer to modify the cities according to the traffic density but to control traffic according to the real needs of city and people. Accidents no longer happen due to reliable communication concepts including car-2-car and car-2-environment communication. Semi or fully autonomous driving cars are the basis for a successful PRT (Personal Rapid Transport).

Combustion engines can only be found in vintage cars. Downtown areas are allowed only for battery or fuel cell powered vehicles. Traffic management controls traffic flow by dynamic toll systems and achieve a smooth and undisturbed traffic stream. A lot of alternative concepts have more or less replaced the individual traffic. Noise has been significantly reduced by electric drives; personal traffic and transport of goods has been decoupled.

Urban mobility is based on shared vehicle concepts. Smart reservation and booking and a dynamic distribution of cars has reduced the required parking space by a factor of 10. This is supported by innovative parking lot concepts including high rack type car parks. Total number of cars has been reduced by cooperative use. One shared car is replacing now 20 individual vehicles.

The need for sustainable mobility concepts becomes obvious when looking at global carbon dioxide emissions caused by transport. Today, successful measures are mostly connected to large infrastructure projects, which are shaped by decades of development, policies and local framework conditions. In terms of transferability, technological and infrastructural solutions are usually applicable to multiple situations and should be integrated into a city's holistic sustainability strategy. Certain patterns have been identified:

- Green mobility has a strong marketing value and becomes a major locational factor for cities.
- Transition towards public transport instead of private mobility concepts.
- Promoting interconnected inter- and multimodal mobility by creating intermodal hubs that offer alternative transport options.
- Introducing car-free living quarter concepts.

Selection of Key Action Fields:

- Targeted combination of different modes of transport.
- Public-transport oriented development.
- Linking multimodal mobility to financial services.
- Enhancing efficiency of urban transport by smart multimodal transport integration.
- Non-motorized transport

2.2.7 Production and Logistics

In the City of the Future, production and logistics are the basis for a smooth flow in transportation and handling of goods, commerce, and service and guarantee for the provision of people with all products of vital importance. However, a reorientation of design and operation of urban manufacturing locations and logistics networks is provoked by the future economic, ecologic and societal boundary conditions.

In a City of the Future, manufacturing locations are designed for minimal environmental stress and pollution to be “urban compatible”. Urban manufacturing locations are usually within walking distance from the living areas – living and working can be arranged easily. Thus, manufacturers and City are operating in a symbiotic manner. Waste heat, excess energy and recycled raw materials will be exchanged between urban supply systems, disposers and production plants. Due to close cooperation of manufacturers and urban providers, materials flows do not suffer any longer from the decentralization. Efficiency of infrastructures is further increased by collaborative use of urban resources. Transportation of goods is done by electrical vehicles or underground only.

Flows and processes for transportation of goods have changed. Core issue of the innovative logistics strategy is distribution of goods, intermodal traffic systems and efficient use of infrastructures by flexible and collaborative pooling of commodity flows. Innovative solutions for (automated) delivery, distribution, express services and other “last mile” services combine a variety of individualized services of commerce and production.

The City of the Future is much more interleaved with production and logistics than today. It provides, plans, and monitors urban infrastructures and even parts of logistics and production themselves. Basic system conditions are changing due to the growing population and density of metropolitan areas, new production and consumption patterns and demographic change. Customized products and e-commerce lead to more individual manufacturing and smaller quantities of goods resulting in higher delivery frequencies and atomization of shipments. It is crucial to not just optimize individual technologies or product components, but also analyze value chains in a systematic and holistic way.

Selection of Key Action Fields:

- Establish flexible and local solutions for delivery services and freight logistics in urban areas.
- Intermodality.
- Quality and optimization of the street network.
- City-compatible noise- and emission-reduced operations must be enforced.
- Network-management, marketing and the provision of necessary infrastructure.
- Urban logistics monitoring and information board (logistics-cockpit).
- Intelligent urban supply network.

2.3 The Need for Microelectronics (1)

Smart Cities are at their very beginning. At present several challenges that industry and businesses face in working together with cities have been identified:

- No single company can meet the needs of a city nor can it implement innovative solutions without partners from the city and businesses from other sectors.
- Companies face challenges to engage cities directly as a customer. Procurement regulations can complicate the ability of companies to develop a reliable relationship with city clients.
- Public contract directives usually lead to large and inefficient bidding processes. They produce high upfront costs on both sides and often do not result in the best solution.
- Fitting solutions to pressing problems are often not implemented either because of lacking evidence-based long-term planning and scenario analyses or because of possible economic risks when considering innovative solutions.

»It is not the strongest or the most intelligent species who will survive but those who can best manage change.« (Charles Darwin)

2.3.1 Smart City – a 'system of systems'

A new study of ACATECH, the German Akademie der Technikwissenschaften, is dedicated to "Integrative ICT for the City of the Future"[16]. Coming from a software point of view, in this study a smart city is regarded as a 'system of systems' or as a huge 'cyber physical system', which is a system comprising *information generation* ('sensing'), *information processing*, and *communication*. However, all these three basic elements are based on micro-/ nanoelectronics and microsystems and cannot be realized without high performance hardware components.

Within a Smart City, urban innovation will therefore be based on an additional infrastructure – the information network –, which will become as essential as the power grid or the water supply.

[16] E. Mühlhäuser, J. Encarnação, Integrierende IKT für die Stadt der Zukunft, ACATECH, 2014, to be published

Figure 3: For realization of a Smart City, Smart Systems are used everywhere to connect everything (adopted from Frost & Sullivan[4])

2.3.2 What makes a city smart? Information!

On the website of the smart city Santander[17],[18], the characteristics of a smart city are summarized as follows:

The city of Santander is an old seaport on the north coast of Spain which had little interaction with the foreign world until Santander was chosen to become Europe's test bed for a sensor-based smart city. Since 2010, 12,500 sensors have been placed in and around the city's downtown district, where they measure everything from the amount of trash in containers, to the number of parking spaces available, to the size of crowds on the sidewalks. In addition, sensors on vehicles such as police cars and taxicabs measure air pollution levels and traffic conditions. The data from these sensors are analyzed in real-time and give city officials the kind of big picture that allows them to adjust the amount of energy they use, the number of trash pickups needed in a given week and how much water to sprinkle on the lawns of city parks.

London, Seoul and Stockholm have been using sensors to monitor traffic and manage congestion for years. Singapore has placed sensors throughout almost every part of its

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[17] http://www.governing.com/topics/urban/gov-santander-spain-smart-city.html
[18] http://www.smartsantander.eu/

physical geography with the goal of becoming the world's smartest city. And Rio de Janeiro has become the poster child for smart cities with its high-tech central operations center, which is staffed by nearly 400 workers who monitor everything from traffic to keywords in local social media in an effort to spot trends -- or problems -- before they occur.

A good portion of the sensors being used in cities are designed to improve the performance of key infrastructure, such as roads, rail, water systems and electrical grids what might lead to severe problems when cities become too reliant on sensors and smart applications to drive services and decision-making. As cities increase their dependence on software to run services, operate infrastructure and make critical fiscal decisions, they increase the risk that something could go wrong.

Ultimately, there's also the question of privacy versus security. Sensors that capture sound, images and locations of individuals can be helpful when we need protection or greater security. But there is always the worry that what starts as surveillance in a democratic society can become something else in a country that becomes autocratic. The nightmare of a "Big Brother society" might become reality.

Key functions of the Santander testbed are

- *Validation of approaches to the architectural model of the IoT.*
- *Evaluation of the key building blocks of the IoT architecture, in particular, IoT interaction & management protocols and mechanisms; device technologies; and key support services such as discovery, identity management and security.*
- *Evaluation of social acceptance of IoT technologies and services.*

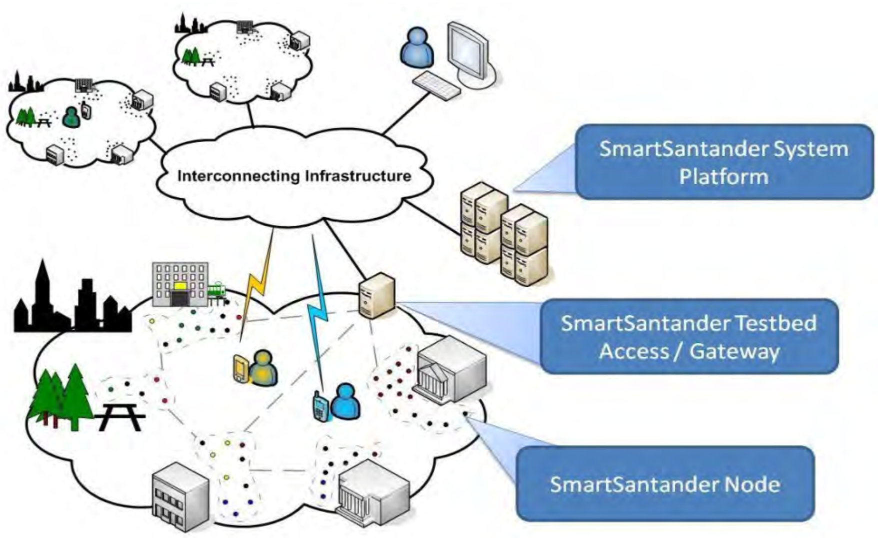

Figure 4: The Santander smart city infrastructure – a testbed for the City of the Future [18]

For realization of such a structure[18], microelectronics and smart systems are needed for generation, transmission, processing and storage of information as well as for all the applications using these data. At the end, energy is needed to operate everything …

This leads directly to the main topics, to be addressed by the electronics industry:

- Information
    - Generation of information
    - Communication and information processing
    - Storage of information
    - Use of information
- Energy
    - Efficiency, reduction of losses
    - Power supply
    - Smart Grid
- Cross-cutting aspects
    - Safety / Security
    - Applications

In the following chapters the different aspects of a Smart Cities are analyzed in more detail to get an overview of the future requirements on *Semiconductor Technologies for Smart Cities*.

3 Microelectronic-relevant research areas

3.1 Urban Processes in Smart Cities

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3.1.1 From Urban Planning to Urban Management Processes.

Urban planning is concerned with the design of the urban environment, including air, water and infrastructure passing into and out of urban areas such as transportation and distribution networks.[19]

Along with global urbanization and digital revolution the traditional approach for urban development and planning has changed with respect to cultural, societal and technical objectives in the direction of a) a more business-like and b) participatory oriented "urban management" approach. It also addresses c) integrated cross-sectorial strategic priorities often based on "sustainable development". Today urban planning reflects environmental aspects. ICT-technologies d) support the urban planning to integrate and visualize the formerly separated planning areas into a context-sensitive view. If such technologies are set-up holistically they can also be regarded also as so-called "City lifecycle management systems"[20].

The change towards a process-oriented planning perspective begun in the last decades of the 20 century when sociologists and urban planners start regarding cities as "complex organizations" that require effective business management. The goal is permanent improvement, corporate performance and optimization. Nowadays urban management is expected to be anticipatory, proactive and sustainable in ecological, economical and societal respect. Urban planning is organized in "processes". The term "process" derives from the reckoning of the city as an organization that needs to be managed correctly. It means basically a course, a development, or generally a system of movements. It appears in many knowledge areas like computing, science, industrial manufacturing, medicine etc. The urban process refers to preexisting concepts of processes and seems to be mainly influenced by the "business project management" area. Here a process is defined as a "set of interrelated actions and activities performed to create a pre-specific product, service or result."[21] Specific business management processes are grouped into sequencing categories such as: initiation, planning, execution, monitoring and controlling, optimization and closing. Urban processes cover many knowledge and application areas. Processes generally fall into two major categories: "Management Processes" and "Product-oriented Processes" (for example build or guarantee specific infrastructures throughout its life cycle).

This change towards the "management-process approach" in urban planning started as "Urban Renewal Projects" at the end of the 20th century in USA. It implies that city-specific

[19] See: Nigel Taylor, Urban Planning Theory since 1945, London 1998.
[20] See: Siemens patent application on a "A city lifecycle management system".
[21] Definition by the "A Guide to the Project Management Body of Knowledge (PMNOK Guide) – Fifth Edition, by the Project Management Institute, Pennsylvania 2013.

"Strategy and Implementation Plans" are developed, which themselves have also to be worked out and implemented as long-ranging process.

Stakeholder involvement is a basic concept for the modern urban process. Their involvement can be foreseen for the preparation, discussion, planning, decision making phase as well as for the monitoring and control and for the execution phase. The output should be the delivery of agreed results. Urban management processes promises an improved level of public-private cooperation, they inherit the possibility to communicate the strategy, to integrate the views and demands, to receive consensus, and to establish reconcilement-cultures. Engaging stakeholders in the urban processes is oriented at the idea of open and deliberative democracy. The voluntary system of pooling contributions related to the proposed developments is supported by visualization-technologies, e-participation and crowd-sourcing tools. In this context the "*Transition Town* Movement" to be understood as "Changing City-Movement" with its growing political importance shall be mentioned. Such environmentally oriented initiatives exist since 2006, promoting plans to changeover to a post fossil, delocalized economy worldwide.[22] Responsive-readiness and change-sensitivity of the approach are of importance.

3.1.1.1 eParticipation process examples: The integrated urban development concept Nürtingen 2025

German organizations promote participation projects with "online-participation" awards.[23] This shall contribute to a stronger promotion of citizen participation at all levels. In 2014 the City of Nürtingen received one on these awards, because it enables the people to participate in the so called "integrated urban development concept of Nürtingen" using an IT-platform. The participation in the strategic development of the city is organized as a process. The IT-participation platform complements a sequence of workshops, in which the Nürtinger citizen can participate in the review of the current urban situation, secondly contribute to general policy guidelines and development directions and finally hand in own project ideas and proposals for the strategic urban development.[24] In spring 2014, they kicked-off from that another participation process for a "Noise Action Plan" to gather ideas and propose instruments to reduce the noise-emission caused by traffic in Nürtingen.

Another eParticipation price went to Berlin, where in an online dialogue Berlin cyclists had the chance to indicate the locations and crossroads they personally perceive as dangerous. The spots were marked on an online map of Berlin. Very well received was the request to describe the specific dangerous spots and make suggestions for improvement. Within a limited period Berlin received 5,000 notes and more than 4,000 comments on spots perceived as dangerous. The project called: "Safe over the crossroad. Participation for more cyclists-safety." This knowledge gained from daily cyclist's mobility was supposed to be included in the further road safety activities and in the planning of cycling infrastructure. [25]

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[22] The movement was initiated among others by the Irish Permaculturalist Rob Hopkins and students of Kinsale Further Education College in Ireland. See: Wikipedia: Transition Towns, http://de.wikipedia.org/wiki/Transition_Towns.

[23] See: http://www.effizienterstaat.eu/Preis-fuer-Online-Partizipation/

[24] http://www.politik.de/politik-de/projekte_entdecken/partizipationspreis/partizipation-projekte/online-dialog-zum-integrierten-stadtentwicklungskonzept-isek-2025/14580

[25] See: http://www.politik.de/politik-de/projekte_entdecken/partizipationspreis/partizipation-projekte/abbiegen--achtung--sicher-ueber-die-kreuzung-buergerbeteiligung-fuer-mehr-radsicherheit/14524

3.1.1.2 Smart Cities Management Process: - Integrated strategies development

Smart City developments are oriented at global or international directives or align to global action plans: one popular example is the "**Agenda 21**"[26]. This is a non-binding, voluntarily action plan with regard to sustainable development. Cities like Berlin formulate corresponding local agendas like the "Berlin Local Agenda 21"[27]. "Sustainability" and "quality of life" is reigned supreme in such agendas.

Since 1990, the concept of "sustainable development" is a strategic guideline for urban development. The concept is broadly agreed in society, economy and politics in Europe and North America. The focus stands on ecological, economic and social aspects. It aims on maintaining an intact environment as a natural basis of life, as well as on economic and social stability. It is a normative approach.[28] Its implementation requires an integrated view on the city. To reach sustainable development sectorial, spatial, economic, technical and social aspects have to be integrated in a planning concept. Of course the values can change in the course of time and other objectives for example like security could range more important than sustainability in the future.

To come back to sustainability - if the goal of an urban process for example is to implement a sustainable mobility and integrated transport policy into a traffic master plan, it is necessary to coordinate multiple departments: These could be space and regional planning, town construction, the environmental and economic development for all traffic related measures. It is obviously a challenge to keep the context view of the city. You need to cross-link formerly separated planning sectors into an integrated view, need to identify overlaps, correlations and reciprocal effects. Policy objectives, goals, plans, indicators and limits have to be monitored, discussed, adapted and extended continuously in the urban process.

The required integrated view can be excellently supported by drawing on real-time data of all kinds of sensors of all relevant areas for real-time monitoring of conditions and activity variables. The collected cross-sectorial data, once monitored and analyzed, is expected to lead to automatic adaptation reactions – in case of under- and over performance of values. This reaction is seen to initiate again another "urban process" in the direction of optimizing towards the defined Key Performance Indicators (KPI). Performing this way in a control loop can help to shorten for example the time consuming search for sources and reasons of undesirable events, like for example sudden air and water pollution, or accident hot spots through installed sensors and IT-networks. The diagram taken from the STREETLIFE project[29] below shows the concept of such a control loop process in the Smart City.

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[26] From Wikipedia at http://en.wikipedia.org/wiki/Agenda_21: The Agenda 21 is a product of the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in 1992. It is an action agenda for the UN, other multilateral organizations, and individual governments around the world that can be executed at local, national, and global levels. The "21" in Agenda 21 refers to the 21st Century. It has been affirmed and modified at subsequent UN conferences.

[27] http://www.stadtentwicklung.berlin.de/agenda21/

[28] Umweltverträglicher Verkehr 2050: Argumente für eine Mobilitätsstrategie für Deutschland. 2014, at http://www.umweltbundesamt.de/publikationen/umweltvertraeglicher-verkehr-2050-argumente-fuer-0.

[29] See: http://www.streetlife-project.eu/index.html

Figure 5: Control loop process is a Smart City[27]

3.1.1.3 Smart Cities: Provision of Implementation Plan and Key Performance Indicators

Urban planning obligations are formulated in "implementation plans" and are oriented at Key Performance Indicators (KPI). "A performance indicator can be defined as an item of information collected at regular intervals to track the performance of a system."[30] KPIs are matched to relevant plan objectives manifested in the implementation plan of the city. The implementation plan includes a range of strategic actions that the governance and key stakeholders across the public, private, voluntary and community sectors agreed to deliver to ensure the implementation of this plan. The activity of continuously keeping the implementation plan under review is an example of another core urban management process. KPIs are used as monitoring regime in the process. To give an example: The city of London envisions in his actual "London Plan" from 2011 that: *"London is: A city that delights the senses and takes care over its buildings and streets, having the best of modern architecture while also making the most of London's built heritage, and which makes the most of and extends its wealth of open and green spaces, natural environments and waterways, realizing their potential for improving Londoners' health, welfare and development." Exemplarily London's corresponding objectives and KPIs are listed in the Implementation Plan. According to that London Plan objectives are the following:*

- Objective 1 meet the challenge of growth
- Objective 2 support a competitive economy
- Objective 3 support the neighborhoods
- Objective 4 delight the senses
- Objective 5 improve the environment
- Objective 6 improve access/transport

The objectives relate to the actual 24 KPIs of London, the first six are exemplarily shown[31]

[30] See: Carol Taylor Fitz-Gibbon (1990), "Performance indicators", BERA Dialogues (2), ISBN 978-1-85359-092-4.
[31] The London Plan, 2011, page 257.

No	Key Performance Indicator	Target	Relevant Plan Objectives*
1	Maximize the proportion of development taking place on previously developed land	Maintain at least 96 per cent of new residential development to be on previously developed land	1, 4, 5, 6
2	Optimize the density of residential development	Over 95 per cent of development to comply with the housing density location and the density matrix (Table 3.2)	1, 2, 3
3	Minimize the loss of open space	No net loss of open space designated for protection in LDFs due to new development	4, 5
4	Increase the supply of new homes	Average completion of a minimum of 32,210 net additional homes per year	1
5	An increased supply of affordable homes	Completion of 13,200 net additional affordable homes per year	1, 3
6	Reducing Health Inequalities	Reduction in the difference in life expectancy between those living in the most and least deprived areas of London (shown separately for men and women)	1
…..			

Table 1: The six most important KPIs of London[31]

To measure how the city is developing in regard to those objectives and KPIs specific statistical indicators are published by the cities for orientation.[32] Since "quality of life" for example is a very complex term, it is broken down in measurable indicators to provide a more practical way to track its state.

Another related new urban process is in determining the Smart City KPIs. This can be organized as a broad and deliberative discussion and decision. Nowadays it is an interesting discussion whether the city governance measures the right KPIs for example for sustainable development. Up till now the definition of KPIs was deeply rooted in expert knowledge. Now the demand is there to shape the KPIs closer to the public's expectations, to daily routines, expected services or closer to politics. This development is documented in the initiative "Beyond GDP", which is about developing indicators that are as clear and appealing as GDP, but more inclusive of environmental and social aspects of progress.[33] Modern IT-tools like Innovative Community Information Software Systems (e.g. the Policy Compass-project at Fraunhofer FOKUS) support the independent indicator development and enable citizen to define the indicators themselves. [34]

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[32] See: "Kernindikatoren zur nachhaltigen Entwicklung Berlins". Datenbericht 2012. Ed: Amt für Statistik Berlin Brandenburg,https://www.statistik-berlin-brandenburg.de/home/kernindikatoren.asp. Or (OECD Better Life Index: http://www.oecdbetterlifeindex.org/, comparable, neutral).

[33] See the political discussion around: Beyond GDP at: http://ec.europa.eu/environment/beyond_gdp/index_en.html

[34] See: Policy Compass project at http://policycompass.eu/. Here people can define own prosperity (and other policy) metrics and indicators by taking advantage of an easy to use visual language for defining variables and functions over open data sets.

3.1.2 IT-technologies

The IT-architecture is regarded as a “cyber-physical system” on a much larger scale, consisting of following spheres of activities: integrated city-development as multidisciplinary approach, dynamic infrastructures, genuine security as integral part of the platform, net as critical infrastructure, steerage and control with focus on user-enabling and teamwork. [35]

3.1.2.1 Smart City Architectures

The Smart City architecture consists mainly of three components, 1) the underlying basic data-infrastructure component which is permanently sensing, integrating, gathering, storing, combining and exploiting all kinds of city relevant data from different sources for all urban planning areas such as mobility, data on buildings, energy, health, security, infrastructure. 2) Analysis, simulation and optimization and planning is done by ICT-“city cockpits” components sitting on the data-infrastructure. 3) The city-cockpit exploits the data from the infrastructure component. This is done also by the end-user component. This end-user component is exploited by companies and citizens for useful personal or business relevant applications. Research projects are implementing corresponding architectures.

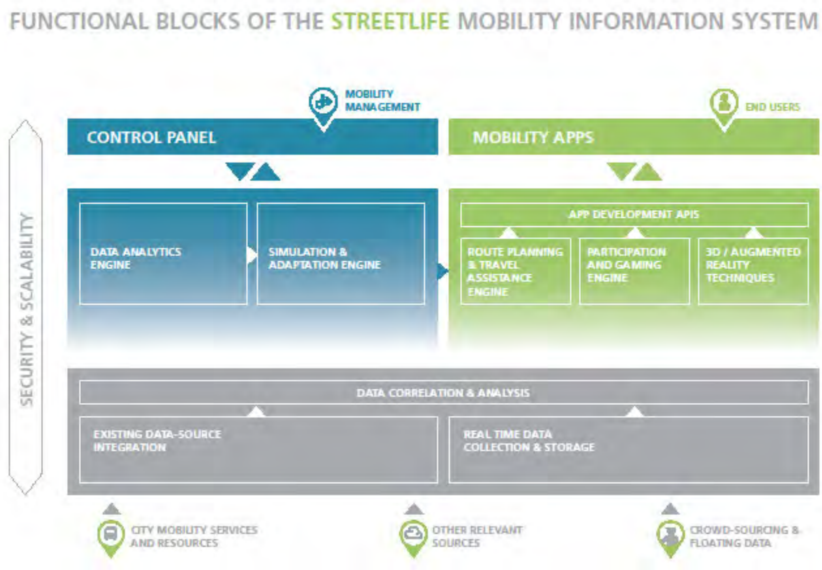

Figure 6: Functional blocks of a smart city architecture. Such architectures are be extended to all planning areas and infrastructures and can be exploited as so-called “City lifecycle management systems” [34]

Figure 6 displays an example diagram showing the functional blocks of a potential smart city architecture developed in the EU-research project STREETLIFE [36] on integrated, carbon-low smart-city mobility. It is consisting of the three basic components: the data layer (for data correlation and analyses), the control panel (for the mobility management) and the apps (for

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[35] Integrierende IKT für die Stadt der Zukunft, Schieferdecker, Ina; et al., 2014.
[36] See: STREETLIFE-project, at: http://www.streetlife-project.eu/project/summary.html.

the end users). Such architectures can be extended to all planning areas and can be exploited as so-called "City lifecycle management systems"[37].
Indisputably, there is a "big brother" aspect in it. The concept of a smart city raises deep concerns with regard to privacy and the protection of personal identifiable information (PII). It is clear that privacy of user data needs permanent consideration and attention. The architecture is flanked by a security concept, including namely authentication, authorization and auditing. Consequently same privacy requirements have also to be addressed towards the Sensor Monitoring Network gathering data.

3.1.2.2 Smart City Cockpits

As said before, urban processes are supposed to exploit the large-scale integrated datasets the city is creating. Visualization and analyses of such data takes place in Smart City Cockpits, where data converges. The city cockpit is a fixed instance within the city governance. It provides the requested context view discussed above and tracks on the performance of the city.

A city-cockpit integrates, analyzes, simulates, evaluates and optimizes continuously in a closed control loop. The results are used to address problems and challenges of all city operations, planning, and development. It discovers the causality links behind the observables and learns to anticipate and avoid the problems. The cockpit could be capable of generating proposals for decisions –based on rule-engines. Also with the information provided by the cockpit necessary enhancements of the infrastructure can be identified – for example after identifying a significant amount of accidents at a cross-road and after analyses of their reason, the traffic infrastructure at that site can be enhanced in form of different constructions. Another aspect is that the city cockpit can forecast developments and events analyzing the data available. Under discussion in the scientific area of knowledge based systems is the capability of such cockpits towards partially automatic conflict management. Fully automatic conflict solutions are not envisioned as good, since conflict solution should be a matter of fair human consideration and should not be left to systems. [38] The input of the human consultation is needed.

The market for City Cockpits is currently developing.[39] Global companies like SAP, Cisco, IBM and Siemens will offer intelligent solutions for the Smart City Analysis sooner or later.

3.1.2.3 3D City Models

New visualization technologies play a major role in urban processes. 3D-city models are of growing importance - originally based on GIS-data, visualizing mainly buildings and streets – are now filled with all available digital data to visualize on request all conditions of the Smart City. The development of such systems is strongly promoted and penetrates the urban planning. Their use will change the way how people understand and plan sustainable future environments. Tools like for example the Esri`s "city engine" are developing rapidly on the market and can meanwhile automatically transform existing 2D-GIS Data into smart and huge

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[37] See Siemens patent application on "A city lifecycle management system".
[38] See: Gordon, T. F., and Walton, D. Legal reasoning with argumentation schemes. In 12th International Conference on Artificial Intelligence and Law (ICAIL 2009) (New York, NY, USA, 2009), C. D. Hafner, Ed., ACM Press.
[39] Willi Kaczorowski, Die smarte Stadt – Den digitalen Wandel intelligent gestalten, Handlungsfelder, Herausforderungen, Strategien, Stuttgart 2014.

3D-City Models. The novelty is that the 3D-models do not rely on manual processing of areal images anymore.[40] The tools can be used by all stakeholders, predominantly used by the conventional urban planning offices, by the urban planning departments operating their integrated city cockpits. 3D-models are equally important for a broad range of academic disciplines including history, archaeology, medicine, geography, and computer graphics research and many more. Developments are of high importance for telecommunications planning and disaster management. In the future software will be capable to compare, analyze, and model everything at every single spot from every angle in a Smart City like for example the 3-dimensional underground situation[41] regarding the movement of trains below the surface and the surrounding technical infrastructure like pipes, wires, cables etc. or they can indicate the air pollution dispersion for the relevant indicators. [42]

3D-models and maps will integrate Augmented/Mixed Reality-features especially regarding real-time information for example on the real-time location of moving objects. [43]
A big advantage of 3D-visualization technology is that it is very effective in communicating complex situations and concepts and built outcomes to a wide variety of audiences. That's why the integrated use of such tools within the Smart City planning process goes along perfectly within the Smart City conceptual pre-setting of "eParticipation": All proposals and models can be once produced shared online for the benefit of the community. This way different and "before and after"-scenarios can be easily compared with each other and the impacts of a critical conditions or new plans can be easily understood and discussed with all stakeholders. Scenarios can be built faster and more cost-efficient.

3D-modelling tools will probably be standard in urban calls for proposals and bids in the city planning. The tools assists with speeding up and providing more accurate, negotiated outcomes to permit applications with developers and architects, the ability to produce high quality still images and videos, and to create, manipulate and view different built outcomes within easy to use and understand simulations. Some urban planning departments already employ a number of modelling software packages as well as GIS to provide the services to Government departments. [44]

3.1.3 Smart Cities are "Senseable" – the Sensing Process

Information exploited in the Smart City Cockpit is fed from heterogeneous sources: Sensors delivering data in real-time, open data of the administrations or weather data, information from social media, videos, audios etc.. The most common sensors are cameras, including video, which sense visible electromagnetic radiation; and microphones, which sense sound and vibration. There are many other kinds of sensors, however. Chemical and biological sensor technologies are developing from analog to digital currently. The measurement

[40] http://www.esri.com/software/cityengine
[41] See: http://www.london.gov.uk/priorities/business-economy/vision-and-strategy/smart-london/enabling-london-to-adapt-and-grow.
[42] See: REPORT TO THE PRESIDENT BIG DATA AND PRIVACY: A TECHNOLOGICAL PERSPECTIVE, Washington May 2014, page 44.
43 Antti Nurminen et al: Mixed Reality Interface for Real Time Tracked Public Transportation, in: 10th ITS European Congress, Helsinki, Finland 16–19 June, at: http://www.streetlife-project.eu/fileadmin/user_upload/Downloads/ITS2014_Paper_Mixed_Reality_Interface.pdf.
[44] http://www.dpcd.vic.gov.au/planning/urbandesign/3d-modelling

technology they are consisting of is coming from the traditional analog “measurement technology” belonging to the area of process engineering. Recently so called “online-measurement” features were added to conventional measurement instruments. The chemical and biological sensor manufacturers are deriving from disciplines like the industrial process engineering, the traditional automation technology, safety technology, electrical engineering and communication technology among other. Their products allow measuring some indicators regarding air quality, including the identification of chemical pollutants; barometric pressure (and altitude); low-level gamma radiation; and many other phenomena on different sensors.[45] The challenge is that the different indicators are normally collected by expensive equipment with high maintenance requirements dedicated to a single indicator measuring very local conditions. A newer development measuring indicators for urban planning for 3D-Models as well as for urban scene extraction is by real-time data provided through ground based LiDAR (a remote sensing technique using lasers) deriving from radio detection and ranging technologies. [46] Airborne LiDAR mapping technology has high potential for many areas within urban planning, like for example Forestry Management and Planning, Coastline Management, Transport Planning, Cellular Network Planning, Oil and Gas Exploration[47]. Meanwhile LIDAR is preferred as a sensor measuring principle for aerosol determination and pollution. Still the results are quite imprecise, but precision is not always regarded as top requirement as discussed below. Apart from that LIDAR is deployed for many other sectors like Biology, Geology, Physics and Astronomy, Archaeology, Meteorology, Military and law enforcement and may more.

Many 3D-models as well as urban scene extraction can be constructed by multi-sensor real-time data. Means they are accomplished using a variety of data sources. These along with new data sources, crowd sourcing technologies and opportunities and new promising quantities and qualities of data (real time (“instant”) data, big data, etc.) opens many new opportunities for Smart City research, urban planning and monitoring. In anticipation of this in 2011 the “SENSEable City Laboratory”, as new research initiative at the Massachusetts Institute of Technology was founded. The institution advertises on its website in following words: “*The real-time city is now real! The increasing deployment of sensors and hand-held electronics in recent years is allowing a new approach to the study of the built environment. The way we describe and understand cities is being radically transformed - alongside the tools we use to design them and impact on their physical structure.*”[48] Consequently the MIT “SENSEable city lab”-projects are various and manifold, experimental. The concept was followed by newly established research departments pushed by the US government like “Urban physics and Informatics” in New York. They promote the new research area “Urban informatics” focusing on data usage “to better understand how cities work. This understanding can remedy a wide range of issues affecting the everyday lives of citizens and the long-term health and efficiency of cities — from morning commutes to emergency preparedness to air quality”. The research department belongs to the brand new “Center for Urban Science and Progress

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[45] LAR http://www.lar.com/home.html, ENDRESS und Hauser http://www.de.endress.com/

[46] See: http://www.lidar-uk.com/usage-of-lidar/

[47] See: REPORT TO TH E PRESIDENT BIG DATA AND PRIVACY: A TECHNOLOGICAL PERSPECTIVE, Washington May 2014, page 44.

[48] See: http://senseable.mit.edu/

(CUSP)[49]" providing units called "Data Warehouse", "Urban Observatory (UO)" - created to observe significant regions of the city at multiple physical wavelengths, a "Quantified Community" and an "Integrated simulation" of New York. Wall Street Journal recently reported that CUSP recently installed high-level infrared cameras on top of skyscrapers detecting and visualizing pollution plumes in real-time coming from specific buildings.[50]

3.1.4 Motivation and Requirements for an urban process in air management

Since a goal of the article is to indicate future requirements for the development of the sensors for Smart City processes, which can be manifold, we exemplarily limit the further exposure to one application area of urban processes: **Air**.

As areas like energy, mobility and buildings are discussed in separate chapters of this study we focus on "air quality", because we suppose that in the future natural resources like water and air will be considered as products of Smart Cities. We envision that the monitoring activity is carried out by a Smart City cockpit visualizing the condition of the complete outdoor air immissions using 3D-visualisation tools. The data for the 3D-visualisation is sensed in real-time and consists of a tailor-made network consisting of a mixture of mobile sensor-stations distributed in the city, satellite sensing via LiDAR, and via crowd sourcing through a **sophisticated Air Monitoring Network**. The results of the city cockpits activities are expected to be published and exploited by all the stakeholders and inhabitants of the city.

We suggest in the following that for the Smart City the health conditions of the humans is the first command variable. As air condition has a significant impact on the health condition of the population and on the surrounding nature, it has to be controlled and optimized. In case of water the tradition of control exists since more than hundred years. In the case of the air quality control no such hard infrastructure facilities exist so far.

Existing monitoring networks of air quality in the cities usually use a limited number of supporting points which are the base for interpolation of spatial distributions of air pollutants and noise. Traffic densities in main roads are typically considered. This approach allows an assessment of spatial mean values of outdoor exposures of the population in urban areas. It fails with respect to highly resolving spatial and temporal data. Therefore, some important questions cannot be answered. E.g. crossroads in cities are often hotspots of emissions, but at such places the predictive power of the existing approach is limited with respect to mean values (dose) and short-term (daily, 8h, etc.) maxima. But, many epidemiological studies found evidence that daily mean values of ultrafine particle (UFP) and NO_2, O_3 are predictors of adverse health effects. Consequently, the quality of the protection of human health could be markedly improved if more detailed exposure data with higher temporal and spatial resolution would be available.

For this demand a new type of monitoring network is necessary. This monitoring network described below cannot replace the existing networks. The combination of both types of

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[49] See: http://cusp.nyu.edu/
[50] See: http://www.wsj.com/video/big-data-knows-when-you-turn-off-the-lights/E1841482-6D57-4882-8559-734B38A3424F.html

networks will be able to improve the health protection and, in the consequence, indirectly also help to minimize traffic related emissions.

The air monitoring network described below is considered as a maximum demand scenario, which we, if we stay realistic, probably can only approach partially in the next future, mostly because the measurement of the indicators needed is currently still based on extremely complex measurement procedures and stand-alone instruments.

To summarize the requirements of the monitoring network would lie in:

- Area-wide, permanent measurement of ultrafine particles combined with a whole set of pollutants (in minimum: NO_x, NO_2, Particulate matter PM10, PM 2.5, Ozone, Noise, rated sound pressure level, temperature and humidity) on small-scale city level
- Variability of the monitoring network according to city-specific conditions (climate, architecture, topography,..), technology, and regarding surveying precision
- Lower maintenance costs of the monitoring network
- Set of indicators to be measured on one instrument for medium and for high measurement precision
- Set of indicators to be measured on an mobile (smart phone,..) for crowd sourcing of information for lower measurement precision
- Protection of Personal Identifiably Information, individual right to denial
- Visualized in 3D-maps of air immissions based on real-time sensed data
- Durability and eco-friendliness
- Artificial Intelligence
- Efficiency, flexibility, adaptability, low-power consumption, security and privacy, flexibility, interoperability, identifiable.

3.1.4.1 Situation

Outdoor air immission measurement is becoming a very hot topic.[51] Air pollution is increasing steadily in the last years especially in the boosting Asian metropolis but also in Europe. The available information shows that the WHO guidelines for the major air pollutants are regularly exceeded in many major urban centers[52].

In Berlin for example the atmospheric load on the main roads is above the EU limit.[53] Germany actually is threatened by a million-dollar heavy court-proceeding by the European Commission regarding its air quality. The reason is that more than half of the urban traffic monitoring stations installed in Germany measure that the allowable annual average of 40 micrograms per cubic meter of nitrogen dioxide (NO_2) is exceeded. Limit violations are also measured in case of particulate matters (PM10). In parallel the WHO advises on even much stricter limits to particulate matter PM10 and will limit values for PM2.5 will be put in force.

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[51] It is in this article distinguish between the terms Immission and Emission. The term immission designates air pollution by pollutants such as nitrogen oxide and particulate matter in outdoor air. This burden is the result of the emissions (emission) of pollutants from a variety of sources and their transport and transformation (Transmission) in the atmosphere.

[52] Air Pollution: Authors: Romieu, Isabelle, in 53. Environmental Health Hazards, Kjellström, Tord, Yassi, Annalee, Editor, Encyclopedia of Occupational Health and Safety, Jeanne Mager Stellman, Editor-in-Chief. International Labor Organization, Geneva. © 2011.

[53] See: Kernindikatoren zur nachhaltigen Entwicklung Berlins. 2. Datenbericht 2014, Amt für Statistik Berlin Brandenburg, Berlin 2014.

Air pollution is meanwhile an economical location factor. According to recent news Coca-Cola China is paying expatriate employees a "hazard pay" to live in China's polluted air. Many measures against air pollution are currently discussed. They are accompanied by websites visualizing real-time Air Quality indices on maps illustrating the air condition for different regions on the world. [54]

Monitoring and improving air is a challenge that embraces several planning sectors like space, city planning, traffic, town and building construction, environmental, economic and energy departments. Immissions arise from complex physical, geological and climate-related situation in a city, delayed effects of environmental damage, unknown positive and negative feedback as well as unknown, often non-linear relationships between the variables, best to be trapped and visualized with means of IT, best to be measured with an area-wide so far not existent measurement network. It is a fact that the distribution of air pollution within different areas of a city is different. Bad air in cities is often associated with the location of main roads and correlates in many cases with socially deprived areas. [55] Means different groups of urban population suffer differently from exposures, which are often invisible but dangerous as in case of particulate matters (PM10).[56]

Uncovering, displaying, analyzing the widespread city-specific situation of air in real time could become a key area of innovation. The industry itself is already anticipating stronger emission standards and driving their technological developments in expectancy of that.

Facing this MIT is already developing in its “Senseable city lab” a sensor-box to be carried by the citizen for their information on the actual air immission they are moving through. In the impressing “One Country, Two lungs” project-video, as result of a recent collaboration between MIT Senseable City Lab and LAAB design office in Hong Kong a team of 'human probes' traverse Shenzhen and Hong-Kong to detect urban air pollution.[57] Here commuters are sensing their cities streets themselves. In the project a prototypical commuter carries on his vehicle back an **array of sophisticated sensors.** The commuter is moving like a tracer running through the streets of the cities. The commuter observes the pollution in real-time and drawing a dynamic, human map of Hong Kong and Shenzen. The commuter carries a display showing actual air condition values he is moving through. Red colors show air pollution while green colors indicate healthier air. It is envisioned, that from such data collected, future apps can be developed, that route citizens through “cleaner or cleanest areas”. It is predictable that the demand for such kind of routers will be high.

The city of Chicago kicked-off a project called the “array of things” where they installed sensor packs on the public infrastructure across the city. A sensor pack contains 56 sensors detecting everything from wind speed, block-by-block carbon dioxide level and pedestrian counts with smartphone and Wi-Fi. In addition, here, the impact of such technology could be

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[54] See for example: Guilin Air Pollution: Real-time Air Quality Index (AQI), http://aqicn.org/map .

[55] See article: http://www.morgenpost.de/berlin/article133215788/Die-Berliner-Luft-ist-sozial-ungerecht-verteilt.html, from 14.10.2014.

[56] See: Social indicators are predictors of airborne outdoor exposures in Berlin, by Ulrich Franck, Heinz-Josef Klimeczek, Annegret Kindler, in: Ecological Indicators, Integrating, Monitoring, Assessment and Management, Volume 36, January 2014, ISSN 1470-160X.

[57] See: “One country, two lungs-project”: http://senseable.mit.edu/twolungs/.

huge high, as it concerns property values and raises public concerns about asthma. Originators can be traced and asked for penalties.[58]

3.1.5 List of Requirements

Requirement 1: *pollutant indicators to be measured*

It is generally accepted that the standard indicators needed to measure outdoor air immission are in minimum: **NO_x, NO_2, Particulate matter PM10** and **PM 2.5** as well as **Ozone**. It makes sense that measurement of these outdoor air pollutants is combined with the standard measurement of **noise**, since noise is also carried by air and noise level is quite cost-efficiently to capture. Then other air pollutants are to be considered additionally, depending on which specific urban environment the survey is aiming at: In this context, the measurement of the **rated sound pressure level** is of further interest. Additionally **temperature** and **humidity** could be measured. Crucial and also a good selling point is if the listed indicators can be measured all **with a single device**. As far as we know, currently no such device exists. It would be highly appreciated to have such a portable device, which can measure all indicators mentioned above.

Online measurement for is very useful for the application area. The federal offices in Germany like the Saxon State Office for Environment, Agriculture and Geology execute already permanent immission measurements and publish half-hour average values for different measurement locations.

Requirement 2: *small-scale measurement.*

Immission values are to be taken in that area where humans are staying on small-scale. The number of measurement stations needed in a city depends on factors like the urban landscape and on the question which accuracy and which special resolution is desired. For example in case the urban landscape is broken up in valleys and mountains then of course there is the need for more measurement stations. The small-scale monitoring of data will be necessary esp. in the city center and in cities with varying altitudes but not in the suburbs. As a rough orientation, for a three million inhabitants, flat city like Berlin, 50-60 measurement-stations would be sufficient. Modelling and simulations programs are capable to calculate the regular situation of the area between the measurements-stations with very minor deviations. But simulation is suitable only for long-term average values, if pollution loads do not change. It is not possible to simulate a sudden event like for example a burning dumpster in a road causing high concentrations.

Additional measurement stations need to be installed, where immissions fluctuate in locations like frequented crossroads. According to the real-time monitoring of the immission the city cockpit should be able to optimize the traffic flow whenever needed, for example through speed regulations as described in the existing "prevention of air pollution plan 2011-2017" for Berlin.[59] In the present sensors are installed at crossroads, but measure only aggregate traffic counting of trucks and cars. But it is a matter of fact that air condition and immission depends

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[58] See: http://www.wsj.com/video/big-data-knows-when-you-turn-off-the-lights/E1841482-6D57-4882-8559-734B38A3424F.html

[59] Der Luftreinhalteplan 2011-2017 des Landes Berlin at: http://www.stadtentwicklung.berlin.de/umwelt/luftqualitaet/de/luftreinhalteplan/.

not only on the amount of vehicles driving but also on the atmospheric conditions, humidity, ventilation of roads etc. All this data should be measured and data gathered in the city cockpit. Here you can discover the effects of different precautions in cause of events that are punctual and short-termed and learn to anticipate and avoid.

Requirement 3**: Variability.

Since the monitoring network should measure the immissions on small-scale in the city a further requirement is in its **variable design.** It should not be rigid. Means not all instruments need to measure with the same accuracy. It should be a) small scale and city specific (regarding topography, geography, architecture, industries, mobility characteristics, weather conditions, public health structure etc.) and b) application area specific (air, water, health, road bridge-condition, underground). The measuring grid will be denser in areas with high spatial variability of exposure values and in areas with high population density.

This requirement makes several preparatory processes necessary like initial measurements or simulations with the goal of understanding the specific needs and conditions. The measurement-network consists of multiple technologically different sensors-stations, all working together, all exchanging information with each other and sending (some maybe receiving) information to (from) the cockpit. The data quality of the different sensor-technologies inserted does not necessary have to be equal for all sensor-stations. The quality of the data needed at special points or situations depends on the conceptual framework of the whole measurement network. A good mixture of qualitatively high-level measurements with instruments that measure big quantities with lower accuracy is optimal. It is imaginable to have plenty of cheaper and smaller, low-quality instruments, half-mobile measuring steadily larger quantities of data with a higher error allowance. Around 5-10 % errors can be tolerated for continuous measurements in this application area of air-quality. A few stationary installed high-precision instruments, expensive and large, providing high-quality data, should be integrated in the network for comparison and precise measurements. It is also imaginable, that the sensor-stations are integrated with and permanently installed on the municipal supply fleet of the city, which is regularly moving around in the city, like busses, garbage trucks. In such cases the emissions of the vehicle itself has to be taken into account. The data needed to complement the remaining area in the 3D-City city air map can be simulated.

Monitoring stations are especially located in areas with high risks of human exposure. These are housing areas with high concentrations of air pollutants and high noise value. Further measurement stations should be placed at critical locations, where the possibility of sudden events is high or where sudden sources of emissions are expected. Such half-foreseeable events could also be monitored for example with technologies like LIDAR that measures from the top-view, area-wide and spatially resolved. It is clear that this technology does not deliver precise values and can only deliver rough conditions. For uninspected sudden events crowd-sourced data can be used and integrated. That data is not precise but has a high density, given that the conventional mobiles used by the people or by the supply fleet integrate the biological sensors needed to measure air condition standard-wise. The crowd-sourced data can complete the real-time 3D-picture on air immission. The inaccuracy of the crowd-sourcing is efficient enough to spot the event, inform the city cockpit about it. Once informed - the city-cockpit can initiate further processes.

Requirement 4: *Lower costs***.**

The next important requirement lies in "low-maintenance-costs". In the moment maintenance costs are very high. The existing instruments for the mentioned application area require in average a weekly maintenance of 1h. For example, in Berlin we have currently an air-quality measurement network (BLUME) consisting of 16-stationary container systems (not all containers measuring the same values) at heavily frequented roads. For a bigger measurement-network positioned for example at 50-60 points in the city, measuring area-wide, the maintenance costs are not affordable. It seems that the maintenance is the limiting factor. Research should be driven in the direction of demand-oriented maintenance efforts in contrast to fixed maintenance intervals. The sensor-station should indicate its need for maintenance electronically to the city cockpits. Another possibility is the operation of drones or unmanned aerial vehicles in the maintenance context. Given that the sensed data can be carried out by integrated measurement-stations measuring all required indicators the drones can pick them up, exchange them and/or carry the station to a maintenance center and return it afterwards. This would save at least the human travel expenses. It is also possible that instead of drones, the municipal supply fleet of the city is able to pick-up and exchange the sensors-stations that need maintenance more or less automatically on their way. A further requirement belonging to this context is that such systems should be capable to perform an on-site evaluation of their own condition.

A reasonable instrument measuring a few of the named indicators for air costs around 6,000-10,000 Euro. The piece price should be definitely lower. Low cost sensors can compensate for the implied lower reliability through their number, ensuring not only a good temporal sampling rate but also a more comprehensive spatial sampling. There are ongoing efforts into evaluating low-cost air quality sensors including by comparing their readings with those of the expensive sensors, with promising first results for sensors and sensor units with prices between 12 USD (Shinyei PPD 42NS) and 300 USD (Dylos DC1100 PRO)[60].

Requirement 5: *Combined measurement of indicators*.

It is a requirement to measure all needed indicators on one item or sensor pack as precisely as possible and build a compact measurement station. This should be as small as possible to be easily handled including low costs for maintenance. Currently you need for every indicator a special measurement instrument or tube. This is especially needed for the measurement of air quality and streaming water quality.

Requirement 6: *Crowd-sourcing capability***.**

To support the citizen to identify health threatening environmental impacts independently autonomously, affordable sensors for smartphones or mobile devices for everyone are needed. They should be able to automatically indicate or record the damage to the infrastructure or a natural resource (air, water, etc.) in the direct surroundings of a person. The device also shall be able to give an automatic alarm. The measurement can happen automatically by driving, walking by, but can also be triggered consciously. Research-Projects are carried out that provide on-board units for cars enabling car-as-a-sensor for monitoring traffic and

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[60] See e.g. http://makezine.com/2014/05/31/air-quality-sensors-how-good-is-good-enough/

environmental conditions by driving. The cars are connected to a Sensor Web Platform with geo support providing data analysis. [61]

It is used for the own safety of the citizen, but the data shall also be gathered in the collective urban database, and shall be used for the urban planning processes. If the surrounding of a person is constantly of bad quality, the citizen can be able to formulate legitimate claims adverse to the governing community or company. New mobile apps shall for example be able to analyse particulate matters in the air. Of interest is also the measurement of radioactivity, although momentarily it plays a role in rare exceptions. The development and deployment of such technologies shall foster a "transparent company" and a "transparent administration". Means good environmental quality in cities shall not be achieved solely through commitment of the urban players but increasingly through self-conducted measurements and evaluations of environmental and product characteristics" (clean air, water, healthy food ...). The accuracy of the crowd-sourcing phenomenon does not need to be as high as in complex high precision instruments. It is conceivable that the resulting "City-sensor-network" (adjusted, calibrated), can calibrate the sensors of future smartphones regularly for more precision for the desired measurements at the site of users.

Requirement 7: *Protection of Personal Identifiably Information (PII).*
The collection of those data has to be performed on a strictly voluntary basis in order to meet the regulatory requirements currently valid in most countries. Effective security mechanisms meeting the current state of technology have to be in place regarding the storage and processing of those data. Anonymization of PII needs to be applied whenever possible and in a way that de-anonymization (e. g., using statistical methods or advanced “data analytics”) is impossible or at least require unfeasible efforts. For example the examination of the drinking or waste water quality on site shouldn’t publish that “Mr. Müller” has a specific disease.

Requirement 8: *Right to denial.*
The denial of being part of a smart city has to be an option, and needs to be supported by effective mechanisms available to control what PII are used for what purpose, by whom, and when. This in particular of importance for so-called “derived data” that are generated by the citizen’s habits, his or her use of services, etc. Since these data are still PII, citizen’s rights apply to them as well.

Requirement 9: *3D Visualization.*
The monitored values could be visualized in comprehensive 3D-maps of air immissions based on sensed data. Momentarily 2D-city models of immissions in form of „air pollution maps” are in use. These show the normal yearly averages or reflect winter-summer values. 3D-immission maps would be useful since in this application area, pollution levels vary with the height. This is true especially for noise and for other pollutants. The distribution of the pollutants is dependent on physical factors like density of buildings, whether, road conditions, etc. Researchers are working on development of 3D-maps for immissions, but such maps would be modelled and simulated by mathematical algorithms.

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[61] See project: http://www.shared-e-fleet.de/.

The development of 3D-maps for visualizing different indicators of air-immission on real-time basis is a future requirement.[62] The sensing scenario on air monitoring network described below can be considered as a maximum requirement, which we probably can approach only partially.

Requirement 10: *Durability and eco-friendliness.*
The demand for a long product life beyond a decade contradicts momentarily the short life cycles of our consumer electronic and communication products (1-3 years for smartphones). The requirement is that instruments shall be principally durable and have a long life cycle at the site of their operation, so they fit to the urban technical infrastructure, which has normally life-cycles of a couple of decades. Endurance should be high, to avoid maintenance efforts and costs of the sensor systems. A long life-cycle means also reliable operation in harsh environments (extreme weather, large temperature ranges, possibly hostile environment by lye, acids, gas). This requirement is especially important given the current trend towards low cost sensors that one can "deploy and forget". The most eco-friendly approach is to have them without built-in obsolescence at least for certain ones. Also instruments should be upgradeable to minimize electronic waste appearance and save natural resources.

The measurement-instruments shall not have any contaminating effects on their surroundings, neither in their production, in their existence and removal. At the end of the life-cycle of the sensor system, it must be disposed properly and environmentally sound. If a removal by maintenance personnel is not possible (because too many sensors or sensors in fixed components "implanted"), a decomposition into individual products, that do not harm the environment, shall be provided (compostable electronics).
A special challenge for such endurable sensor systems which are quite time costly and labor-intensive to deploy is that they must collaborate and communicate in a networked world with short life-cycle items like smartphones. One way to avoid the pollution through sensing devices is to design those with the repurposing possibility already taken into account from the beginning.

Requirement 11: *Artificial intelligence.*
Digital measurement-stations should detect anomalies when something happens. Secondly it is desirable that they "proactively" analyze, classify and report for example the kind of bacteria or the group of substances for example contaminating the air or water. This should not necessarily happen on the tiny, embedded, low power (or even energy scavenging) device, but wherever the data is transmitted to. For that they would need additional computing units. The extent, to which these "computing units" are located directly at the sensor or in the case of sensor networks in their local area, shall be decided in each individual case.

Requirement 12: *Efficiency.*
They shall efficiently, precisely and reliably measure and assess the quality and quantity of the monitored product (water, air, and road). Herewith the range extends from the measurement of biological and chemical contamination to systems for the detection of

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[62] ZAHRAN, E.S., BENNETT, L. and SMITH, M., 2010. An approach to represent air quality in 3D digital city models for air quality-related transport planning in urban areas. In *Computing in Civil and Building Engineering, Proceedings of the International Conference*, W. TIZANI (Editor), 30 June-2 July, Nottingham, UK, Nottingham University Press, Paper 10, p. 19, ISBN 978-1-907284-60-1.

structural defects (water pipe just before bursting, pavement defect or cavity under street, corrosion damage in components). Accordingly implanted sensors could report the attainment of the limits to the cockpit in time. The failure of one individual sensor should not falsify the measurements provided by the sensor network as a whole.

Requirement 13: *Flexibility and adaptability*
From this considerations the next requirement can be derived: **flexibility** and **adaptability**: Networked electronic components with long life will have more than one generation of communication and data standards at their interfaces to the network infrastructure. This artefact is taken into account in the design of these systems (software defined network). Stricter environmental laws will reduce limits for pollutants. The sensor system must be able to calibrate to these new requirements. This includes the possibility to upgrade, for example to change the sampling frequency or the physical admissible range for the measured values.

Requirement 14: *Low-power-consumption***.**
The measurement-stations shall have little, preferably no power consumption (stand-alone power generation in the semiconductor or use of the energy potential from its immediate environment of use – energy scavenging) in order to achieve low installation and operation costs.

Requirement 15: *Interoperability***.**
The data collection/transmission network subsystem should as well be flexible, reliable (e.g. through redundancy), interoperable, with low deployment, installation and maintenance costs, able to cope with the unforeseeable changes required in the future. Each sensing device should timestamp its measurements at the sources and attempt to synchronize its own clock either with the radio sync signal (such as the one broadcasted in Germany) or with the other end during the data transmission. Wireless and mesh networks should be preferred for their flexibility.

Requirement 16: *Identifiable*.
The deployed sensing devices should have and send with their measurements a unique ID and either known position or should be able to infer their own position (e.g. GPS or WLAN-based localization) or collect and send together with the measured data the information required to infer their position.

3.1.6 List of Abbreviations

Abbreviation	**Explanation**
GIS	Geographic Information System
KPI	Key Performance Indicator
LIDAR	Light detection and ranging
NO_x	nitrogen oxide air pollutants: nitric oxide (NO) and nitrogen dioxide (NO_2)
PM	Particulate Matter
PII	Personal identifiable information (PII)
UFP	Ultrafine Particles
UFZ	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ

3.2 Information & Communication

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The term »smart cities« mainly refers to recent ICT-based urban innovation initiatives like those by cities (for example by Aarhus, London or Yokohama), by corporations (for example by IBM, Siemens or Atos) and by research (funding) frameworks such as in the EU or US[63]. This highlights the important fact that ICT is a necessary element for any smart city solution, although it is not sufficient to implement leading-edge ICT to make a city smart[64]. In the following, the status and some future projections on ICT for smart cities are given.

3.2.1 Future Key Products

Two of the key enabling technologies of smart cities are Cyber Physical Systems (CPS) and the Internet of Things (IoT). Through CPS, the physical world is linked to the virtual world. Interconnected CPS form the Internet of Things (IoT). In IoTs, smart "things" interact among themselves and the physical world. They gather information from their environment and may react to physical events, with or without human intervention[65]. This leads to a completely new dimension in the information and communication world, whereby people and things can be connected *Anytime*, at *Anyplace*, with *Anything* and *Anyone*, ideally using *Any path/network* and *Any service*.

In a smart city, storage, computation and communication services will be highly pervasive and distributed. They will be based on a highly decentralized, but common pool of resources of smart objects, machines, and platforms in urban space. A dynamic network of networks will interconnect resources, services, and people and enable value-added services and semi-automated urban processes in a smart city, where people are to be in control and responsibility of the urban processes.

Yet, ICT constitutes the backbone of smart cities[66, 67] and turns to a public infrastructure needed not only for connectivity and communication (as discussed in the broadband communication debates), but for information[68]. Like the IoT architecture, ICT for smart cities consists of four main layers[63,69,70,71,72,73], namely the

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[63] acatech, "Integrating ICT for the City of the Future", *acatech Report*, August 2014.
[64] acatech, "Smart Cities. German High Technology for the Cities of the Future", *acatech Position Paper,* 2011.
[65] acatech, "Cyber-Physical Systems: Driving Force for Innovation in Mobility, Health, Energy and Production," *Acatech Position Paper,* 2011.
[66] http://wikibon.org/wiki/v/Defining_and_Sizing_the_Industrial_Internet
[67] E. Lapi, N. Tcholtchev, L. Bassbouss, F. Marienfeld, I. Schieferdecker: Identification and Utilization of Components for a linked Open Data Platform, IEEE 36th Annual Computer Software and Applications Conference (COMPSAC), July 2012, Izmir, Turkey.
[68] Ina Schieferdecker, Walter Mattauch: ICT for Smart Cities: Innovative Solutions in the Public Space. In: Zander / Mosterman: Computation for Humanity, Information Technology to Advance Society. CRC Press, Nov. 2013.
[69] O. Vermesan*, et al.*, "Internet of Things Strategic Research Roadmap," *Cluster Strategic Research Agenda,* 2011.
[70] I. T. Union, "Internet Reports 2005: The Internet of Things – Executive Summary," 2005.
[71] W. Miao*, et al.*, "Research on the architecture of Internet of Things," in *Advanced Computer Theory and Engineering (ICACTE), 2010 3rd International Conference on*, 2010, pp. V5-484-V5-487.

1. Perception or Device Layer,
2. Network or Transmission Layer,
3. Middleware Layer or Information Processing Layer and the
4. Application layer.

The functionality of each of these layers is based on some fundamental technologies (key products). For example,

1. *smart sensor nodes* and wireless sensor networks (WSNs) are the pivot of the perception layer;
2. *Tb/s telecommunication* equipment, robust communication networks and protocols enable the network layer;
3. the *information processing* layer relies on high-performance, parallel computing and virtualization of storage, computing and analytics services; and
4. smart mobile devices are the driving forces of *data-driven services* and the application layer, which are characterized by new human-computer interfaces, multimedia technologies and information presentation and visualization solutions.

In addition, ICT for smart city solutions encompasses specific challenges for a full spread acceptance and deployment including:

- Development of concepts and approaches for *data-driven innovation* based on *trust and ownership of data* while at the same time assuring *security and privacy* in complex urban environments,
- Development of concepts for the *resilience and safety* of ICT-based urban infrastructures including energy, water and other supply networks while at the same time assuring flexibility in the *timely evolution* of the ICT components, and
- Development of scalable concepts for the *semantic interoperability* of urban data and information supporting near real-time data analytics and information exchange in heterogeneous environments.
- Development of a *reference architecture for ICT in smart cities* including open formats, protocols, services and interfaces for the vertical and horizontal integration and interoperability of ICT components.

In the following, status and trends along the main layers of the IoT architecture, key products and technology drivers are discussed. Within this study, the topic of ICT for smart cities can only be discussed rather generic and should be addressed in more detail in a follow-up work.

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[72] R. Khan*, et al.*, "Future Internet: The Internet of Things Architecture, Possible Applications and Key Challenges," in *Frontiers of Information Technology (FIT), 2012 10th International Conference on*, 2012, pp. 257-260.
[73]X.-Y. Chen and Z.-G. Jin, "Research on Key Technology and Applications for Internet of Things," *Physics Procedia,* vol. 33, pp. 561-566, 2012.

3.2.2 Smart Sensor Nodes

Wired and wireless sensors, RFID tags and further automatic identification and data capture (AIDC) methods constitute basic monitoring and communication capabilities in smart cities. They can turn devices and systems into smart objects[74], which are objects with perception capabilities, embedded intelligence and high level of autonomy and communication and are to be interconnected as discussed in Section 3.2.3.

3.2.2.1 Localization Support

Being able to localize and being localized is a feature that is claimed for and pushed by numerous available applications onto well-known application stores for mobiles. Cities will be a major playground for these applications, and issues to be solved mainly deal with hybrid technics convergence. Key words are precise localization and long-term tracking, whether outdoor or indoor. In cities, tracking elderly people for safety reasons, help disabled person with assisted mobility, or provide every person with leisure, like sports and fitness for quantified-self, or pro-efficient information can be cited as applications of interest. The geographic accuracy to be reached is still a target, and cm-range seems a reasonable performance in human environment and behavior.

Technology of interest is here Ultra-Wide Band (UWB), providing accuracy at the cost of reasonable power consumption[75]. The impulse response manner of UWB has been proven to be integrated into low-power CMOS technology nodes. Nevertheless, in city environment, features like range and accuracy scalability will be helpful to better adapt the application expectations to the performance/power consumption requirements[76].

In addition, it now has to be demonstrated its compatibility with other RF standards and the ability to co-integrate it into hybrid solutions. Here, co-existence/co-integration with RFID, IEEE802.15.4, and Bluetooth are future trend to enable low-cost solutions.

3.2.2.2 Computation Features

Smart sensors pre-process collected information, so that information of interest is to be communicated only. The computation capabilities include commonly required functions such as sensor information gathering, filtering by various policies and rules, data comparison and analysis, data mining, context modelling, context-aware processing, self-localization, and context-aware decision and estimation.

Smart sensors are typically miniaturized, use low-power micro-controllers, and provide very limited resources processing power and memory. By that, the deployment, configuration and re-configuration of the computation functions (including localization and communication) constitute a challenge in itself. New programming and update methods are required.

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[74] N. L. Fantana, *et al.*, "IoT Applications — Value Creation for Industry", in Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems, River Publishers, 2013.
[75] Denis B.., Ouvry L., Destino G., Macagnano D., Abreu G. : "Localization and Tracking for LDR-UWB Systems", Mobile and Communication Summit, 16th IST, Budapest, Hungary, July 2007
[76] D'Errico R. et al. : "An UWB-UHF semi-passive RFID system for localization and tracking applications" in IEEE International Conference on RFID-Technology and Applications, (RFID-TA 2012), Nice, France, November 2012

3.2.2.3 Short Range Communication Chip Sets

During the last decade, many low-power integrated RF devices have been described and proposed on the market. There has been a growing interest in WSN for building monitoring / power management for instance, which pushed the development of appropriate integrated RF solutions. In parallel, frequency bands and standards have also evolved: 169 MHz, 433 MHz, 868 MHz, 915 MHz, 2.45 GHz - IEEE802.15.4, BT, Z-Wave, EnOcean, Sigfox, 6lowPan, TVWS, UHF RFID etc.

In the smart city context, interoperability between standards / frequency bands has to be considered. To do so, more flexibility and possibility to fast-switch from one setting to another is expected. Supported by intensive spectrum sensing, digital-oriented RF front-end will provide with adequate solutions able to adapt the RF communication link to any available communication available in the city. This is especially of interest when considering the mandatory mobile aspect of the intra-city environment, as well as inter-city mobility of a vast majority of people living in large cities.

Further System-on-Chip addressing short-range communication will then have mandatory features for flexibility – frequency band, data rate, modulation scheme. These features will also pave the way for adaptability on the RF front-end, considering the correct balance between expected performance and power consumption. Here, paradigms are related to the adequate sensitivity versus communication distance range/propagation conditions, and selectivity versus spectrum occupancy.

3.2.2.4 Harvesting-Based Communication

Energy harvesting (also discussed in Section 3.4.1.1.2) consists in turning the ambient energy into electricity to directly power ICT appliances, for instance. In cities; various ambient energy sources such as light, thermal gradients, vibrations, air flows etc. can be converted into electricity and can be a tremendous opportunity to develop fully autonomous devices, possibly embedding sensors and RF communication links for smart cities. These systems will be able to work for years without battery and without any human intervention or maintenance, greatly simplifying their deployment scenarios. Yet, the output power of ambient energy harvesters is generally limited to the 100µW to 1mW range, which is quite low but enough to intermittently supply systems. Finally, optimization of both energy harvesters and power consumption of ICT systems has to be considered.

Many ambient energy sources can be exploited in the smart cities context; like light, wind and inductive energy harvesting, which are probably the most common and the easiest ones to harvest: Sun light can be turned into electricity with photovoltaic cells with a conversion efficiency of 20%: their output powers vary from 10-50µW/cm² (in buildings/offices) to 10-20mW/cm² (outside - sunny day). This is doubtless the most robust source and the easiest to implement, but not always available in city environments. Wind energy harvesting is already exploited with large-scale devices to power buildings, cities and industries. Of course, wind energy harvesting can be also implemented with small-scale devices to supply sensors such as air quality or weather sensors. Output powers are in the 1-20mW/cm² range which is enough to supply basic functions and data emissions. The last solution, when light or winds are not available, is to exploit inductive energy harvesting. AC currents generate a magnetic field around the wires in which they circulate. These magnetic fields can be collected by using a coil placed nearby, enabling for example to develop non-intrusive autonomous current sensors able to follow the power consumption of the device they are set on in order to know and to optimize its power consumption. Finally, whatever the ambient energy source, a power management circuit is required to turn its raw output power into a robust and viable energy source to supply systems. This power management circuit must be reliable, able to self-start, ideally enabling a battery-free operation and low-power while offering decent conversion efficiency.

3.2.3 Robust Communication Networks

At present, wired and wireless networks support world-wide communication by globally-accepted communication standards. Upcoming networks will include the world of things and bring interconnection of things, machines and humans to new quantitative and qualitative dimensions. The inclusion of vast amounts of small devices with limited resources and resulting imperfection will impose new challenges with respect to the complexity, dynamics, and resilience of communication networks.

3.2.3.1 Wireless Sensor Networks

Next generation of RF communication links, including Wireless Sensor Network, will have to integrate sensing ability to get the knowledge of the spectrum occupancy, thereby standards in use and/or availability of communication channels as a major improvement for the Quality of Service (QoS) as well as for the exposition to RF power level. Overcrowding of the spectrum in cities impose to consider a better share of it and get rid of strong interference. Specific technologies must thereby be investigated especially as optimizations in that filed still remains difficult to be implemented. In cities, propagation channel modelling is a first step in spectrum knowledge, with a second step being the ability of the front-end to consider these data for optimization[72]. A strong work has to be done regarding the just adaptation of the RF front-end to the expected performance for a given communication, for which the channel model is an important feature. This can be regarded as Sense & React concept.

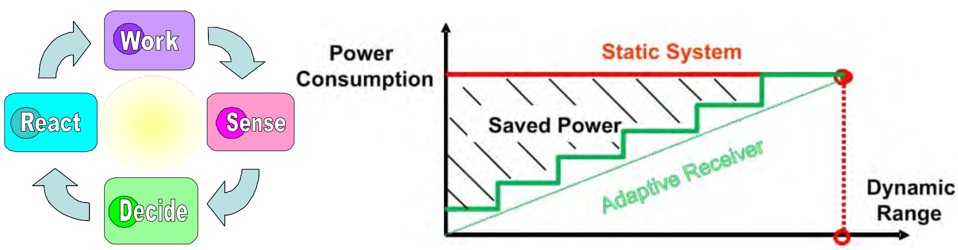

Figure 7: Sense & React concept for power use optimization

The spectrum sensing is thereby a mandatory feature to enable the correct adaptation of the front-end, either RX or TX, to the specifications required for a good quality communication link. It is also important to mention that the constitutive building blocks of RF ICs will have to embed flexibility but also decision process to guarantee the correctness of the front-end characteristics and performance.

3.2.3.2 Machine-to-Machine Communication

Smart cities will be equipped with appliances and devices able to communicate information in an automatic manner by machine-to-machine communication (M2M). Current solutions are based on mobile cellular network (either 3G or 4G). They necessitate interfacing with operators and the use of SIM card. New operators are emerging like Sigfox[77] which provides dedicated M2M cellular network, communicating at very long range / low data rate, so well adapted for city environment. New standards and alliances are also emerging, supported by major players. Here can be cited Thread, AllSeen, HyperCAT etc. which are mainly based on existing PHY solutions, but considering adapted protocols to enable multiple applications support, and reduce power consumption.

So, the target for further M2M system is to make it compatible working with already existing operator-based solutions, and at the same time anticipate the need for lower-cost / lower power consumption ones when volumes will reach announced billions target. To do so, IC design activities have to prepare SoC architecture to enable various bandwidths and modulation scheme to be adequately operated for various standards. The target is then to be able to address all these possible communication links, without the need to re-spin system and equipment, while anticipate future demand for connection to energy harvester systems.

For example, various applications are expected inside buildings. WSN are used for monitoring and automatic control. This is led by means of Smart Grid deployment which enable power management and energy saving.

3.2.3.3 Tb/s Telecommunication Equipment

Cellular communications will face an important improvement with the arrival of 5G at the horizon of 2020. Higher data rate and better connectivity are key points. Convergence of various technologies will also be implemented, mixing classical modulation schemes already available for 3G and 4G, with mmW communications or low to medium data rate providing IoT information. In this new vision of the communications in cities, mobility must be regarded as a key point[78]. These new ways of RF links will make use of disseminated pico-cells, able to communicate locally at very high data rates and requiring therefor a high-level of knowledge of the propagation characteristics in the considered environment. Either at sub-GHz or 60 GHz, the fading, shadowing and multi-paths behavior will require to be known accurately.

The convergence of the various standards in use and aggregated into 5G will also depend on the methods developed for the propagation models. For that, advanced ray-tracing techniques are to be refined and related algorithms are to be embedded at low cost into chipsets.

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[77] Sigfox: http://www.sigfox.com
[78] Dussopt L. : “Beyond 2020 Heterogeneous Wireless Network with Millimeter-Wave Small-Cell Access and Backhauling”, Future Networks 12th FP7 Concertation, RAS Cluster Meeting, Brussels, October 2013

In smart cities environments, ICT may help people to be informed and get real-time data of any kind. This can be done using various available technologies. For low data rate, Bluetooth or IEEE802.15.4 technologies are already known, and high data rate/short range can be developed around either mmW communications[79],[80] or high data rate contactless RFID[81]. This latter will make use of pure RFID modulation scheme to typically 20 Mbps range, or hybrid RFID/UWB enabling much higher data rates above 100 Mbps[82].

Downloading multimedia information can therefore be easy with the deployment of interactive displays or dedicated centers.

3.2.4 Data-Driven Services

In smart cities, many new businesses and services are driven by urban data[83, 84] (see also Section 3.1). Such data-driven innovation in smart cities is supported by

1. Open and/or commercial data platforms that provide the municipal authorities, businesses and members of the public with controlled and semantically high-quality access to data sets and data flows, which represent often huge, quite heterogeneous and highly dynamic volumes of data (big data).
2. Service platforms that provide all stakeholders with base and value-added services.
3. Social media (online social networks) that can be used for self-organization or participatory approaches in cities.

3.2.4.1 Data Storage in Clouds

Despite of the progress in data storage capabilities, methods and algorithms are needed to *optimize data* and information to be stored: Given the amount of data and information that the Internet of Things is going to generate, storage requirements and costs should not increase exponentially, but rather data optimization should be used to limit storage wherever possible and useful.

Furthermore, *software-defined storage* can be used to balance and optimize the usage of available storage capabilities.

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[79] Siligaris A., Richard O., Martineau B., Mounet C., Chaix F., Ferragut R., Dehos C., Lanteri J., Dussopt L., Yamamoto S., Pilard R., Busson P., Cathelin A., Belot D. and Pierre Vincent : “A 65-nm CMOS Fully Integrated Transceiver Module for 60-GHz Wireless HD Applications” IEEE Journal of Solid-State Circuits, Vol. 46, n°. 12, December 2011

[80] Jany C., Siligaris A., Ferrari P., Vincent P. : “A novel harmonic selection technique based on the injection of a periodically repeated oscillations train into an oscillator“, Microwave Symposium, IMS, Tampa, FL, USA, June 2014

[81] Pelissier, M.; Gomez, B.; Masson, G.; Dia, S.; Gary, M.; Jantunen, J.; Arponen, J.; Varteva, J : "A 112Mb/s full duplex remotely-powered impulse-UWB RFID transceiver for wireless NV-memory applications" VLSI Circuits (VLSIC), 2010 IEEE Symposium on, June 2010

[82] Heires V., Belmkaddem K., Dehmas F., Denis B., Ouvry L., D’Errico R. : “UWB Backscattering System for Passive RFID Tag Ranging and Tracking”, Int. Conference on Ultra-Wideband (ICUWB2011), Bologna, 2011

[83] Tcholtchev, N.; Farid, L.; Marienfeld, F.; Schieferdecker, I.; Dittwald, B.; Lapi, E.; , "On the interplay of open data, cloud services and network providers towards electric mobility in smart cities," Local Computer Networks Workshops (LCN Workshops), 2012 IEEE 37th Conference on , vol., no., pp.860-867, 22-25 Oct. 2012

[84] E. Lapi, N. Tcholtchev, L. Bassbouss, F. Marienfeld, I. Schieferdecker: Identification and Utilization of Components for a linked Open Data Platform, IEEE 36th Annual Computer Software and Applications Conference (COMPSAC), July 2012, Izmir, Turkey.

In addition, it needs to be investigated how filtering and aggregation at the point where data is taken can limit the amount of data to be stored in the backbone, no matter if it is in the cloud or on traditional server infrastructures. The pure exponential increase of collected data requires intelligent and flexible approaches to data filtering and aggregation to limit data storage requirements in first place.

3.2.4.2 Data Collection and Provisioning Features

Central functions for the collection and provisioning of data[85] include

- Storage of user/customer data for data/information collected by sensors
- User data & operation modelling for creating new sensor data models to accommodate collected information and the modelling of the supported operations
- On demand data access by providing APIs to access collected data and information
- Device event publish/subscribe/forwarding/notification services to enable near real-time handling of data/information
- User rules/filtering to enable individual filters and rules for event correlation
- User task automation and work flow management for supporting automated data/information processing

These functions will be realized by software/hardware platforms requiring powerful computation, storage and communication capabilities, see the sections above.

3.2.4.3 Big Data Solutions

Big data is about the processing and analysis of huge data repositories, which are impossible to treat by conventional analytical databases. In the Internet of Things, the majority of data will be produced by devices and machines. Data production rates are exponential and follow basically also Moore's law.

The biggest challenge of big data will not be the data storage, but rather to make sense of the data. Big data requires new approaches for distributed, cloud-based processing, visualization and display. Research is required for new indexing, search, computation, and aggregation algorithms.

In addition, data privacy, data security and data quality research is needed. The more central data becomes in smart cities (like in any other smart solution in industry or society), reliability, accuracy, precision, and other quality and security aspects of data become central as well. Yet, the supporting functions will once again be realized by software/hardware platforms requiring powerful computation, storage and communication capabilities, see the sections above.

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[85] O. Vermesan, P. Friess (eds), „Internet of Things – From Research and Innovation to Market Deployment", River Publishers, IERC Cluster SRIA, 2014

3.2.5 Technological Requirements

Based on the future key products discussed above, this section will discuss main technological requirements for microelectronics in smart cities.

3.2.5.1 Low-Power Consumption and Flexibility of RF Front-End

When dealing with either low- to medium-rate WSN into cities or mmW communications, key words are low-power consumption and flexibility of RF front-end, while being compatible with low-cost devices.

Current estimations of IoT deployments consider very high volumes for sensor systems able to communicate through RF channel. Here, billions of sensors per year are expected. So, advanced CMOS technologies must be envisioned, which enable low-power consumption and low-cost. FD-SOI 28 nm has demonstrated its interest for reducing the power consumption, compared to bulk CMOS technologies and wider channel length. The adaptation of SoC design in the scope of ULP RF solution must be favored, which of course has to include the consideration of new architecture for the front-end to get the best from this very advanced technology.

Multimedia mobile communications are requiring much higher data rates then for IoT, and Millimeter-wave (mmW) silicon technologies have emerged to enable thanks to advanced technologies. Performance, integration and power consumptions were then improved and mass-market could thereof be considered seriously. Still, mmW IC design is oriented towards mixed technology using III-V technologies and BiCMOS enables a very good balance between analog and digital performance. Nevertheless, advanced CMOS technologies can be operated at frequencies much higher than 100 GHz. Their use for high volume market can be made possible if advanced modelling of these technologies is considered and made available for mmW SoC integration. In addition, as the operating wave-length of 60 GHz communications is short, antenna foot-print is very limited and its integration into very small module containing the various IC and/or SoC, as well as passives can be envisioned. 3D technologies are now matured and heterogeneous integration of various technologies, including the antenna, is possible.

3.2.5.2 New Semiconductor Technologies

In the area of Information and Communication Technologies, various semiconductor technologies are complementing one another (and are in most cases also competing). Among those are Silicon CMOS (Complementary Metal Oxide Semiconductor), SiGe HBT (Silicon/Germanium Heterojunction Bipolar Transistor) as well as III/V Compound Semiconductor FET (Field Effect Transistor) and HBT technologies. Depending on the application and the market scenario, each of these technologies features its own advantages with respect to performance, integration capability and cost. In general, CSICs (Compound Semiconductor ICs) exhibit superior performance compared to silicon-based devices with respect to the high-frequency properties in terms of high operation frequency and bandwidth, as well as noise figure, output power and efficiency.

CMOS ICs are by far the least expensive choice when fabricated in huge piece numbers, i.e. multi-million quantities. However, CSICs can be very competitive in small and medium markets serving niche applications. But even in very large quantities, the use of CSICs can be a cost-effective solution which has proven by the III/V-HBT based power amplifier chips which enable high-efficiency transmit modules found in the vast majority of produced mobile phones. About one billion of these amplifier circuits are produced every year.

The never-ending trend in all semiconductor technologies mentioned above is to offer increasing clock frequencies and/or bandwidth to cope with the steadily increasing need for data transmission capacity in stationary and mobile applications. However, at the same time most applications call for lower power consumption simultaneously, especially for mobile communication applications. The requirement for extremely low-power electronics is especially strong in devices which are powered through energy-harvesting by exploiting the light, thermal or mechanical (vibration) energy supplied by the environment. Communicating sensors and sensor networks monitoring the condition of traffic or traffic infrastructure, buildings and residential apartments are obvious applications for energy harvesting.

A further trend in semiconductor technologies is miniaturization and multi-functional integration leading to high-performance, versatile, small, light-weight and cost-effective building blocks. The progress in this area is accompanied and fostered by advanced mounting and packaging techniques for individual chips or chip sets in multi-chip modules.

The mobile communication infrastructures are characterized by decreasing cell size (from micro-cells to pico-cells) to achieve high data throughput for a large number of people especially in crowded areas, such as airports, train stations and sport stadiums located in densely populated metropolitan regions. This necessitates robust, energy-efficient and broadband transmitters for the increasing number of base stations which have to be installed. Power amplifiers based on the emerging compound semiconductor material Gallium Nitride (GaN) have proven the ability to resolve all these issues simultaneously.

Wireless ultra-high-speed short-range data links for PAN (Personal Area Networks) and IoT (Internet of Things) applications exploit the very high frequency bandwidths available at millimeter-wave (30 – 300 GHz) and sub-millimeter-wave (> 300 GHz) frequencies. These data links can be realized today using preferably III/V or emerging SiGe components. However, CMOS technologies are making a tremendous effort to advance into this frequency regime using smallest gate dimensions of 28 nm or less.

3.2.5.3 Software Flexibility

Software is a key innovation enabler in microelectronics. The newly coined terms software-defined everything (SDE) or software-defined anything (SDx) point at the ongoing trend to transition towards flexible hardware-based functions and features by software. This important trend is highlighted by these new, yet ambiguous terms. They group approaches like software-defined radio, software-defined storage, software-defined networking, software-defined architectures or software-defined security. Such approaches bring software more "in command" of multi-piece hardware systems and allow for software control of a greater range of devices.

The more central software becomes in microelectronics, the more hardware/software co-design and software engineering need to become focal points of microelectronics R&D. This has for example also been reflected by the newly created European ECSEL joint undertaking[86], which has been launched in 2014 as a partnership between the private and the public sectors for electronic components and systems. It replaces the previous ENIAC and ARTEMIS JUs in the fields of nanoelectronics and embedded systems and will run for 10 years.

In order to foster efficient, reliable and high-quality software in microelectronis, ECSEL addresses for example design technologies to manage complexity and diversity, including safety and security, to enable model-based engineering and virtual engineering methods as well as integration methods enabling smart functionality, automation and reliable operation in harsh and complex environments.

3.2.6 Roadmap

Data-driven innovations in smart cities, enabled by IoT, cloud technologies and “big data” approaches, are mainly driving the so-called “More Moore” technologies: processors, logics and memories. Today, the cloud is extended towards “instant data” applications, driven by smart devices and the Internet of Things. Developments, applications and needs, arising from the smart cities are covering both, “Big” and “Instant” data.

Figure 8: Innovations in Nanoelectronics (“More Moore”) are mainly driven by data processing[87].

Whereas the leading edge “More Moore” technologies are mainly relevant for big data applications, instant data applications, as needed for smart cities, will focus more on the combination of sensors, data pre-processing and communication (smart, embedded Systems, Cyber Physical Systems)[88]: “*The so-called Cyber Physical Systems (CPS) – the bringing together of real-world interfaces with highly performant and networked information processing – is a key capability that enables a unique value proposition; more functionalities with same hardware investment for end users.*

[86] ECSEL: http://ecsel.eu
[87] M. Badaroglu, System Integration, SEMICON Europa 2014, TechArena
[88] ECSEL, “MASP - A Multi Annual Strategic Plan for the ECSEL Joint Undertaking”, August 2014

In their report IDC estimates that *"……the embedded system and semiconductor value chain is about $7.8 billion in 2010, and should grow at a compound annual growth rate of 7.6% over the next 5 years. By 2015, the overall value of these specific areas will reach $11.8 billion."*[89]

Markets trend analyses for different application areas indicate that in the last decades the Embedded Systems market has been growing faster than the traditional computing market: "*Approximately 2% of the sold microprocessors are used for IT and PC and 98% for the embedded systems such as cars, trains, medical devices, airplanes, household devices, traffic management systems, in mobile devices etc.. Every year more than 3 billion Embedded Systems are integrated in the devices and other systems for a total market of about €160 billion.*"[90]

Many emerging embedded applications now share networks and components in configurations whose conceptual structure no longer readily maps to their physical structure. In parallel, open networks of embedded systems applications from multiple domains are coupled: everything can, in principle, be connected to everything else. Networked embedded systems are in effect, become the neural system of society.

In addition to the market opportunities, the economical and societal challenges shaping the Embedded Systems scene include the necessity:

- to increase the R&D investments in Europe in order not to lose its present leading position,
- to consider the impact of the new Internet economy, and the "rise of the Embedded Internet"[91] to take advantage of the strong demand arising from the young generation to remain and stay connected to their communities "the Always Connected Society".

The greatly increased speed with which these systems are penetrating into homes and the environment at large makes CPS an unlimited source of imaginative innovations in products and services. They offer the capability to disrupt current businesses as well as creating new ones (e.g. the lighting industry penetrating new business domains such as security or elderly care, or massive deployment of sensors for environmental monitoring or road traffic management schemes)."

Due to the strong increase in numbers of (sub-)systems on the one hand and data volume on the other, Cyber Physical Systems, as well as big data and cloud applications will continue to drive low power technology in terms of hardware technologies, architectures, algorithms and design. This is a broad scope highly interesting for Europe and the European industries.

[89] IDC Report, "Intelligent Systems- Next big opportunities", August 2011
[90] Bitkom, „Eingebettete Systeme – Ein strategisches Wachstumsfeld für Deutschland Anwendungsbeispiele, Zahlen und Trends.", 2010
[91] Intel, "The Rise of the Embedded Internet", White Paper, 2009

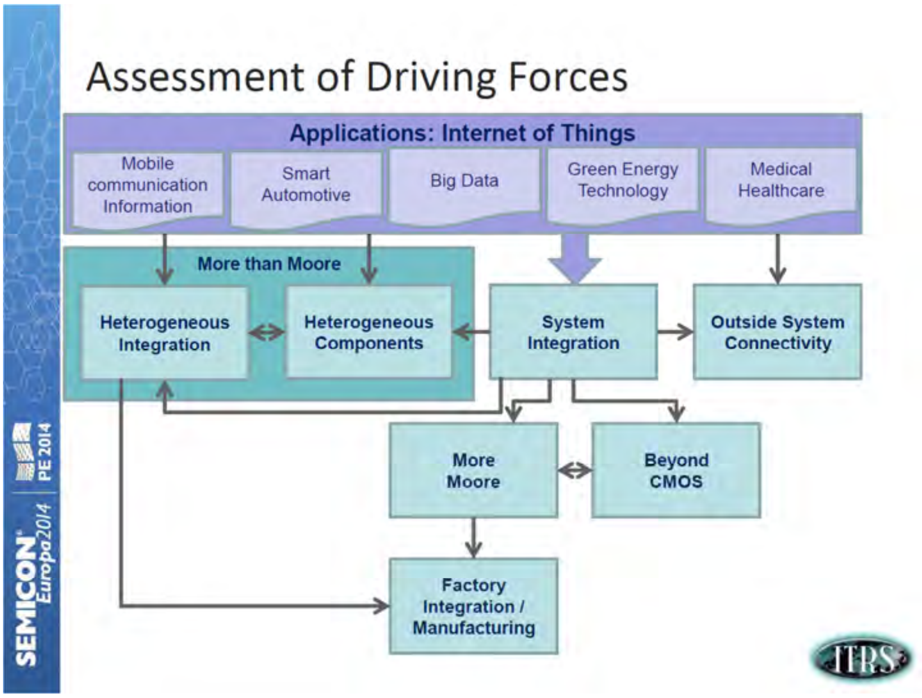

Figure 9: Internet of Things – a driving force for European semiconductor business[92]

The International Roadmap for Semiconductors ITRS has already included this shift in paradigm into its latest updates. The newly set up ITRS 2.0 will introduce an additional, system-oriented level and will by that being extended to cover also topics like hetero integration&components, system integration and outside system connectivity[90]. By this, ITRS will address the whole technology basis for Cyber Physical Systems and the Internet of Things.

A complementary roadmap is given by the Strategic Research and Innovation Agenda (SRIA) of the IoT European Research Cluster - European Research Cluster on the Internet of Things (IERC)[83]. This roadmap discusses future technological developments and Internet of Things Research Needs for 2015-2020 and beyond 2020.

3.2.7 Strategic Research & Economic Impact

According to the Bosch IoT strategy white paper[93], the five key markets of IoT are manufacturing, smart cities, utilities, automotive and smart buildings. In 2020, intelligent buildings will bring 213 billion EUR IoT-based revenues, automotive 176 billion EUR, utilities 44 billion EUR, smart cities 21 billion EUR, and manufacturing 17 billion EUR. Smart cities will produce in 2022 the majority of IoT-based traffic: 2,416k terabytes per annum, which leads to a tremendous increase of amount of data that needs to be managed and analyzed.

In addition to the above mentioned challenges on semiconductor technologies and solutions for ICT in smart cities, a strategic research challenge is to develop an ICT reference

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[92] M. Graef, P. Gargini, ITRS 2.0, SEMICON Europa 2014, TechArena, 2014

[93] Bosch IoT strategy white paper: http://www.bosch-si.com/lp/iot-white-paper.html?ref=ig-global-2014H1-iot-strategy-whitepaper, February 2014

architecture including interfaces, formats, protocols and services for the collection, provisioning, analysis and communication of urban data to the different components, systems, and applications of the various stakeholders involved. First plans are being discussed at standardization bodies like ITU or CENELEC.

They need to be supplemented by applied R&D to investigate efficient ways of interfacing domain-specific solutions for the management of urban infrastructures to enable integrated, cross-domain approaches. Specifically, cross-domain solutions spanning e.g. energy, mobility, transport or logistics in a smart city will enable a cross-sectorial optimization for sustaining cities of the future. As stated in[64], the ICT for the city of the future will be constituted by Dynamized Integrative Cyber-Physical Systems. These are to be developed along six key areas:

1. Concepts and methods for dynamized urban infrastructures
2. Construction and quality assurance of genuine security
3. Multidisciplinary and integrative urban development
4. The field – including (i) sensors, e.g. for monitoring real processes in the city, (ii) ‘things’, i.e. machines, devices, vehicles, systems, etc. and (iii) human beings, i.e. both the people working in the field (cf. ICT solutions for blue-collar workers) and members of the public (cf. citizen services) – as an integral part of the ICT platform
5. The network itself as a dedicated public urban infrastructure and as a critical infrastructure
6. The urban control to focus on user empowerment and teamwork

Within this study, the topic of ICT for smart cities could only be discussed rather generic and should be addressed in more detail in a follow-up work.

3.2.8 List of Abbreviations

Abbreviation	Explanation
AC	Alternating Current
AIDC	Automatic Identification and Data Capture
API	Application Programming Interface
BiCMOS	Bipolar-CMOS (technology)
CENELEC	Comité Européen de Normalisation Électrotechnique
CPS	Cyber-Physical System
CMOS	Complementary Metal Oxide Semiconductor (technology)
CSIC	Compound Semiconductor IC
FD SOI	Fully Depleted Silicon on Insulator (technology)
FET	Field Effect Transistor
HBT	Heterojunction Bipolar Transistor
IC	Integrated Circuit
ICT	Information and Communication Technologies
IDC	International Data Corporation
IERC	IoT European Research Cluster
IoT	Internet of Things
ITRS	International Technology Roadmap for Semiconductors
ITU	International Telecommunication Unioon
mmW	Millimeter Wave
M2M	Machine to Machine (communication)
PAN	Personal Area Network
PHY	Physical layer
RF	Radio Frequency
RFID	Radio Frequency Identification
RX	Receiver
SiGe	Silicon-Germanium
SIM	Subscriber Identity Module
SoC	System on Chip
SRIA	Strategic Research and Innovation Agenda
TX	Transmitter
UHF	Ultra High Frequency
ULP	Ultra Low Power
UWB	Ultra Wide Band
WSN	Wireless Sensor Network

3.3 Safe and Secure Cities

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Co-Authors: *Oliver Ambacher, Christine Hennebert, Anne-Julie Maurer, Francois Tuot, Malisa Vucinic*

This chapter focuses on secure generation of information and secure transmission of said information in sensor networks. We first define smart domains and relate product examples to four different smart domains – mobility, health, society and energy. Next, we discuss security class definitions which entail different technological requirements.

Regarding secure generation of information, we describe the types of sensors required using the example of safe mobility in smart cities. On the topic of secure transmission, we explain issues of authentication, access, authorization, and privacy as well as bootstrapping and deployment. We also discuss the importance of secure public key infrastructure.

The third part focuses on the roadmap, which highlights the technological and microelectronic challenges which lie ahead. Finally, we evaluate the expected economic impact in the safety and security area, and list the research areas which we advise should be focused on in future calls.

3.3.1 Future Key Products

3.3.1.1 Smart domain definition and product examples

Urban population has constantly increased during the past years, and the trend is that 70% of the human being will live in towns in 2050. So cities will have to deal with a high level quality living environment required by citizens. As a consequence most of the solutions will be linked to massive deployment of services served by multiple devices on a networked infrastructure with high level of security and reliability.

It is already a fact that the deployment of such services has started in such domains as Transportation, Energy, health, eGovernment interacting and with specific security level according to the threats and assets to protect. So Smart City can be seen as a global environment as depicted in the picture below.

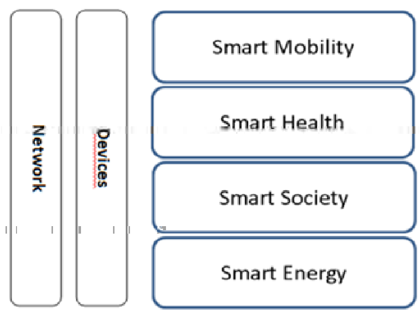

Figure 10: Global environment of a Smart City

Smart mobility:

This domain will target resource efficient transport with more safety on new generation of vehicles. Efficient multi-modal transport will be addressed as well to replace individual personal car. Main security topics are:

- Authentication and billing
- Malicious update of firmware in cars
- Malicious apps download
- Privacy (Geo-localization, anonymous payment, big-data management…)
- Secure execution

Smart energy:

This domain will target on smart grid in order to reduce energy consumption and community energy management (smart buildings, greenhouse, heating systems…). Main security topics are:

- Protection against cyber attacks
- Privacy
- Billing

Smart health:

This domain will target on home care and well-being including usage of sensors and measurement devices and remote medicine for diagnosis. The development of smart wearable devices is a global trend. Main security topics are:

- Protection against cyber attacks
- Liability
- Integrity of data
- Confidentiality

Smart Society:

This domain will target technologies for future internet services and many kinds of e-services. Main security topics are:

- Privacy
- Authentication
- Payment
- Certification

3.3.1.2 Security classes definition

Fact is that objects deployed in Smart Cities, and more generally in the IoT, are extremely heterogeneous. Their degree of importance in the network is diverse, some nodes may have a critical role in the global system, and others can be insignificant even in case of malfunction. Therefore, the criticalness of a node has to be assessed in more detailed. What kind of malfunction can cause a problem? The node can become unavailable, a sensor can send biased information, an actuator can answer properly but be nonfunctional, and a node can spoof the identity of another node…

Independently of their criticalness, the objects are exposed to a wide variety of threats: they may be accessible to the citizen, or at the opposite, embedded in roads asphalt. Generally, when nodes are accessible to users and therefore to attackers it is considered that its hardware and software may be compromised without remote access. Faced to this threat, a secure approach would be to embed a smartcard or a secure microcontroller in each object. However, for obvious cost reasons, it is not reasonable to embed such component in node that will cost a few cents.

The relevant question to ask is: regarding to the corresponding threat model, what kind of feature shall be protected in the node? Usually, it will not be necessary to protect all features of a given node. This chapter will focus on basic blocks for enhancing security of sub-features of IoT network nodes. To help this classification, we propose a set of basis security classes that can be applied to a node; a node can comply with one or many classes:

- No security requirements
- Secure identification (human and devices)
- Secure firmware (and potentially secure updates)
- Secure communication
- Hardware electronic integrity
- Hardware sensor integrity (and actuator, package…)
- Quality of service, availability
- Resilience (in case of a major event)
- Linkable to a citizen, to a service, to a place
- Secure deployability

3.3.1.3 Matrix linking security classes, smart domains and product examples

We propose to crosslink the previous security classes with the different smart domains and some consistent product examples.

Domain	Item	Threats	Risks	Main security requirements
Smart Energy	Smart meter	Counterfeit of Grid technical data	Grid fault or misuse	Secure communication
		Tamper of meter (modify consumption, recover keys...)	Fraud with economic loss Power loss	Hardware electronic integrity Secure identification
		Eavesdropping of consumption and billing data	User privacy violation User Behavior recording	Secure communication
	Heating sensor at home	Tamper of sensor (modify consumption)	Fraud with economic loss	Hardware sensor integrity
Smart Health	Air pollution sensor	Eavesdropping of communication	Extraction of information for other purposes	No security requirements
		Tamper device configuration Non trusted firmware	False information reported Inappropriate decision taken	Secure firmware Secure identification
	Medical file privacy	Cyber-attacks on servers	Access to sensitive personal data User privacy	Secure identification Linkability to a person
		Eavesdropping during connections	Identity usurpation	Secure communication
Smart Mobility	Traffic management for collective transportation	Cyber-attacks on servers	False information reported Inappropriate decision taken	Secure communication
		Reliability of device	Non accurate information Lack of information	Quality of service, availability
	Traffic management for individuals	Individual geo-localization	User behavior recording User privacy	Secure communication Hardware electronic integrity
		Modification of various sensors	Wrong information reported to system	Hardware sensor integrity
Smart Society	e-Administration	Network attacks	Untrusted websites collecting user credentials for fraud	Secure communication
		Phishing	Identity usurpation User privacy	Secure identification
	Safe city	Denial of service of a security device	Public security attempt Economic loss	Quality of service, availability Resilience
		Tamper device configuration Non trusted firmware Sensor cloning	False information reported Inappropriate decision taken	Secure deployability Secure firmware Hardware electronic integrity

Table 2: Smart domains and security classes

3.3.2 Technological Requirements

3.3.2.1 Secure generation of information

The secure generation of information and the transmission of said information in sensor networks in order to protect citizens requires that the data collected by the sensors be processed accurately, and that the data from the sensors to the monitoring, analysis or control units (which can be stationed at a larger distance) be transmitted securely. The types of sensors in urban centers will be used for instance to monitor air quality, traffic density or gatherings of people in crowded places. The sensors must be equipped with a (receiver-) transmitter unit, which has to meet the following conditions:

- sufficiently high data rates
- secure transmission encryption of the measurement data

- low energy consumption per transmitted bit
- high reliability, lifetime and robustness
- low acquisition and operation costs

The sensor networks (see also chapters 3.1 and 3.2) which are relevant for urban centers are manifold and multifunctional. Due to the high number of measuring points they will also become increasingly complex. Apart from the secure generation and transmission of information, data filtering, evaluation, graphic presentation, forecasting and control must happen efficiently and securely both in relation to the customer and the user. How such a sensor network can in future contribute to the safety of the population will be explained in the following using the example of mobility in smart cities.

The increasing urbanization in Europe leads to more people living in confined spaces. In order to ensure safety and security of mobile systems in urban areas, it is of utmost importance to enable analyses which allow forecasts of how situations might develop. In addition, monitoring and controlling traffic and goods flows must be handled proactively. Sensors, e.g. to determine the exact position, distances and densities of mobile systems, are at the heart of such a network; consequently it is of value to evaluate their impact on safety and security in urban areas (see chapter 3.7).

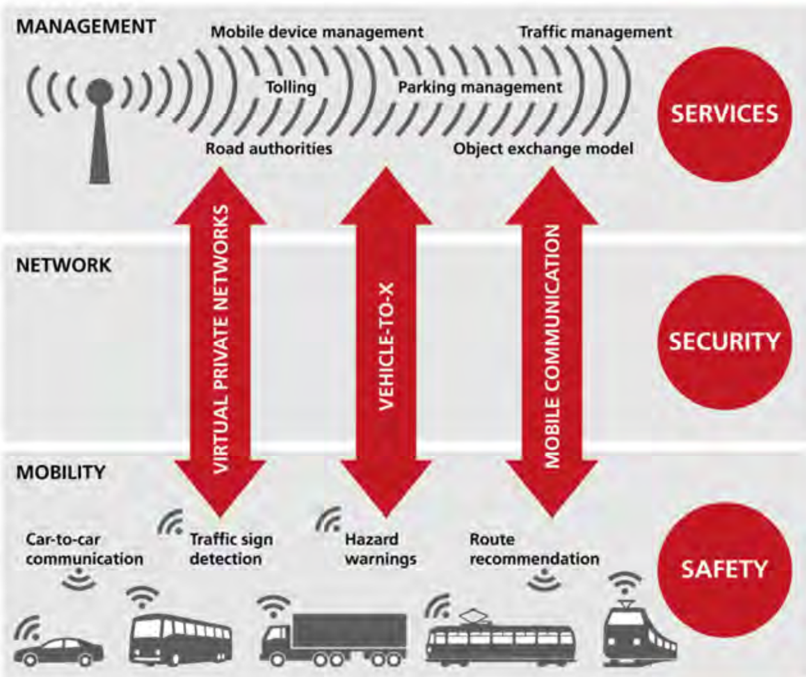

Figure 11: Organization levels which have to be developed to ensure safe generation and communication of sensor data in order to optimize the security of mobile systems in future urban environments.
© Erhan Ergin - Fotolia.com/Fraunhofer IAF

Mobility (see chapter 3.6) is one of the central topics in urban areas where smart, safe and easy transportation is required for a large number of people. How can we guarantee safe mobility in a smart city? Today, 70 people die in traffic accidents in Europe every day. In Germany alone there are now 52 million cars on the street (1.6 cars per adult), with this number increasing particularly strongly in urban areas. Accidents are only one result of this:

2.3 million accidents each year, causing 350,000 injuries and 3,500 deaths. Other issues are inefficiency caused by traffic jams, air pollution caused by exhaust gas, noise pollution and the use of fossil fuels. These are the challenges we have to meet. Research is needed in order to provide a sensor and communication network to collectively control mobile systems. Examples of sensors include driver assistance systems, distance control, night and fog vision and gas sensors (inside of the car and near the engine). From a superordinate point of view, a large number of cars, busses, trucks, etc., have to be connected and guided by a traffic management system.

The future traffic management system could organize mobile systems by given priorities in different urban areas, e.g.:

- fastest and most secure navigation of vehicles to the desired destination taking into account public transport and public routes
- traffic management taking into consideration a) traffic calming in residential areas during resting hours, and b) air pollution caused by heavy traffic
- automatization / activation of the self-driving system of each car when entering a defined urban area (the car automatically logs into the existing network for further guidance to the destination)
- elimination of traffic lights and traffic signs thanks to traffic management which is automated, real-time and tailored to the needs of each individual car in a predefined urban area
- automated 360° recognition of people and obstacles in order to avoid collisions
- central gathering of local weather conditions in order to regulate the driving behavior and the “cabin climate”

The motivation for science and development is created by the enormous complexity of the control and sensor system because of the high amount of possible scenarios and the high number of challenges related to future combination of communication/sensor networks and the networks of mobile systems.

3.3.2.2 Authentication, Authorization, Access control and Privacy

Having in mind the complex architecture of smart cities there is a clear need to propose a high level of security & confidentiality in order to avoid intrusion, attacks and data or identity theft. Considering the varieties of devices networks and applications, specific solutions have to be studied according to the threat level and impact in order to authenticate users authorize the access to the services & network and protect privacy.

Figure 12 shows a schematic description of the model where those security features have to apply, considering that various devices are connected directly to the network or through a gateway via wireless or wired networks.

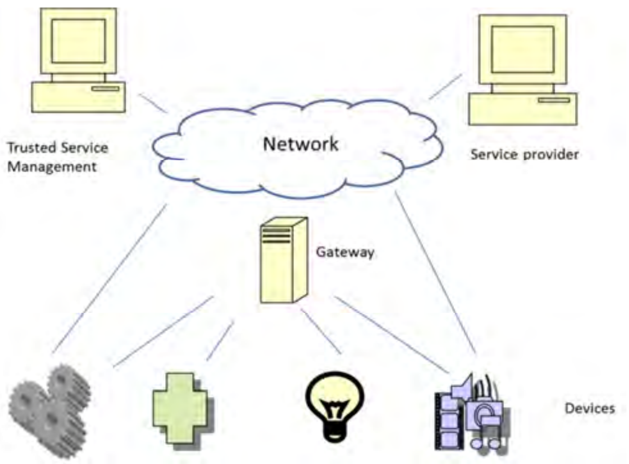

Figure 12: Schematic description of security needs in a network environment

Authentication:

Authentication is the process of determining whether someone or something is, in fact, who or what it is declared to be. In IoT device authentication is basically something different of the user based authentication (as instance user name and password).

Authorized device notion of unique device and copy protection to ensure uniqueness using mechanism as Physical Unclonable Function (PUF) could be an alternative for devices as sensors actuators needing authentication.

In other use cases the usage of gateways with a secure element and the introduction of a trusted third party TSM should permit to deploy strong authentication model like as instance Smart Grid and Smart Governance.

Authentication used to link a device to an individual (for liability and service charge) need to define rules for such link update, transfer, revocation. So authentication mechanism has also to support this kind of features, such as in Smart Health and Smart Mobility.

Access control:

The IoT requires access control mechanism to access the resources as gateway or devices in order to prevent unauthorized use of these resources, in other words credentials and associated control rules and operations. As a consequence, it has to support various authorization & models according to the heterogeneity and diversity of the devices or gateways.

There is also a need to handle all security operation by itself without Human control using new techniques as self-learning to reach a self-management behavior.

Privacy:

Much information in IoT can be seen as personal data so there is a clear need to support anonymity and restrictive possession of this kind of data.

Crypto technologies to enable protected data storage processing and eventual sharing. Technologies as Homorphic encryption are interesting in this perspective.

Preservation of geo-location or citizen behavior through anonymization techniques are key features. Privacy by design should be studied in order to address identification, authentication and anonymization.

On another hand, legal issues have to be considered since European countries have different national policies. It could conduct to strong technical differences in implementation and may limit deployment if regulations are not fully adapted (Smart health, Smart mobility).

3.3.2.3 Bootstraping and deployment

The security solutions used for IoT are usually designed for dedicated scenario requirements without considering generic interoperability with the Internet Security Protocols (ISP) stack. Protocol translation is done by the gateway device at the boundary between the LAN and the WAN domains. However such translation is the main obstacle to achieve end-to-end security between IoT constrained devices and remote applications[94,95,96].

A typical way to proceed in this case is to implement "hop-by-hop" security, involving independently securing with different credentials the WAN and the LAN parts of the communication. This type of solution requires a rekeying operation at the level of the gateway and means that data is always available in clear in this device. Furthermore it leads to a concentration of credentials in the gateway increasing significantly the risk associated to a compromised gateway device.

The *bootstrapping* phase addresses the secure addition of a new object to the IoT network thanks to trust operations including authorization and authentication. The bootstrapping is not specific to any MAC or PHY layers. It concerns each component that would like to communicate with other components without any previous knowledge of the one with the others. Attacks must be prevented thanks to the *threat analysis of the whole network*. The resulting system should guarantee that only *trusted instances of applications* can run over the IoT network and the infrastructure. Moreover, the life of a thing begins at manufacture. The device identity and the secret keys used during the running cycle are provided during the bootstrapping phase. Once deployed, the device is under the control of its owner.

An architecture built around a security management platform is commonly adopted. The proposed security framework handles all the security aspects detailed in[97]. It could be implemented in three steps:

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[94] René Hummen, Hanno Wirtz, Jan Henrik Ziegeldorf, Jens Hiller, Klaus Wehrle, "Tailoring end-to-end IP security protocols to the Internet of Things", *21st IEEE International Conference on Network Protocols (ICNP)*, 2013
[95] J. Granjal, E. Monteiro, J.S. Silva, "On the Effectiveness of End-to-End Security for Internet-Integrated Sensing Applications", *IEEE International Conference on Green Computing and Communications (GreenCom)*, pp. 87-93, 2012
[96] V. Gupta, M. Millard, S. Fung, Yu Zhu, N. Gura, H. Eberle, S.C. Shantz, "Sizzle: a standards-based end-to-end security architecture for the embedded Internet", *3rd IEEE International Conference on Pervasive Computing and Communications*, PerCom'2005, pp. 247-256, 2005
[97] Tobias Heer, Oscar Garcia-Morchon, René Hummen, Sye Loong Keoh, Sandeep S. Kumar, Klaus Wehrle, "Security Challenges in the IP-based Internet of Things", *Journal of Wireless Personal Communications*, vol. 61, no. 3, pp. 527-542, December 2011

- The *Bootstrapping at low-level (LAN)*: consists in securing the “small” data between the object and the gateway / proxy / modem linked to the WAN. It may consist in crediting the components of the LAN with a shared session key that we can call "local" session key.
- The *Bootstrapping at “high-level” (WAN)*: consists in distributing the access rights under the form of access-token and cryptographic keys to the components of the WAN – connected to internet - authorized to exchange information or to access to resources.
- The *Session establishment*: addresses the problem of distribution ephemeral session credentials from the object to the user in order to implement “hop-by-hop” or “end-to-end” security.

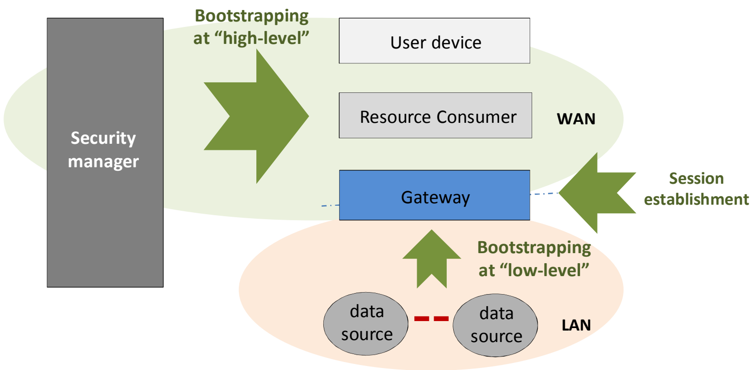

Figure 13: the three phases of security deployment

The bootstrapping at “high level” in the WAN can be performed thanks to protocol as OAuth2.0[98]. OAuth2.0 was recently introduced by Google to provide third-party applications access to constrained resources. It introduces an authorization server distinct from the data application path. The authorization server provides an access-token to the application to access to the remote resources whatever the credentials of the end-user.

Nowadays, there is no standard to perform the bootstrapping of the objects located in the LAN to the network. A variety of techniques co-exist. The bootstrapping technique most familiar to the general public is to connect via WiFi a computer, tablet or smartphone to the modem / box at home. To bootstrap, simply note the key value that can be read on the modem and enter this value using the keyboard when the device tries to connect to private and secure WiFi network. In this case, all devices connected to the same modem share the same key.

The problem is more complex with the connected objects:

- The objects are headless and/or physically difficult to access,
- The confidentiality should be ensured between different nodes which involve managing the group concept,

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[98] OAuth 2.0, http://oauth.net/2/

- The objects are inexpensive, purchased bare, resource constrained and communicate via a low-power radio standard as IEEE 802.15.4.

Several techniques have been envisaged to secure a pair of nodes, starting from nothing – an insecure channel – and leading to a secure channel:

1. Channel estimation based: Based on the assumption of the channel reciprocity, the channel estimation by both devices of a peer-to-peer communication gives temporal signals that "mirror" the one of the other. These two signals could be considered as two correlated random sources and a common secret can be forged secretly and independently inside each device.

2. This technique implies that the two devices are close, the communication channel is stationary during the time of one symbol and that little interference perturbs the channel. Each peer should also embed a pulse generator to send a Dirac – in the perfect case – and a channel estimator to compute the channel impulse response. As these capabilities are difficult to embed, this technology is not yet mature to be transferred in the industry.

3. In-band pairing: No additional interface or hardware is needed, but the applicability with IEEE 802.15.4 standard is questioned. As the devices communicating with low-power IEEE 802.15.4 on UDP are usually resource constrained, the management of certificates and the implementation of a PKI is too costly. Lightweight handshake could be envisaged at the application layer thanks to DTLS but the session key establishment remains an issue. At the network layer, compression schemes for IPsec have been proposed in order to fit into 127-bits length frames. IPsec AH or IPsec ESP may be available in transport mode only for low-power communications. No security association is proposed leaving aside the issue of bootstrapping.

4. Secure storage for private key needed: PUF, TPM-like. To physically secure secret credentials as cryptographic private key, a secure element – TPM-like – could be used. This hardware is now provided inside numerous devices as computer or tablet, but remains costly for resource constrained devices.
   The PUF – as Physical Unclonable Function – enables to forge a singular secret inside a device based on its singular characteristics provided at manufacture. From this secret, cryptographic keys or identity can be derived before initiating a handshake with another device.

5. Based on the assumption that the public key or the certificate of the service provider is already deployed inside the node memory, and that the node is able to generate its own cryptographic features – thanks to an embedded "true" random number or a PUF for example – lightweight handshake protocols can be launched to establish a secure channel. This implies that lightweight asymmetric cryptography technique is embedded into the node. This solution is a compromise that allows the node mobility and needs an appropriate management of lightweight certificates. The actual standards

– as X.509 – leads to certificates too big to be embedded into resource constrained nodes.

6. Out-of-band: A different channel could be used to share a secret key between two devices while ensuring that the information is broadcast on the air without confidentiality. Carelessly, everybody located in the coverage area of the transmission is able to eavesdrop the secret. An USB link, a button-to-button or a LED transmission can be used to share the secret and/or the cryptographic material before the deployment of the node. This technique could require an additional PHY/MAC layer embedded into the node only used for the bootstrapping operation. The maintenance of the keys may be delicate if the secret is lost and this situation must be avoided. This solution may be easy to use and “plug and play”.

The choice of a bootstrapping technique must involve the architecture of the network, the technology of the nodes, the supported uses cases or applications running over the network, the criticality of the data exchanged. A threat analysis should be launched that considers the vulnerabilities of the system and to determine the risks that we want to cover.

All of these techniques aim to secure a connection between two components. In the Internet of Things, the ultimate goal is to protect the resource emitted by the object and hide the identity of its owner. This requires rethinking these techniques by introducing the concept of groups and managing cryptographic features with flexibility for groups of individuals and / or objects.

3.3.2.4 Need for secure anchors in small & cheap objects

The introduction of standard security protocols to constrained environments in many instances also necessitates the use of a Public Key Infrastructure (PKI). Although PKI was initially deemed too heavy for constrained devices due to the large computational overheads of asymmetric cryptography, latest generations of smart objects, mostly based on 32-bit ARM MCUs, successfully cope with it. However, due to the obvious performance reasons, constrained devices are not expected to verify long certificate chains and very often end up using a local, domain-specific PKI with its corresponding trust anchors (root trust certificate). In the following, we present main cases where X.509 PKI and appropriate trust anchors are necessary to provide various security services.

3.3.2.4.1 Peer Authentication with Datagram Transport Layer Security (DTLS)

As mandated by CoAP[99], end-to-end security in IoT is based on DTLS protocol, the UDP equivalent of its TCP counterpart, TLS. Certificate mode of CoAP requires X.509 certificates for client/server authentication and therefore necessary root trust certificates need to be put in place before either of the communicating parties can validate its peer’s identity and complete the security handshake. The mandatory-to-implement cipher suite in CoAP Certificate mode is TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 using the Elliptic Curve Diffie-Hellman

[99] Z. Shelby, K. Hartke, C. Bormann, “The Constrained Application Protocol (CoAP)”, IETF, RFC 7252, June 2014

(ECDHE) key establishment guaranteeing perfect forward secrecy[100]. X.509 certificates need to be signed using the secp256r1 elliptic curve and SHA-256 hash algorithm. However, in order to support lower end devices with humble computational capabilities, CoAP also supports the use of raw public key validated using an out-of-band mechanism. Pre-validated raw public keys in this case are functionally equivalent to the PKI trust anchors and secure management and storage mechanisms should be consequently used.

3.3.2.4.2 Authorization with OAuth 2.0

As discussed in Chapter 3.3.2.3, separate authorization and application domains in typical IoT deployments necessitate the use of three party authorization protocols. In that sense, OAuth 2.0 [96] is an often-discussed protocol candidate to be adapted for constrained environments[101, 102]. Due to the energy constraints, smart objects need to be able to stateless validate access-tokens presented by clients, avoiding the communication with Authorization Servers for individual requests. In OAuth, this functionality is achieved using the Bearer Tokens[100] that are often implemented as signed data objects. Naturally, public keys needed for verification of these signed objects are distributed either as X.509 certificates or in the raw, pre-validated form, similarly to the CoAP/DTLS case.

3.3.2.4.3 Application Level Security

Recognizing many functional incompatibilities of DTLS and CoAP, most notably group communication and end-to-end security in the presence of intermediate proxies, solutions have begun to emerge that place security at the application layer in the form of secured data objects[103], [104]. These data objects encapsulate source authenticity identifiers together with application data and are signed with the private key of a smart device. Consequently, they need to be verified by clients using the appropriate certificate. The advantage of such approaches is the functional simplicity on constrained side, and complexity shift, including a large part of the cryptographic burden, towards clients that are often not constrained. Naturally, a PKI infrastructure and necessary root trust certificates are assumed in order to guarantee source uniqueness of data objects.

3.3.2.4.4 Network Bootstrapping

As discussed in Section 3.3.2.1, due to the lack of end-user interfaces, smart objects often pose numerous challenges during the bootstrapping phase. On-going work within IETF utilizes standard protocols like EAP and PANA to allow devices to be recognized by the network they want to join and be provided with Layer 2 cryptographic material[105]. Authentication of devices at this early stage is based either on X.509 or IEEE 802.1AR

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[100] H. Tschofenig, “A Datagram Transport Layer Security (DTLS) 1.2 Profile for the Internet of Things”, IETF work in progress, draft-ietf-dice-profile--03.txt, July 2014

[101] H. Tschofenig, “The OAuth 2.0 Internet of Things (IoT) Client Credentials Grant”, IETF work in progress, draft-tschofenig-ace-oauth-iot-00.txt, July 2014

[102] H. Tschofenig, “The OAuth 2.0 Bearer Token Usage over the Constrained Application Protocol (COAP)”, IETF work in progress, draft-tschofenig-ace-oauth-bt-00.txt, July 2014

[103] M. Vučinić, B. Tourancheau, F. Rousseau, A. Duda, L. Damon, R. Guizzetti, “OSCAR: Object Security Architecture for the Internet of Things”, WoWMoM, IEEE, pp. 1-10, June 2014

[104] L. Seitz, G. Selander, and C. Gehrmann, “Authorization framework for the internet-of-things,” in WoWMoM. IEEE, 2013, pp. 1–6

[105] M. Richardson, “Security architecture for 6top: requirements and structure”, IETF work in progress, draft-richardson-6tisch-security-architecture-02, April 2014

certificates, burnt into devices during manufacturing. Naturally, for mutual authentication with the gateway of the network, a new joining device needs to be provisioned with the appropriate trust anchors necessary to validate gateway's identity certificate.

3.3.2.4.5 Trust Anchor Provisioning and Ownership Management

As outlined above, securely provisioned trust anchors are the most important pre-requisite for any phase of smart objects' lifetime. Current approaches outline the need that these should be provisioned together with device's identity certificate during manufacturing[103]. Implicitly, once the device is sold, the manufacturer needs to ensure transitioning to consequent owners by bootstrapping the device to trust the PKI of a new joining domain. However, the use of the Trust Anchor Management Protocol (TAMP) is not envisioned[98], and current solutions are mostly proprietary. Still, the need for a dynamic management of trust anchors is apparent, as devices may change many owners during their lifetime. In that sense, re-use of authorization mechanisms and protocols would be highly beneficial as it would avoid an additional complexity layer and further increases in firmware code size.

On the other hand, an equally important aspect is the storage of trust anchors and other sensitive cryptographic material, as in many deployments devices can be physically compromised. In those cases, tamper-resistant hardware chips with secure storage, such as Trusted Platform Modules (TPM), could be of great use. However, energy consumption of TPMs is still deemed very heavy for smart objects. While their functional requirement is undeniable in the wide context of system security architectures, published performance results[106] reveal a clear demand for the development of new generation chips that could be used both on network gateways and constrained devices. In the same context, independent secure storage microchips need to be carefully designed in order to minimize the impact on overall system performance and energy consumption.

3.3.3 Roadmap

There are strong movements supported by scientific funding agencies in Asia, the USA and Europe (mainly on a national level) in various fields such as energy saving, renewable energies, environmental protection, safety and security and quality of life. Especially the aspect of safety and security has huge potential for applications of sensors. Detection systems for tsunamis and earthquakes, security monitoring of old infrastructures like roads and bridges, health care for the elderly, monitoring of radiation and pollution in the environment, secure (mobile) communication technologies, safe traffic and transportation, etc., often require innovative and low cost sensor systems. A number of sensors are already implemented in some of those applications and expected to increase in number due to the strong movements mentioned above.

Considering our aging society, any kind of personal health monitoring sensors have a high possibility to require beyond 10 billion sensors, as the number of people aged 65 years and

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[106] T. Kothmayr, C. Schmitt, W. Hu, M. Brunig, and G. Carle, "A DTLS based end-to-end security architecture for the Internet of Things with two-way authentication," in LCN. IEEE, pp. 956–963, 2012

older will exceed 35 million in 2020 in countries like Japan, Germany or the USA. Disposable sensors monitoring information through urine or blood, for example, are good candidates to be successful. Sensors to detect residual agricultural chemicals also have high potential, as there is common demand to ensure secure food and drinking water for every human being.

In addition to the established continually growing applications like automotive and smart phones, potentially increasing applications include large disaster detection systems (e.g. tsunami and earthquake detection) linked to infrastructure, e.g. bullet train control, robots which assist the elderly, or personal medical care. More specifically, very tiny radiation sensor tags have the potential to be attached to the plastic packing of food items. If a few of these bags are sold every month, a number of 50 million households per nation will easily make 10 billion sensors, which can create a sensor network or a sensor cloud which can be applied for safety and security issues. Adding all these applications it is easy to imagine how quickly we will reach a state of "abundance" as predicted by Fairchild Semiconductors:

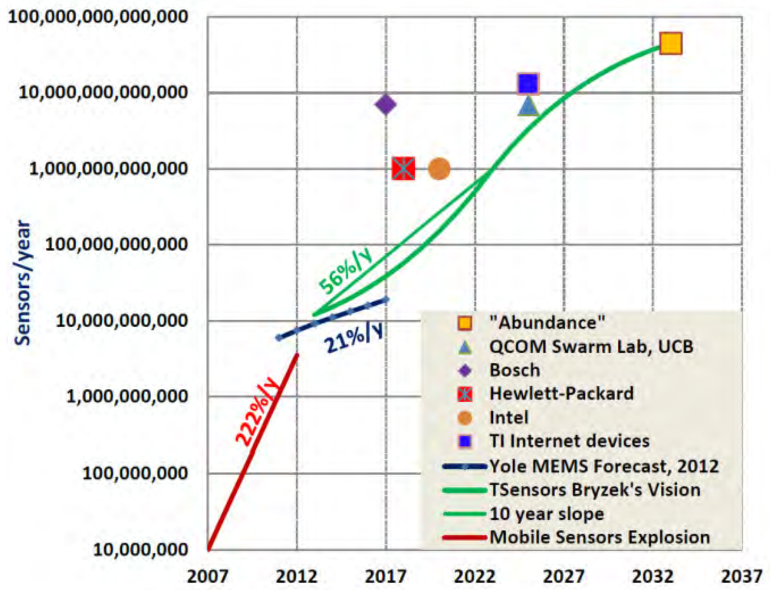

Figure 14: Forecast of the increase in the number of sensors produced each year on a global level until 2037. (Source: Fairchild Semiconductors[107])

Sensors have also been deployed into many consumer devices (iPhone, gaming consoles). While 10 million sensors were deployed in 2007, this number grew to 3.5 billion in 2012, which equals a CAGR of 200%. In addition, sensors are increasingly used in many applications of daily life: wearable smart systems, context computing and sensing, bringing human "senses" to computers, Internet of Things, etc. The stark rise of sensors will of course also drive the semiconductor market in general, creating new technologies and sensor concepts enabling new possibilities for safety and security aspects.

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[107] http://www-bsac.eecs.berkeley.edu/scripts/show_pdf_publication.php?pdfID=1365520205

The data which billion or even trillions of sensors on a national or global level will generate must be transferred by secure communication technologies with suitable standards and protocols. Several key requirements have to be met: Low cost, low power consumption and high data rate. It will also be challenging to connect a larger number of devices in a single network in a more local region like a town. Today, several protocols and standards exist, which are often tailored to specific applications and which serve some of the requirements mentioned above, but not all at once. This is exemplified in the following graph:

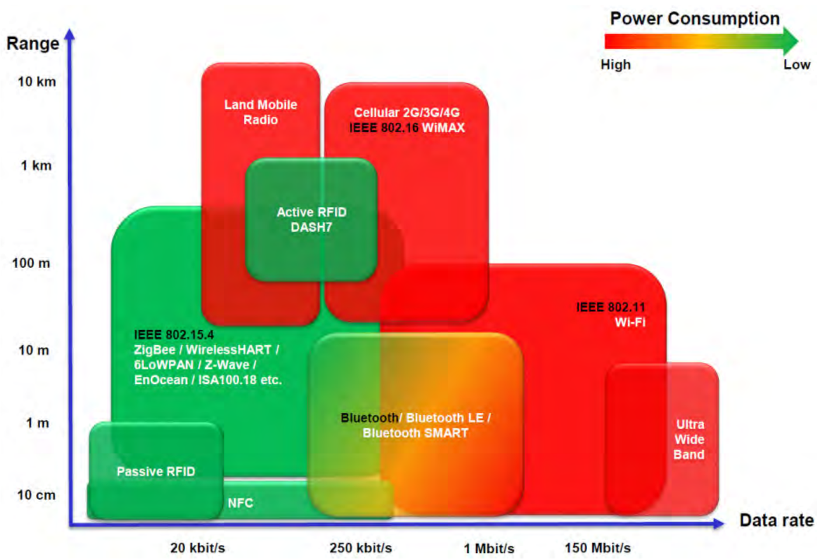

Figure 15: Current protocols and standards for wireless communication in dependence of data rate and operating distance [108]

For the Internet of Things (IoT) industrial market, protocols based on the IEEE 802.15.4 are likely to prevail because they meet industrial requirements such as low power consumption, long range, and the ability to link a large number of devices. Strong market acceptance is expected in 2018 when the protocol is fully mature. In the consumer market, Wi-Fi, telecom and Bluetooth are currently widely used. They could be replaced by low-power low data rate protocols such as ZigBee starting 2016. In the long run (~2024), when sensors networks and clouds appear, new systems based on energy efficient microelectronic devices and must be developed.

Data protection and security are a key issue in the IoT and the main hindrance for market penetration. Consumers are already very critical of websites which might amass and store their private data. Regarding security, any device which produces data must be absolutely tamper-proof. As of today, there is no standard data protection for the IoT, and many governments do not have fixed regulations. These are expected to appear in 2017 and will change the way companies will deal with private data.

[108] Yole Development, "Sensors & Technologies for The Internet of Things", 2014

One of the biggest challenges is that the power of today's data generation, analysis and transmission solutions cannot meet the demands of a trillion sensor universe. The data output from trillions of sensors would overwhelm the computational capability of the internet. 5 exabytes of data are generated globally every two days, which is approximately the amount created between the dawn of civilization and 2003. Moreover, energy consumption is an issue – solutions such as energy harvesting and self-power sensors must exist before a trillion sensor universe can become reality.

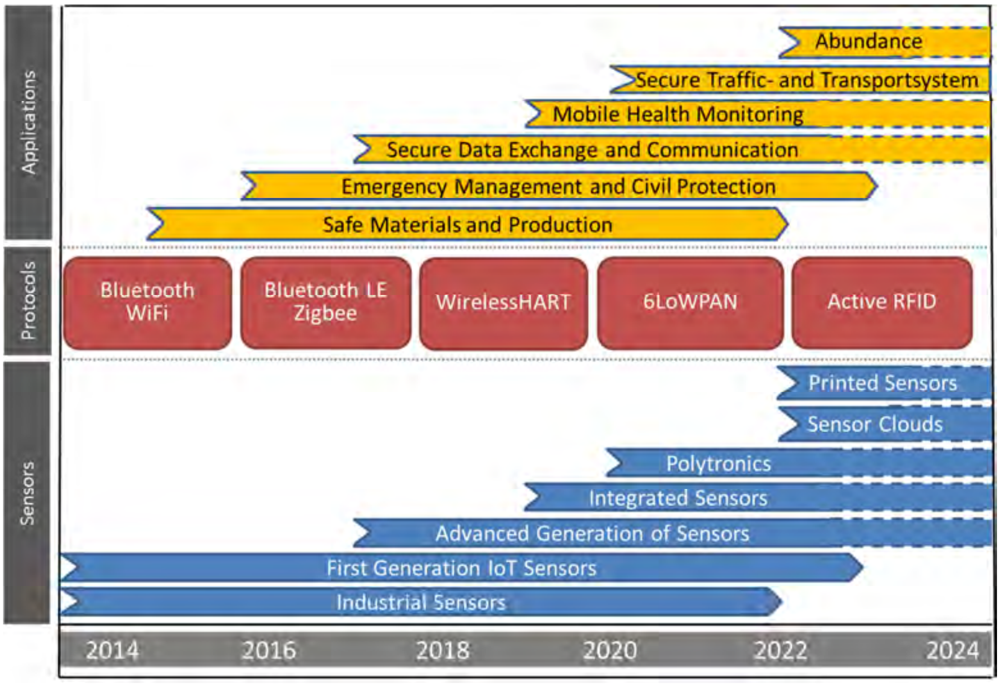

Figure 16: Roadmap for possible applications, protocols and sensors related to the aspect of safety and security in smart cities[106, 109]

In order to match the roadmap of applications and protocols, the following diverse but representative technological and microelectronic challenges have to be mastered in order to provide the sensors and systems needed:

- Modern Concepts
    - Evaluation of risk potentials in smart cities which can be reduced by sensors
    - Concepts for emergency management in smart cities
    - Algorithms to extract relevant information provided by (virtual) sensor clouds
    - Data filters to protect privacy
    - Integration of semiconductor-based sensors into the packaging of consumables, clothes, mobile cell phones
    - Matching the chemical connections of the sensory data to the needed information
    - Enabling chemical sensors for the immense diversity of chemical-biological space,

[109] Swapnadeep Nayak, "Internet of Things-Technology Penetration and Roadmapping", 2012

    - Enabling manufacture of sensors that require diverse materials and processes.

- (ii) Novel Materials and Technologies
    - Printable polymers with improved electronic performance
    - Carbon nanotubes with unique chemistry, stability, and ultra high surface area at low cost
    - New materials for nanocatalysts and sensor active elements

- New Devices
    - Efficient energy harvester as power source for microsensors
    - Energy efficient microelectronics
    - Low power data links for sensor communication
    - Picocells (small and smart mobile base stations) for mobile and cost effective communication of sensor clouds
    - High data rate communication links and networks for secure communication systems
    - Robust sensors to detect residual agricultural chemicals
    - MEMS thermal platforms for low power chemiresistor and conductivity sensors
    - Printed electronics and 3D printing of electrochemical sensor for ultra-low cost.

- Innovative Systems
    - Data exchange and communication systems for extreme high data rates
    - Data exchange between car and car as well as between car and traffic control
    - Optical technologies integrated by MEMS into tiny low cost spectrometers and chromatographs
    - Cheap systems for monitoring of drinking water and food
    - Sensor systems for monitoring the mechanical stability of streets, bridges and buildings
    - Compact radar systems for car to car and car to environment control and communication

3.3.4 Strategic Research & Economic Impact

3.3.4.1 Research areas to be investigated in future calls

Although on-going standardization and industrial efforts already leverage research accomplishments achieved in the past decade, many challenges in deploying large-scale networks consisted of smart objects remain. In parallel, research and development challenges persist in minimizing the energy consumption of individual components such as secure elements, cryptographic co-processors, and Trusted Platform Modules, in order to make their integration feasible on low-cost and energy constrained objects.

3.3.4.1.1 Bootstrapping using out-of-band channels and standard IP protocols

As described in Section 3.3.2.3, user-friendly and secure bootstrapping remains a big unknown. In that sense, out-of-band channels established by means of different technologies are often used to exchange initial parameters necessary to join a network, such as the radio channel and different attributes or secrets necessary for authentication. Near Field Communication (NFC) is commonly used for this purpose and manufacturers often integrate passive NFC elements on smart object platforms, for the sole purpose of bootstrapping. However, when it comes to bootstrapping hundreds or even thousands of smart objects, the process using NFC becomes tedious and the new innovative use of other technologies is often sought. Researchers have demonstrated efficient bootstrapping protocols that are based on the visible light channel (VLC)[110, 111] where the objects establish a unidirectional channel with a network gateway. For this purpose, Light Emitting Diodes are used to encode randomly selected keys, which are detected on the gateway by means of a digital camera. On the other hand, one could imagine the establishment of a unidirectional channel from the gateway towards individual objects, leveraging for instance a light sensor available on many platforms, which would allow scalable exchange of network parameters. In parallel, on-going standardization and research work within IETF uses standard protocols like PANA and EAP to allow a smart object to join a network, based on the assumption that it already possesses the necessary secrets and parameters[103].

3.3.4.1.2 Secure session management with DTLS and memory requirements

Datagram Transport Layer Security (DTLS) protocol was designed for client-server interactions in the Internet with the server being a powerful machine with plethora of resources and the client most often a personal computing device. The same protocol (DTLS) is used in IoT networks to secure the communication channel between a smart object and a client. Therefore, when it comes to DTLS, smart objects will run the same role (web server) that powerful machines are running in the traditional Internet. Possibly multiple clients may still want to communicate with a single smart object, therefore requiring DTLS session management. In the Internet, this is not a problem as servers typically have large amounts of RAM memory available for the purpose but this is not the case with smart objects. In effect, it is common to have smart objects with available RAM memory on the order of 10s of kilobytes for the entire operating system and networking stack. As a consequence, smart objects cannot keep open many instantaneous sessions and need to close old sessions once new ones are initiated, which puts a significant burden on smart objects, as they need to perform the expensive DTLS handshake often. This example clearly stresses the constant requirement for more memory even on low-cost SoC, but in the same time lays the ground for a system level research on achieving true, Internet-like end-to-end security without sacrificing on performance and lifetime of smart objects. Recent works mostly tackle this problem by

[110] Perković, Toni, et al. "Multichannel protocols for user-friendly and scalable initialization of sensor networks." *Security and Privacy in Communication Networks*. Springer Berlin Heidelberg, 2009. 228-247

[111] Saxena, Nitesh, and Md Borhan Uddin. "Blink'em all: Scalable, user-friendly and secure initialization of wireless sensor nodes." *Cryptology and Network Security*. Springer Berlin Heidelberg, 2009. 154-173

introducing a trusted third party on the network gateway that can either completely remove the need for the handshake101 or perform some parts of it on behalf of the smart object[112].

3.3.4.1.3 Performance of DTLS handshake in radio duty-cycled networks

In order to save energy, smart objects often exploit a radio duty-cycling scheme that allows them to sleep extensive periods of time. For example, it is common nowadays to have smart objects with MCU and radio transceiver switched off for more than 99.9% of the time, while still performing the desired functionality and responding to external requests. This is commonly achieved by tight time synchronization among nodes in a network and a pre-defined packet exchange protocol. The side effect, however, is that network latencies significantly increase in respect to those commonly measured in the traditional Internet. In that context, once DTLS handshake needs to be performed between two smart objects, due to the many exchanged packets and possibly up to 3 round trip times, overall completion time ranges from couple of seconds up to one minute, depending on the level of radio duty cycling in the network[101]. This imposes significant energy load on smart objects, as they have to perform idle listening while waiting for remaining DTLS messages in the handshake and thus unnecessarily waste energy. Common approaches to reduce this impact include packet compression, in order to reduce number of bytes in each exchanged packet[113] or delegation of the parts of the handshake to a trusted third party[110], as briefed in the previous section. However, the performance of DTLS handshake remains an open problem as these solutions do not provide sufficient level of security and introduce new attacks.

3.3.4.1.4 Authorization and Access Control

Authentication, Authorization and Accounting (AAA) with billions of devices connected to the global network poses numerous technical and research challenges, as standard protocols like RADIUS or OAuth 2.0 cannot be directly applied. IETF has recently chartered a working group ACE to survey the available solutions and possibly design a new protocol that will allow a client to access a reading on a smart object (Resource Server) once granted permission by the Authorization Server (AS). The AS enforces a granted authorization request by sharing an access token with the client, which is then presented to the smart object. However, existing solutions mostly require a constant communication between the smart object and AS in order to validate the tokens, which is often not feasible in IoT applications. To avoid this, OAuth 2.0 uses the Bearer Tokens whose possession implies immediate access right, but their verification on smart objects typically involves expensive digital signature verification operation and/or knowledge of absolute time in order to verify if the token has expired or been re-played by an attacker. An efficient and secure method for verifying client’s access rights locally on a smart object, without previous knowledge of the client, always-on communication with AS, or absolute time remains an open and very important research challenge. Recent proposal[102] meets these requirements at the cost of high computational overhead of public key cryptography.

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[112] R. Hummen, H. Shafagh, S. Raza, T. Voigt, K. Wehrle, Delegation-based authentication and authorization for the ip-based internet of things, in: IEEE SECON, 2014

[113] S. Raza, H. Shafagh, K. Hewage, R. Hummen, T. Voigt, Lithe: Lightweight Secure CoAP for the Internet of Things, Sensors Journal, IEEE 13 (2013) 3711-3720

3.3.4.2 Economic impact for component manufacturer

Gross Domestic Product, hence the overall economic activity has been mainly driven by the industrial production over the centuries. As trending urban migration patterns will lead to 70% of the population living in cities by 2050[114], cities are becoming an important innovation platform. In the same time, the growing pressure on municipal infrastructure necessitates new technologies to more efficiently manage services and infrastructure, while improving quality of life and fostering innovation[115]. While $8.1 billion was spent on smart city technologies in 2010, that number is projected to reach $39.5 billion by 2016 [116]. With the introduction of ubiquitous sensing devices in transit and building infrastructure, real-time data on everything from energy-efficiency to traffic congestion becomes readily available facilitating more effective use of resources, minimizing waste, improving public sector productivity… As stated in Morgan Stanley's report[117]: "*Assuming the global cost base of manufacturing is $25 trillion today, 2-4% cost savings from Internet of Things (IoT) as a result of 50% penetration of IoT, we could see $500 billion in cost savings*." However, research indicates that the perceived insecurity of wireless (sensors) networks is a major inhibitor to further market growth. As a consequence, security must not be regarded as an "extra", rather a "must", and should be integrated with different IoT components and platforms from the early design phase.

It is estimated that the device business will reach $45 billion in 2024, contributing to a total IoT market of $400 billion, with a production increase in security and public safety sectors from 1.2 million units in 2018 to 405 million units in 2024[118]. As a consequence, market value of the security and public safety sectors will grow from $60 million in 2018 to $1785 million in 2024. The market value of the hardware ecosystem, including Research & Development, component manufacturing, and integration, will grow from $9.458 million in 2014 to $46.338 million in 2024, and by mid-2019, it is estimated that hardware will become the main source of value for IoT devices, with a progression from $9.4 billion in 2014 to $70 billion in 2018[116]. Therefore, we are likely to see a moderate, 17% increase rate of hardware market value by 2024.

As previously mentioned, IoT hardware components need to address security from the early stages. In that sense, we are already witnessing that majority of low-power MCUs targeting IoT applications have hardware acceleration for symmetric cryptography (AES). In parallel, radio transceivers have long been equipped with independent AES computation blocks, with security extensions of different wireless standards often implemented in hardware[119], in order to minimize the energy cost of secure communication that is crucial for IoT applications such as smart cities. Furthermore, various network security protocols required by industry standards necessitate the use of public key cryptography based on Elliptic Curves (EC). This

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[114] World Health Organization. 2010. Urbanization and Health. 88, 4, 241-320
[115] http://www.who.int/bulletin/volumes/88/4/10-010410/en/
[116] ABIResearch, 2011. "$39.5 Billion Will Be Spent on Smart City Technologies in 2016", http://www.abiresearch.com/press/3768-$39.5+Billion+Will+Be+Spent+on+Smart+City+Technologies+in+2016
[117] B. Cohen, E. Almirall, H. Chesbrough, "The City as a Lab: Open Innovation meets the Collaborative Economy", Call for papers, California Management Review, 2014
[118] Yole Developpement, " Sensors & Technologies for The Internet of Things: Businesses & MarketTrends 2014 -2024", May 2014
[119] Chipcon Products from Texas Instruments (TI), "Cc2420 data sheet," http://focus.ti.com/lit/ds/symlink/cc2420.pdf

has therefore prompted the inclusion of peripherals providing hardware acceleration of EC cryptography in order to bear its overhead feasible for devices constrained in energy and computation capabilities. Higher-end IoT platforms, such as network gateways, are also expected to integrate independent secure elements.

Finally, with the increased popularity in wearable electronics, industry will, from the safety point of view, need to consider switching to health and environment friendly materials. Furthermore, billions of devices and their eventual replacements raise many questions regarding the disposal, recycling, and the overall effect on the environment. Therefore, the use of carbon-based materials, organic semiconductors and polymers needs to be considered by component manufacturers, but its economic impact is yet to be evaluated.

3.3.5 List of Abbreviations

Abbreviation	Explanation
AES	Advanced Encryption Standard
AH	Authentication Header
AS	Authorization Server
CAGR	Compound Annual Growth Rate
CoAP	Constrained Application Protocol
DTLS	Datagram Transport Layer Security
EAP	Extensible Authentication Protocol
EC	Elliptic Curve
ESP	Encapsulating Security Payload
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IPsec	Internet Protocol Security
ISP	Internet Security Protocol
LAN	Local Area Network
LED	Light Emitting Diode
MAC	Media Access Control
MCU	Micro Controller Unit
MEMS	Micro-electro-mechanical systems
NFC	Near Field Communication
PANA	Protocol for Carrying Authentication for Network Access
PHY	Physical Layer
PKI	Public-Key-Infrastructure
PUF	Physical Unclonable Function
RADIUS	Remote Authentication Dial In User Service
RAM	Random Access Memory
SoC	System on Chip
TAMP	Trust Anchor Management Protocol
TPM	Trusted Platform Module
USB	Universal Serial Bus
UDP	User Datagram Protocol
VLC	Visible Light Channel
WAN	Wide Area Network

3.4 Energy

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The need of utilizable energy is omnipresent in today's modern society. It starts in the morning when the alarm bell rings, when taking a hot shower, brewing coffee, using the underground, working on the computer or watching television, in all cases either electricity, heat, cold, light or motion is required.

Figure 17 gives an overview about primary and utilizable energies. Utilizable energies, like electricity, heat or cold are fundamental for the development of smart cities. Today over 50 % of the world population lives in urban areas and their number is increasing rapidly (about 70 % by 2050) [120]. Accordingly the demand of energy in cities is substantial and still growing.

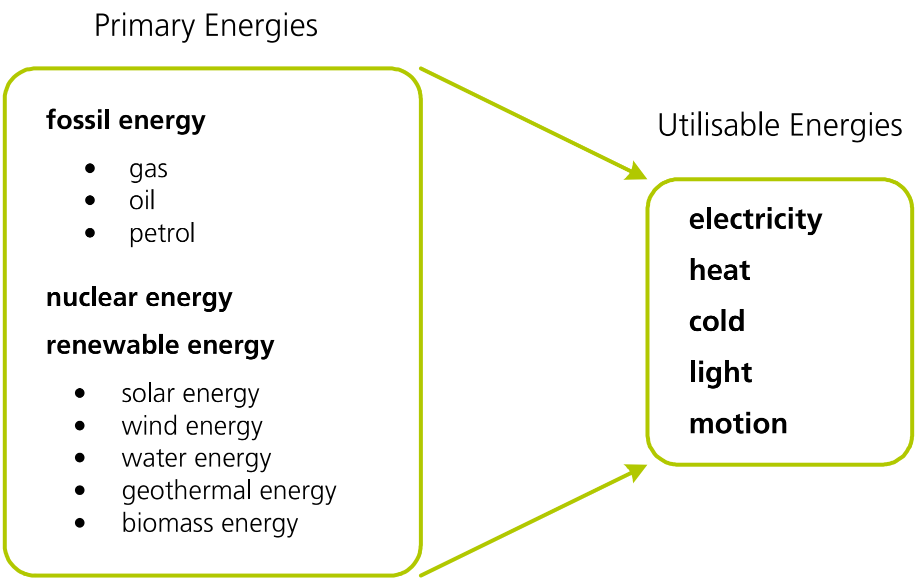

Figure 17: Overview Energies in Smart Cities

Environmental issues caused by the combustion of fossil energy sources and the shortage of resources leads to a rethinking of the energy supply and a rational use. Already over 80 % of the worldwide CO_2-Emission is generated in cities, which is mainly caused by the heating of buildings [121]. The future goal of the energy revolution is a carbon neutral, sustainable and efficient but also affordable energy supply based on renewable energies. This development veers towards the electrification of urban areas and the "all-electric society". The International

[120] "Urban and Rural Areas 2009," Department of Economic and Social Affairs, Population Division, New York, 2010.
[121] "Visionen zur Morgenstadt: Leitgedanken für Forschung und Entwicklung von Systeminnovationen für nachhaltige und lebenswerte Städte der Zukunft," Fraunhofer Institute for Industrial Engineering IAO, Stuttgart, Feb. 2012.

Energy Outlook says, that until the year 2040 the net-generation of electricity will almost be doubled to a value of 39.0 trillion kWh per year [122].

With the 20-20-20 agenda the European Union aims to rise the share of renewable energies for the overall energy consumption up to 20% until the year 2020 [123]. The distributed generation and the intermittent in-feed of renewable energies lead to instabilities and thus great challenges for the energy grid. The impacts to the grid are [124]:

- voltage drop and rise problems,
- fluctuation of real, and reactive power,
- harmonics caused by non-linear loads (e.g. power electronics converters),
- resonance caused by compensation capacitor banks, filters, etc.,
- increasing fault level,
- intermittent in-feed, surplus and under production of energy.

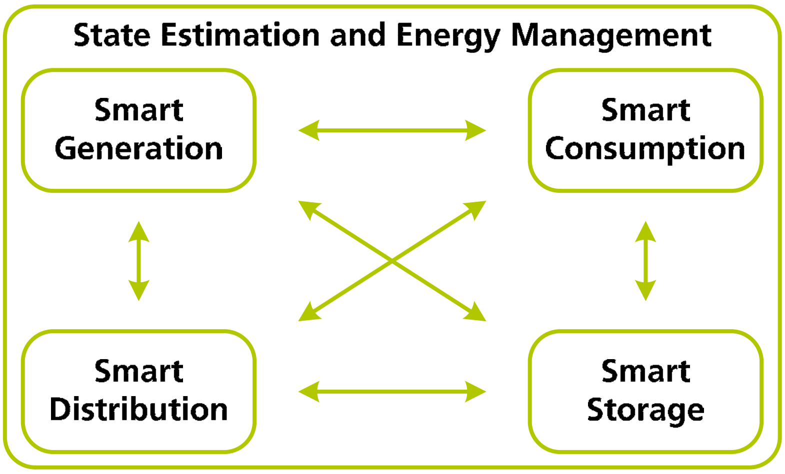

Figure 18: Overview of the future key products. [125]

To handle the challenges caused by the promotion of renewable distributed energies and the alternation of the energy supply, the energy grid and the future cities have to become smarter. Power electronics together with microelectronics and semiconductor integrated circuits (IC) are essential to assure the energy supply of the future und are key enabler for smart cities. The

[122] U.S. Energy Information Administration, “International Energy Outlook 2013: With Projections to 2040,” Washington, DC, Jul. 2013
[123] P. Office, *DIRECTIVE 2009/72/EC.*
[124] A. Kechroud, Myrzik, J. M A, and W. Kling, Eds, *Taking the experience from Flexible AC Transmission Systems to flexible AC distribution systems*. Universities Power Engineering Conference, 2007. UPEC 2007. 42nd International, 2007.
[125] Verband der Elektrotechnik Elektronik Informationstechnik e.V, *Die Deutsche Normungsroadmap: E-Energy / Smart Grid*. Frankfurt am Main: VDE, 2010.

estimated energy savings potential is more than 25% of the current electricity consumption in the EU countries[126].

The focus of this chapter lies on the investigation of the need of semiconductors for the supply and provision of smart cities with electric energy. This includes the smart generation, the smart storage and the smart distribution of energy as well as the energy management and state estimation. The smart consumption of energy is also an important aspect of the energy challenges of smart cities and is covered in the chapter buildings of this survey. In Figure 18 an overview about the future key product is given.

First the future key products and their technical requirements are discussed. Further a rough roadmap of the semiconductor development for the next 4-8 years is given and the strategy for the research and the economic impact is proposed.

3.4.1 Future Key Products

The energy supply of smart cities involves the smart generation of electricity using renewable or environmental energy sources, the smart storage of the energy in hybrid systems, the sophisticated and efficient distribution of the energy and an intelligent energy management.

3.4.1.1 Smart Energy Generation and Conversion

3.4.1.1.1 Renewable and Distributed Energies

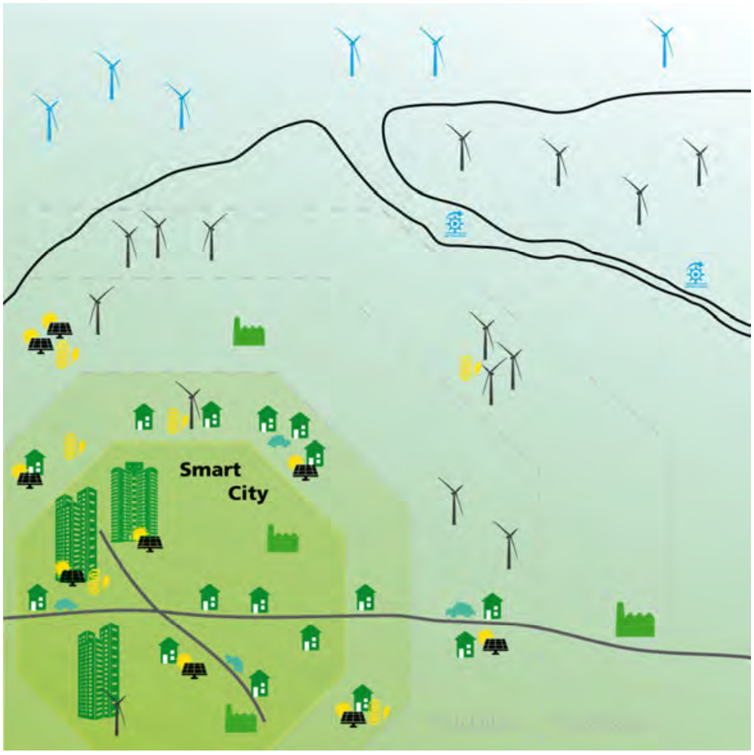

Figure 19: Block Diagram Multi-Energy Smart Grid

In Smart cities a big proportion of predominantly renewable energy will be generated close to where it is consumed. But the main energy demand will be satisfied by electricity produced in larger plants outlying to the cities (e.g. offshore wind parks, etc.). In a Smart Grid decentralized power generation and storage are clustered to virtual plants, which manage consumption and generation, based on local weather forecast and an intelligent demand side prediction. The figure below shows the power supply and energy generation of urban areas.

[126] G. Meneghesso, "Integrated power & energy efficiency: Power device technologies, simulations, assembly and circuit topographies enabling high energy efficiency applications," Catrene Scientific Committee Working Group, 2013.

In the city, open spaces will be used to generate electricity or heat (and cold). For instance photovoltaic (PV) systems or small wind turbines are mounted on every building roof and large glass planes are also used to generate PV energy or heat. The combined heat and power generation, for example using waste combustion or biogas is also extensively used.

For the smart generation of renewable energies highly efficient power electronics at varying load conditions, like DC-AC converters for PV and AC-AC converters for wind turbines are required.

3.4.1.1.2 Energy Harvesting

In smart cities there is an increasing need of mobile and distributed and small-sized electronic devices for collecting data, condition monitoring and tracking. The idea of self-powered devices is not new and is actually known for centuries. One of the earliest examples is the self-winding watch invented in about 1770 [127].

In the present time energy harvesting is applied for battery-less and wireless sensing, e.g. cargo monitoring/ tracking or bridge monitoring. For future cities the application are much wider, for example the monitoring of the cold chain of foods (e.g. meat), the tracking of shipments or deliveries for the optimization of the logistic chain, wireless sensor networks for condition monitoring of buildings, the collection of environmental data or implantable biomedical devices for structural health monitoring [128].

The bottleneck of these applications is the adequate supply of the devices with energy. As the capacity of battery storages is limited and the charging is formal, self-sustaining and self-powered systems are required.

Energy Source	Characteristics	Efficiency	Harvested Power
Light	Outdoor Indoor	10-24%	100 mW/cm² 100 µW/cm/cm³
Thermal	Human Industrial	~0.1 % ~3 %	60 µW/cm³ ~1-10 mW/cm³
Vibration	Human ~Hz Machines ~khz	25-50%	~4 µW/cm³ ~800 µW/cm³
RF	GSM 900 MHz WiFI	~50 %	0.1 µW/cm² 0.001 µW/cm²

Table 3: Overview of energy harvesting estimates [129]

The idea is to harvest small scale electric energy (~µW) from environmental and ambient energies. There are many physical quantities which can be used for this purpose, like solar

[127] V. Leonov, “Energy Harvesting for Self-Powered Wearable Devices,” in *Wearable Monitoring Systems*, A. Bonfiglio and D. de Rossi, Eds.: Springer US, 2011, pp. 27-49.
[128] C. Lu, V. Raghunathan, and K. Roy, “Efficient Design of Micro-Scale Energy Harvesting Systems,” *IEEE J. Emerg. Sel. Topics Circuits Syst,* vol. 1, no. 3, pp. 254–266, 2011.
[129] Texas Instruments, “Energy Harvesting: Ultra Low Power Meets Energy Harvesting,” White Paper, Dallas, Texas SLYY018,A, 2010

radiation, mechanical motion or vibration, thermal gradients or radio-frequency (RF) transmission[128, 130, 131]. Table 3 gives an overview about the efficiency and energy crop of the methods.

The block diagram below (Figure 20) gives a theoretical overview of the technology and the components of an energy harvesting system. The energy transducer generates electric energy (either ac or dc-voltage, depending on the technique) using environmental conditions. Within the power management system a converter converts the dynamic output voltage to a constant and applicable dc-voltage. Maximum power point tracking (MPPT) improves the reliability and efficiency of the conversion. The stable dc-voltage operates either directly the application (sensors, ICs) or is buffered in an energy storage system (capacitor, battery, etc.). For some applications the energy must be collected for a certain time before it can be performed e.g. only once a day. The potential need for advancements in the semiconductor technology is highlighted in the block diagram.

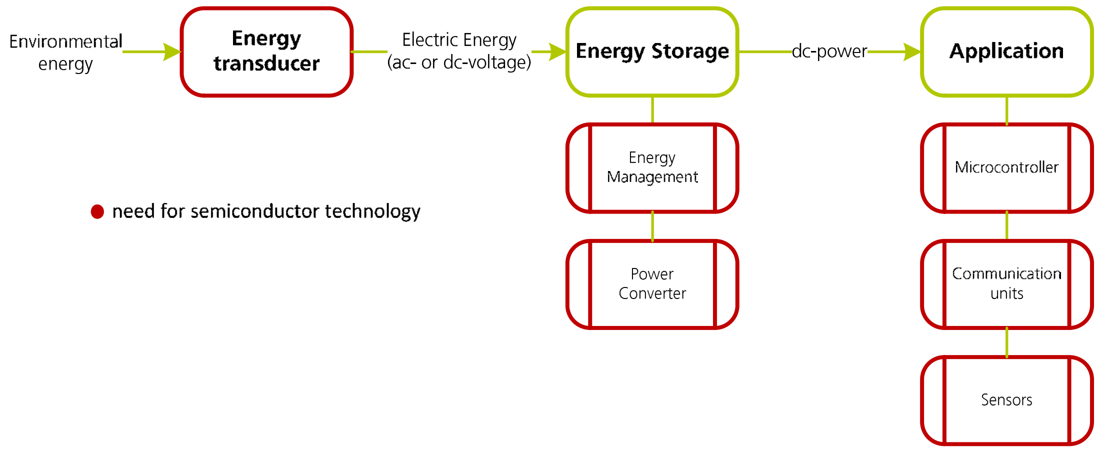

Figure 20: Need for semiconductor technology for energy harvesting.

3.4.1.2 Smart Energy Storage

Energy storage systems are the key enabling technologies for a sustainable and reliable energy supply of smart cities. As renewable energies cannot consequently deliver energy when needed, smart storage systems are essential to buffer the shortage of energy when wind is not blowing, sun is not shining or when cogeneration plants generate excess energy. Energy Storage is needed at very different operating conditions, thus different storage technologies are crucial for a successful implementation of renewable energies. In a Smart Grid of a Smart City, energy consumption and generation are aligned and efficiency losses of intermediate energy storage are minimized. Small stationary battery systems buffer the local energy

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[130] P. Spies, M. Pollak, and G. Rohmer, "Energy harvesting for mobile communication devices," in *Telecommunications Energy Conference, 2007. INTELEC 2007. 29th International*, 2007, pp. 481–488.
[131] A. Pirisi, F. Grimaccia, and M. Mussetta, "An innovative device for Energy Harvesting in smart cities," in *2012 IEEE International Energy Conference (ENERGYCON 2012)*, pp. 39–44.

fluctuation of buildings and mid-size storage systems (e.g. Redox -Flow batteries) cover load peaks of urban industrial production or current overproduction of waste incineration and (biogas) plants. Outside the cities, energy will be stored e.g. by Power-to-Gas (P2G) or Compressed-Air technologies, when temporary overproduction of renewable energy does not find enough consumers.

3.4.1.2.1 Storage Technologies and Battery Management Systems

Many approaches are already available, like Lithium-Ion batteries, power-to-gas transformation, heat storage systems or local hybrid storage systems. There are also ambitions to utilize the capacity of electric vehicles as temporary and mobile energy storage systems. During the past 10-15 years Lithium-Ion-Batteries have been extensively studied and commercially available Lithium Ion Batteries (LIB) are now state of the art for Stationary Energy Storage Systems. However, production costs are still an issue and focus of R&D projects aim for new anode or cathode materials with higher capacity at lower costs or efficiency optimized production processes. The Fraunhofer Technology Roadmap for LIB [132] precisely describes the development needs and also gives insight to now emerging post Lithium technologies like Lithium-Sulphur- or Lithium-Air- Technologies.

Power-to-gas has a great potential, as gas has a high energy density and can easily be stored, transported and retransformed into power, not bounding on the location of production or in-feed. Energy surplus from renewable energy sources (great sunlight) is used to produce hydrogen by electrolyzation and hence methane by anaerobic digestion. These processes have to be optimized and made more efficient.

3.4.1.2.2 Battery management for smart energy management systems

The heart of every energy storage system is its energy management system (EMS). A stupid energy management accepts charging whenever power is available and discharging whenever power is required. For a single photo voltaic (PV) home system this strategy may be a convenient solution, but it’s not a smart solution for a smart city of the future: If every PV system starts storing PV energy in the morning a large amount of conventional energy will be required during this time. In the afternoon the battery systems become fully charged, resulting in a strong increase of PV energy in the grid. In contrast a smart energy management knows the variation of energy consumption of the day as well as a prognosis about the expected PV energy. With this knowledge a smart charging and discharging is possible which enables grid stabilization over the day. In addition smart battery systems may be used to stabilize short term fluctuations of the required energy in the grid. On the technical side such a smart energy management system requires intelligent software algorithms and communication interfaces. On the economic side payment models have to be developed to make this smart behavior financially attractive, otherwise the stupid EMS solution from today will be much more attractive to PV storage system owners (more details in chapter 3.5 “Buildings”).

State of the art battery management systems (BMS) usually consist of a precise cell voltage measurement unit, some temperature sensors, often a current sensor, and a microcontroller with communication interface. Either the BMS or the charger has the ability to equalize cell

[132] “Lithium-Ionen-Batterien 2030,” Technologie-Roadmap, Karlsruhe, Jun. 2010.

voltages. Today, passive cell balancing is widely used, which is a cheap, robust method, and unfortunately energy consuming method. In future active cell balancing solutions will become important, since their energy efficiency is much greater. First systems are already on the market, but there is still much development required.

If large energy is required, high voltage systems are preferred, since high voltages are much easier to handle than high currents. Storage systems for electro mobility operate usually in the range of 400 to 600 volt DC. PV home storage would also benefit from high voltages in this range. Unfortunately, actual systems on the market are based on former lead acid accumulator systems operating on 48 volt DC. Obviously, the electronics for a high voltage system differs from that of a low voltage one. Usually, high voltage battery management systems are divided in separated low voltage sub modules. These slave modules are connected to a high voltage string, which is controlled by a separate BMS master board.

Two of Fraunhofer BMS developments are typical for this kind of application[133]. The first solution consists from the electrical side of separated single cell modules. Each cell can be switched on and off individually. Thus the number of cells in the string can be changed dynamically, controlled by the BMS master. With this approach defective cells can be switched off without any disturbance to the whole battery system, which is quite important if the energy storage system shall be operated without service over a very long time.

The dynamic switching of the cells is also a very effective cell balancing method. Furthermore, the stack voltage can be adapted dynamically to other electrical components like PV cells or efficient operating points of DC/DC or DC/AC converters. In this application the BMS was combined with a bidirectional DC/DC converter[131133]. The converter is plugged between PV cells, BMS and DC/AC converter, enabling a smart integration of the storage system into existing PV systems. This single cell approach is limited to small currents as they are used in home PV systems and similar applications. If high currents are required, the number of switches has to be reduced. Within the Fraunhofer System Research for Electro-mobility a high current battery management system was developed, which can handle currents up to several hundred amps. In this case each module consists of 12 cells. In case of a cell defect a complete module has to be disabled, resulting in a 9% energy loss of the total system. Again this module switching is used to balance system voltage over the stack. Obviously, a second balancing method is required to equalize the cell voltage within the sub module and will be integrated into the system. Depending on the application different cell balancing modules with active or passive cell balancing can then be combined with the BMS board.

Semiconductors have impact on these technologies:

- Electrochemical storages have to be monitored, as they have aging effects and varying capacity (state of health, state of charge) and due to critical consequences of mistreatment, they ideally need to be precisely controlled on cell level. Integration of electronic compounds like Battery Charger, central Battery Management Systems, sensor-analysis and communication modules is not a critical issue for Stationary

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[133] Fraunhofer ISIT, *BMS and DC/DC converter development.*

Storage with low space and weight requirements compared to E-mobility systems. But Stationary Battery Storage will benefit from E-mobility developments where BMS for battery cell arrays or single cells need to become more efficient and smaller (see chapter E-mobility). Future key products are special ICs for BMS which do include cell temperature evaluation and electrochemical testing like Impedance Spectroscopy.

- For the connection to the grid more efficient and adaptive power converters and power electronics like switches are required.

3.4.1.3 Smart Energy Transmission and Distribution

Renewable energy sources usually are located far away from congested urban areas e.g. offshore wind parks. Thus the required energy must be transmitted over long distances to smart cities, before it can be distributed to the costumers (cf. Figure 19).

3.4.1.3.1 Energy Transmission

The main technological segments for the high voltage transmission (HVT) are the high voltage dc (HVDC) transmission or the flexible ac transmission systems (FACTS)[134].

- HVDC - A promising technology for large distance transmission is the high-voltage direct-current technology, which is already in use for some offshore links and intercontinental circuits. A present example is the realization of the HVDC link to the BorWin3 offshore wind park with a transmission power of 900 MW. Besides the transmission of large amounts of energy HVDC systems can also be used for the connection of two ac networks with asynchronous frequencies or different frequency control philosophies. Further applications of HVDC are point-to-point transmission and multi-terminal systems (dc-networks), power delivery to large urban areas and underground/ submarine cable and offshore transmission. Semiconductors are employed for the ac-dc power conversion and the transmission control. The two so far applied conversion methods for HVDC are the classical current-source converter (CSC) technology based on thyristors and the self-commutated voltage-source converter (VSC) technology based on pulse-width modulation using high power transistors (IGBTs). The greatest impact on the overall energy loss of the HVDC transmission is contributed by the converter valves (thyristors or IGBTs) with about 50 % using CSC and 70% using VSC technology. Thus efficient thyristors, IGBTs and circuit breakers (CB) are the key enabling technologies for HVDC networks. [135,136,137]

- FACTS - With the utilization of power electronics the power flow within the ac grid can be controlled and managed. These systems comprise the control of the reactive power (from 100% inductive to 100% capacitive), of the voltage in manners of

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[134] Frost & Sullivan, "Analysis of the Global Semiconductors Market for Smart Grids: Demand for Efficiencies and Power Give Rise to a Growing Opportunity for Semiconductors," Market Engineering NAF8-26, Dec. 2012.

[135] Hui Pang, Guangfu Tang, and Zhiyuan He, "Evaluation of losses in VSC-HVDC transmission system," in *Energy Society General Meeting*, pp. 1–6.

[136] C. M. Franck, "HVDC Circuit Breakers: A Review Identifying Future Research Needs," *IEEE Trans. Power Delivery*, vol. 26, no. 2, pp. 998–1007, 2011.

[137] M. Bahrman and B. Johnson, "The ABCs of HVDC transmission technologies," *IEEE Power and Energy Mag,* vol. 5, no. 2, pp. 32–44, 2007.

magnitude and sign, of the phase angle and of the frequency. Losses are curtailed by ensuring the reduction of reactive power through inductance and capacitance components [134]. There are already different kinds of implementations available, e.g. the static Var compensator (VCS), which uses thyristors to achieve a fast control of the reactive power injections or absorption or a static voltage source (SVS), which can be considered as an AC- voltage generator, whose output voltage, frequency and phase angle are controllable [124]. The main advantage of FACTS is the enhancement of the grid capacity and the reduction of investment in network expansion for employing distributed renewable energies.

3.4.1.3.2 Energy Distribution

Once the energy is transmitted to the urban areas it must be distributed to the end-user. As for transmission systems the focus lays on the electronic and smart control of the power flow. It is believed, that by 2030 most of the electrical power flow between generation and distribution is managed by power electronic devices[138].

So far power electronics, mainly converters, are used in distribution grids only to interface the power generation (e.g. photovoltaic) to the grid. But alike for FACTS, power electronics can also be used to control and support the distribution grid, named flexible ac- distribution system (FACDS).[124124]

3.4.1.3.3 Utilization of Semiconductors

The utilization of semiconductor for the transmission and distribution (T&D) is highlighted in the diagram below.

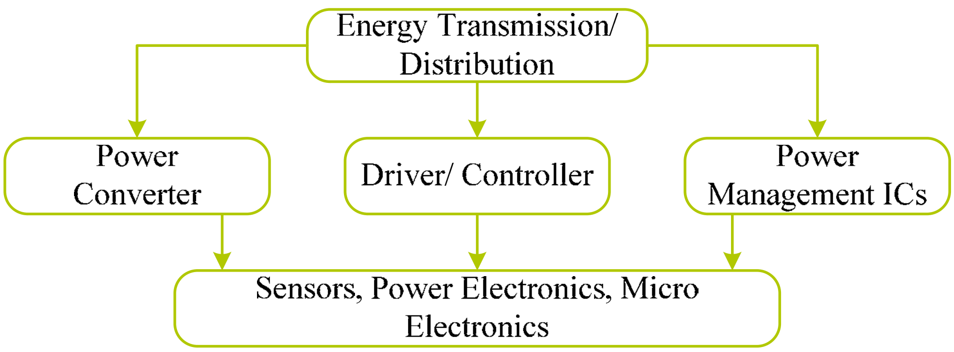

Figure 21: Semiconductor utilization for the energy transmission and distribution [120120]

Feature components are thyristors, IGBT and MOSFETs, but also sensors and integrated circuits.

[138] "Advances in Power Electronics Enabling Future Smart Grid: Advanced Power Electronics Driving Next-Generation Power Grid," Technical Insights D4CE-TI.

3.4.1.4 Smart Energy Management

Smart cities will have a great need for intelligent mediation between the energy generation and the demand. The aim of smart energy management is to handle the intermittent in-feed of the renewable energies and the dynamic demand of energy, e.g. by e-mobility (see also chapter 3.6 “Mobility in Smart Cities”).

3.4.1.4.1 Multi-Energy Smart Grid

So called Multi-Energy Smart Grids are energy networks which intelligently integrate the actions of all generators, consumers, storages and utilities connected to it, in order to assure a sustainable, economic, and secure energy supply [138,139]. The energy carriers of multi-energy smart grids relevant for smart cities include primary electricity, but also gas, heat and cold.

The accurate forecast of the energy demand and also the generation (e.g. weather prognosis for photovoltaics (PV) or wind power (WP) as well as the state estimation of the smart grid are essential to efficiently control the energy flow and to offer a reliable and sustainable energy supply.

For that the energy-grid and relevant devices and components have to be equipped with sensors, actuators, intelligent controllers and an appropriate information and communication interface for the interaction.

Especially sensor systems and their networking allow grids to become smart and aware of bottlenecks and fault protection, and help to automate the grid control and functioning. The key advantages of smart grids are [134132]:

- equitable power distribution,
- control of consumption overloads,
- optimized use of power,
- power efficiency,
- reduction of peak demand and
- intelligent monitoring and control.

The information- and communication-technologies (ICT), like protocols, communication ICs and data processing are discussed in the chapter 3.2 “Information & Communication”. Especially for the distribution of energy in smart cities decentralized intelligence play a great role.

Another key trend and future technology is the virtualization of power plants as well as energy storages by virtually combining distributed renewable energies and respectively energy storage systems, with the aim to optimally integrate these energy units into the energy grid.[140]

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[139] Verband der Elektrotechnik Elektronik Informationstechnik e.V, *Die Deutsche Normungsroadmap: E-Energy / Smart Grid*. Frankfurt am Main: VDE, 2010.

[140] “BDEW-Roadmap: Realistische Schritte zur Umsetzung von Smart Grids in Deutschland,” Berlin, Feb. 2013

3.4.2 Technological Requirements

3.4.2.1 General Aspects

Semiconductor technology is essential for realizing smart grids for smart cities. The intermittent in-feed of renewable energies, the bi-directional energy flow and the dynamic energy demand, lead to stringent requirements concerning the energy supply. The performance of the grid is depending on the quality and capability of the electronic components, which are crucial for efficient control and conversion of electrical energy.[138,141]

To answer the performance goals of the energy supply of smart cities, advanced power electronics (PE) in manners of performance, reliability, efficiency and packaging are required[126, 138]. For the smart city / smart grid application PE need to operate at high temperatures above 200°C with a switching frequency of more than 10 kHz and voltage ratings above 10 kV [138]. PE devices need to be highly efficient and the goal is to enhance performance without compromising on the price and size of the device. The reliability of the power electronics is requested to ensure the energy supply of smart cities. The evolution of power semiconductors has arrived at a level where packaging restricts the achievable performance of the final device. A package for a power semiconductor has to remove the heat, provide security insulation against the heat sink, conduct current and has to be electromagnetically and thermo mechanically reliable. [126]

3.4.2.2 Power Electronics

There's a wide spread of power electronic applications with different application needs and required figure-of-merits (cf. Figure 22 to Figure 25).

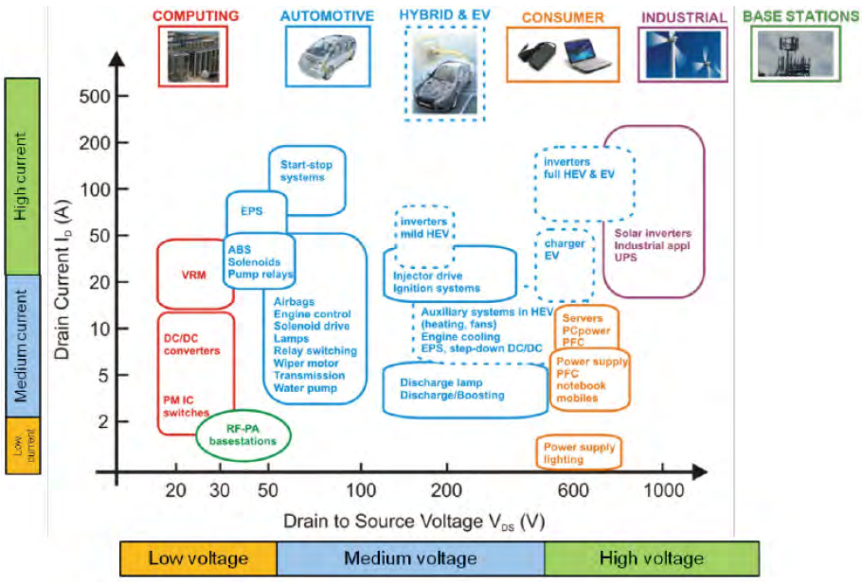

Figure 22: Overview on power electronic applications[126]

[141] "Power Electronics for Distributed Energy Systems and Transmission and Distribution Applications," Engineering Science and Technology Division ORNL/TM-2005/230, Dec. 2005

Efficient stabilization and control of AC flow requires fast and efficient power electronic components. Most popular FACTS equipment types are based on thyristors, GTOs or IGBTs. Power semiconductors used in such systems must demonstrate high efficiency and high loading capacity both during nominal and overload operation. Current operating voltages of DC cables can reach levels of several hundred kilovolts, which puts a strong pressure on power electronic components to demonstrate high power handling capability to support high transmission capacities. For the packaging of power electronics a more sophisticated thermal design and so a longer life time of the packages are required. More functions included in the power semiconductor package can reduce system costs and losses.[134, 138]

The important trend is to reduce the size of power electronic components. This is motivated by devices that can offer efficiency gains and cost reduction. This trend also opens up newer opportunities as designers can incorporate increased functionality in a limited space.

Silicon-based devices are commonly used in the market, thanks to their proven performance, reliable manufacturing and competitive cost. But the technology presents limitations in terms of switching frequency, efficiency and operating temperature.

To meet miniaturization and performance goals and to overcome the limitations of conventional silicon technology, new materials with superior electrical properties are being introduced. Wide-bandgap semiconductors like silicon-carbide (SiC) or gallium nitride (GaN) are gaining momentum in the market and are regarded as the future material for power grid applications[126]. Therefore, a co-existence of silicon-based power devices and wide-bandgap power devices will be observed in the future. Consequently there is a need for further technological and device performance development for power semiconductors on these 3 base-materials. Additional efforts toward realizing higher efficiency focuses on introducing enhanced circuit designs.

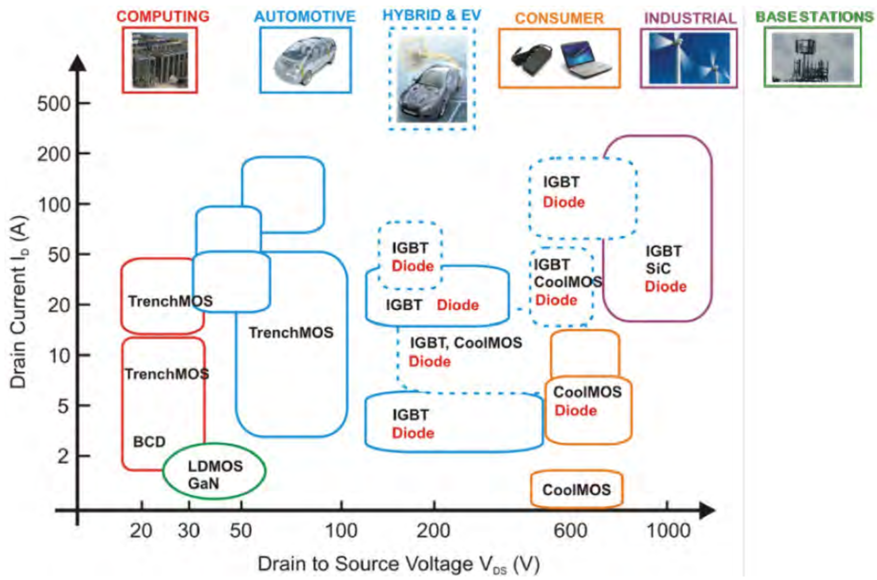

Figure 23: Overview on power electronic components[126]

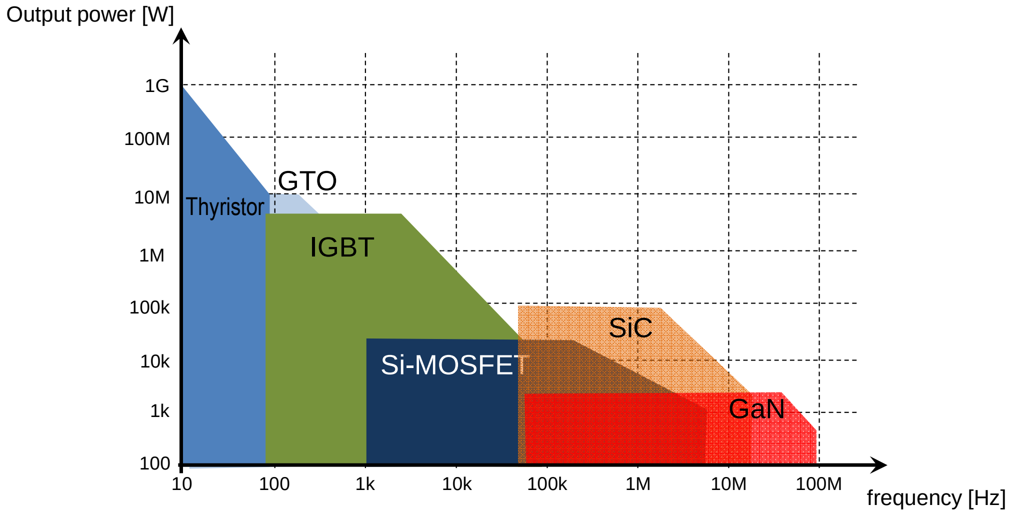

Figure 24: Power device technology by application frequency[126]

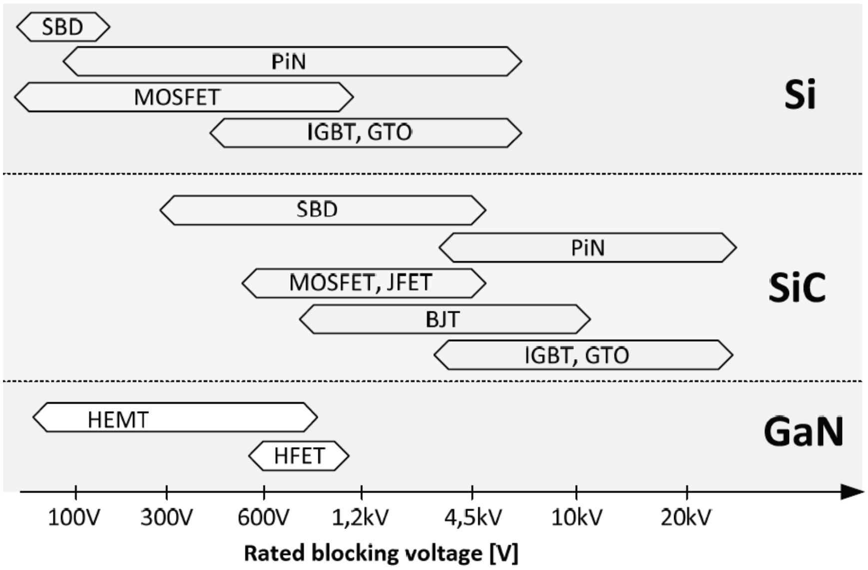

Figure 25: Device structures for different semiconductor materials[142]

3.4.2.3 Micro Electronics for Power Management

In Smart Cities microelectronics play an important role. On the one hand for the control of power electronic devices such as rectifiers, converters or switches, to manage the energy flow in the future energy grids and on the other hand the efficient power management. For that highly efficient microelectronics, integrated circuitries and sensors are required (Sensors are discussed in the chapter 3.1 (Urban processes) and 3.2 (ICT)).

For future applications low power integrated circuits and microelectronics for control purposes are required. Specialized ICs and SoCs for battery management systems and energy

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[142] S. Araújo, *On the perspectives of wide-band gap power devices in electronic-based power conversion for renewable systems: [Kompetenzzentrum für Dezentrale Elektrische Energieversorgungstechnik ; Elektrische EnergieVersorgungsSysteme]*. Univ, Diss.--Kassel, 2013. Kassel: Univ. Press, 2013

harvesting are necessary to handle the functionary requirements (see previous chapters). The voltage levels of the electronic circuits, like system-on-a-chip (SoC), integrated circuits (IC) or regulators have to be scaled down and current consumption must be decreased to assure performance with small amounts of energy.

To facilitate better functionalities in demanding applications, the microelectronic devices have to become less power consuming to enable longer operating duration. Since integrated circuits are the key source for heat generation an efficient power management and selection of operating parameters, but also a smart design is required[143]. Power management systems enable energy efficiency by replacing conventional methods with energy saving devices and regulating power supply methods[143].

An integrated power management is indispensable to convert the fluctuant and intermittent environmental and renewable energy (e.g. vibration, sunlight) into a stable power source[144].

The micro scale energy transducer technologies need to be improved to enhance the crop of energy and so the extent of the applications. Energy harvesting transducers like thermo-, piezo- or electro-dynamic generators provide a high dynamic range of output voltages and currents. Thus power management electronics like voltage converters and charge circuits for batteries must cope with this dynamic range.

Thermo-generators provide very low voltage levels like a few millivolts but high currents. Piezo-electric materials produce higher voltage levels up to 50 or 100 volts, but very low currents in µA range. Thus, the requirement for semiconductor technologies regarding energy harvesting is to lower the start-up voltages down to several mV to handle sources with low output voltages. Coincidentally, the leakage currents must not increase. Furthermore, to work with high-impedance sources like piezo-electric materials, currents in the low µA range should be processable.

Since piezo-electric generators may produce also very high voltage levels (e.g. 50 – 100 V), interface circuits in semiconductor devices should work with higher voltage level, although only small currents will be provided.

Since in energy harvesting systems a transition from high loads like powering a transmitter to light loads like powering a microcontroller in stand-by mode occurs, voltage converters should provide a high efficiency in different modes of operations. This will also affect the requirements to the leakage currents of semiconductor devices. Leakage currents have to be handled carefully as they approach the range of the output current of the energy harvesting transducers[145].

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[143] "Next Generation Power Management For Electronic Device: Enabling Energy Efficient and Greener Electronics with Cutting Edge Power Management Technology," (Technical Insights D51E-TI, Dec. 2013

[144] D. S. Ha, "Small scale energy harvesting - principles, practices and future trends," in *14th International Symposium on Design and Diagnostics of Electronic Circuits & Systems (DDECS)*, 2011, p. 9

[145] P. Spies, M. Pollak, and G. Rohmer, "Energy harvesting for mobile communication devices," in Telecommunications Energy Conference, 2007. INTELEC 2007. 29th International, 2007, pp. 481–488

Since mechanical harvesters often utilize very short pulses of mechanical energy a fast settling time of voltage converters is required. Such fast settling times will also be valuable during the transitions between different operations modes.

To enable energy harvesting applications, especially the sleep modes of micro-controllers should be implemented in an energy-efficient way. A lot of sensor applications remain in sleep mode most of their time. Thus, ultra-low power clock circuits will be necessary to keep the overall power consumption at a minimum.

For battery management systems (BMS) microelectronic devices or ICs for advanced cell monitoring, state estimation and charging/discharging control have to be developed and algorithms and methods investigated. Active cell balancing solutions will also become important, since their energy efficiency is much greater. First systems are already on the market, but there is still much development required.

3.4.3 Roadmap

3.4.3.1 Power Electronics

3.4.3.1.1 Roadmap for silicon based high-voltage MOSFETs

The main challenge in high-voltage power MOSFET applications is the continuous efficiency improvement. This can be achieved by high-voltage MOSFETs with reduced device capacitances and consequently area-specific on-resistance. The trend to lower area-specific on-resistance will continue with parallel process improvements on the doping control and charge balance improvements by 1…3% per region (cf. Figure 26). Different approaches by multi-epitaxy or deep trenches are used to reach this target.

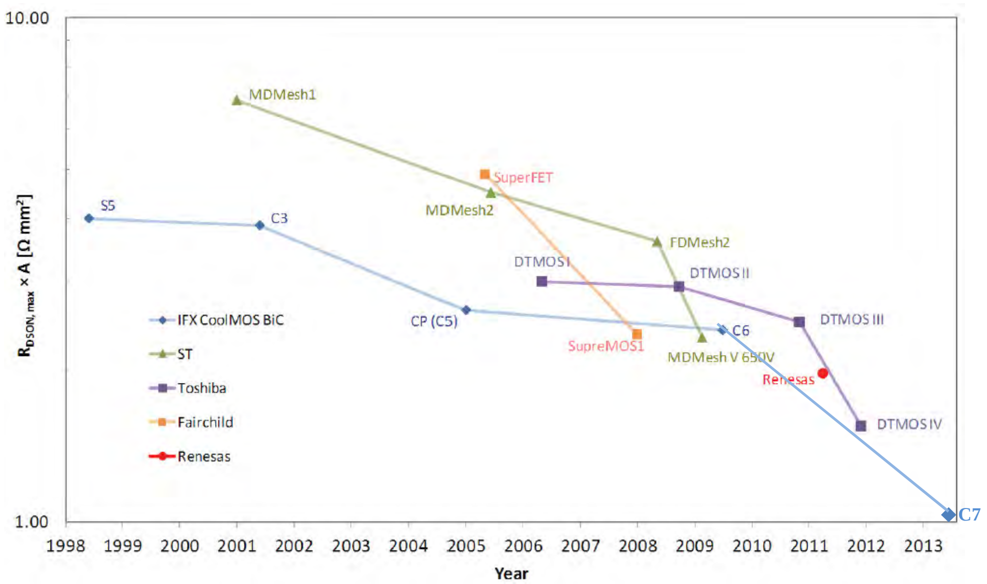

Figure 26: R_{DSOn}*A-Roadmap for different semiconductor manufacturers[126]

The R&D activities on superjunction devices are mainly focused on

- Further reduction of specific on-resistance
- Reducing E_{oss}, C_{oss} and Q_{oss} (i.e. energy and charge stored in output capacitance) to improve the efficiency of hard-switching circuits
- Realizing and improving R_{on} of 900V rated MOSFETs
- Improving avalanche ruggedness
- Reducing Q_g and R_g to enable higher switching frequency operation

3.4.3.1.2 Roadmap for silicon based IGBTs

IGBTs play the key role in mid to high-power applications. The device concept reaches unrivalled on-state performance when large output currents are required. The introduction of the field-stop concept, a combination of PT-, NPT- and thin-wafer technology allowed continuous improvements in industrial applications as well as the market acceptance in consumer electronic applications. To continue this trend, the following R&D activities on IGBTs are necessary:

- Further reduction of wafer thickness, e.g. by use of wafer bonding technology
- Reducing $V_{ce,sat}$ and E_{off} to improve the application efficiency
- Improved soldering techniques and reduced back- and top-side thermal resistance

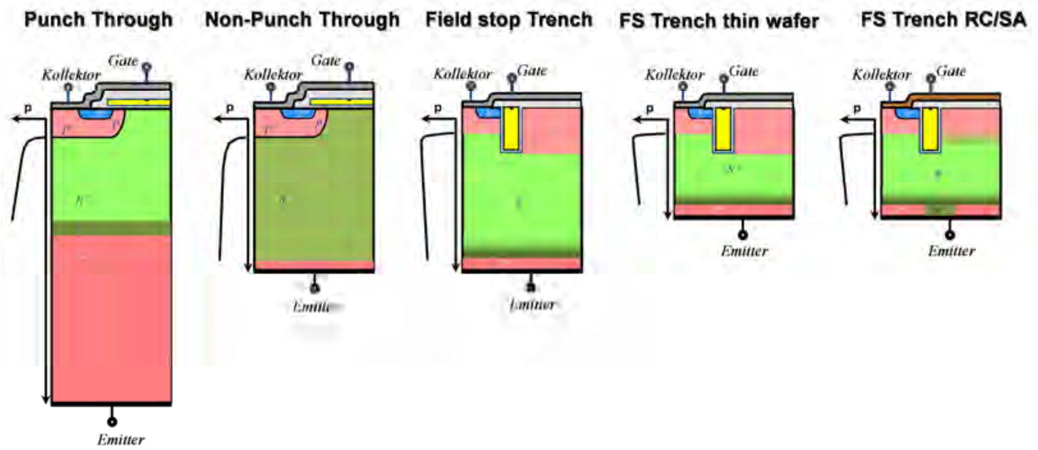

Figure 27: IGBT device concept history and roadmap

3.4.3.1.3 Roadmap for Silicon Carbide and GaN

Commercial SiC power devices are available since several years. Different device concepts are utilized to improve especial the area-specific on-resistance for transistors as well as the E_{oss}. Nevertheless, defect control and gate oxide quality is still a concern for silicon carbide. Therefore, the following R&D activities on SiC devices are necessary:

- Improved wafer size and defect control to achieve larger device areas and output currents
- Improved channel resistance for MOSFETs together with improved gate-oxide quality

For GaN power devices, a lot progress was made in the last years on GaN technology as well as device concepts for achieving high breakdown-voltages of more than 1000V and positive threshold voltages. First 600V HEMTs are available on the market, whereas normally-on HEMTs are todays standard. Device manufactures are combining them in cascade-configuration with Si-MOSFETs to achieve a normally-off characteristic. Also, the high defect density (10^9/cm²) compared to SiC (<10^4/cm²) is still a concern. Therefore, the following R&D activities on GaN devices are necessary:

- Improved defect control to achieve larger device areas and output currents
- Monolithic normally-off transistor concepts in 600V and 1200V

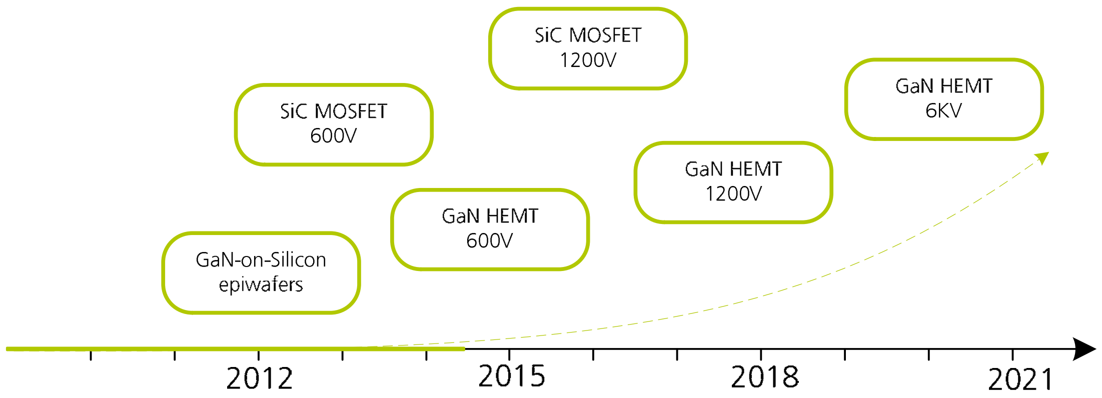

Figure 28: SiC and GaN roadmap [138]

3.4.3.2 Micro Electronics

The main future trends of Micro Electronics are enhancement in the performance and efficiency and the high integration level and thus higher application processor capabilities. Especially for low power applications (e.g. energy harvesting, sensor networks) the power supply voltage will be decreased in the future. To enhance the performance the on-chip clock frequency will be increased. The table below highlights the estimated future trend.

	2015	2017	2019	2021	2023
Power supply voltage (V)	0.83	0,80	0.77	0.74	0.71
On-chip local clock (GHz)	5,95	6,44	6,69	7,53	8,18

Table 4: Technology Trend Targets [146]

Regarding semiconductors for battery management, one demanding application will be the monitoring of a large number of individual battery cells which are connected in series to generate high voltage above 400V. This results in a high input voltage of the semiconductor devices. Presently, the limit is at around 50V which enables modules of 12 battery cells. To

[146] "INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS: 2013 Edition," Executive Summary, 2013.

monitor more battery cells with less semiconductor devices, higher on-chip voltages should be possible.

Especially second-life applications of automotive battery cells will require more monitoring features in battery management systems. The worn-out automotive battery cells from vehicles which have a lower energy-to-weight ratio due to aging can be used in stationary storage devices, for example in solar plants or wind parks. Since these used battery cells have a different degradation, they have to be controlled and monitored very carefully. Techniques used here are impedance spectroscopy and active charge transfer (active balancing) between the cells. Especially, the impedance measurement requires precise ADC building blocks with low off-set.

Power management semiconductor devices will integrate more inductive or capacitive elements. This will be achieved by higher switching frequencies and thus reduction of the required inductive or capacitive device parameters. With the rise of the switching frequency, more attention has to be paid to the switching losses. These can be limited by lower supply voltages of the semiconductor devices.

Further challenges will be posed to semiconductor devices by micro-batteries. These tiny batteries which capacity ranges below 1mAh need proper charging and monitoring, but the dedicated battery management system may not consume much energy by its own. Sleep currents in the range of a few nA require ultra-low leakage currents of transistors in these battery management ASICs.

The main future trends in microelectronics for power management are shown in the figure below. To enable the best possible cost-benefit ratios power densities of microelectronic components will increase. Future key trends are customized power management solutions, which include unique MOSFETs, PMICs and drivers. With the advent of social networking and cloud computing the demand for highly efficient power management modules has accelerated. Digital power management will have higher importance in the market.[143]

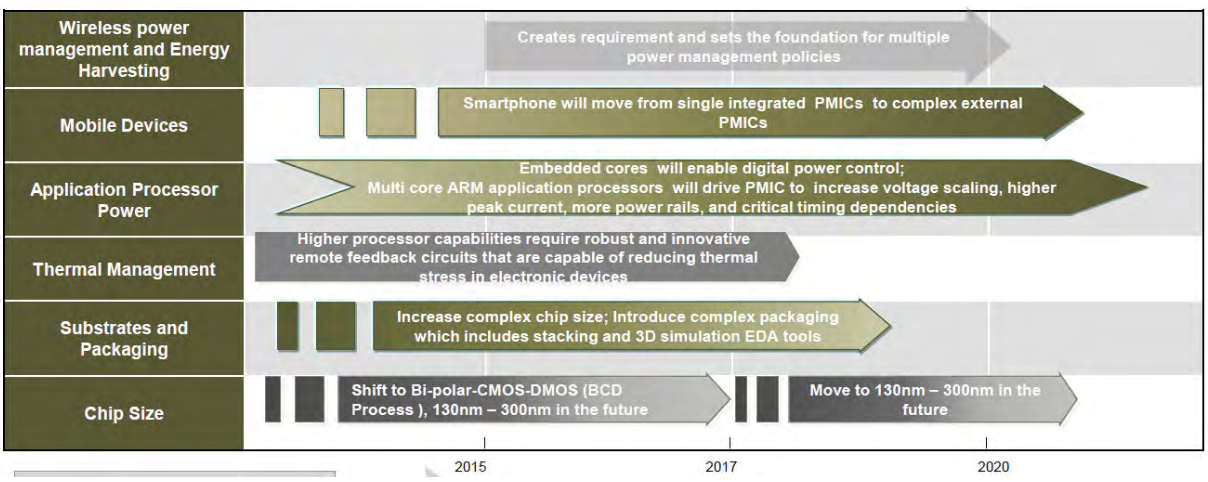

Figure 29: Roadmap Power Management Systems

3.4.4 Strategic Research and Economic Impact

The strategic research should be aligned to overcome the three major challenges discussed in this chapter, which are the component size, the power density and power consumption (on state losses) of semiconductors.

The reduction of size or miniaturization is motivated by devices that can offer efficiency gains and cost reduction. This trend also opens up new opportunities as designers can incorporate increased functionality in a limited space. [147]

But also power electronics for FACTS and HVDC-systems need to be reduced in size. So far the installation of such systems claims a lot of space, as many components are required to fulfil the power capability requirements. Miniaturization is closely related to the increase in power density.

Increasing the power density leads to more effective components, in manners of size and performance. Thus smaller power electronic devices and systems, as FACTS, with fewer components could be realized.

Additionally the reduction of the power consumption and the on-state losses should be in the focus of the ongoing research. Pure semiconductor switches with minimal on-state losses and the use of new wide band-gap power semiconductor devices, e.g. with silicon carbide (SiC) or gallium nitride (GaN) need to be developed.[148] [149]

The highlighted future key products have direct impact on the living quality in urban areas and smart cities. New semiconductor technologies help to integrate renewable energies and to effectively control the energy grid to deliver a sustainable, secure and stable energy. Efficiency and reduced losses of the semiconductors together with an intelligent end effective control and energy management lead to economic impacts such as saving energy and cost reduction. The increasing demand of micro- and power electronic devices for smart grid applications lead to increasing employment in the field of research and fabrication of semiconductor technology and also in the affected industry sectors.

As the grid stability is compromised by the in-feed of renewable energies, new semiconductor technologies are necessary to overcome these problems. The stability of the energy grid has an economic impact for industrial nations as their economic success is depending on a reliable production and export.

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[147] "Advances in Power Electronics Enabling Future Smart Grid: Advanced Power Electronics Driving Next-Generation Power Grid," Technical Insights D4CE-TI.

[148] C. M. Franck, "HVDC Circuit Breakers: A Review Identifying Future Research Needs," *IEEE Trans. Power Delivery*, vol. 26, no. 2, pp. 998–1007, 2011.

[149] S. Linder, "High-power semiconductor devices. Review and comparative assessment," *Russ. Electr. Engin,* vol. 78, no. 10, pp. 509–514, 2007.

3.4.5 List of Abbreviations

Abbreviation	Explanation
AC	alternating current
BMS	battery management system
CSC	current source converter
DC	direct current
EMS	Energy Management System
EU	European Union
FACDS	flexible ac distribution system
FACTS	flexible ac transmission system
G-2-V	grid to vehicle; power-flow from the grid to the vehicle
GaN	gallium nitride
GSM	Global System for Mobile Communication
GTO	gate turn-off (-transistor)
HVDC	high voltage direct current
HVDC	High Voltage Direct Current
HVT	High Voltage Transmission
IC	Integrated circuits
ICT	information- and communication technology
IGBT	insulated-gate bipolar transistor
LIB	Lithium Ion Battery
MOSFET	metal-oxide-semiconductor field-effect transistor
MPPT	maximum power point tracking
NPT	Non-Punch-Through
P2G	Power to Gas
PMU	phasor measurement unit
PT	Punch-Through
PV	photovoltaic
R&D	Research and Development
RF	Radio frequency
SiC	silicon carbide
SoC	system-on-a-chip
SOC	state of charge
SOH	state of health
SVS	Static Voltage Source
V-2-G	vehicle to grid; power-flow from the vehicle back to the grid
VCS	Static Var Compensator
VSC	voltage source converter
WiFi	trade mark for a local area wireless technology
WP	wind power

3.5 Buildings

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Co-authors: *Martin Kemmerling, Hans-Jürgen Schliepkorte*
Contributors: *Klaus Pressel, Michael Kunzer*

3.5.1 Future Key Products

3.5.1.1 Trends and market drivers

The development towards smart buildings within the next 10 years is driven by three mega trends that are omnipresent:

1. *Energy costs and greenhouse gas prevention*
   Costs for conventional carriers of energy such as coal, oil and gas are likely to increase during the next decade. Other sources of energy such as nuclear power or hydrogen fusion cannot immediately replace the conventional energy source because of technical difficulties. Furthermore governments have started to enforce energy efficiency laws in order to limit the manmade climate change due to greenhouse gas emissions. The increasing percentage of energy from renewable sources like wind and sun is strongly volatile and requires demand side management as well as energy storage. Furthermore solar energy and earth-heat / cooling energy are available at the place of the building and can be harvested.

2. *Lifestyle / Comfort / Safety / Security*
   Prices for powerful microelectronic equipment are still dropping. Due to the smart phone rush people today are equipped with and used to powerful mobile communication / computing / control devices which may serve as user interfaces as well as sources of information. These effects create an environment which allows for implementing new comfort functions in buildings such as automatic control of lighting, HVAC or multimedia, safety functions like presence monitoring and security functions like advanced intrusion detection, all at a very attractive price.

3. *Aging society / Health*
   The fraction of elderly people needing assistance in daily live is increasing in all industrial countries. Here general smart building functions like surveillance of sources of heat or water, automatic lighting control together with special functions such as advanced emergency detection and communication systems become necessities rather than lifestyle accessories. This creates an increasing demand for assistance functions in buildings, for example at home and in care facilities.
   There is also a trend to monitor vital parameters using wearables or other sensors to observe the daily life activities of elderly people like presence and motion detectors, bed sensors and locating sensors. The goals of these systems are the detection of emergency situations and care demand.

These trends yield four groups of key products that will be designed to satisfy customer demands in the next decade. The next sections will briefly discuss the market situation and the state of the art for each of the key products.

3.5.1.2 Solid State Lighting

Solid state lighting technologies today potentially provide unrivaled energy efficiency as well as superior control of brightness and light color. Since the ban of conventional light bulbs from the European markets by EC laws to enforce energy efficiency SSL technology massively penetrates the market. The vast majority of the actual SSL devices address the retrofit market: The devices adapt to the existing infrastructure, i.e. electric energy specifications (110 / 230 AC) and fixtures. In this configuration some of the potential of the technology is lost. New infrastructures concerning specification of supply of electric energy as well as control information transfer would not only yield even better energy efficiency but also strongly improved control of light quality which serves demands in terms of health and lifestyle. Recently there was substantial research on the influence of light temperature and intensity on human well-being and productivity that showed that both parameters can be improved significantly by proper control of light quality.

Figure 30: Solid state light bulbs for retrofit (source: Wikipedia[150])

Potentially, data transfer by SSL is also an option. Therefore recently new infrastructure systems got into focus of industrial research, but currently there is no mature system available which could replace the current lighting infrastructure.

Due to the size of LEDs and their flexibility of arrangement new lamp designs and applications are possible. For example extremely flat lamps or light strips that can be integrated in furniture or other building components can be realized.

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[150] http://upload.wikimedia.org/wikipedia/commons/7/76/LED_bulbs.jpg,, Original uploader was Geoffrey.landis at en.wikipedia

3.5.1.3 Sensors, room control, smart home systems

Analysts expected the Smart Home market ”to take off next year“ for almost a decade now. A strongly increasing number of start-up companies as well as the smart phone boom now suggest that this expectation becomes a reality now. The smart home market is addressed from four directions, which are control of room conditioning (HVAC, lighting; driver: convenience and energy efficiency), multimedia (driver: lifestyle), AAL (driver: ageing society) and security / alarm systems (see Figure 31). Each of these directions is represented by companies with traditional expertise in their respective area, offering more or less closed systems with emphasis put on functionality using the strengths of the respective company. However, all of these functions require very similar technical infrastructure which creates a demand for open systems that can potentially integrate all of the above functions. There are several such systems under development or in early stages of market introduction, but currently it is not foreseeable, if there will be one or a multitude of different systems.

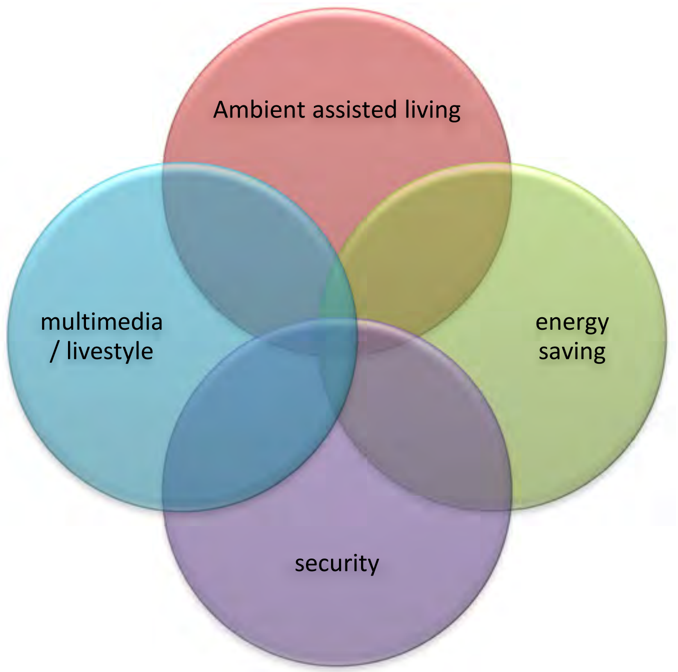

Figure 31: Smart home products are driven by user demands from four different areas, which can be satisfied which similar technical infrastructures.

In addition to the Smart Home market there is a partially overlapping Smart Building market that concentrates on applications in the area of commercial buildings. Focus of these products is a preferably cost-efficient operation of buildings, because the long-time operation is in most cases significantly more expensive than its construction. Smart building technologies allow innovative facility management, for example maintenance on demand. There is an extra benefit for the owner by an increased attractiveness for leasers and users.

In this area numerous products have been established that provide integrated and partially heterogeneously networked intelligent solutions using network technologies such as BACnet, KNX or LON. The penetration of the building market by these technologies will strongly increase in the future; additionally other communication technologies, especially wireless types will come along which are very interesting for the backfitting of buildings.

For the reason of multimedia integration to a common level in the future the trend of merging different protocols and applications using internet protocol (IP) based system integration will increase; current examples are Voice over IP and Video on Demand. The importance of mobile applications like mobile working using notebook, PC, tablet computer and smartphone will strongly increase; therefore the relevance of WLAN infrastructures in buildings will increase in the same way. Related trends are higher data rates, lower latency, higher availability and more security. Possibly in the future WLAN will be replaced by new technologies that allow a seamless mobile indoor and outdoor usage and offer enhanced data rates (e.g. LTE picocells or future 5G technologies).

3.5.1.4 Building Energy-Management

According to several information sources buildings consume in the range between 39% and 48% of total primary energy and therefore are an attractive target for measures to increase energy efficiency. This could mean saving of energy through less wasting of energy or, since the share of volatile energy generation from renewable sources like sun and wind is increasing, consumption or storage of energy when it is available rather than when it is actually needed. In future many buildings will be equipped not only with renewable energy harvesting systems like solar heat, PV etc., but also with storage capacities for thermal (heat and cold) energy and possibly for electric energy as well.

Another important trend is the use of micro block heating stations. During the recent years the known CHP technology (Combined Heat and Power) used in block heating stations has been increasingly applied also in smaller buildings, even in single family residential houses. Based on their very high energy effectiveness (up to ninety percent) these block heating stations have significant advantages in relation to conventional facilities for the electricity and heating supply. Because of their electric power generation micro block heating stations are also interesting for applications in the coming Smart Grid, if a decoupling of heat production and electric power generation will be achieved by heat storage technology. These decentralized stations can be used for the balance of volatile energy portions like solar or wind power.

The facts mentioned above create the need to manage generation, storage and use of energy consistently to get optimal system efficiency and reduce cost for the building owners/users as well as for society. Figure 32 gives an idea of the complexity of building energy management.

To implement energy management systems the following groups of devices are needed:

- Smart meters, which
    - make the connection to the energy delivering grid,
    - supply information on the state of the grid (i.e. energy prices) and energy demand from inside the building for analysis.
- Sensors, which supply information on weather conditions and user demands
- Controller which evaluate all incoming information and generate control decisions
- Power switches to control energy flows.

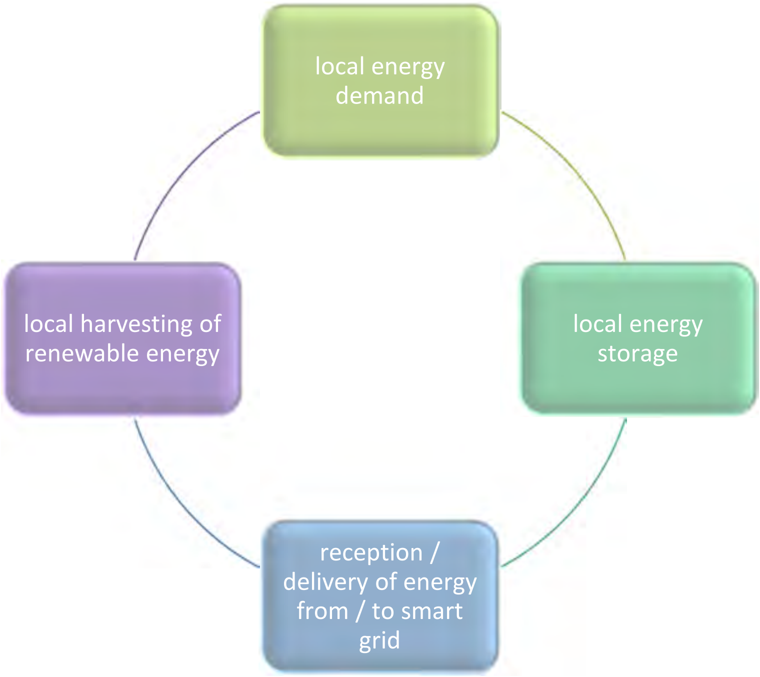

Figure 32: Energy management in buildings means finding the optimum operation strategy using all degrees of freedom that the infrastructure offers: local demand management, local renewable energy harvesting, local energy storage and reception/delivery of energy to the smart grid.[151]

After the first hype in the recent years Smart Meter technology is currently in an introduction phase. There is a strong focus on the security aspect (in Germany a particular certification by the German Federal Office for Information Security "BSI" is required). In the coming years, additional technologies for Smart Meters will be offered in order to make them more attractive to possible users. For example in industrial applications a current monitoring

[151] SMA Solar Technology AG

functionality of single electric circuits will be of great interest in order to identify possible energy savings. Today, for this purpose the so-called sub-metering is an appropriate technology, which might be complemented or even replaced by a new technology called “Nonintrusive Load Monitoring” (NILM). In the future the NILM related complex signal processing algorithms will require additional hardware components for an economic implementation of the NILM approach.

3.5.1.5 Indoor communication

Electronic indoor communication takes place in 3 different application domains:

- Building automation control including security systems at medium or low data rates
- Interactive IP-based user applications at medium or high data rates (Ethernet-LAN for PCs, video-on-demand, 4k-TV etc.)
- Non-interactive applications like indoor navigation, local information broadcasting

Building automation as well as user applications need wired and wireless solutions while non-interactive applications involves communication of building infrastructure to mobile devices which must be wireless.

Each of these application domains relies on quite different technical specifications and requirements e.g. speed vs. energy consumption. Thus, there will likely be several different communication technologies to satisfy these requirements.

Considering the increasing proliferation of smart home systems, multimedia devices, electronic gadgets etc., new technologies will be necessary to ensure the robustness, ease of use and deployment as well as security of the communication systems. This concerns the problem of running many wireless networks in close vicinity, where interferences of the different networks will appear. The other issue is the ease of deployment and maintenance of wireless networks, which must be done by the end user in most cases to keep the cost within reasonable limits. Finally, with a growing share of buildings being equipped with electronic control systems, the threat of criminal abuse or jamming will occur more frequently.

New user applications like indoor navigation, localization, identification, payment are currently under research. There were several research efforts to use SSL technologies for information delivery as well. Possible applications are indoor navigation or distribution of audio information e.g. for audio guides in museums.

The existing NFC (Near Field Communication) standard has been established in 2002 in order to support wireless data communication over very short distances for example in the area of micropayment; several field trials have been performed during the recent years: e.g. at Deutsche Bahn (Touch&Travel).

But also further building applications are possible by the use of NFC technology: additional, for example location related information can be retrieved wirelessly (e.g. information about exhibits in a museum, nutrition hints for food products in a supermarket …). Although today many smartphones are already equipped with NFC technology most applications are not area-wide available or not workable.

3.5.2 Technological Requirements

3.5.2.1 General aspects

There are some general aspects which must be considered when designing new products for smart building. These are

- *Long replacement times*
  For buildings replacement times of at least 15 years or more for technical equipment and infrastructure are quite common, which is much longer than in e.g. consumer electronics. It is expected that, by 2050, about half of the existing building stock in 2012 will be still operational [152].This has created a situation in which the modern communication technology is far ahead of the possibilities of existing infrastructure found in building stock. When modernized, investors expect to get devices with long service life to amortize.
- *Interoperability*
  Currently there are no generally agreed technical standards in the market that satisfy future technological requirements. For lighting the current infrastructure fails to support the enhanced possibilities of SSL technology, for wireless communication there are several standards that have different ways to trade-off speed vs. power efficiency. At present it is not foreseeable which of the competing standards will survive. To reduce the risk of investment openness of interfaces allowing applications to converge and ecosystems to develop is important.
- *Cost efficiency*
  Although energy prices keep rising they are usually still a rather small fraction the average end users budget. Therefore all systems designed to increase energy efficiency have to be extremely low cost for purchase and deployment. They also have to feature low power operation to be effective in an efficiency optimized building environment.
- *Simple system integration and user interface*
  Demanding system integration increases cost and complicated and complicated operation or frequently needed user input makes systems unattractive and in many cases also ineffective. Since most of the future key products mentioned above will not be deployed and operated by experts but end users proper design of user interfaces is crucial.

3.5.2.2 Technological requirements for SSL

Solid State Lighting can be applied indoor and outdoor. The technical requirements differ according to the application: Outdoor applications of SSL are basically street lights. Here high lumen output is required to reduce the number of necessary lamps, on the other hand there is little if any interaction needed between the user and the light source. For indoor applications the situation is vice versa: While medium or low lumen output compared to recent standards is acceptable in many cases user interaction is a must. This applies to control of light intensity (at least on/off), but will be extended to color temperature or light color. These control functions have to be integrated in smart home or other room control systems to keep the

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[152] "Energy-efficient Buildings PPP beyond 2013 – Research & Innovation Roadmap," ECTP, E2B, July 2012

systems easy-to-use. The other important requirement is the color temperature and color rendering index (CRI). While being less of an issue for outdoor applications both quantities are very important indoor. Currently the color temperature of SSL can be adjusted as needed and CRIs of up 95 can be realized, which equals to CRIs of the best compact fluorescent lamps (CFL, CRI typically < 85)

Modern SSL technology offers basically two advantages compared to standard lighting:

- Superior energy efficiency
- Control of color temperature or color of light

LEDs are driven by current controlled DC which currently must be converted from 110 or 230 V AC. The respective electronic power supplies must be extremely efficient to keep the system efficiency high. Currently there are experiments with low voltage DC power supply infrastructures, but there is no wide spread system available. Whereas retrofit is very important for indoor applications it is less an issue outdoor. For outdoor applications the replacement of a larger part of the optical and electrical system of a street light or the complete street light to yield optimum efficiency often is advantageous.

LEDs have the highest energy efficiency at low operation temperatures, i.e. room temperature. Therefore the heat still produced by the LED must be deflected as good as possible, which used to be a minor concern in standard light bulbs. Furthermore, due to the different optical characteristics of LED, new optical constructions for lighting are required.

The control of light intensity used to work by variation of the supplied power. The standard dimmers are not always applicable for retrofit LED lamps. Control of color requires an additional communication channel which could be realized as a signal transmitted through the cable supplying the electric power or via an additional wireless channel (e.g. wifi as for Philips Hue, Zigbee or z-wave). For this communication channel the required data rates are low, thus low power protocols can be used. This situation changes considerably if SSL technology is to be used for wireless communication purposes such as localized information distribution, indoor navigation or audio guide systems in museums.

3.5.2.3 Technological requirements for Smart home/building

For the implementation of the Smart Home / Smart building applications mentioned above several network, infrastructure and component technologies will be required in the future.

3.5.2.3.1 Sensors

There will be many improvements and progress in the area of building automation and facility management. With the help of special sensors for example room parameters such as temperature, air humidity and air quality will be measured and used for an automatic air conditioning with additional consideration of the user behavior. For this data acquisition, especially in the case of non-accessible locations and for the backfitting of buildings, the market looks for wireless and maintenance-free sensors that generate their supply energy from the environment. If this method of energy supply called “energy harvesting“ is not feasible, low-power sensor technologies and the usage of energy efficient wireless data communication protocols will be mandatory, in order to achieve an acceptable lifetime with battery powered operation.

3.5.2.3.2 User Interfaces, operating and configuration devices

The increasing pervasion of buildings by networked electronics implies the need for innovative operating concepts, which can be handled intuitively and will be accepted by users and operators.

Wherever possible operating devices will be mobile and must be integrated into the building network by wireless communication technologies. Usually they are powered by battery and should have a long operation time. This is the reason for high energy efficiency requirements of these devices. Displays will therefore increasingly be realized using e-paper or e-ink technologies.

For authentication purposes in case of critical operation and configuration tasks, which are limited to a restricted group of people, biometric technologies like face recognition or voice detection will replace the "classic" input of PINs or passwords. In parallel RFID technology will further be used for authentication and access control purposes.

3.5.2.3.3 System integration (networks, wireless systems, gateways, integration beyond building limits)

In spite of numerous efforts to standardize smart building systems a large variety of different technical solutions (bus systems, communication protocols, interfaces), dependent on the specific applications, the system providers and the technical requirements, have been established and are in use. Currently technologies like KNX, LON, M-Bus, Bacnet, Dali, ZigBee, Z-Wave, EnOcean and further proprietary systems are in use.

Even if there is a settlement in the future, network solutions in buildings will remain heterogeneous and individual dependent on specific requirements and products available on the market. For a complete integration of all components in a building it will be necessary to have – besides of sensors, actuators, control units, user interfaces – additional devices for the connection of network segments based on different communication technologies. These gateway devices have to meet technical requirements such as energy efficiency, reliability, easy maintenance (for example automatic firmware update) and security. All these requirements can potentially be met by higher semiconductor integration, for example by realization of a "one-chip gateway" (including power management, communication interfaces, as well as safety and security structures).

3.5.2.3.4 Safety and security

Some parts of buildings, in both residential and commercially used buildings, are equipped with sensors for the detection of dangerous situations. Examples are fire and smoke detectors, gas detectors, intrusion detectors and water leakage detectors. For this kind of detectors special requirements regarding availability, reliability, safety and security are relevant. Similar requirements are valid for the related communication paths and the related devices and for components of access control systems, locking systems and (dynamic) emergency exit control systems.

The technical requirements for the functional safety of systems and devices are described in the EN61508 standard (with some individual requirements for specific applications). In many cases (dependent on the safety integrity level, SIL) the safety requirements can only be met by the implementation of redundant hardware and software structures, self-test mechanisms and cryptographic methods to achieve data integrity over communication paths. Also in communication networks safety, security and reliability can only be guaranteed if redundant transmission paths are implemented.

3.5.2.4 Technological requirements for Electric energy and storage management

Building energy management in our days is handicapped by a number of problems, which are mainly of economic nature and could be solved by technological measures. These issues are:

- *High cost of sensors and sensor deployment*
  The number of sensors is limited by the cost that are generated in the installation phase used on communication and energy supply. Smart sensors are needed which run at very little or no external power, are easy to integrate physically and logically into communication infrastructures yet employing secure communication protocols.
- *Complicated business models for users and technology suppliers, high risk*
  Currently there are little if any market incentives for users to implement demand side management since the price for electric energy is more or less insensitive to energy supply by renewable sources. The advantage of energy management actions is hard to quantify because of the volatility of user demand and local renewable energy sources if applicable.
- *Electric energy storage*
  Electric energy from renewable sources like sun, wind, ambient air temperature etc. is volatile, i.e. the availability is not synchronized with demands. Currently there are no methods to store electric energy in buildings in a cost effective way. Useful storage capacities are sufficient to supply energy for no more than 24 hours, i.e. about 10 kWh per household for residential buildings.
- *Building equipment capable of demand side management*
  The alternative to electric energy storage is synchronize electric energy demand with availability. This can be done using long time constant processes like heating and cooling of buildings as energy storage or by delaying energy intensive but not time critical processes like washing until energy is readily available. Especially the latter requires energy supply forecasts from a smart grid and thus intense communication.
- *Energy transparency*
  To identify energy flows and control energy consumption transparency is needed. This requires individual meters for consumers of electrical energy or smart meters that are capable of identifying major consumers by their typical consumption profile.
- *Highly efficient electric power switches, AC/DC DC/AC converters*
  Current storage technologies (i.e. batteries) store electric energy supplied as DC, while the infrastructure for electric energy distribution is based on AC. Highly efficient converters are needed to minimize losses and optimize overall efficiency.

Besides this access the CHP-technology to the Smart Grid there is a strong demand for technology to enhance the energy efficiency of block heating stations and to improve their maintenance. The costs for maintenance are currently very high; so condition monitoring of these facilities is very important to adapt the maintenance to the effective demand.

Energy supply facilities (also valid for water supply) are parts of a complex infrastructure with very high requirements regarding availability, reliability, safety and security. Devices and systems which build-up these facilities have to meet them.

3.5.2.5 Technological requirements for indoor communication

3.5.2.5.1 Low data rate communication for building automation

Building automation systems usually have long time constants, e.g. of the order of hours for heating systems. Even for less inertial processes like lighting, a time delay of 100 milliseconds is acceptable, which can be realized easily with most contemporary communication systems. In many cases a bidirectional communication link is preferable to make sure control commands are received and executed. For a typical room there are at least about ten participants for the communication process: Sensors for door and window, temperature, air quality, humidity, lighting and occupancy, on the other hand actuators like controls for HVAC, windows, lamps, blinds etc.. The installation and configuration of such communication nets should require as little effort as possible and must not involve special expertise in order to keep installation and maintenance / upgrade cost low. For wireless systems the operating distance should be at least several meters. The protocols must be robust and secure.

3.5.2.5.2 High data rate communication for user applications

In future there will be an increased demand for user applications that require higher standards: There will be interactive applications like video communication, telepresence, or working on remote machines as well as video on demand and 4k TV.

3.5.2.5.3 Unidirectional wireless communication for indoor navigation

Currently there are several use cases for unidirectional localized data transfer. Indoor navigation can be realized by short range wireless transmission or by optical means such as infrared or integrated in SSL technology.

3.5.3 Roadmap

3.5.3.1 SSL

SSL technology has undergone a very fast development during the last years. By optimization of the construction an increase of nearly 100% in luminous efficiency from 80 lumen/Watt to 150 lumen/Watt was achieved during the last two years. From 2011 to 2012 the sales of SSL products increased by 26% [153]. While the retrofit market is and will be very important, the

[153] N. Bardsley, S. Bland, D. Chwastyk, C. de Monasterio, L. Pattison, F. Welsh, and M. Yamada, "Solid-State Lighting Research and Development – Manufacturing Roadmap," Lighting Research and Development, U.S. Department of Energy, September 2013

luminaire manufacturing will change dramatically. Because of the long life time and small size of LEDs lamps with non-replaceable light sources become interesting for the customer, which demands high flexibility in the production. "*While there is potential for color-mixed solutions, much basic work remains to make that practical. The workhorse for current lighting products is phosphor-converted blue light, and there is still potential for efficacy improvement and cost reduction in that technology*"[152].

The prices for retrofit LED lamps have dropped to a level where LED technology is still more expensive than standard lamps on purchase but will pay off during lifetime due to longer replacement intervals and much lower energy consumption. Experts predict the priced to drop to 25% in 2020 compared to the level in 2012.

Principal cost drivers for LED-based luminaire products will migrate from LED package-oriented issues such as control of epitaxial processes and the development of cost-effective high throughput deposition to more luminaire-oriented issues such as automated assembly, code flexibility, streamlined testing, and system-oriented design for manufacture.

"*While OLED technology is not quite at the level of LED performance or cost-competitiveness, OLEDs offer profoundly different lighting capabilities that can complement LED sources. OLEDs can be large-area, low-brightness sources that could eventually be produced on large-area flexible sheets at low cost, whereas LEDs are small, high-brightness sources produced by semiconductor manufacturing processes. Analysis of OLED technology also shows a path to high efficacy, approaching that of LEDs. The combination of low-brightness and high-brightness sources can enable more effective utilization of light, further improving energy savings by using less light to achieve the target lighting levels (known as light utilization).*"[154]

3.5.3.2 Smart home

The smart home market currently experiences an intense atmosphere of departure. The SoCs available today provide computational and communication resources to set up advanced control functions and attractive user interfaces. The roadmap for market introduction is estimated to be[155]

- Pre market phase -> until now:
- Now to 2015 -> niche markets
- 2016-2020 ->beginning mass market
- From 2021 on -> developed mass market

This corresponds to a sequence of products of increasing complexity as eco system, user acceptance and market demand grow:

- Single components like radio controlled power plugs, autonomous thermostats

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[154] N. Bardsley, S. Bland, L. Pattison, M. Pattison, K. Stober, F. Welsh, and M. Yamada, "Solid-State Lighting Research and Development – Multi-Year Program Plan," Solid-State Lighting Program, U.S. Department of Energy, May 2014

[155] T. Keiser, „Der Smart Home Markt bis 2025 – Wie positioniere ich meinen Betrieb strategisch richtig?," Hannover, March 2012

- Proprietary systems with centralized intelligence: in Europe many startups as well as major companies start to offer systems that integrate several control functions like heating, lighting, multimedia
- Standard based systems with centralized intelligence: sensors and actuators communicate with the central intelligence based on standard communication links and protocols, and interoperable systems
- Standard based high end systems with centralized or decentralized intelligence: sensors and actuators communicate with the central intelligence based on standard communication links and protocols integrated in hierarchies of control levels
- Multi standard, self-organizing systems with distributed intelligence

Many of the technical open issues will be addressed in software. On the other hand, there are three basic issues which must be tackled with hardware:

- Intelligent sensors,
- Energy supply for wirelessly connected parts and
- communication between parts of the system

For many functions in the smart home information is needed on user presence and activity. Here intelligent sensors based on optical technologies are applicable. Modern image processing algorithms must be combined with low cost / low power hardware to get sensors that satisfy privacy demands (no transmission of image data) as well as restrictions on power consumption.

Manufacturers of building components (facade elements, windows etc.) will more and more apply RFID technology and wireless sensors because of several reasons: optimization of the manufacturing and logistic processes, quality management and the leadership within competitors.

Examples are pressure measurement in window panes, temperature monitoring in active facade elements, corrosion detection in concrete parts or electrochrome glass elements.

Sensor data provided by this technology will increasingly be used for computer aided facility management, building maintenance and optimization of the building's energy efficiency.

Accustomed control elements like switches or push buttons will move into the background. Dependent on the specific function of a building and the related processes (for example offices, hospitals, care homes, manufacturing plants) different user interfaces technologies and devices will be appropriate: speech input and analysis, image sensors with gesture detection, touch-screen technology known from tablet computers and smartphones. With the support of related apps (tablet computer and smartphone application programs) also these devices can be used as personal operating devices for building automation systems; first applications of this technology are already in use.

It is expected that there will be more applications with safety-relevant functions and requirements in the future. Because of this system engineers will have a rising demand for semiconductor components which provide integrated redundant hardware structures, self-test circuitry, fault detection and back-up mechanisms.

3.5.3.3 Building energy management

Key points of the future R&D will be

- Metering technologies (measurement technology, integration into the building control system, security)
- Implementation of NILM algorithms for the mass market, Sub-metering technologies
- Building energy management systems able to optimize supply and demand according to price signals sent to consumers, but also energy cooperation between buildings at district level,
- Energy equipment sufficiently interoperable
- Low cost and low maintenance sensors

For residential buildings and flats a large impact is expected from smart home products featuring energy management functions. The recent drop in price of PV as well as the advances in CHP technology call for intelligent electric energy management solutions to either consume or store locally or feed the electric energy to the grid. First solutions are seen on the market. With respect to electronic equipment the relevant facts are discussed in section 3.4.3.

3.5.3.4 Indoor communication

Indoor communication may take place wireless or wire bound. For wireless communication the internet of things will rely on so called 5G technologies for mobile applications, which will play a minor role for stationary applications in smart buildings. The 5G technologies are currently subject to intense research[156]. However, for wireless smart building applications a lot of communication standards exist:

- 802.11 WLAN
- 802.15: WPAN (e.g. Bluetooth, WirelessHART, Zigbee)
- Z-Wave, EnOcean, DECT, RFID, proprietary systems in ISM-bands

that with respect to building automation all suffer to a certain degree from the same problems:

- Reliability and robustness is often not sufficient
- Security is not ensured due to the lack of encryption
- The systems are too complicated to install / configure
- The systems consume too much energy for battery-free autarchic operation.

Though there is work going on for each system to overcome the problems, currently there is no roadmap for an organized development. From an end users perspective the 802.11 is interesting, where a very detailed roadmap exists[157].

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[156] European commission: 5G Infrastructure PPP: The next generation of communication networks will be “Made in EU”. 5G-factsheet, http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?doc_id=4445
[157] http://www.ieee802.org/11/Reports/802.11_Timelines.htm

For wirebound communication there are several relevant standards as well. For the end user the most important technology is Ethernet. The roadmap here is defined by the Ethernet Alliance[158]. The relevant milestone is 400Gbit Ethernet estimated for 2017. Communication over power line is an alternative wirebound communication solution, which requires no extra cabling apart from power distribution nets, but experiences problems with distribution cabinets. This makes power line communication useful for communication in flats and small houses. The HomePlug alliance released a new standard in 2011 for gigabit-class powerline networking which is suitable to support high data rate application like video on demand[159]. Finally, new low data rate solutions are currently under development offering the advantage of very easy and inexpensive installation by very slim cables[160].

3.5.4 Strategic Research & Economic Impact

3.5.4.1 SSL

Currently there are following fields for further improvement:

- Luminous efficiency is still under research. Currently about 50% of the theoretical upper limit of luminous efficiency can be reached. Improvements concern the LED semiconductor chip and packaging technology.
- High lumen output is an issue for applications that currently require HPS or HID solutions, such as conflict areas in street lighting (i.e. road interchanges). Here, no LED solution is available today for major conflict areas. These will remain lit with 600W-2000W floodlights until LED technology offers substitutes. Manufacturers foresee that higher lumen output solutions will be available by 2015, with the goal of replacing today's 400W-600W HPS solutions. Higher wattage equivalencies (1000W-2000W HID) are expected to be available by 2018.
- Driver circuits for LED contribute a large share of SSL system cost. With an efficiency of up to 90% there still room for improvement, but major concerns are reliability and durability with low cost and integration of control of light intensity, color temperature and light color. Especially for retrofit the form factor, weight and power density (W/cm^3) is important.
- Integration of color control in infrastructure

Economic impact:

IHS estimates that the global lighting market generates total annual revenue of nearly $100 billion[161]. Globally, IHS estimates that LED products accounted for 18 percent of lighting revenues in 2013, which corresponds to revenues of $16 billion. When expressed in terms of unit sales, the greatest contribution has come from replacement lamps. The largest global lighting company, Philips, reported that in the fourth quarter of 2013, revenues from LED-

[158] http://www.ethernetalliance.org/subcommittees/roadmap-subcommittee/
[159] HomePlug Powerline Alliance: "HomePlug™ AV2 Technology", White paper, 2011
[160] http://www.provedo-automation.de/
[161] A. Tao, "LED Market Overview: LEDs & the SSL ecosystem", HIS Boston, USA, 2013

based lighting increased by 48 percent and now represents 34 percent of all their lighting sales. Navigant Research forecasts dramatic increases in revenue from global commercial LED sales at the expense of existing lamp technologies through 2019, which will then be $28 billion[162]. From 2019 to 2021 there is a slight decrease in LED revenue.

3.5.4.2 Sensors for smart home and building energy management

Many of the market barriers to overcome are economic issues or technical problems that could be solved in software. Since cost is a major issue the main strategic research task is to provide sensors that detect user presence, activity level, position, number of persons or the identity of a person in a room and have following properties:

- Low cost hardware
- Low power operation (battery life order of years or completely autonomous)
- Protect privacy

Economic impact:

The economic impact is hard to predict as in the past many studies overpredicted the growth and market acceptance. In 2011 the European market for home automation had a volume of €207 million with a predicted CAGR of 7,7% [163]. On the other hand due to rapidly decreasing system costs and possible further financial incentives through energy savings the situation might change rapidly. In Europe there is a lot of activity in the industry to set up a market for smart home systems mainly motivated by energy savings. This movement sees companies from small startups to major players like RWE or Deutsche Telekom. Therefore a strong growth is likely to be seen in the next years.

3.5.4.3 Power converters for building energy management

In future buildings many energy converters and storage device will installed creating the demand for efficient conversion of electric energy, i.e. AC/DC, voltage shift etc. . This will create a strong demand for devices and circuits to handle the conversion requirements. For detail on devices see chapter 3.4 .

Economic impact:

The economic impact of building energy management is expected to grow 16-18% per year until 2018 starting from a European market volume of $1.25 billion[164] .

3.5.4.4 Indoor communication for smart home and building automation

A substantial part of the cost and effort to run smart home systems is installation and configuration. To establish the required low data rate communication links either cable (robust, secure, possibility to supply power) or wireless solutions are required (no effort for cable installation) that are

[162] J. Foote and B. Gohn, "Energy Efficient Lighting for Commercial Markets- LED Lighting Adoption and Global Outlook for LED, Fluorescent, Halogen, and HID Lamps and Luminaires in Commercial Buildings: Market Analysis and Forecasts," Navigant Research, 2013

[163] Frost & Sullivan: European Home Automation Market - On the Route to Mass Commercialization, 2012

[164] Frost & Sullivan: "Energy Management Opportunities: European HEMS and BEMS Markets", 2012

- configuration free
- bi-directional
- low power
- highly reliable and secure.

These communication systems will be enablers for the smart home as well as for advanced building control. The economic figures therefor are the same as for sensors given in section 3.5.4.2.

For wireless high data rate communication Wifi is most important. Here the challenge is to provide high data rates suitable for video on demand or 4k TV in an environment where many participants visible to each other must share the bandwidth.

3.5.5 List of Abbreviations

Abbreviation	Explanation
AAL	Ambient assisted living
AC	alternating current
CAGR	Compound annual growth rate
CFL	Compact fluorescent lamp
CRI	Color rendering index
CHP	Combined heat power
DC	Direct current
HID	High intensity discharge
HPS	High pressure sodium
HVAC	Heating, Ventilation, Air Conditioning
IP	Internet protocol
LAN	Local area network
LED	Light emitting diode
LTE	Long term evolution
NFC	Near field communication
NILM	Non-intrusive load monitoring
OLED	Organic light emitting diode
PV	Photo voltaic
RFID	Radio frequency identification
SoC	System on chip
SSL	Solid state lighting
WLAN	Wireless local area network

3.6 Mobility in Smart Cities

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Contributors: Gabriel Kittler

Among the most prominent visions of change to mobility in smart cities is the advent of electro-mobility. This driver of innovation will have a huge impact on urban traffic system. Cars using fossil fuels have dominated the cities over the last century bringing along a significant amount of smog (see Figure 33) and traffic jams in urban areas from individual traffic.

Figure 33: Air pollution at Bay Bridge in San Francisco on "save the air day" (8th Jan. 2010)[165]

The evolution of hybrid and electric cars in Europe and North America has just recently begun. Cities like Shanghai are already populated by electric motorbikes for individual transportation which helps to reduce pollution and traffic congestions – and provides motorized transportation for the lower class citizens.

Aside of individual mobility, mobile internet access and availability of real time information will result in a development of present information systems towards novel information and communication technologies for smart mobility. Mobility-on-demand and demand forecasting, traffic monitoring and control as well as an interconnection with smart grids and sensor networks are cornerstones enabling smart mobility. Dynamic pricing schemes allow for active demand management. A detailed summary of these concepts and their interaction was, for example, given by Mitchell[166]. Additionally, public transportation including trams, metro and buses using electric propulsion are already available in a large number of cities around the globe. The extension of these technologies aids in the development of "Smart Cities".

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[165] "New smog limits to hit Bay Area counties hard", SFGate, published Jan. 8th 2010, retrieved 11th Jul. 2014, http://www.sfgate.com/science/

[166] W.J. Mitchell, "Mobility on Demand – Future of transportation in cities", MIT Media Laboratory, June 2008

Presently, the traffic systems in cities are governed by topologies that were introduced following the high demand of individual traffic. Future traffic systems will require a stronger incorporation of the demands of the inhabitants and other stakeholders that are affected by mobility. This will be assisted by the availability of semi-autonomous and autonomous transportation which is both facilitated by new vehicle and infrastructure technology.

According to Rifkin, the next economic cycle, which he calls "Third Industrial Revolution", will be based on the following five innovations[167]:

- Roll-out of renewable energies
- Buildings as micro power plants
- Energy storage using Hydrogen grids
- Smart power grids
- Electric vehicles for energy storage

Electro-mobility together with these innovations will create a multiplication effect for mobility in Smart cities. Moreover, smart mobility must blend into the city in order to keep a high pace of mobility. At the same time, the impairing impact that mobility has today in cities on the environment must be reduced, e.g. parking lot shortage, air pollution, noise.

3.6.1 Mobility-Based Applications Evolving in Smart Cities

In order to derive the future technological requirements for semiconductor devices, an application-pull approach is pursued in this study. Therefore, the applications for smart mobility evolving in the future are discussed first.

3.6.1.1 Infrastructure

The cost and lifetime of traffic infrastructure (e.g. streets and railroads) is very long compared to the typical lifetime of a car. Therefore, introduction of new infrastructure for smart mobility either requires significant investments or must be accomplished by reusing existing infrastructure. The latter might allow for a fast utilization of improved technologies. It is, however, limited to existing solutions based in this infrastructure. In contrast, development of novel infrastructure is resource and time consuming, but offers the opportunity of introducing new technologies following different paradigms. In the scope of smart cities in general and smart mobility in particular, it will be necessary to follow both roads – further optimization of existing solutions and development of future concepts.

Following the theory of long waves in economic life from Kondratieff (cycles)[168] , long term boosts in economy were achieved when a novel demand could only be satisfied by the introduction of a new infrastructure, e.g. mass production in factories, transportation of goods by railway. Consequently, a summary of infrastructure requirements for the implementation of smart mobility has to be derived to judge its impact on an economical scale.

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[167] J. Rifkin, The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World, New York: Palgrave Macmillan, 2011.
[168] N. D. Kondratieff und W. F. Stolper, „The Long Waves in Economic Life," *The Review of Economics and Statistics,* Nr. 17 (6), pp. 105-115, Nov 1935

3.6.1.1.1 Innovative, Safe and Sustainable Transportation

A key approach of smart mobility in the smart city of tomorrow will be a paradigm shift towards sustainable and safe transportation concepts. This includes demand-driven transportation like car-sharing, but also a reduction of emission towards a zero-emission goal. With respect to infrastructure, sustainable and safe transportation may include installations for autonomous driving. This contains, for instance, communication between traffic lights and traffic signs with cars and buses. Also, the automatic traffic control systems necessary to accomplish this goal require versatile sensor systems, information systems and mobile communication equipment like radar applications for distance measurement. Detour planning will allow for a reduction of traffic jams and an optimization of traffic flow during construction work in order to reduce emission and pollution in cities.

Another approach to tackle pollution is the implementation of traffic dependent taxation systems and incentives for carpooling. This also includes car-free residential zones with alternative means for “last mile” transportation requiring additional infrastructure such as parking lots with battery charging capability etc. Such a methodology will require a link between multimodal transportation systems to financial services calling for an interconnection of different data sources using information technologies far beyond today’s state. Moreover, IT systems must be available that can cope with the highly dynamic data generated in the smart city concerning the current status and needs of its users. Otherwise, effective control mechanisms will not be implementable.

3.6.1.1.2 Local Accessibility, (Inter-) National Accessibility

Accessibility of local and national points-of-interest also raises the demand for new infrastructure projects. In order to promote the acceptance of public transportation, intermodal hubs offering multiple transportation options (bus, tram, train, subway) need to be established. In general, a development of smart mobility towards public transportation is envisioned to tackle the aforementioned issues with today’s traffic implications in cities.

3.6.1.1.3 Vehicle Propulsion Using Electric Grid and Hydrogen

In order to foster the acceptance of electric vehicles (and possibly vehicles with fuel cells), the charging/refilling infrastructure needs to be expanded. Charging stations for electric energy in parking lots also enables energy storage for smart grid infrastructure in the batteries of electric vehicles. This could be part of the solution towards an increased incorporation of regenerative energies with respect to peak power demands.

Similarly, introduction of hydrogen fueled vehicles will require a roll-out of hydrogen refueling stations across the smart city.

3.6.1.1.4 Intelligent Networking of Transportation

For national and international travels using public transportation, a solid infrastructure using buses, trains and aircrafts has been established. However, “last mile transportation” in cities relying on buses, tram, subway and trains is often unsufficient, giving rise to an increased amount of individual transportation. Optimization of the urban transportation network may be a solution towards a higher acceptance of public transportation. This is particularly true towards delivery services and logistics where goods consolidation and route optimization as well as access to detailed, accurate and real-time information is mandatory as described in Chapter 3.7.1. Optimization strategies create a demand in forecasting and combining as well as coordinating of different transportation methods even and especially across different transportation companies. In turn, new requirements for the provision and handling of information from different sources arise. For example, reservation and booking systems as well as electronic ticketing using multiple carriers is mandatory to provide the traveler with information on travel routes, duration and price. The availability of information to the public is a cornerstone towards the implementation of these systems. This again creates an increased demand in security of data transmission and personal data. A concept of a central multimodal ICT platform is depicted in Figure 34.

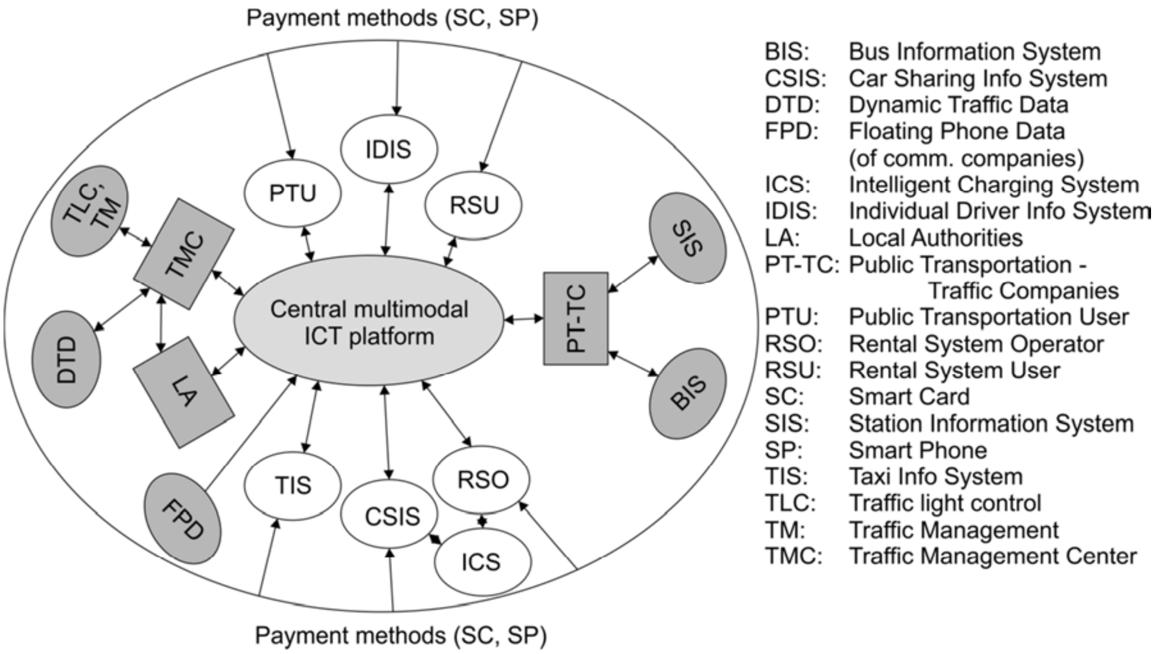

Figure 34: Central multimodal ICT platform for Smart Mobility in urban areas, adopted from Wolter[169]

For the majority of these systems, human-machine and machine-machine interfacing must be developed to enable compatibility in infrastructure-to-infrastructure communication (I2I).[170]

An intelligent transportation network may also include “virtual shopping” in order to reduce individual traffic. An online tour through a supermarket or a boutique diminishes the need to physically proceed to that store. An order could be readily served by delivery with a transportation vehicle serving several customers. The “internet-of-things” is already prospering today.

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[169] Wolter S., “Smart Mobility – Intelligente Vernetzung der Verkehrsangebote in Großstädten”, in Proff. H. et al. (ed.), „Zukünftige Entwicklungen in der Mobilität“, Gabler Verlag, Wiesbaden 2012, pp. 527 – 547

[170] Acatech – Deutsche Akademie der Technikwissenschaften e.V. (ed.), „Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0“, April 2013

3.6.1.2 Vehicles

Even though the lifetime of vehicles is short compared to that of infrastructure, the allocation of new vehicles creates a demand for new infrastructure. Therefore, developments in vehicle technologies for the cities of tomorrow are reviewed.

3.6.1.2.1 Electric/Hybrid Cars and Buses

The propulsion method of choice in smart cities will be electric engines for the sake of zero local emission and availability of electrical energy as well as the high efficiency. A combination with combustion engines (hybrid vehicles) is feasible to extend the range of these vehicles for "out-of-town" transportation. Already today, electric vehicles achieve sufficient range for most urban-based trips. Recuperation of energy allows for an increase in energy efficiency compared to conventional breaking.

The fuel cell offers the ability to store the energy in a fluid or gaseous (chemical) form, providing electrical energy on demand in the electric vehicle for propulsion. Similarly, short time energy storage using mechanical systems like flywheel masses are already employed in buses since the 1950s.

Finally, providing energy by overhead contact wires or inductively coupling energy through the road are visions for driving electric engines.

3.6.1.2.2 Railroad, Subway, Trams

The traction of electric railroads, subways and trams requires off-vehicle provision of energy due to the large masses involved. Subsequently, a high energy efficiency and light weight of the drive train are also desired for these systems. Beside the electric engine, a reduction of energy consumption can be achieved using compact, light-weight and highly efficient drive inverters.

Beside the electric engine, magnetic monorails are another new technology that has been recently development for transportation in urban areas using electricity.

3.6.1.2.3 Electric Bicycles

In order to allow for greater flexibility on the "last mile", new solutions like electric bicycles –which may be available for rent on demand – will likely evolve in Smart Cities. Similarly to other electric vehicles, an energy efficient drive train and modern battery technology is required.

3.6.1.2.4 Autonomous Driving

To facilitate autonomous driving, additional sensor and communication systems in cars are necessary. This includes both sensors to monitoring of the environment and wireless systems for communication with other cars using machine to machine interfaces. Moreover, data on construction work and detours must be transmitted to the vehicle and included in route planning. Inertial sensors with precise and highly-accurate reading with respect to position and bearing are required in order to reliably detect and predict the state of vehicles and outside traffic participants.

Additionally, vehicles themselves can also act as sensors, collecting traffic information and sharing them with the traffic infrastructure and other vehicles. The vehicles will have to employ communication and sensing over a "short range" in order to identify oncoming and preceding traffic, traffic lights and signs and pedestrians. This information is required to keep the vehicle on track and to avoid accidents. IR/UV sensors, car radar and ultrasonic sensors can be used to collect data by the vehicle itself. Additionally, the vehicles can deploy short-range communication to share relevant data with other vehicles.

Then, vehicles also require communication over a "long range". This is a distance that is beyond the car's field of view. Again, short-range communication will be used to pass information on quickly from vehicle to vehicle (V2V). A damaged vehicle on a curved road could be indicated by passing traffic or the stalled vehicles itself. However, the information that can be broadcast is limited and information about traffic jams or detours will be available by mobile phone appliances or similar RF based communication channels (V2I). There is a strong link to Logistics in Smart-Cities (see Chapter 3.7.1).

The implementation of these systems will also aid in a severe reduction in car accidents and related injuries and deaths. Presently, human error is by far the main reason for car crashes. Reports of human error rate range from 90% to 93% [171].

3.6.1.2.5 Vehicles as Energy Storage for Smart Grids

As previously mentioned, the energy storage in electric vehicles constitutes to a large energy capacity. When all electric vehicles that are not driving are hooked up to an intelligent charging system, their combined energy storage capability may be sufficient to cope with the fluctuations in energy production from regenerative energies, addressing some of the demands for Smart Energy as discussed in Chapter 3.4. This may provide part of the solution that Smart Grids are facing due to the increase in renewable energy production.

Clearly, only a portion of the capacity of the batteries can be used for the stabilization of smart grids. Nevertheless, the temporary storage capability of 10 Million electric vehicles with a battery capacity of 50 Ah at 400 V is impressive, even if only 10 % of the capacity can be used by the energy provider for temporary storage and 33% of the vehicles are available for storage (90%+ charged and not driving). This constitutes to a total energy of 6.6 GWh and could severely assist in overcoming the weather-dependent over- and underproduction from renewable energies. Even though amount of energy per vehicle is small, the sheer amount of vehicles can make a difference.

3.6.2 Semiconductor technology demands from these applications

Following the application pull methodology, the demand for semiconductor devices and technologies can be derived.

[171] NHTSA, U.S. Department of Transportation, "National Motor Vehicle Crash Causation Survey – Report to Congress", DOT HS 811 059, July 2008, Springfield, USA

3.6.2.1 Infrastructure
The preceding applications indicate demands for semiconductor devices in infrastructure for smart mobility.

3.6.2.1.1 Traffic systems
The acquisition and processing of real-time traffic data requires the implementation of stationary sensor networks, e.g. at intersections and mobile sensor networks, e.g. for detours. These systems will include traffic monitoring using **CCD cameras** as well as **IR and UV sensors and sensor arrays**.

In order to minimize the effort in setting up these sensors, solutions using wireless data transmission are desired. The requirement for a power line connection may be omissible for some applications when battery powered, solar cell charged sensor networks can be employed. This technology has already evolved in today's traffic infrastructure but will likely be rolled out to a large extent in the future.

3.6.2.1.2 Information technology
For wireless data transmission of a large number of sensors in parallel, energy efficient RF power amplification will be mandatory, e.g. class S amplifiers using **Si LDMOS, GaN HEMT, GaAs or InAs HBT** RF devices. Higher operating frequencies would allow for a larger bandwidth (higher data rates) or more communication partners per base station. Similarly, mobile applications (like smartphones or other handheld devices) require efficient power amplifiers. Wireless sensor nodes based on WLAN technology are limited to 52 participants under the basic protocols.

In order to process this increasing amount of data from traffic surveillance and demand forecasting efficiently, a strong demand in data processing and storage can be foreseen. This necessitates to the evolution of green data centers to cope with the ever increasing demand in electrical energy for data processing. To this extent, **More-Moore integration for CMOS logic circuits** is on the forefront of reducing power consumption by minimizing device capacitances. In parallel, new methodologies like ternary or reconfigurable logic need to be investigated further in an attempt to facilitate some concepts of the wide field of **More-than-Moore technologies**.

3.6.2.1.3 Electric infrastructure
Promotion of electric vehicles also requires the availability of charging systems away from home. The high energy efficiency of these charging stations will have to be provided by switch mode power supplies with high energy efficiency. Advanced p**ower semiconductor devices in silicon and silicon carbide technology** will be able to achieve this requirement.

3.6.2.2 Vehicles
With the advent of electric and hybrid vehicles, operation of transportation systems in smart cities will more strongly rely in power electronic systems in the future. While this energy will be provided from different sources (battery, fuel cells, tracks, inductive coupling), it has to be transformed depending on the particular application using drive inverters and power converters.

3.6.2.2.1 Electric/Hybrid Cars, Buses (medium voltage)

Traction for electric vehicles requires high efficiency, small size, and low weight drive inverters. As the size of such inverters is inversely proportional to the switching frequency that can be applied, silicon power devices may not be the best choice to satisfy these requirements. Instead, **silicon carbide (VDMOS, UMOS) and gallium nitride (HEMT) based power devices** are promising candidates towards very compact and efficient drive inverters operating at voltage levels between 400 V and 800 V and at switching frequencies beyond 50 kHz[172] .

Aside from drive inverters, DC-DC converters will also be employed for electric and hybrid cars as well as buses in order to provide electricity to lighting, safety and entertainment systems on-board (similar to today's 12/24 V grid in cars/trucks).

Also, availability of DC-AC converters in electric vehicles for recharging from wall plugs also provides the foundation to use the connected energy storages (secondary batteries) to store electric energy in case of overproduction (especially from photovoltaic or wind energy) or to provide electric energy to the grid in case of a spike demand. (See Chapter 3.6.1.2.5)

The increasing reliability demands to electronic systems associated with autonomous driving require semiconductor-based safety circuits typically realized in application-specific integrated circuits (ASICs). Moreover, solid state fuses and relays may be introduced to satisfy this requirement for automotive applications.

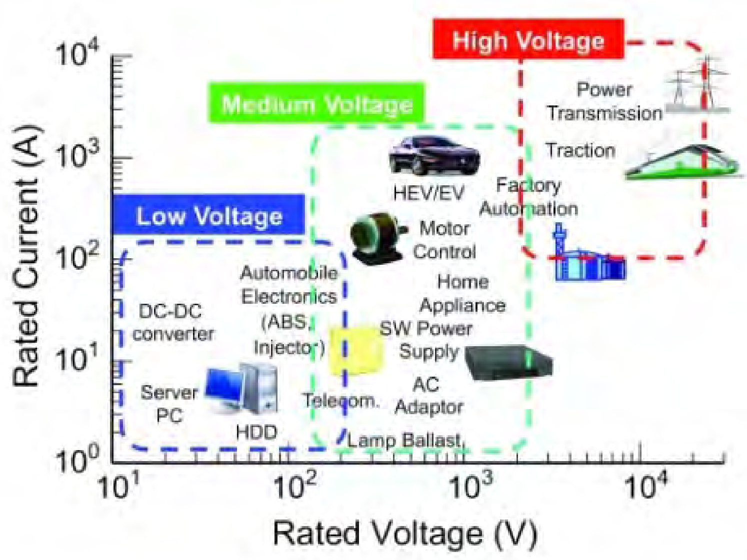

Figure 35: Overview of voltage ratings for different power electronic applications[173]

A summary of different applications requiring power electronics is depicted in Figure 35.

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[172] K. Shirabe et al., „Advantages of high frequency PWM in AC motor drive applications", Energy Conversion Congress and Expositon, 15.-20. Sept. 2012, Raleigh, USA, pp. 2977-2984

[173] Kimoto T., "Ultra-high voltage devices for future power infrastructure", www.compoundsemiconductor.net, 23.04.2014 (downloaded 25.06.2014)

While power losses in switch mode converters for the “Low voltage” range are readily served by discrete silicon power MOSFETs, “Medium voltage” and “High voltage” applications demand further progress in semiconductor device developments. Further power electronic components implemented for Smart Energy (see chapter 3.4.2.2) are also relevant to Smart Mobility.

The increasing reliability demands to electronic systems associated with autonomous driving require semiconductor-based safety circuits typically realized in application-specific integrated circuits (ASICs). This technology will also be used to implement circuits to evaluate sensor and 3D camera signals to monitor both the interior and the vicinity of the vehicle.

Car radar applications require operation of power amplifiers at low output power and frequencies in the range of 77 GHz. This is a tough specification even for GaAs pHEMTs for realizing car-bound, radar-based adaptive cruise control and collision avoidance systems.

Moreover, novel solid state fuses and relays may be introduced to satisfy this requirement for automotive applications.

3.6.2.2.2 Railroad, Metro, Trams (high voltage)

As seen in Figure 35, “High voltage” applications in the context of smart-mobility are related to traction in trains, metro and trams. There, drive inverters are powered by silicon IGBTs today, resulting in low switching frequencies and bulky solutions. Progress beyond the state-of-the-art can be expected from silicon carbide power devices. But commercially available SiC devices are limited to operating voltage of 1200 or 1700 V necessitating further developments on this sector to minimize operating expenditures by highly efficient, small size, and low weight drive inverters and DC-DC converters.

3.6.2.2.3 Electric Bicycles and Motorbikes

Regarding solutions for demand-driven, zero (local) emission “Last Mile” transportation, electric bicycles and motor bikes present a feasible approach. High efficiency for these vehicles can already be achieved using silicon power devices today, but they also require small size and low weight energy conversion systems. The development on wide-bandgap semiconductor devices at “Medium and High voltages” may also foster solutions for these “Low voltage” applications.

3.6.3 Roadmaps

A roadmap towards the development of power inverters based on silicon carbide technology has been projected by a Japanese consortium from Mitsubishi, Hitachi, Toyota, Fuji, Nippon Steel, Toshiba and AIST as depicted in Figure 36.

Providing power switches that are capable of handling voltages in excess of 10 kV will enable the implementation of high voltage applications that presently cannot be addressed using silicon technology.

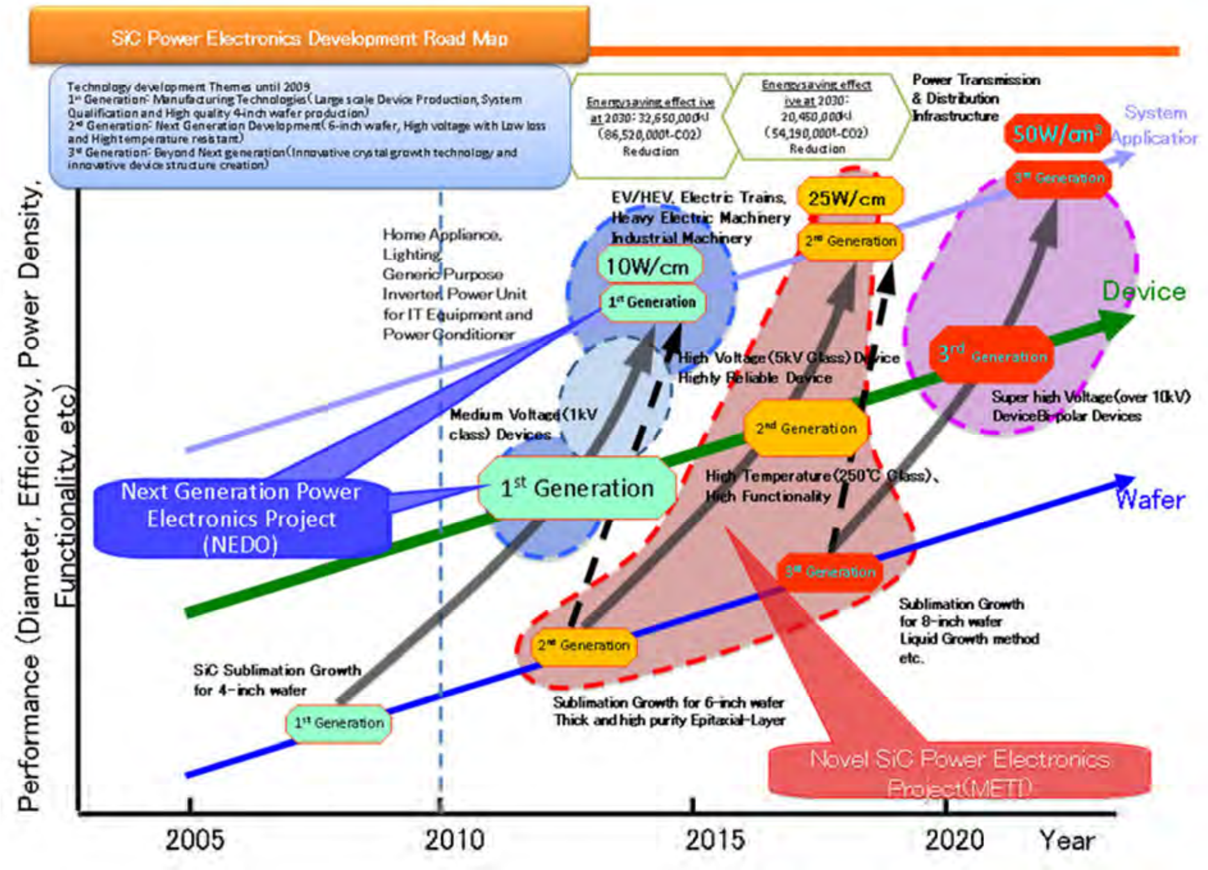

Figure 36: Proposed Roadmap for SiC device development from Japanese "Future Power Electronics Technology" consortium[174]

In order to ensure information transmission from wireless/autonomous sensor nodes to related systems at high data rates, energy-efficient RF power amplifiers need to be implemented. Here, silicon and GaN devices are projected to replace GaAs amplifiers in the next few years.

For smart-power solutions in mobile applications, energy efficient circuits will be a key building block to conserve energy. Ultra low-standby power ASICs could enable this kind of solutions.

The International Technology Roadmap on Semiconductors has identified several grand challenges of traditional More-Moore scaling due to increasing power consumption and diminishing returns on performance[175]. Following the ITRS, in the near term, cost-effective manufacturing including traditional photolithography and factory integration will help to "keep the pace" of Moore's Law. To enhance performance of semiconductor circuits in the future, ITRS suggests to implement non-classical CMOS channel materials and new memory structures and to shift from traditional scaling towards equivalent scaling and functional diversity through "unconventional approaches". Moreover, EUV lithography is considered as a big hope to achieve resolutions of 16nm and below.

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[174] FUPET Consortium, "R&D Partnership for Future Power Electronics Technology: SiC Power Electronics Development Road Map", http://www.fupet.or.jp/e_roadmap.html, July 25th 2014 (downloaded July 25th 2014)
[175] ITRS Edition 2013, "Executive Summary 2013", http://www.itrs.net

3.6.4 Strategic Research & Economic Impact

The improvement of present silicon carbide and gallium nitride technology and the development of novel devices – especially with higher breakdown voltages – will have a tremendous impact on the implementation of compact, highly efficient power inverters and converters for next generation electric, zero-emission mobility. These disruptive technologies will also be usable for smart grid applications like the decentralized energy storage in electric vehicles and households.

A major incentive for companies to implement energy efficient systems is the reduction of manufacturing costs by using wide-bandgap semiconductor devices despite its higher costs. With the capability to increase switching frequency, smaller and lighter traction inverters with cheaper passive components can be fabricated. Additionally, higher efficiency implies less power losses and the cooling subsystem of these components requires less effort. Even though it may only be considered contribution (1-5% of electrical power consumption), it will help to relax the pressure on the electric grid infrastructure (see Chapter 3.4).

Increasing the data rates in automotive applications will be required to cope with the larger number of sensors and remote data sources in cars. Presently, car bus systems (e.g. CANbus) are suitable for remotely controlling the vehicle (brakes, accelerator, turn signals, steering etc.). But this does not include transmission of camera sensor data, GPS data or laser scanning data to a central ECU – instead this data is evaluated by software running on a separate computer which then actuates the vehicle via CANbus. In the future, a series-production car with autonomous driving capability may implement this functionality integrated into a central ECU that is supplied by all sensor data via a high-speed onboard bus system.

Novel sensor platform technologies based on disruptive technologies including advanced materials, biotechnology and photonics will allow for the realization of self-sustaining sensor networks used in environment monitoring that can also be implemented for autonomous driving and traffic monitoring.

Particularly important are energy-efficient sensor and data conversion systems in battery powered vehicles like electric bicycles or smartphones.

3.6.5 List of Abbreviations

Abbreviation	Explanation
AC	Alternating Current
ASIC	Application Specific Integrated Circuit
CAN	Controller Area Network
CCD	Charge Coupled Device
DC	Direct Current
ECU	Electronic Control Unit
EUV	Extreme UV
GPS	Global Positioning System
HBT	Heterojunction Bipolar Transistor
HEMT	High-Electron-Mobility Transistor
IGBT	Insulated-Gate Bipolar Transistor
IR	Infrared
ITRS	International Technology Roadmap on Semiconductors
I2I	Infrastructure-to-Infrastructure communication
LAN	Local Area Network
LDMOS	Laterally Diffused Metal Oxide Semiconductor (transistor)
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
RF	Radio Frequency
UMOS	Modification of a VMOS (Vertical MOS) transistor
UV	Ultraviolet
VDMOS	Vertical Diffused MOS transistor
V2I	Vehicle-to-Infrastructure communication
V2V	Vehicle-to-Vehicle communication
WLAN	Wireless Local Area Network

3.7 Production and Logistics

Author: Guido Dolmans
Contributors: Juan Augusto, Seppo Saari, Matthijs Vonder, Yan Zhang

Around one in ten (9.8 %) of all enterprises in the EU-27's non-financial business economy were classified as manufacturing in 2009, a total of 2.0 million enterprises. The manufacturing sector employed 31 million persons in 2009, generated EUR 5812 billion of turnover and EUR 1400 billion of value added. In 2010 turnover increased to EUR 6400 billion[176]. Based on these numbers, production and manufacturing turn out to be one of the most important contributors to EU's employment and economy. According to EU industrial policy 2012[177], the EU industrial targets are set to:

- raising the share of manufacturing in EU GDP from 16 % to 20 % by 2020;
- raising industrial investment in equipment from 6 % to 9 % by 2020;

Linked to production, logistics is the second part to be tackled in this chapter. As shown in Table 5, according to the yearly gross revenue, the top three global third-party logistics providers (3PL) are all based in Europe. The total gross revenue of the top three companies add up to more than 70 billion in 2013. As shown in Figure 37 (next page), the logistics centers are distributed across the entire Europe, and are especially concentrated in Netherlands, Belgium, Germany and France.

Ranking	Third-Party Logistics Provider	2013 Gross Logistics Revenue (USD Millions)	Base country
1	DHL	$31,432	Germany
2	Kuehne + Nagel	$22,587	Switzerland
3	DB Schenker Logistics	$19,732	Germany

Table 5: Top 3 global third-party logistics providers

3.7.1 Future Key Products

"Last mile" logistics deliveries generally contribute to problems such as pollution, noise, congestion and unsafe environments within cities. However, if distribution vehicles would be used more efficiently, it should theoretically be possible to reduce the amount of vehicles in city centers. The main goal of logistics operators is customers' satisfaction, through quick and on-time deliveries, at a low cost. The cost is mainly influenced by fuel and time consumption. To maximize vehicles efficiency, through better coordination, goods consolidation and route optimizations, access to detailed, accurate and real-time information is crucial. Better resource utilization also implies lower operation costs and improved profit margins for transport operators.

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[176] FACTORIES OF THE FUTURE, MULTI-ANNUAL ROADMAP FOR THE CONTRACTUAL PPP UNDER HORIZON 2020.

[177] http://ec.europa.eu/enterprise/policies/industrial-competitiveness/industrial-policy/communication-2012/index_en.htm

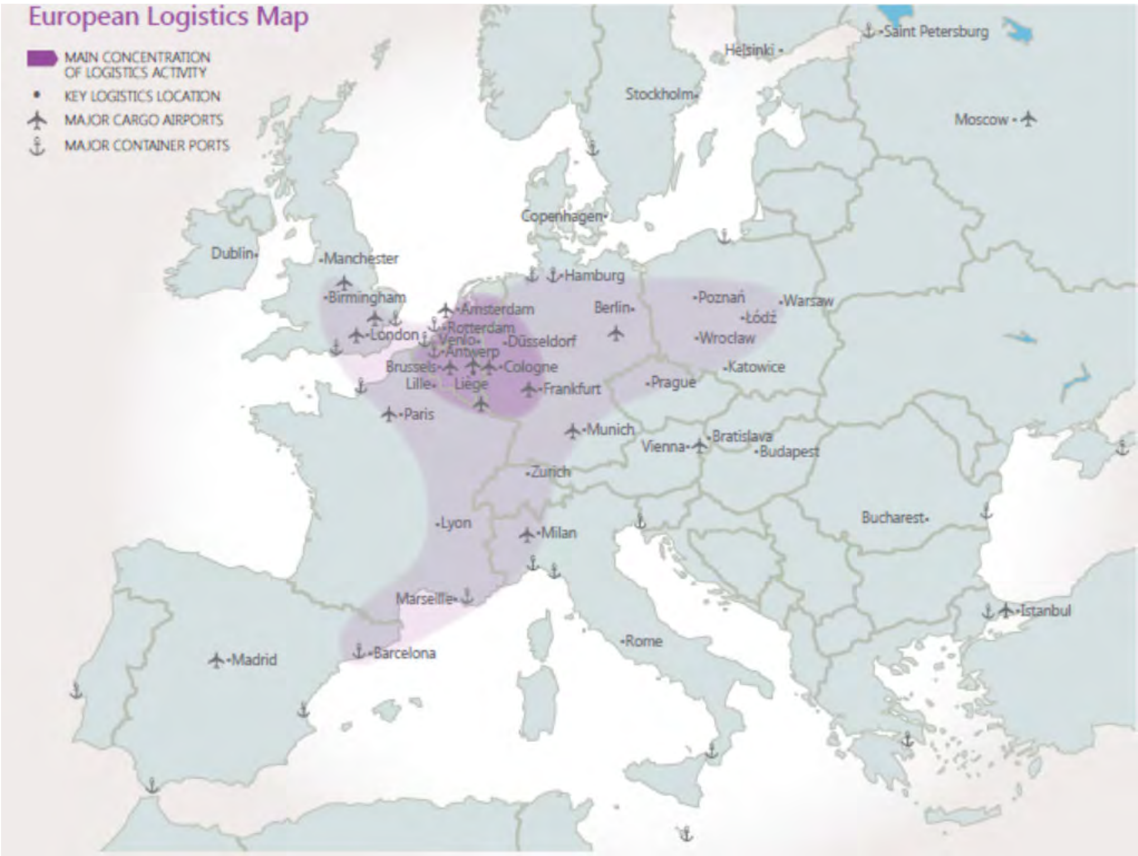

Figure 37: European logistics map[178]

New production paradigms are been designing perfectly integrated with the Smart City paradigm. The production place will not be any more inside the city, but this does not mean that people who work there must move there every day. Design, maintenance and managing tasks are more and more "virtualizing" with the support of ICT technologies, and finally employees will work in virtual factories. Remote data-monitoring and actuator-controlling will be key for that, but data reliability and availability must be imperative.

3.7.1.1 Logistics: Quality and optimization of the street network

A better street network is needed to reduce congestion, noise and environmental pollution caused by urban transportation. Another benefit is the enhanced end-customer quality of service through transport flexibility and adaptability. It will also improve the competitiveness and profitability of logistic chain owners, transporters, receivers, etc., through enhanced efficiency.[179]

Car automation: There is a strong link to chapter 3.6 "Mobility in Smart Cities" (see sub-chapter 3.6.2.1.1 "Traffic systems"). Cars and infrastructure will be equipped with cameras, sensors, radar, radios. Wireless communication connections between vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-infrastructure (I2I) can be

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[178] EUROPEAN LOGISTICS & INDUSTRIAL MARKET REPORT 2014, http:// *content.knightfrank.com/research/237/documents/en/**2014**-1775.pdf*
[179] Bits & Chips magazine, May 2014, special issue on smart cities

divided into two categories: safety applications and non-safety applications. In V2V communication, the vehicles share information about road parameters, transmit accident or collision information. The communication between vehicles and infrastructures (V2I) can take place with road side units that transmit messages, and where vehicles can pay toll or parking payments. V2I for safety is about the wireless exchange of critical safety and operational data between vehicles and highway infrastructure, intended primarily to avoid or mitigate motor vehicle crashes but also to enable a wide range of other safety, mobility, and environmental benefits. V2I communications apply to all vehicle types and all roads, and transform infrastructure equipment into “smart infrastructure” through the incorporation of algorithms that use data exchanged between vehicles and infrastructure elements to perform calculations that recognize high-risk situations in advance, resulting in driver alerts and warnings through specific countermeasures.[180] In the I2I communication network, the road side units exchange data that is received from the vehicles with each other.

In October 1999, the United States Federal Communications Commission (FCC) allocated 75MHz of spectrum in the 5.9GHz band to be used by intelligent transportation systems (ITS). In April 2014 it was reported that U.S. regulators were close to approving V2V standards for the U.S. market, and that officials were planning for the technology to become mandatory by 2017.[181] In 2003, this wireless spectrum was used in Europe and Japan in electronic toll collection. The systems in this unlicensed ‘Wifi’ band are called ‘dedicated short range communications’ (DSRC) with typical 300m range and bit rates between 6-27Mbps. DSRC systems in Europe, Japan and U.S. are not compatible. The features of DSRC are low communication delay and high data transfers. The data rate in Japan is 1–4 Mbps, 250 kbps in Europe, and 3–27 Mbps in USA. The protocols of the wireless connections have to be standardized; examples are the standards IEEE 802.11p and IEEE 1609. For the USA, the communication systems are called 802.11p DSRC WAVE Communication, and in Europe it is called 802.11p ETSI TC ITS Communication. IEEE 1609 standards for wireless access in vehicular environments have emerged with resource manager protocols, security services protocols, networking protocols, and multichannel operation protocols. IEEE 802.11p is the updated version of the Wifi IEEE 802.11b standard that works on data link and physical layers and enables communication between high speed vehicles. The IEEE 1609 protocol also applies to the rest of the OSI layers.

Wireless communication networks are key technology to automate and control traffic. A possible scenario is to allow only cars equipped with a compatible communication system on the automated highway. Interesting venues on the car communications are the yearly Car 2 Car Forum, ITS World and European Congresses, Drive C2X Event.

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[180] http://www.its.dot.gov/research/v2i.htm
[181] http://www.voanews.com/content/vehicles-may-soon-be-talking-to-each-other-/1886895.htm

Figure 38: Car automation street scenarios

Street parking sensors.

Parking is the second to third highest revenue generator for cities. According to Navigant Research, cities are losing up to 40% of possible parking revenue through inefficiencies. With smart parking, these inefficiencies are significantly reduced to provide an estimated 20 – 30% increase in parking revenue. State-of-the-art systems can monitor real-time occupancy information on individual parking spaces and also keep track of the time that a car is parked at a certain location. Real-time wireless buried sensors are used, and when space is occupied longer than 30 minutes, parking control gets a text message. The detection is based on magnetometer and IR sensors. Long range wireless communications at 900 MHz is necessary to have short installation periods at the streets to avoid breaking up the streets too long. This can be done with appropriate wireless technology that is self-configuring. An example is the *Sensit* system (Nedap) in city of Kortrijk (received smart city award in Belgium). This platform is fully wireless and does not require wiring for either communication or power, making it specifically suited for installation in on-street parking spaces or upper decks of parking facilities. The system consists of wireless sensors buried in the ground, a communication network and a software application. The sensors detect occupancy of a parking spot in real-time. The underlying technology is based on the changes in the local earth-magnetic field and is also based on infrared. An algorithm determines the best choice: one of the two technologies, or a combination of the two. Another example is the Streetline system.[182] This system has wireless parking sensors that can be installed in minutes to provide years of continuous service without the need to change batteries, and connects to a wireless mesh network that offers reliability and availability. This mesh network is built using a series of unobtrusive and easy-to-install "repeaters" that are placed on streetlights, telephone poles, etc. These repeaters then relay all the data from the parking sensors and meters via the Internet to mirrored data centers. The entire system is modular and scalable to support any size deployment, from 100 to 50,000 nodes and beyond.

[182] http://www.streetline.com/parking-analytics/parking-sensors-mesh-network/

Figure 39: Wireless parking sensors in smart cities

Besides parking sensor capabilities, also sound levels or road surface temperature detection are possible with the Streetline system. By measuring these city elements in real time, responses in real time are possible to analyze trends and set policies based on data, and also to reduce the environmental footprint of the smart city. More important is that we use the data to improve the way we live and work in our cities.

3.7.1.2 Logistics: City-compatible light, noise- and emission-reduced operations

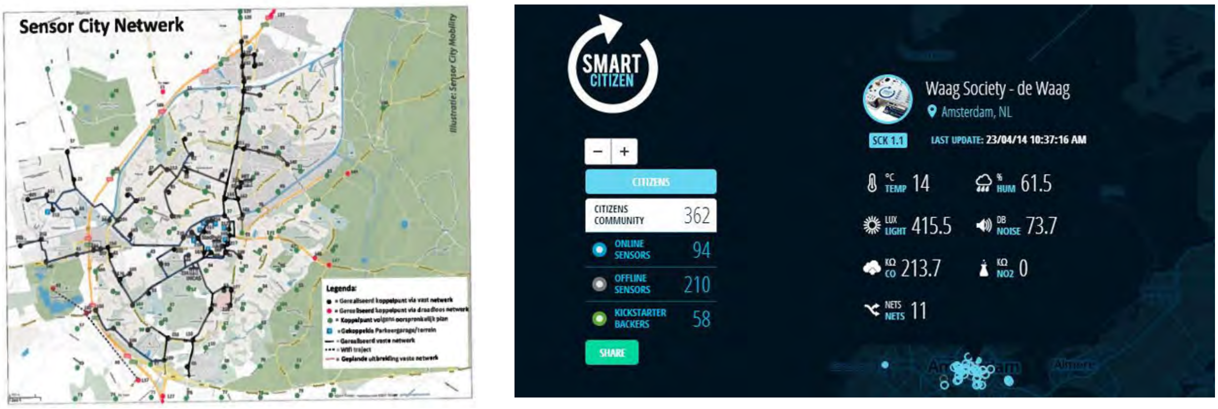

Figure 40: Cloud based sensor city network (left: Assen sensor city project, right: Amsterdam smart citizen project)

Several cities have sensor network trials. An example is the smart citizen kit released to citizens of Amsterdam. In the project "Amsterdam smart citizen", a network of sensors was installed all through Amsterdam. The sensors measure humidity, noise pollution, temperature, CO, NO_2 and light intensity. Distributed measurements were taken by participants at their homes. Another example is an experiment where more than 150 travelers in the Assen region (east part of the Netherlands) tried out various new services based on the use of sensor technology in the cars or on the smartphones. The advanced car unit combines GPS data with noise and emission data. The results deployed in Living lab Assen in the Netherlands were meant for personalized travel advice. The car unit consists of an on-board unit with GPS, accelerometers, and velocity meters. The unit communicates with fixed and mobile sensors in the city network. The data can be used to give a personalized advice for switching from car to public transportation. This service aims to minimize travel time for motorists in general and for individual motorists by means of route planning that takes current and expected future traffic conditions into account and that spreads traffic over all available routes. Not all motorists are advised to take the same route for a given journey. The sensor data can also be uploaded to the cloud to create a real-time city sensor map. The car unit connected over the air to a device gateway server can also provide other services such as track and trace, parking, traffic management, insurance, and safety.

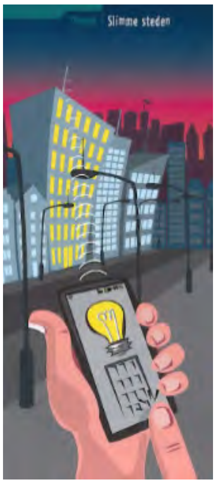

Figure 41: Intelligent street lights and light control systems

Intelligent street lighting refers to public street lighting that adapts to movement by pedestrians, cyclists and cars. Intelligent street lighting also referred to as adaptive street lighting dims when no activity is detected, but brightens when movement is detected. This type of lighting is different from traditional, stationary illumination, or dimmable street lighting that dims at pre-determined times. Tests have been done in Amsterdam and Leiden involving placing 50 'smart' light masts, to try out the flexible switch system. The street lights can be monitored, switched on-off, or dimmed. A country like the Netherlands has 4 million street lights, using more than 700 GWh per year. Safety is improved by switching on the lights when detecting a car or person, or when an authenticated message is received. In Europe, there is the E-Street initiative. This research group focused on ways to reduce energy usage in outdoor lighting systems in the European Union (EU). The E-Street group strongly influences EU standards and legislation for intelligent outdoor lighting systems. Street lights can be made intelligent by placing cameras or sensors on them, which enable them to detect movement. Additional technology enables the street lights to communicate with one another. Some companies also offer software with which the street lights can be monitored and managed wirelessly. Clients, or other companies, can access the software from a computer, or a tablet. From this software, they can gather data, pre-set levels of brightness and dimming time; receive warning signals when a light defects. The benefits of this type of technology are energy savings, maintenance cost reduction, CO_2 emission reduction, light pollution reduction, and increased safety.

3.7.1.3 Logistics: Intelligent Transportation

There is a strong link to chapter 3.6 "Mobility in Smart Cities" (see chapter 3.6.1.1.4 "Intelligent Networking of Transportation"). Logistics and supply chain management define the procedure of transporting goods within a company, from suppliers to customers, or the operation of focal firms, the companies that are in the middle of a supply chain. This procedure involves the distribution of goods, transportation, storage, loading and unloading, delivery. Intelligent transportation is the crucial part to decide the efficiency of the whole system. In a modern logistic system, smart transportation network is part of the key infrastructure, which is based on the following technologies:

- Global Positioning System (GPS)
- Geographic Information System (GIS)
- Intelligent computing/decision
- Reliable and real-time communication

3.7.1.4 Production: Industrial Internet and Smart Factory

Industrial Internet, promoted by GE, builds cloud-based services with intelligent analytics. Massive sensing data from industrial machine and equipment are converged, and from which unique insights are extracted to set new performance standards in different industries. The key elements of Industrial Internet are shown in Figure 42. Based on advanced sensors, controls and software applications, machines and facilities all over the world are connected by networks. Advanced analytics are carried out by combining the physically distributed systems. Again, with the aid of networks, people at work or on the move are connected anytime and anywhere to support more intelligent design, operation, maintenance, better quality of service and safety. This allows the collection and analysis of an enormous amount of data, which can be used to improve machine performance, and inevitably the efficiency of the systems and networks that link them. Even the data itself can become "intelligent," instantly knowing which users it needs to reach.[183]

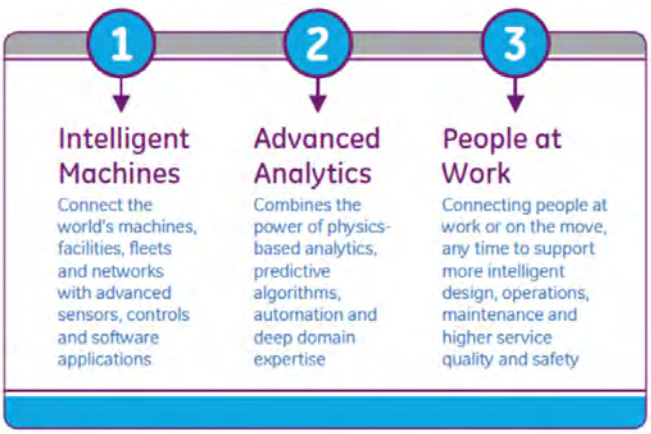

Figure 42: Key elements of industrial internet[183]

With the aid of new technologies, such as secure, cloud-based networks, intelligent information goes through a brand new loop, as shown in Figure 43, which can also be shared

[183] Peter C. Evans and Marco Annunziata, "Industrial internet: Pushing the boundaries of minds and machines", Nov. 2012

across machines, networks, individuals or groups to facilitate intelligent collaboration and better decision making. This makes it possible to apply the synergy offered by big data to industry as well.

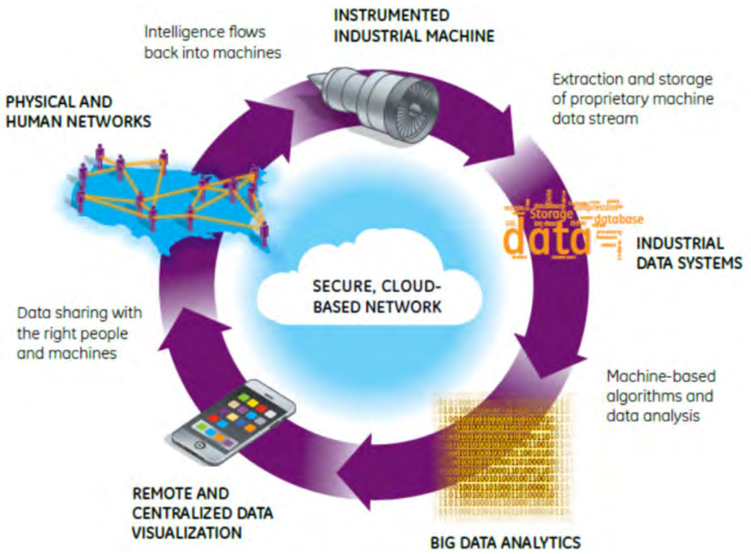

Figure 43: Data loop in Industrial Internet[183]

As shown in Figure 44, GE's Fuel and Carbon Solution (F&CS)[184] use onboard computers, sophisticated software and proprietary analytics to optimize jet fuel use, reduce operating costs, and cut carbon dioxide emissions. GE gives the example that if an average-sized airline used F&CS to achieve a 2% improvement in fuel consumption, it would be equivalent to removing more than 10,000 cars from our roads. Jeff Immelt, CEO of GE, said “We are moving into big data, but it’s not because we want to become Google. It’s because we are dramatically evolving manufacturing.”

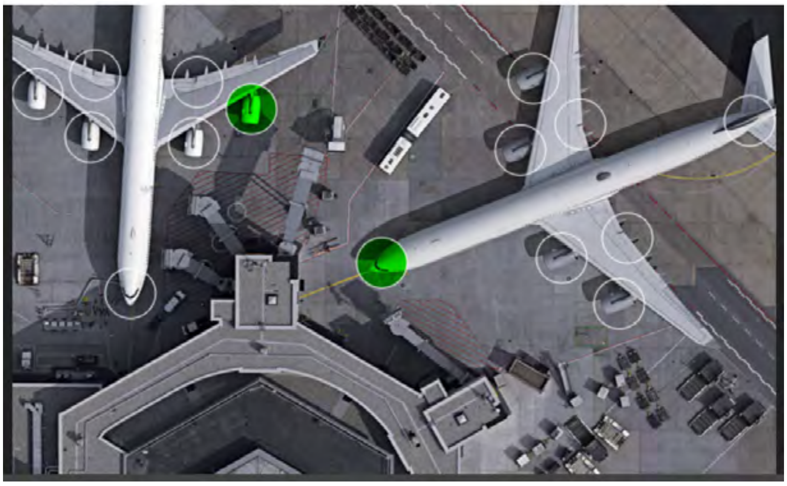

Figure 44: GE’s fuel and carbon solution

Industry 4.0[185], is a running project launched in the high-tech strategy of the German government. The basic idea of Industry 4.0 is to enable automatic control along the entire

[184] http://www.ge.com/stories/industrial-internet
[185] http://www.bmbf.de/de/9072.php

value chain by creating intelligent networks with connected machines, work pieces and systems. The main purpose is to improve production efficiency in complex manufacturing environment with methods of self-optimization, self-configuration, self-diagnosis, cognition and intelligent support of workers. At the same time, the Internet of Things will also be addressed in the "Industry 4.0" project, as shown in Figure 45. Under the heading "Smart Production", there will be a stronger focus on areas such as intra-company production logistics, human-machine interaction and the use of 3D in industrial applications.

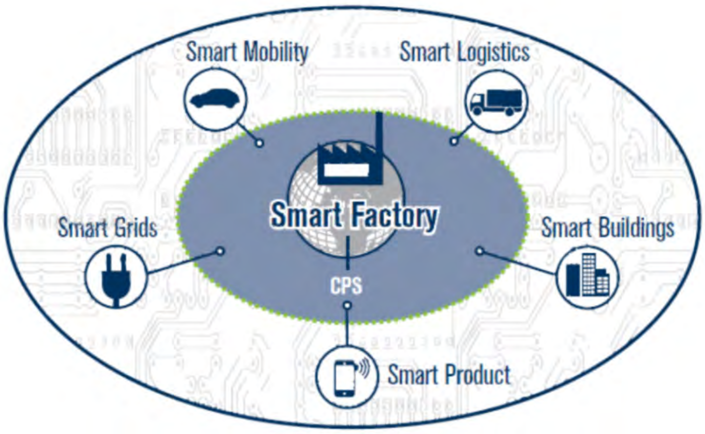

Figure 45: Industrial 4.0 and the Smart Factory as part of the Internet of Things and services[186]

There are similar initiatives in other European countries, such as "smart industry" in the Netherlands[187], "made different" in Belgium, AMRC "Factory 2050" in UK, and European Factories of the Future Research Association (EFFRA).

3.7.1.5 Production: Industrial robot, 3D sensing and 3D printing

Nowadays **industrial robot** is widely adopted in welding, painting, assembly, pick and place, product inspection, and testing.[188] Different technologies are involved in industrial robots design:

- sensing
- 3D object recognition, localization and tracking
- machine learning
- machine vision
- standardized communication interface

With the aid of variable sensors and computer vision, all the assigned tasks are accomplished by the robots with high endurance, speed, and precision. Linked to such a cooperative system, artificial systems with cognitive capabilities are presented to ICT as a new challenge.

3D printing, also called additive manufacturing, is to make a three-dimensional object from a 3D model or other electronic data source primarily through additive processes in which successive layers of material are laid down under computer control. A 3D printer is also a

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[186] http://www.bmbf.de/pubRD/Umsetzungsempfehlungen_Industrie4_0.pdf
[187] http://www.fme.nl/dsresource?type=pdf&objectid=default:56674&versionid=&subobjectname
[188] http://en.wikipedia.org/wiki/Industrial_robot#History_of_industrial_robotics

kind of industrial robot. 3D printing helps to shrink the whole production cycle. It also offers a way to offer quick customization to different customers with different preferences and needs. Another advancement within the 3D Printing space is the 3D printing of circuits and wiring, which could really expand on the applicable uses of the technology. In April 2014, IBM Research in Zurich unveiled a microscopic 3D printer, as shown in Figure 46. It is capable of writing nanometer resolution patterns into a soft polymer, which can subsequently be transferred to silicon, III-V (gallium arsenide -- GaAs), or graphene substrates. This technology can be applied in the creation of microchips and microprocessors.[189]

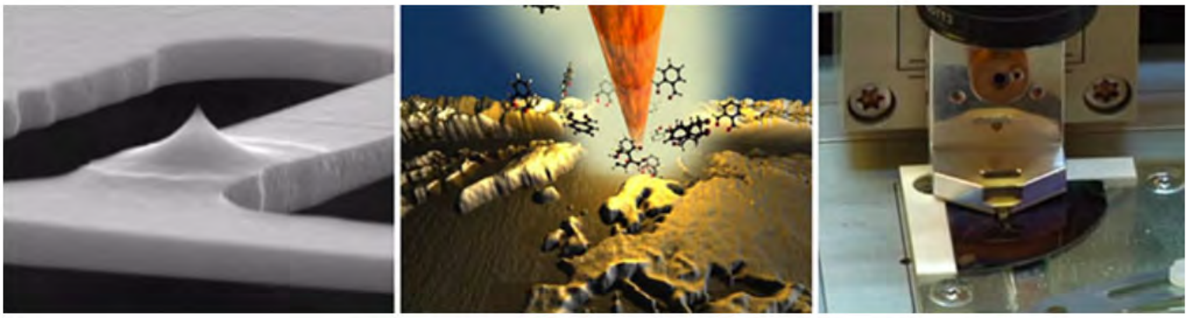

Figure 46: IBM's 3D printer to revolutionize chip prototyping

Early this year Canalys[190] announced its forecast for the fast-evolving 3D printing market. It was predicted that the size of the market, including 3D printer sales, materials and associated services, will reach US$16.2 billion by 2018.

3.7.2 Technological Requirements

3.7.2.1 Technological Requirements for Logistics

Most sensors for car automation only support line-of-sight of operation. These sensors can provide warnings and messages to the driver to increase safety. Wireless communication can complement the sensors to enable operation in non-visible scenarios, and gradually take over the act of driving our vehicles. Street parking sensors have to be self-configuring and self-healing to avoid hassle. Ultra-low-power operation is of importance since the parking sensor owners do not want to replace or recharge batteries frequently. For the city-compatible noise- and emission-reduced sensor city network more advanced sensor units are needed that measures more parameters (e.g. air quality). In the intelligent street light case, standardization of the wireless protocols is critical.

Microsoft research describes the sensing in smart cities as a Gaia organism where data is used to support governance. An example is that air and sound pollution is being monitored and the city can stimulate or discourage specific transports[191].

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[189] http://www.eetimes.com/document.asp?doc_id=1322091
[190] http://www.canalys.com/newsroom/3d-printing-market-grow-us162-billion-2018
[191] Microsoft research, http://research.microsoft.com/en-us/projects/urbancomputing/urban_computing_yuzheng_2013.pdf

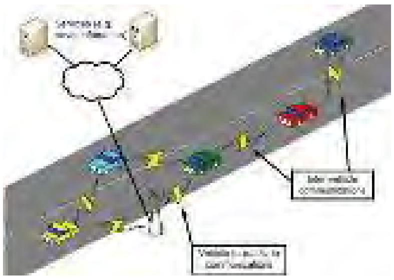

Figure 47: Logistics scenarios

3.7.2.2 Technological Requirements for Production

Starting from product design, a typical product life cycle follows different procedures, from raw material extraction & processing, product manufacture, package/distribution, product reuse/consumption, and finally till end of product life or recycled stage. In each individual stage, energy, material, and also human resource are adopted as the input, and then it is moving forwards in product manufacturing as well as generating waste. This "waste" can be in the form of energy or materials but may also appear as occupational injuries or negative social and economic impacts on the local community.[192]

In a macroscopic view, we talk about the complete value chain of production, which is a physical representation of the various processes involved in producing goods (and services), starting with raw materials and ending with the delivered product. Since value is and should be added in this chain, the initial goal of improving production is based on the ideal to maximize the added value, or to minimize the waste. In recent years, significant attentions are paid to the aspects related to environment and sustainable development, such as how to optimize the usage of resource, and how to minimize the industry pollution. In general, smart production focuses on the following aspects:

- Manufacturing efficiency
- Operational efficiency
- Resource scarcity
- Environmental protection

Manufacturers must transform their operations by automating, executing, and managing the performance of uniform global business processes across their value chain. This means end-to-end integration of processes spanning supply chain, production, maintenance, distribution, quality, and labor operations—regardless of where these facilities and operations are physically located.[193] Naturally, wireless networks provide a method to fulfil this goal by connecting the physically distributed system in a cooperating system.

[192] http://www.sustainableproduction.org/proj.SustainableProductsInitiative.php
[193] http://blogs.ec.europa.eu/orep/guide-to-resource-efficient-manufacturing/. "Guide to resource efficiency in manufacturing"

Reliable and high-quality data (see also Section 3.2.4) is the key to successful performance. It is almost impossible to imagine well-functioning processes without proper data. In the light of these simplified statements, it is amazing to notice the kind of problems due to lack of data or wrong or unreliable data caused during everyday production processes. It has been claimed that most of the disasters in modern industry are in some way caused by improper or missing data. Data quality has to be improved at sensor-level by developing self-learning, context aware and intelligent sensor networks that evaluate the measured data with other data sources. Problems related to missing data will be solved by developing ad-hoc and disposable sensors that can be used to gather critical information. Through information management plans, critical data and information from the production's point of view has to be defined. Quality of information fed into systems by humans will be improved by user-interface technologies. Using (sensor) data provided by others makes one vulnerable for errors of this data when generated or transported. Especially when the data is used, transformed and upgraded by several parties in the chain. Design for auditability provides means to get insight in the data/information chain, to reason with uncertainties of measurements. The advance in the state of the art is carried out in overcoming the different technological challenges in data quality weakness applied to many of the key industrial sectors of the European industry. Intelligent decision making systems in industrial applications have a real challenge not only in terms of their basic functional performance, but also to prove themselves in the absence of real implementations that validate the reliability and usefulness of these systems.

The ICT related technological requirements can be summarized into two categories:

Information and communication technologies

In order to benefit from big data, distributed machines, manufacturing processes, and workers should be connected seamlessly to facilitate real-time information exchange, prompt responsiveness, better decision making, and finally optimization of a highly-distributed complex system. Information and communication technologies play a crucial role here (see also Section 3.2). Both transmission and storage of massive sensing data pose new challenges to ICT. Information should be conveyed promptly and reliably, and should also be stored safely and be retrieved quickly.

New models and methods for decision making and prediction

Different from conventional industrial systems, the more complex and cooperative systems should be described by new models to have information correlation, dynamic description, and behavior prediction. Data mining of massive data sets across greatly varied platform and format involves methods at the intersection of artificial intelligence, machine learning, statistics, predictive analytics, and database systems.

ICT is the key enabler for improving a production system at three levels[194]:

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[194] Factories of the future PPP – strategic multi-annual roadmap, prepared y the ad-hoc industrial advisory group.

- *Smart factories*
  Agile manufacturing incorporating novel sensors and robotics with automatic control, planning and automation.
- *Virtual factories*
  Connected with network, production procedure and management are linked to and based on physically distributed assets.
- *Digital factories*
  Improved management and decision systems are built upon advanced simulation, modelling, and prediction methods.

3.7.3 Strategic Research & Economic Impact

Machinery and equipment production is important for Europe. When equipment are sold and assembled in the global market, the optimization of the remote maintenance and supporting life-cycle services are critical for a business success. They can be improved, and so do the OEE figures, with a change from corrective maintenance to a real life cycle business model, based on a more reliable data exchange among all the actors, devices, systems and tools involved.

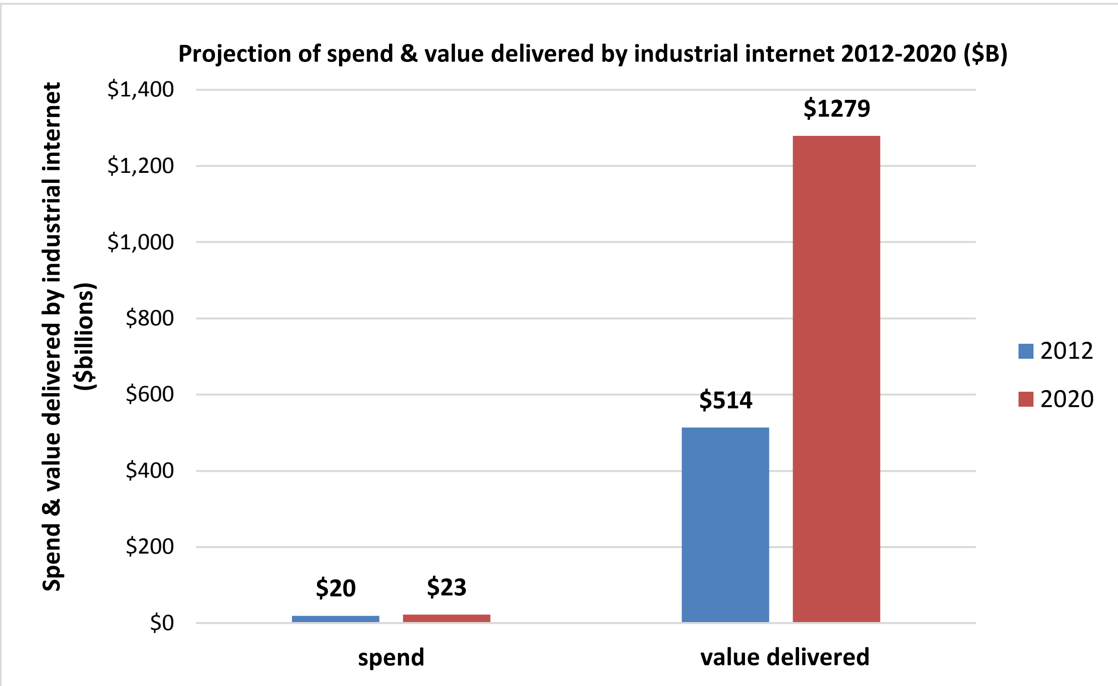

Figure 48: Projection of spend and value delivered by industrial internet[194]

Within the ProcessIT.EU collaboration, a European roadmap for industrial process automation has been developed.[195] The roadmap discusses the skilled worker issue, environmental issues, industry as part of the energy systems in a smart city, information questions, etc. With respect to semiconductor technologies, expectations are set in the

[195] Processit.eu, automation for process industries, European roadmap for Industrial Process Automation

roadmap regarding increased information transparency between field devices and enterprise-wide systems, real-time sensing and networking in challenging environments, management of critical knowledge for maintenance decision support, automation systems for flexible distributed production.

According to wikibon[196], spending on the Industrial Internet is projected to grow from $20 billion in 2012 to about $514 billion in 2020. The value created is expected to grow from $23 billion in 2012 to about $1,279 billion in 2020, shown in Figure 48.

Thanks to the cooperative information sharing, by applying intelligence to industry, significant impact can be found in both energy production and consumption sections, as shown in Figure 49. In 2011, the world produced more than 13.0 billion metric tons of energy, when converted to an oil equivalent basis (Btoe) for comparative purposes. Industry internet can be applied to all the energy production sources, and for the energy consumption, industrial internet will impact both industry and heavy-duty transport parts, which count 44% of the total energy consumption.

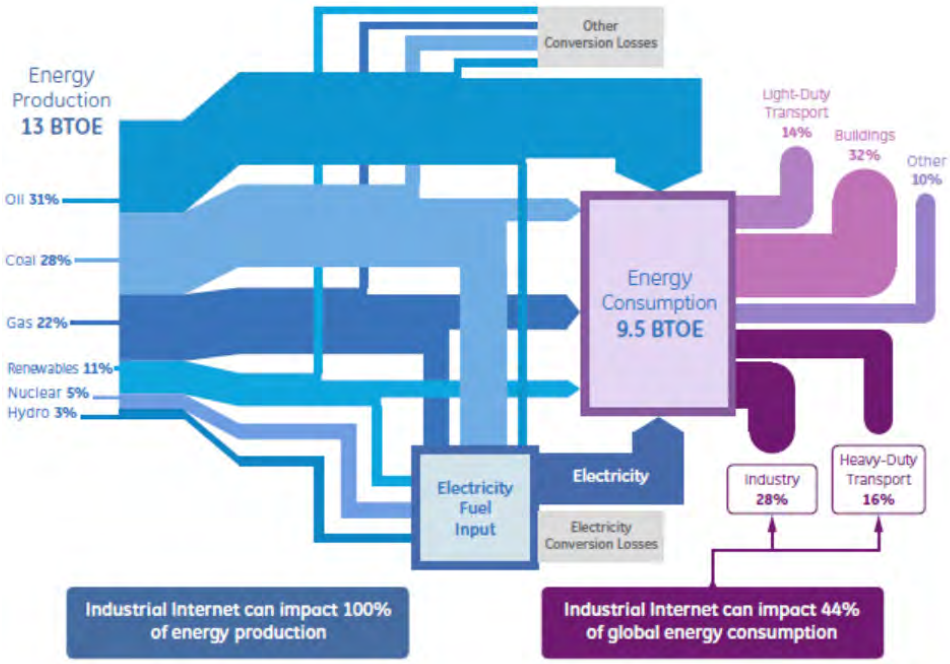

Figure 49: Global energy flows estimated by GE Global Strategy & Planning[183]

[196] http://wikibon.org/wiki/v/Defining_and_Sizing_the_Industrial_Internet

3.7.4 List of Abbreviations

Abbreviation	Explanation
Btoe	oil equivalent basis
C2X	Car-to-X… communication
DSRC	dedicated short range communications
EFFRA	European Factories of the Future Research Association
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	United States Federal Communications Commission
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning Systems
ICT	Information & Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
ITS	intelligent transportation systems
I2I	infrastructure-to-infrastructure
OEE	Overall Equipment Effectiveness
OSI	Open Society Institute
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
3D	Three-dimensional
3PL	third-party logistics providers

4 The need for microelectronics (2) - Executive Summary & Recommendations

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Aim of this study was to identify the smart cities' specific needs for microelectronics and to derive the next important steps in microelectronics research and development. It was expected to find a strong application pull which can lead the semiconductor business into the next years, but planning of Smart Cities today is still on a rather conceptional level with only a few thoughts on concrete technological requirements. Realization of today's Smart City projects is still done on the basis of off-the-shelves products. Even the attribute "Smart City" is not yet clearly defined and will be enhanced by or has to compete with "Smart Regions". Every Smart City or Smart Region will have its own specific requirements. Thus, only little concrete requests could be identified. **Application pull is still weak and is not yet a real driver.** By this, it can be derived, that the limiting factors for today's application development are product specifications of devices and components already available on the market and cost.

In contrary, technological experts have already clear expectations on what will be needed and can be achieved in future to realize applications as discussed today in an efficient manner. Technology has already started to tackle the upcoming issues like data volume and energy consumption for new applications. **New applications for smart cities are therefore being driven by technology push again.**

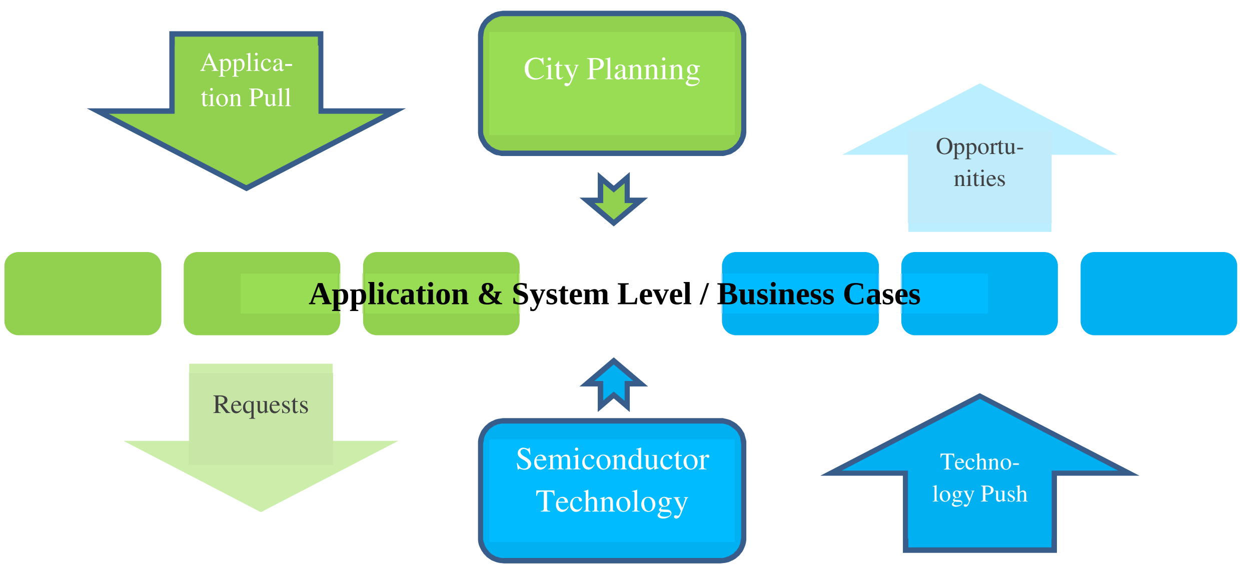

Figure 50: Application Pull and Technology Push do not yet match at the Application & System Level

In summary, although Smart Cities is a hot topic today, **a continuous semiconductor value chain for Smart Cities does not exist yet**. There is still a gap between planning and technology which becomes visible especially on the level of concrete applications / business cases. Specific needs from the planning / applications side are still unknown, and therefore cannot be met by the technological possibilities. The other way round, the technology offers are more or less unknown to the city planners. They are not fully aware of the technological possibilities. Today, there is no common language between both sides, and it is a most pressing issue to establish direct links between the semiconductor people and the city planners. To address this issue, it may be helpful to continue this study on the system level and to evaluate concrete application scenarios and business cases together with industry and city planners. Such a study has to be closely connected to the Internet of Things, because Smart Cities will utilize the same technologies and can be regarded as part of the IoT.

For realization of all the visions, stories and roadmaps sketched in the descriptions of the key area of interest, information and communication technology (ICT) will be the most important key. Taking into account the huge number of sensors which is expected to be installed worldwide (Figure 14, , page 75), *power, RF bandwidth and secure communication* will become the biggest issues in infrastructures like smart cities.

4.1.1 Information & Communication

Referring for example to the Bosch Sensor Swarm approach[107], experts expect 7 billion people served by the internet by 2017 with 1000 linked sensors per person. This results in 7 trillion sensors; a great part of this will serve as infrastructure in smart cities, monitoring everything: air quality, traffic, flow of goods, people, etc.

To build up such an infrastructure, the following issues have to be solved:

- Sensors / Sensor infrastructure with data preprocessing (CPS, “instant data”) based on zero energy sensor nodes/systems
- Miniaturization / packaging / lifetime
- Communication (-> Sensor networks) with a focus on high data rates @ low power and security issues (reliability, resilience, manipulation)

to form a new, public ICT infrastructure, connecting these sensors, transmitting and processing data and derive actions (simulation, control, inform, entertain, educate, …). Hewlett Packard[110] expects a growth of the internet data communication by a factor of 1000 by 2018, just to handle the sensor data traffic.

4.1.2 Safety / Security

A second issue is the aspect of safety & security. All means for data collection, processing and transmission must be trustworthy, reliable and secure. Data must be protected against manipulation, stealing or misuse. Privacy of information must be ensured. Safety of all measures to influence or control urban processes must be guaranteed. Moreover, while all processes in a Smart City will rely on information, the complete new information infrastructure has to be secure, reliable and trustworthy.

Although on-going standardization and industrial efforts already leverage research accomplishments achieved in the past decade, many challenges in deploying large-scale networks consisted of smart objects remain.

First, user-friendly and secure bootstrapping remains a big unknown. In that sense, out-of-band channels established by means of different technologies are often used to exchange initial parameters necessary to join a network. Researchers have demonstrated efficient bootstrapping protocols that are based on the visible light channel where the objects establish a unidirectional channel with a network gateway. Furthermore, one could imagine the establishment of a unidirectional channel from the gateway towards individual objects, leveraging for instance a light sensor available on many platforms, which would allow scalable exchange of network parameters.

Then, datagram Transport Layer Security (DTLS) protocol was designed for client-server interactions in the Internet with the server being a powerful machine with plethora of resources. Therefore, when it comes to DTLS, smart objects will run the same web server that powerful machines are running in the traditional Internet. But smart objects cannot keep open many instantaneous sessions because of their small amount of RAM. Solutions would be to require more amount of RAM and to develop more efficient protocols concerning the session lifecycle.

In order to save energy, smart objects often exploit a radio duty-cycling scheme that allows them to sleep extensive periods of time. Network latencies significantly increase in respect to those commonly measured in the traditional. Overall completion time of a DTLS handshake ranges from couple of seconds up to one minute. New approaches should be studied for more time efficient session establishment mechanisms.

Authentication, Authorization and Accounting (AAA) with billions of devices connected to the global network poses numerous technical and research challenges, as standard protocols like RADIUS or OAuth 2.0 cannot be directly applied. IETF has recently chartered a working group ACE to survey the available solutions and possibly design a new protocol that will allow a client to access a reading on a smart object (Resource Server) once granted permission by the Authorization Server (AS). The goal is to meet these requirements without the cost of high computational overhead of public key cryptography.

4.1.3 Energy

Another main issue will be the energy consumption of the ICT infrastructure. In 2006 the information technology in the US has consumed already 1.5% of the US electricity[197]. It is predicted that by 2020, 14% of the worldwide electrical energy will be consumed by the ICT

[197] D. Miller, Low energy optoelectronics for interconnects, INC10, Washington DC, May 2014

sector (corresponding to 8% primary energy) [198]. For the operation of Germany's ICT infrastructure about 40 TWh of electric energy in 2015 will be necessary, whereof 90% will be evoked by wireless communications[199].

This issue has to be tackled by using low power microelectronics and optics for sensing, processing and communication. It is also recommended to have a closer look on the wireless communication technologies, where a big potential for improvement can be seen in terms of efficient algorithms, telecommunication systems, circuits and devices.

For the further development of the semiconductor market in Europe an intensive research in semiconductor technologies is therefore indispensable. For the future energy supply of smart cities using smart grid technology mature power- and microelectronic components are required.

In future the sophisticated supply of cities with energy has to face several challenges, as the steady increase of renewable energies and their intermittent infeed to the grid, the distributed generation and the transmission of energy over long distances to urban areas and finally the efficient distribution to the costumers.

To realize the energy supply of smart cities, utilizing semiconductor components and devices, the focus of the research should lie in a comprehensive investigation of the promising new wide-bandgap materials: silicon-carbide (SiC) and gallium nitride (GaN), but also in the improvement of existing silicon (Si)- technology and in advanced circuit design.

The goal of the research must be the reduction of on-state losses, and by that the increase of the efficiency of the semiconductor components. Another recommended field of research and development is the miniaturization and the improvement of the power density and the electronic strength to enable an efficient and sustainable electronic control of the generation, transmission, distribution and consumption of energy in future cities. the miniaturization and integration, which plays and essential role in microelectronic components for energy- and battery management for local and distributed systems, goes hand in hand with the desire of increasing the power density. Overall, the efficiency of the power- and microelectronics should be the major aim of the R&D.

It is recommended to put effort in the research and development in the fields of:

- semiconductor materials,
- miniaturization,
- power density and
- efficiency.

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[198] M. Pickavet, W. Vereecken, S. Demeyer, P. Audenaert, B. Vermeulen, C. Develder, D. Colle, B. Dhoedt, and P. Demeester, ―Worldwide energy needs for ICT: the rise of power-aware networking,‖ 2nd International Symposium on Advanced Networks and Telecommunication Systems, ANTS 2008, December 2008

[199] VDE Kongress Smart Cities, 2014

4.1.4 Applications specific needs

4.1.4.1 Buildings

With respect to microelectronics and smart buildings there are the following topics, where further research is recommended:

- *Solid State Lighting*
  For solid state lighting there are four major issues. The first is the non-availability of SSL devices with high luminous output, which are needed for outdoor lighting. The second recommendation is the increase of efficiency for low cost power converters. In order to remain competitive with manufacturers outside EC it is necessary to improve all parts of SSL luminaires of which the power converters are an important part. Especially for indoor lighting the potential of control of color temperature should be addressed, which requires the integration of control functions into current lighting infrastructure (retrofit) or introduction of new lighting systems. Finally the manufacturing process must be made more flexible to meet the demands of a market of individually shaped luminaires without replaceable sources of light.
- *Sensors for Smart Home and Building Energy Management*
  For Smart Home, AAL and energy management applications sensors are needed that for example allow determining the presence and activity of people inside the building. Other sensors are needed to measure air quality or other measurands of the technical building equipment. These sensors need to be low cost, low power and must be intelligent, i.e. they can be tailored to privacy requirements in hardware and only transmit the information really needed.
- *Power Converters*
  Increased deployment of renewable energy harvesting equipment in smart building demands for highly efficient power converters and storage. The recommendations given in the chapter on energy are strongly supported from the smart buildings perspective.
- *Indoor Communication*
  High data rate applications will call for further improvement of standards like Ethernet and 802.11. For low data rate applications like energy management extremely low power, highly secure, robust and easy to deploy wireless communication systems should be developed. For all wireless communication systems the problem of coexistence of many networks should addressed by developing tools and procedures to monitor communication, manage resources (i.e. bandwidth) and resolve problems in high traffic situations.

4.1.4.2 Mobility

In order to promote and accelerate the transition to „Smart Mobility", several recommendations can be given towards the development of microelectronic devices:

- Most importantly, power semiconductor devices allowing for high switching frequencies in drive inverters and power converters are essential for the achievement of small, light-weight and reliable systems. Silicon carbide and gallium nitride are promising technologies and power devices are entering the market. However, further work is required towards both higher reliability for automotive applications and the increase of breakdown voltage. The true potential of these wide bandgap semiconductors – operation beyond 6.5 kV – are not yet commercially exploited. However, this constitutes to voltage classes encountered in electric trains, where grid voltages may be as high as 25 kV.

- Also, there is a demand for RF power transistors with cut-off frequencies beyond 10 GHz. These devices could be facilitated to manufacture RF amplifiers capable of transmitting data at higher data rates and with more parallel participants. A requirement that arises from the larger number of wireless sensors, traffic data and wireless applications associated with autonomous driving and demand-driven mobility. Similarly, car radar applications require RF devices operating at 77 GHz and beyond.
- Similarly, highly integrated sensor chips with dedicated functionality have to be developed. These sensors will likely be fabricated in Asia, but the design and implementation in systems could be based in Europe.

4.1.4.3 Production & Logistics

To successfully integrate "Smart Productions & Logistics" into a Smart City, it is recommended to focus on the following topics:

- Production is an important contributor to EU's employment and economy. According to EU industrial policy 2012[200], the EU industrial targets are ramping up the share of manufacturing and raising industrial investment in equipment from 6 % to 9 % by 2020. Smart city technology will be needed to meet these industrial targets.
- Design, maintenance and managing tasks are more and more "virtualizing" with the support of ICT technologies, and finally employees will work in virtual factories. Remote data-monitoring and actuator-controlling will be key for that, but data reliability and availability must be imperative. ICT developments should focus on these virtual factories.
- Industrial production and retail sales are two EU key industrial market drivers. This market indicates new demands for new logistics facilities, including huge e-fulfilment centers at the heart of national and regional distribution networks, local delivery centers serving individual cities and returns processing centers.

4.1.5 Next steps

The major finding of this study is that it is obviously too early for a clearly defined application pull on the semiconductor business. As a result, this study gives some hints on possible technological issues which have to be solved in the near future. For more concrete results a refinement is necessary. This refinement can be done according to the following steps:

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[200] http://ec.europa.eu/enterprise/policies/industrial-competitiveness/industrial-policy/communication-2012/index_en.htm

- Instead of focusing on technologies only, a follow up study should address the system level which may be the bridge between technological developments on the one hand and application specific needs on the other. This will help establish a communication path between the semiconductor business and the end users.
- Together with industry, real applications and business areas should be defined. Taking into account the outcome of the study, potential candidates for such applications are:
    - Zero energy sensor network for air quality monitoring
    - Logistics - Monitoring and controlling the flow of goods
    - Traffic – Sensor controlled parking management
    - Smart home – a building block on the way towards smart cities
    - Power electronics for Smart Grid and Smart Mobility
- Such a follow up study has to consider cross-cutting aspects like
    - Long lasting standards / architectures
    - Reduction of installation effort
    - Overall cost reduction
    - Miniaturization
    - Packaging / Reliability

  which could not been addressed here.