# SAVING ENERGY

## THROUGH INNOVATION AND TECHNOLOGY


A White Paper By:

Infineon Technologies
Automotive, Industrial & Multimarket Business Group


Never stop thinking

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# EXECUTIVE SUMMARY

The ability to maintain existing levels of energy services for the next 25 to 50 years is seriously challenged. It is put in jeopardy by the global forces of increasing economic activity in developing countries, geopolitical tensions in the key energy producing countries, and the threat to the environment caused by the rise in emissions and global temperatures. In the next quarter century, global energy demand and corresponding $CO_2$ emissions are projected to increase by more than 50 percent. This increase in demand is expected to be met through traditional energy sources, primarily fossil fuels (including natural gas). Liquid fuels will remain the most important fuel for transportation; most of the increase in oil supply will be met by a small number of OPEC producers, and the consuming countries will be vulnerable to supply disruptions and price shocks. Consequently, sustainability and security policies require a concerted effort from governments and industry across the globe to promote conservation and innovative energy research.

The solution to short-term growth in energy consumption can be delivered, not by creating more, but by wasting less. While carbon capture and renewable energy sources will be essential in the medium to the long term, new power electronics technologies are part of the conservation equation. They will yield improved efficiency by significantly reducing wasted energy throughout the entire energy ecosystem, from generation through transmission to consumption (End-Use).

Today the global efficiency rate for converting primary energy into useful (or transmittable) energy at power plants is about 35 percent. That efficiency rating could be increased to 45 percent by replacing existing conversion and transmission technologies with state-of-the-art semiconductor solutions (Section 1.3). In transmission and distribution, technical losses are up to 10 percent, another area which can be improved by the introduction of modern technologies and improved management practices.

- TRANSPORTATION SECTOR uses about 27 percent [Figure 1.5] of final useful energy, most of which comes from liquid fuels. Many technologies can be used to improve the fuel efficiency of vehicles by up to 40 percent, including energy-efficiency improvements in engines, weight reduction, friction and drag reduction, and the widespread use of hybrid electric vehicles (HEV) and diesel engines.
- INDUSTRIAL SECTOR uses up to 51 percent of the useful delivered energy. Energy savings of 40 – 60 percent [Figure 1.5] could be realized with the use of efficient motor systems with variable speed drives, process optimization in systems of multiple components, and improved monitoring and process control.
- COMMERCIAL & RESIDENTIAL SECTORS together make up to 23 percent of the delivered energy use. There are several opportunities to reduce the energy demand by 50 – 80 percent [Figure 1.5] through the use of efficient appliances, cooling, and lighting, as well as reduced standby losses and improved heat insulation.

Taking advantage of all the opportunities that are available for each sector has the cumulative potential for cost-effective efficiency improvements of up to 50 percent, which is the projected increase in demand in the next quarter century.

Today 33 percent of all energy consumption is in electrical energy, and is expected to grow to 67 percent by 2040 [Figure 2.1]. Power electronics is enabling technology to efficiently distribute and use electric power, and to generate electrical energy from renewable sources (wind, solar, etc.). Power electronic converters can be found wherever there is a need to modify the electrical energy form (i.e. modify its voltage, current or frequency). Many market segments, such as domestic and office appliances, HVAC, consumer digital, communications, factory automation and drives, traction, automotive and renewable energy, can potentially benefit from the application of power electronics technology. Advanced power electronics could, for example, realize savings of more than 50 percent in energy losses in converting from mains or battery voltages to those used in electronic equipment.

Infineon addresses each of these market segments and meets its requirement effectively, using its competencies and a wide array of power electronic products covering the complete power and energy management cycle for all industrial applications. In addition, Infineon is advancing its R&D efforts and delivering innovations for efficiency improvements, system miniaturization, increased quality, greater reliability, higher power density and overall cost savings.

In conclusion, the world is rapidly moving to a day when more types of energy sources will be used. Power electronics will be the enabling technology that will provide efficient, intelligent and optimal use of these energy resources, yielding a more secure, flexible and sustainable way of life.

SECTION 1:

# ENERGY AND SUSTAINABILITY

## INTRODUCTION

The underlying technologies of energy processing systems in use today were developed and evolved as a response to the requirements of society in the 20th century. Currently, this process is also shaped by the sustainability requirement, which, according to UN-adopted definition, is described as "the ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." Broad international consensus recognizes that a sustainable and reliable supply of energy is one of the major conditions for the sustainability imperative. In addition to energy supply, this section will discuss energy usage and energy efficiency, the critical parts of energy processing systems.

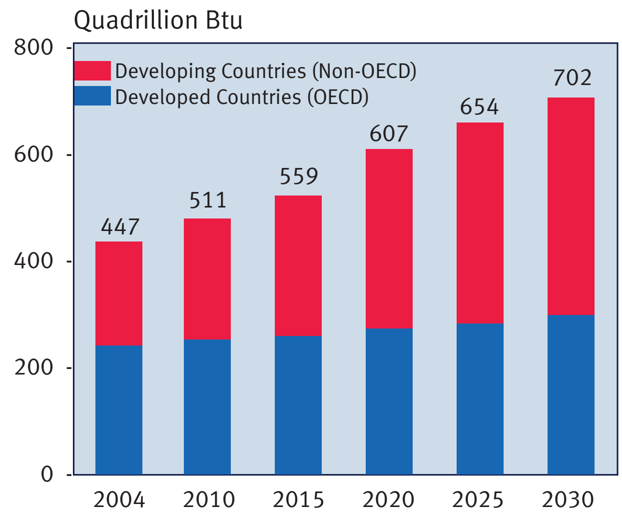
## 1.1 ENERGY USAGE AND FUTURE DEMAND

Energy demand is growing in parallel with population growth and economic expansion. According to the International Energy Outlook 2007*, projections for global energy growth include:

- Market energy consumption is projected to increase by 57 percent in the next 25 years.
- Total energy demand in the developing (non-OECD) countries increases by 95 percent, compared with an increase of 24 percent in the developed (OECD) countries [Figure 1.1].

*published in May 2007 by the U.S. Energy Information Administration (EIA)
http://www.eia.doe.gov/oiaf/ieo/index.html

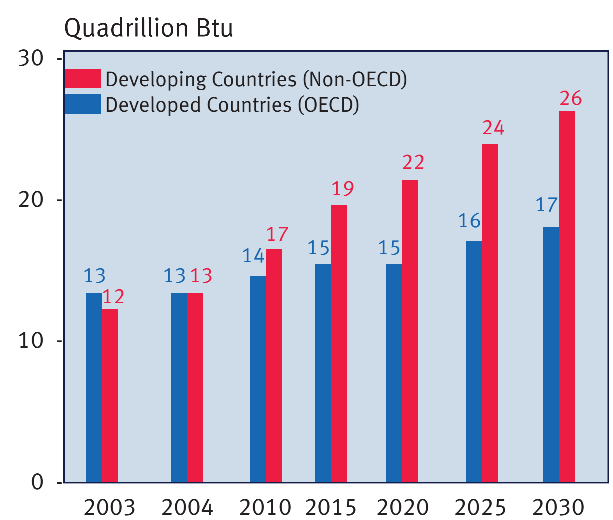
FIGURE 1.1: WORLD MARKET ENERGY CONSUMPTION, 2004-2030




Source: 2004 Energy Information Administration (EIA)
Release Date: May 2007

- During the same period, energy-related carbon dioxide emissions are projected to increase by 59 percent, from 27 billion metric tons to 43 billion metric tons [Figure 1.2].
- Emissions from developing countries are projected to exceed those from developed countries by 57 percent, and the twin forces of urbanization and industrialization will accelerate this trend.

FIGURE 1.2: WORLD ENERGY-RELATED CARBON DIOXIDE EMISSIONS BY REGION, 2003-2030




Source: 2003 and 2004 Energy Information Administration (EIA)
Release Date: May 2007

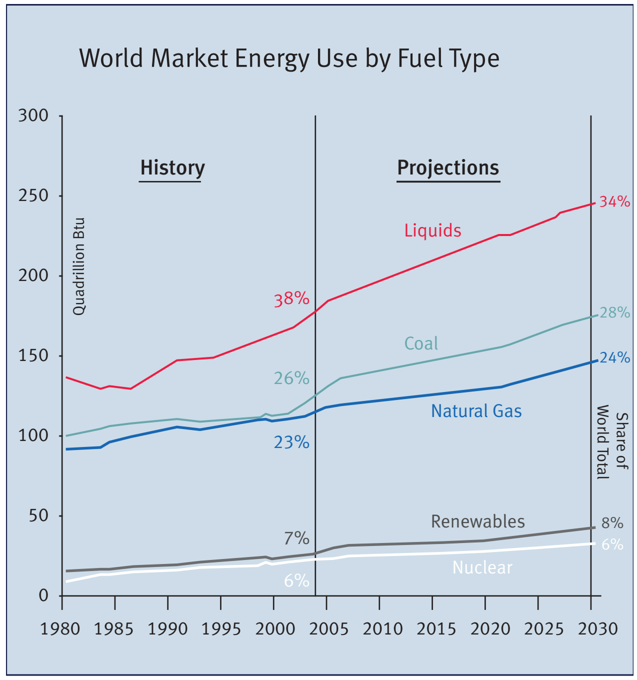
Much of the growth in energy demand is coming from developing economies in Asia, including China and India. Energy demand in this region is projected to more than double over the next 25 years and account for more than 65 percent of the increase in energy use for the developing regions as a whole.

## 1.2 ENERGY SUPPLY

Based on EIA projections through 2030 [Figure 1.3], the traditional sources of energy supply are projected to meet the 50 percent increase in energy demand over the same 50-year period–assuming that existing laws and policies remain in effect:

- Fossil fuels will continue to supply much of the increment in market energy.
- Liquids will remain the most important fuels for transportation.
- Coal is the world's fastest-growing fuel type.
- Unconventional fuel production (including biofuels, coal to-liquids, and gas-to-liquids) will account for nine percent of the world liquid fuel supply.
- Higher fossil fuel prices, energy security concerns, improved reactor designs, and environmental considerations are expected to improve the prospects for nuclear power generation.
- Finally, there are many projections up to year 2030 for the share renewables will contribute to total world energy consumption, from a conservative eight percent estimate by EIA to a 30 percent estimate by Greenpeace and the European Renewable Energy Council. Much of the growth in renewable energy consumption is projected to come from mid- to large-scale hydroelectric facilities in non-OECD Asia as well as Central and South America. This growth will also come from wind, solar and bio-mass facilities.

FIGURE 1.3: WORLD ENERGY SHARE BY FUEL TYPE, 1980-2030




Source: EIA, IEO2007

The International Energy Agency (IEA), the energy policy advisor for many developed countries, forecasts that under the current planning scenario (based on projection of the current trends with energy demand increasing by more than 50 percent and corresponding $CO_2$ emissions increasing at the same pace) the energy future we are facing today is dirty, insecure and expensive. World oil demand is projected to reach 116 million barrels per day in 2030, an increase of 38 percent from 84 mb/d in 2005. Most of the increase in oil supply will be met by a small number of major OPEC producers; non-OPEC conventional crude oil output will peak by the middle of the next decade. China will overtake the United States as the world's biggest emitter of $CO_2$ before 2010.

These trends will accentuate consuming countries' vulnerability to a severe supply disruption and resulting price shock. They will also amplify the magnitude of global climate change. It has become increasingly clear that there are severe challenges related to energy sustainability and security. Addressing this issue will require vigorous action at national levels, considerable international cooperation, substantial research and development, and innovation to implement transitions to sustainable and secure energy systems.

Although there is no single technology or solution to energy security and sustainability, according to IEA recommendations, international consensus will drive governments' need to adopt a portfolio approach to their research, development, and demonstration programs that will focus on the short-, medium- and longer-term actions:

- Short Term: Improved energy efficiency is key – it calls for strong policy actions. It includes improving the efficiency of fossil fuel power generation, including coal, as well as energy transmission and end-use.

- Medium Term: The capture and storage of carbon emissions will be essential.

- Long Term: Cost-effective renewables will be vital to sustainability.

Energy efficiency can make a major contribution to meeting the global energy demand. The following paragraphs in this section describe the energy efficiency opportunities available along the energy value-chain.

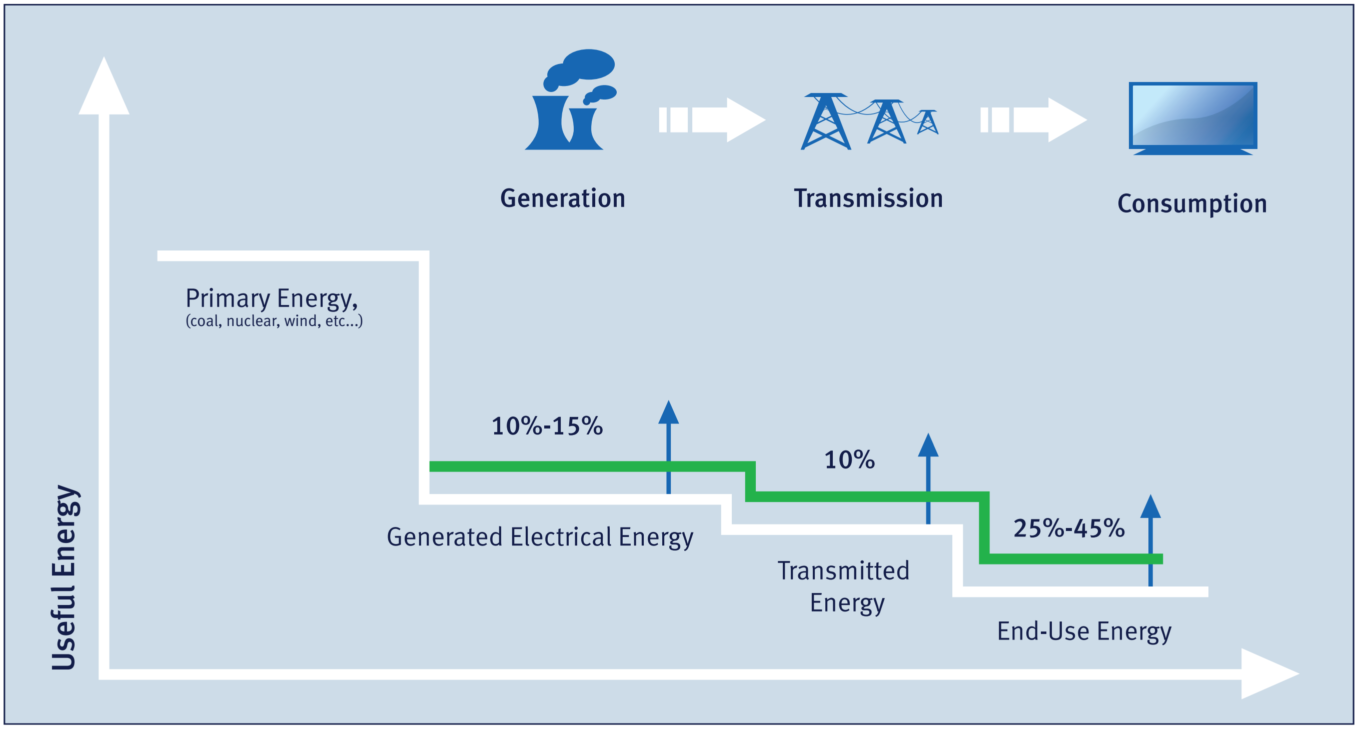
Section 2 of the paper describes the impact of wider application of power electronics on the energy value-chain. Section 3 describes the innovations in power electronics that will enhance energy efficiency opportunities.

## 1.3 ENERGY EFFICIENCY

Energy efficiency refers to the ratio between energy outputs (services such as electricity, heat and mobility) and inputs (primary energy). Energy efficiency has increased considerably since the 1970s. This improvement resulted from a response to energy price increases and supply, as well as independent technology improvements and government policies. By IEA estimates, without the energy savings achieved since 1973, energy demand in 1998 would have been 50 percent higher. However, the rate of energy savings has slowed significantly after 1990, when rapid demand growth and lower energy prices reduced focus on energy efficiency. In the last two years, energy efficiency has returned to prominence due to the dramatic increase in energy prices, threats to fuel supplies and a general consensus on the harmful impact of emissions on physical health and global climate change.

Today, the global efficiency of converting primary energy to useful energy is about one-third, according to the World Energy Council (WEC), a 94-member country organization that provides research and education on all aspects of energy consumption. In other words, two-thirds of primary energy is dissipated in the conversion process, mostly as low-temperature heat. Further significant losses occur when the useful energy is transmitted and delivered as energy services in residential, industrial, transportation, public, and commercial sectors. During the next 20 years, the amount of primary energy required for a given level of energy services could be cost-effectively reduced by 25 to 35 percent in industrialized countries. Reductions of more than 40 percent are cost-effectively achievable in transitional economies within the next two decades. And in most developing countries—which tend to have high economic growth and old capital and vehicle stocks—the cost-effective improvement potential ranges from 30

FIGURE 1.4: ROLE OF ELECTRICAL ENERGY EFFICIENCY ALONG THE ENERGY VALUE-CHAIN




Source: World Energy Council

to more than 45 percent, relative to energy efficiencies achieved with existing capital stock. Although not exactly to scale, the green line in Figure 1.4 shows the relative efficiencies achievable along the energy value-chain.

The following sections describe in detail the efficiency opportunities that exist along the three major steps of the energy value-chain of Power Generation, Transmission and Consumption.

## POWER GENERATION

By WEC estimates, energy efficiencies in power generation can be achieved by improving the availability of existing plants, or by replacing the existing power plant fleet (with an average worldwide efficiency of approximately 30 percent) with state-of-the-art technology achieving 45 percent efficiency today (Source: “Performance of Generating Plant: New Realities, New Needs,” 2004 ISBN 0 946121 19 2). Such actions would reduce global $CO_2$ emissions by about one billion tons per year, or about four percent of global anthropogenic sources of $CO_2$.

## TRANSMISSION AND DISTRIBUTION

Even the best-managed electricity transmission and distribution systems cannot operate without energy losses. These losses can be technical, such as those occurring during long-distance transmission or grid failures, or they can be non-technical, like those resulting from illegal connections to the distribution grid or non-payment for the electricity consumed. While the average worldwide losses in transmission and distribution are in the range of 10 percent, in some developing countries non-technical losses could reach up to 50 percent of the total electricity transmitted over the network (Source: WEC, “Pricing Energy in Developing Countries,” 2001). Technical losses can usually be decreased by the introduction of modern technologies and improved management practices, but it is the absence of comprehensive metering and ineffective payment systems that lead to high non-technical losses.

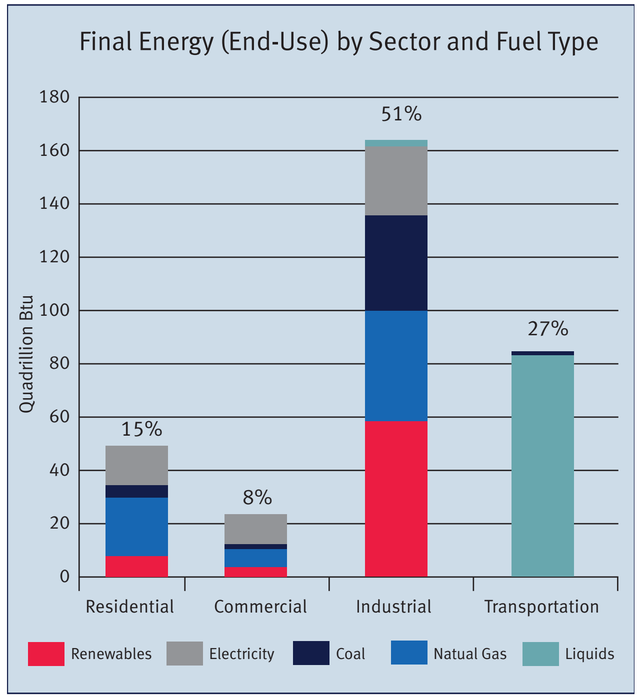
## CONSUMPTION (END-USE)

Numerous and varied economic opportunities exist for energy efficiency improvements, particularly in the final step of converting useful energy to energy services. The percentage of End-Use energy [Figure 1.5] by each of the major sectors is Industrial –51 percent, Transportation –27 percent, Residential –15 percent and Commercial –8 percent. Taking advantage of the opportunities that are available for each sector has the largest potential for further cost-effective efficiency improvements. It would mean less costly energy services and lower energy-related pollution and emissions. Sector-wise details of energy efficiency measures and the broad savings are described next.

## TRANSPORTATION SECTOR

The Transportation Sector uses about 37 percent of the final useful energy, most of which comes from liquid fuels. Demand for transportation energy is expected to grow as the developing economies add more road transport, representing more than 70 percent of the total energy demand increase in this sector. Many technologies can be used to improve the fuel efficiency of motor vehicles by up to 40 percent. Examples are energy-efficiency improvements in engines, weight reduction, friction and drag reduction, and widespread use of hybrid electric vehicles and diesel engines. The time needed for new options to penetrate the market is considerable because of the timescale for commercializing new technologies, development of new fuel supply infrastructure and the extent of replacement of the current capital stock of vehicles. So the next steps are likely to be an increasing array of hybrid options, with advanced engine technologies. In any case, almost all OECD countries and an increasing number of non-OECD countries are implementing new or revised End-Use efficiency measures for the transportation sector, adapted to their national circumstances.

FIGURE 1.5: 2004 FINAL ENERGY DEMAND IN THE WORLD BY THE MOST IMPORTANT SECTORS AND FUEL SOURCE




Source: EIA, IEO2007

## INDUSTRIAL SECTOR

The Industrial Sector uses up to 51 percent of the useful delivered energy. There are three general measures that are applicable in this sector for efficiency improvements:

- Efficient motor systems: 65 percent of the electricity use by industry is used to drive electric motor systems (EC, 1999). Use of Variable Speed Drives (VSDs), High Efficiency Motors (HEMs), efficient pumps, compressors and fans can achieve energy savings of up to 40 percent (UU, 2001). These measures could have an average payback period of three years (Keulenaer et al, 2004).

- Process optimization and integration: Process optimization and integration – or pinch – technology refers to the exploitation of potential synergies that are inherent in any system that consists of multiple components working together. The energy savings potential of 10 – 20 percent using pinch analysis (Kumana, 2000) far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation and steam trap management.

- Improved monitoring and process control: Energy and cost savings of around five percent or more is possible for many industrial applications of process control systems (Worrell and Galitsky, 2005).

## COMMERCIAL & RESIDENTIAL

The Commercial & Residential Sectors together make up to 23 percent of the delivered energy use. There are several opportunities to reduce the energy demand in these sectors:

- Efficient appliances: Implementation of the current best practice can save approximately 30 percent on the average specific energy use of appliances (Joosen and Blok, 2001). With advanced technologies, energy consumption of these appliances can be reduced by 80 percent (Cicero, 1997). The specific energy use of office appliances can be reduced by 50 – 75 percent through a combination of power management and energy-efficient computer systems (Harmelink et al, 2003).

- Efficient cooling: Introduction of current best practice cooling equipment could lead to a specific electricity reduction of approximately 40 percent. In case new techniques are used, such as vacuum insulation, specific energy savings up to 80 percent can be achieved compared to the current average energy consumption (Harmelink, 2003).

- Efficient lighting: Lighting accounts for approximately one-third of the electricity consumption in buildings (Munkejord, 2003). Energy savings options for lighting include compact fluorescent lights (CFLs) and light emitting diodes (LEDs). The savings potential for lighting is estimated to be 50 percent.

- Reduced standby losses: Standby power losses (when the appliances are "off") are on average responsible for 5 – 13 percent of the electricity use in households in OECD countries (Lebot et al, 2000). Replacement of existing appliances with appliances having the lowest standby power losses has the potential to reduce standby power consumption by 90 percent (IEA).

- Reduce electricity use during non-office hours: The electricity consumption outside of office hours is estimated by Harmelink et al (2005) to be 25 percent. By a few simple measures this can be reduced by 90 percent.

The greatest opportunity for realizing these energy savings is when consumers replace their broken appliances. On average, 20 percent of households are in the market for at least one of their major appliances every year (report by Pew Center).

# SECTION 2:

## ROLE OF POWER ELECTRONICS IN ENERGY EFFICIENCY

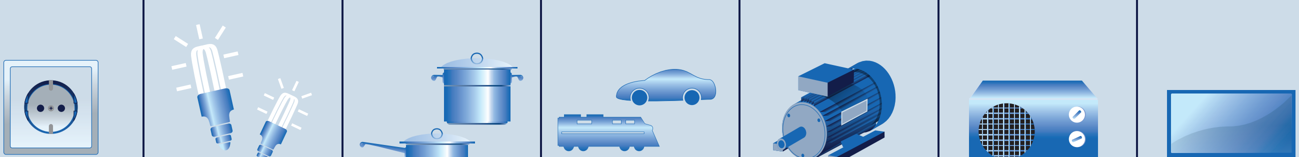
Power electronics is the technology associated with the efficient conversion, control and conditioning of electric power by static means from its available input form into the desired electrical output form. Power electronic converters can be found wherever there is a need to modify the electrical energy form (i.e. modify its voltage, current or frequency). Therefore, the power handling capability of converters ranges from several milliwatts (as in a mobile phone) to hundreds of megawatts (as in a HVDC transmission system). A power electronic converter is built around one (or more) device(s) operating in switching mode (either “on” or “off”). With such a structure, the energy is transferred from the input of the converter to its output by bursts. The power conversion systems can be classified according to the type of the input and output power:

- AC to DC (rectification): Used every time an electronic device is connected to a main supply (computer, television, etc.).
- DC to AC (inversion): Used in a wide range of applications, from small-switched power supplies for a computer, to adjustable speed motor control for HEV, to large electric utility applications to transport bulk power.
- DC to DC (conversion): Used in most mobile devices (mobile phone, PDA, etc.) to maintain the voltage at a fixed value.
- AC to AC (conversion): Used to change either the voltage level or the frequency (international power adapters, light dimmer, etc.).

Today 33 percent of all energy consumption is in electrical energy, and is expected to grow to 67 percent by 2040 [Figure 2.1]. Power electronics is *the* enabling technology to efficiently distribute and use electric power, as well as to generate electrical energy from renewable sources (wind, solar, etc.).

FIGURE 2.1: ELECTRICAL ENERGY SAVINGS POTENTIAL THROUGH POWER ELECTRONICS

| Power Supply | Lighting | Inductive Cooking | Traction Drives | Motor Control | Air Conditioner | Standby Power (TV, PC, Audio) |
|---|---|---|---|---|---|---|
| 1% Saving Potential | 25% Saving Potential | 25% Saving Potential | 20%-30% Saving Potential | 30%-40% Saving Potential | 30%-40% Saving Potential | 90% Saving Potential |
| | (By Electronic Ballast) | (Using Induction Instead of Electronic Ovens) | (Using Power Semiconductors e.g. Recuperation of Braking Energy) | (Using Inverters) | (Using Intelligent Compressor Control) | |



Source: Eupec GmbH: BVG- Berlin: Siemens / ECPE.

Many market segments such as domestic and office appliances, HVAC, consumer digital, communications, factory automation and drives, traction, automotive and renewable energy can potentially benefit from the application of power electronics technology [Figure 2.1]. Advanced power electronics could, for example, realize savings of more than 50 percent in energy losses in converting from mains or battery voltages to those used in electronic equipment. The following sections describe these savings in detail.

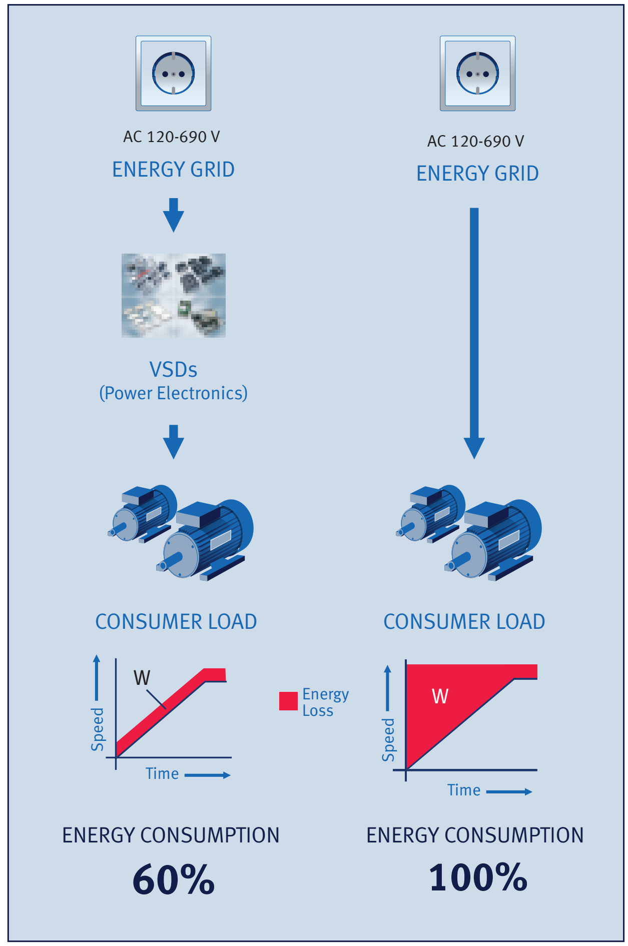
## 2.1 MOTOR CONTROL: ENERGY SAVINGS WITH VARIABLE SPEED DRIVES (VSD)

Over half of all electricity is consumed by electric motors. In industry, electric drives account for nearly 60 percent of industrial electricity consumption (Fraunhofer ISI, "Motor Challenge," 2005). These are the motors in elevators, refrigerators, air conditioners, washing machines and factories. The vast majority of these motors do not have electronic controls. Electric motion (motion excluding transportation) accounts for 80Q British thermal units. Simple electric motors (without intelligent control electronics) account for about 70Q Btu.

These simple electric motors are either fully on or fully off, which is like driving with the gas pedal pushed all the way to the floor then taking it off, over and over again. Not only is this not a good way to drive, it also turns out to be less efficient. By converting all such simple electric motors to variable speed, it is possible to cut power consumption by almost half [Figure 2.2] or approximately 40Q Btu, which amounts to 10 percent of the total energy consumption.

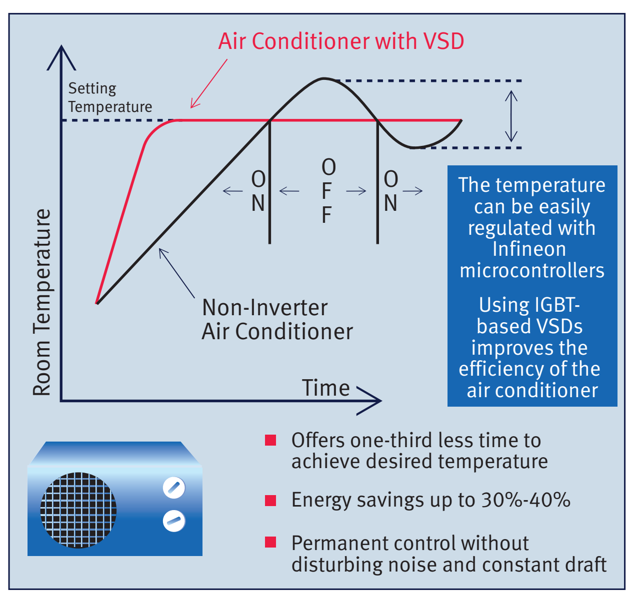
An example is the typical air conditioner [Figure 2.3], which uses a bimetallic switch to turn the motor on when the temperature gets too hot and turn the motor off when the temperature gets too cold. This method of control typically wastes half of the energy that could be saved if a modern, variable-speed electric motor were used. For a typical 20 cubic foot unit, this cuts a household electrical bill by about US$70 per year.

FIGURE 2.2: ELECTRIC DRIVES WITH VARIABLE SPEED CONTROLS




Source: ZVEI 2006

FIGURE 2.3: A/C CONTROLS WITH AND WITHOUT SMART ELECTRONICS




Source: Eupec GmbH

This savings represents approximately US$900 million of energy savings from just one motor application. Smart IC control electronics, with IGBTs transistors and some simplifications to the motion control circuitry are dramatically reducing system costs and cause an ever-faster adoption of energy-efficient electronic motor controllers.

While the evidence is compelling to the expert, the consumer cost value placed on energy savings is not as compelling. To be adopted, variable-speed electric motors have to offer a significant and tangible benefit.

**VSDs IN TRANSPORTATION: HYBRID ELECTRIC VEHICLES**

The transportation sector, using about 27 percent of the end-use energy, relies heavily upon petroleum-based liquid fuels. This is likely to increase as the global number of vehicles is expected to grow to 1.2 billion vehicles by 2020—from the current 750 million vehicles—as the developing economies add more road transport.

In a typical road transport vehicle, only 25 percent of the energy contained in one unit of oil when burned is used for mobility and accessories; the rest is wasted in the form of exhaust heat (40 percent), cooling (30 percent), friction and radiation (5 percent).

While in motion, energy is also wasted in braking, idling, and in stop-and-go traffic. Hybrid Electric Vehicles work on the principle of recapturing this wasted energy with an electric motor (acting as a generator) and storing the energy in the battery for later use. Along with saving energy, HEVs have other advantages over conventional vehicles.

However, the benefits provided by HEVs are heavily dependent on the type of the HEV system [Figure 2.4]. The larger the size of the electric motor and the energy storage system, the higher the functionality and fuel efficiency (FE) benefit.

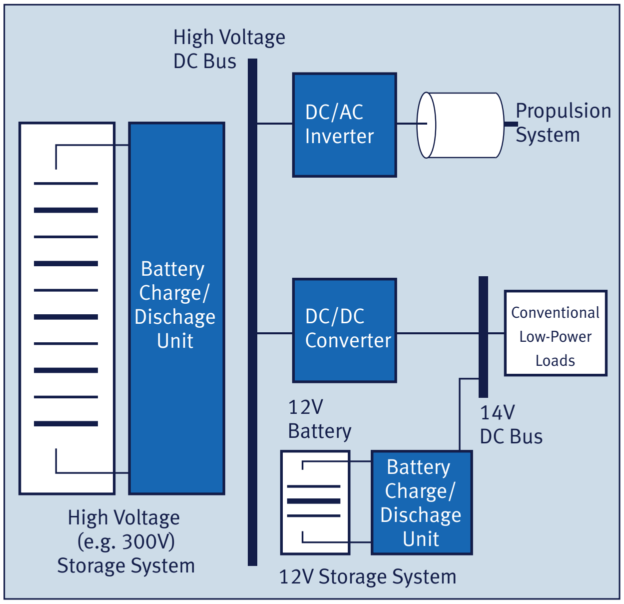
One process that is common across all the HEV systems is the conversion, storage and later usage of energy. Power Electronics is the enabling technology that makes this process possible. A High Voltage (HV) DC line runs from the battery to the sub-systems and the components of the HEV system [Figure 2.5].

An inverter will convert direct current (DC) from the car's batteries to alternating current (AC) to drive the electric (traction) motor that provides power to the wheels. The inverter also converts AC to DC when it takes power from the generator to recharge the batteries.

FIGURE 2.4: HEV SYSTEMS, FUNCTIONS AND FE IMPACT

| HYBRID SYSTEM | VOLTAGE LEVEL | HYBRID LEVEL | ENGINE STOP/ START | ENGINE ASSIST | REGENERATIVE BRAKING | ELECTRIC LAUNCH | FE (PERCENT) |
|---|---|---|---|---|---|---|---|
| **Conventional (Gasoline)** | | None | Possible | No | No | No | 3 |
| **Stop/Start Hybrid** | 14V | Micro | Yes | Minimal | Minimal | No | 5 |
| **Crank-ISG "Mild" Hybrid (Saturn Vue Greenline)** | 42V | Mild | Yes | Modest | Modest | No | 8-12 |
| **"Medium" Hybrid (Honda Civic)** | 144V | Medium | Yes | Yes | Yes | No | 30-40 |
| **"Full" Hybrid (Toyota Prius, Ford Escape)** | 300V | Full | Yes | Yes | Yes | Yes | 40-55 |

Figure 2.5: HEV DC Bus




## 2.2 ENERGY EFFICIENCY IN LIGHTING APPLICATIONS

Electric lighting accounts for approximately 15 percent of the world's total electrical energy consumed. A large part of this is attributed to the roughly 11 billion incandescent lamps in the world today.

Incandescent bulbs work by using electricity to heat up the wire causing it to glow and produce light. Unfortunately the heat comprises about 90 – 95 percent of the electricity and only 5 – 10 percent is emitted as useful light. A much more efficient way to create light is to use fluorescent lamps. Here, smart electronics (electronic ballasts*) convert and then regulate the flow of electricity through the glass tube. Fluorescent lamps equipped with smart IC technology use approximately one-fourth of the energy of incandescent bulbs; a 23-watt fluorescent lamp is comparable to the light from a 100-watt incandescent bulb.

Another technology that has been appearing in more new lighting products is the LED. By directly converting electricity to light with bright LEDs, the efficiency improves to between 28 – 60 percent vs. 5 – 10 percent for incandescent bulbs [Figure 2.6]. New technologies like silicon carbide light emitting diodes (LEDs) are lighter, more flexible, and offer even more energy savings. These devices also last longer than incandescent bulbs by a factor of 25 or more.

FIGURE 2.6: COMPARISON OF LIGHT INTENSITIES

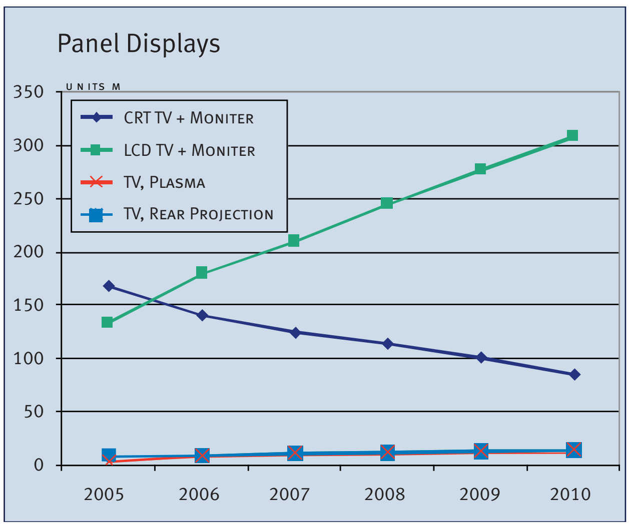
| Light Source | Lumens/watt |
|---|---|
| Incandescent | 9 Lumens/watt |
| Compact Fluorescent | 22 Lumens/watt |
| LED | 58 Lumens/watt |

** Electronic Ballasts in FL or CLF are 25% more efficient than traditional 'iron' or transformer-based ballasts. These devices are basically switching power supplies with an integrated high-frequency inverter/switcher. Properly designed electronic ballasts should be very reliable. Since these ballasts include rectification, filtering, and operate the tubes at a high frequency, they also usually eliminate or greatly reduce the 100/120 Hz flicker associated with iron ballasted systems.*

## 2.3 ENERGY EFFICIENCY IN INFORMATION TECHNOLOGY

The broadband revolution is a major computer-based transformation, on par with the birth of the personal computer and the rise of the Internet. Broadband refers to a communication channel that has high bandwidth, or equivalently, can transfer a lot of information very quickly. There are only 700 million personal computers in the world, and there are 1.6 billion TV sets in the world [Figure 2.7].

FIGURE 2.7: FORECAST FOR CRT AND FLAT PANEL DISPLAYS

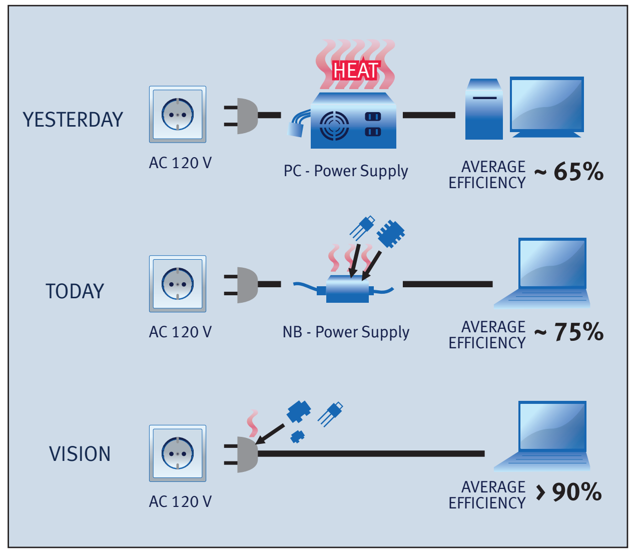



Source: Gartner, November 2006

As usage of on-demand content grows, the shift to broadband digital media will lead to a large migration to digital TV, which in turn will lead to much greater energy demand. A large screen HDTV set uses approximately 2.5 times more power than an analog TV made in 2000 (500 W/year vs. 200 W/year). In addition, more Internet bandwidth directly increases the sales of servers (a multi-processor computer with large disk space), routers, and switches (these last two electronic devices are used to move information around on the Internet). Also, when these devices are "off" they are still "on;" they require what is called standby power. Standby power alone accounts for about 10 percent (or 50W – 100W for a typical home) of the wasted power in power supplies (a power supply is the unit in these devices that converts the utility electricity into a form that is useful for the electronic circuits).

Power electronics enable the manufacturers of the power supplies that drive consumer electronics and computer servers to increase the operating efficiency of these supplies by more than 95 percent [Figure 2.8] and reduce the standby power that provides "instant-on" capability.

FIGURE 2.8: STANDBY POWER EFFICIENCY USING POWER ELECTRONICS




## 2.4 POWER ELECTRONICS IN RENEWABLE ENERGY SYSTEMS

The projected increase in worldwide energy demand and concerns for energy security and the environmental impact of $CO_2$ emissions are increasingly motivating the use of renewable energy systems, like solar and wind power plants. These systems are sustainable and can be used locally, especially for residential and commercial customers.

SOLAR POWER SYSTEMS are being used in systems that generate a few kilowatts (such as a system on top of a one-family house which is enough to cover the family's electricity needs) all the way up to several-megawatt plants. One of the world's largest solar power plants is planned to be built in Germany. With an installed power of 40 MW it will deliver the electricity for approximately 20,000 households.

A SINGLE WIND POWER SYSTEM can already produce power output up to 7 MW. Large systems like this are specialized for offshore installation in coastal areas. The economical and efficient transmission of the energy over long distances (from the ocean to the coast) can be realized by FACTS (Flexible AC Transmission Systems) and HVDC systems (High Voltage Direct Current).

New technologies like hydrogen fuel cells, ocean energy systems, biogas power plants and solar thermal power plants will be the challenge of the future and will increase the variety of sustainable energy sources. Power semiconductor devices, in particular IGBTs, play a critical role for the realization of all of these decentralized energy generation systems.

Power semiconductor devices play a critical role for the realization of all of these decentralized energy generation systems. They enable connection of an individual energy generation system to the general power network or grid and ensure a high quality of network voltage and frequency (basic quality properties of electricity). Based on the application, the power semiconductors range from 0.5 kW all the way up to 5 MW. Typical residential and commercial solar power systems range from 2 kW up to 1 MW, wind power systems from 10 kW up to 5 MW, hydrogen power stations up to several megawatts.

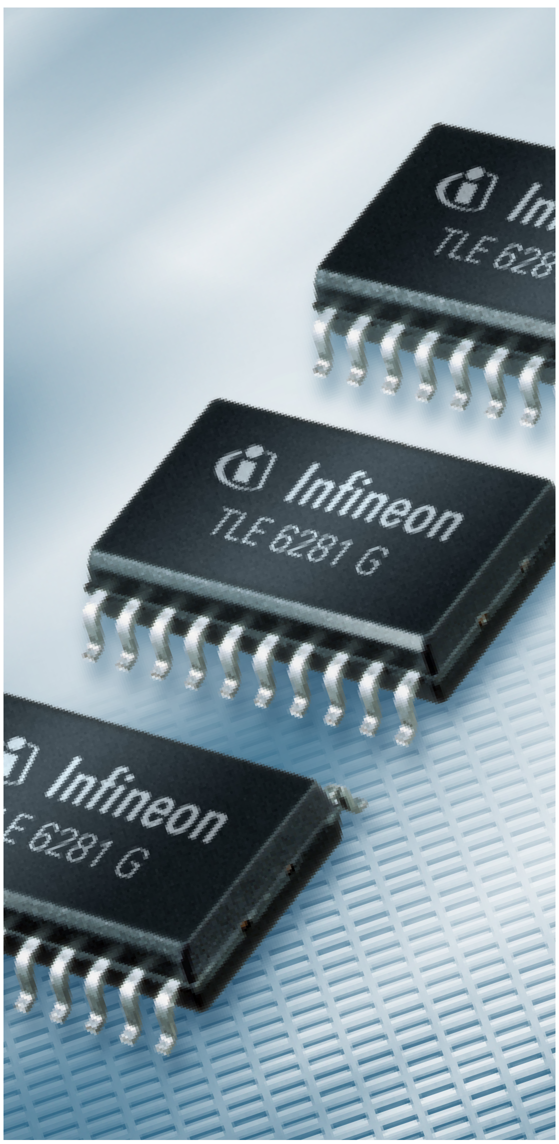
Infineon power semiconductors include light and electrical triggered thyristors, diodes with currents ranging from 10 A to 4,000 A and voltages from 200 V to 9,000 V as well as all types of IGBT modules, from 6 A to 3,600 A and voltages from 600 V to 6,500 V. Additionally, we offer complete Bipolar and IGBT stacks and assemblies, like the new PrimeSTACK, a complete switch assembly for power electronic circuits containing all the necessary components for current, voltage and temperature measurement, based on the proven 62mm IGBT modules. These devices are all used in the power supplies and electronic conversion equipment which manage our electric energy use.

FIGURE 2.9: POWER ELECTRONICS APPLICATIONS FOR RENEWABLE ENERGY SYSTEMS

# SECTION 3:

# TECHNOLOGY DEVELOPMENT AND INNOVATION

Section 2 discussed the role of power electronics in the energy efficiency spectrum of applications. In this section, we discuss the key technologies involved in power electronics applications, Infineon's position in supplying these technologies, and the future trends in power electronics technology.




## POWER SEMICONDUCTOR TECHNOLOGY

Production of the "analog" chips used in power electronics is a specialized process that is very different from the more widely known "digital" chips, such as computer memory and logic ICs. Analog circuits process continuous signals (these have many different voltage levels, while digital chips process signals that have discrete levels, two voltage levels that represents either "on" or "off").

For smart power and analog the key competencies required are:

- Analog (linear) design: This kind of design is dependent on a deep understanding of the relationship between the integrated circuit design elements and the goals of the device.
- Materials science: The electrical properties of the integrated circuit are defined by the physics of the materials used, which often are not the materials used in the "standard" or digital CMOS-integrated circuit products.

Examples of power semiconductors include products such as the CoolMOS® MOSFET transistor technology. In this product family, Infineon design innovation circumvents what engineers had previously called "the silicon limit," a characteristic of the material that limited performance of MOSFET transistors.

A second example is power diodes based on silicon carbide (SiC). SiC was previously used to make integrated circuits, but was abandoned for easier-to-process pure silicon. Advances in technology and design, many led by Infineon, have made SiC very useful in power supplies. These power supplies are used in computers, communication equipment, TVs, audio equipment, and other electronic devices.

Infineon innovations in the field are driven by commitment of resources, including large R&D expertise and investment in its own manufacturing (unlike standard digital chips, tight control over processes is a key competitive element).

## HIGH VOLTAGE (HV) MOSFET

This technology features an on-state resistance (resistance is one figure of merit for these devices, lower is better) that, in a given package, is approximately two-thirds that achieved by the established and previous generation of CoolMOS® superjunction technology, and is just one-fifth that of conventional MOSFET transistors.

The ideal high-voltage switch for use in electronic power supplies would theoretically have no resistance when conducting electricity, and would prevent any electricity from flowing when the device is "off," or not conducting. While the ideal device is "off," it wouldn't be sensitive to very high voltage in the circuit—it "blocks" very high voltage. In practice, these ideal qualities prove to be impossible. For most manufacturers of these devices, doubling the voltage-blocking capability typically leads to an exponential increase in the on-state resistance, a physical effect often referred to as "the silicon limit for performance."  The new CoolMOS® CS/CP devices are based on a new internal structure that overcomes this limit.

The innovative process technology of the CoolMOS® CS/CP MOSFET generation gives an industry-leading on-state resistance as low as 45 mΩ (in a standard package), yet still provides blocking of up to 600 V.  What this means is the low resistance improves power supply efficiency (as much as 20 percent, depending upon power supply type), which helps lower system costs by increasing output power for a given amount of loss, not to mention the obvious energy savings.

## IGBT TECHNOLOGY

For all motor drive application areas in industry and traction (e.g., electric trains), Infineon develops and produces IGBT chips and the various required packaging configurations (IGBT modules) to support application requirements.

Beginning from early efforts in IGBT technology development, the requirements concerning power electronic components have increased substantially, leading to new product development by Infineon. These developments led to new Trench/FS (Field Stop) IGBT and latest generation EMCON diodes, optimized with regard to their losses and more closely adjusted to the respective application conditions to achieve a higher efficiency level. Today's range includes IGBT devices from a few amperes only up to several thousand amperes and voltages from 600 V to 6,500 V.

Today, Infineon power semiconductor products form an essential part in industrial, traction and other applications where high power needs to be controlled and conditioned. These range from single components in discrete housings to highly integrated power semiconductors in module configuration.

## 3.1 INFINEON'S INNOVATIVE NEXT GENERATION TECHNOLOGIES– SILICON CARBIDE-BASED COMPONENTS: SCHOTTKY LEDS, AND MOSFETS

As noted earlier, SiC was previously a material used to make integrated circuits, but today easier-to-process pure silicon is the most popular chip-making material. Advances in technology and design, many led by Infineon, have made SiC very useful in power supplies.

SiC can withstand voltages eight times higher than pure silicon. It can also conduct current up to 100 times more freely and its extraordinary thermal conductivity is better than even gold (gold is the best thermally conductive metal). Thermal conductivity, the ability of electronic circuits to get rid of the heat they produce, is an important design consideration when these devices are engineered. A phenomenon known as current leakage is typical in all semiconductors, but is becoming a very inconvenient problem in today's microprocessor integrated circuits due to the reduced size of their geometric structures. On the other hand, SiC leakage is 16 orders of magnitude less than silicon, and rises far more slowly at higher temperatures. These characteristics improve the ability of SiC devices to help save energy.

For example, an SiC DRAM (computer memory chip) would hold its charge for about 100 years. A Pentium® microprocessor manufactured with SiC, could boost clock speeds to 75 GHz, or three times faster than the physical limit of silicon alone.

Infineon is ahead of other semiconductor companies and has already created SiC Schottky diodes, which can run 10 times faster or occupy 1/10th the space of a similar silicon-only circuit. An electric utility level power switch built out of SiC would shrink the module from the size of a small truck to that of a breadbox.

Today's second generation SiC Schottky diode, in concert with CP series MOSFETs, allows power supplies to operate 500 – 1,000 percent faster than the silicon units they replace. At the same time, both current and voltage overload tolerance have been improved by a factor of several times. Presently, SiC materials are used in bright LEDs and ultra-fast diodes, however, both JFET (a JFET is a junction FET and similar to a MOSFET) and MOSFET transistors are in development using this technology. The material characteristics of SiC pose new challenges for the fabrication of MOSFETs, but the potential efficiency payoffs in applications such as photovoltaic converters and hybrid vehicles are driving R&D. Existing JFET prototypes show conduction behavior (at blocking voltage of 1,800 V) over two orders of magnitude better than the best available silicon-based technologies, with operating temperature capability limited mainly by existing packaging technologies, not the wafer material limits, as is the case with silicon. This is a direct consequence of SiC being more thermally conductive than silicon, and having a much higher intrinsic temperature.

**IN SUMMARY, INFINEON PROVIDES:**

- Leading edge technology and an innovative, broad product portfolio covering the complete power and energy management cycle.
- System expertise with broad application competence and 50 years of experience in industrial semiconductors.
- Excellent quality in products and processes, producing highly reliable products for all industrial and transportation applications.
- Market leadership in the Standard Power Modules Market, the basis for energy efficiency and mobility (number 1 in USA, number 2 worldwide, and number 1 in Europe).

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