POSITION PAPER

DESIGNING LEAN, GREEN SILICON MACHINES

ONE OF THE MOST IMPORTANT ENGINEERING CHALLENGES OF OUR TIME

cadence™

INTRODUCTION

Everyone loves solar energy. It's clean, renewable, and delivered free daily. However, it took millions of years for green plants to store the solar energy in the 1000 billion barrels of oil that existed on Earth when humans drilled the first oil well in 1858. Since then, we have burned up 750 billion of those barrels, and most of that consumption occurred in just the last 25 years. Together with burning coal, this rush to toss fossil fuels onto the bonfire has also released more carbon dioxide than the world's oceans and forests can handle, trapping the sun's rays in the atmosphere like greenhouse glass and leading to the climate change that now threatens everything from crops to coastlines. This is why finding ways to cut energy usage is one of the most important engineering challenges of our time. Cadence is at the forefront of this effort, developing new technologies to help engineers create green chip designs for energy-efficient electronic products.

SEMICONDUCTORS: THE SILENT CONSUMPTION ENGINES

Electronics dates back only about 100 years, to the invention of the vacuum tubes like those used in early radio transmitters. But electronics really got off the ground in the last half century with the invention of the semiconductor, which sparked such innovations as palm-sized transistor radios that people could carry with them on the go, or bantamweight computers that rockets could carry to the moon.

From mobile phones with built-in video cameras to cars that know how to steer out of a skid, the power packed in tiny semiconductor devices has spawned a lifestyle revolution. The combination of low-cost, high-performance personal computers and the Internet also gives us unprecedented access to virtually limitless entertainment and information. Unfortunately, our newfound electronic lifestyle consumes an amazing amount of electricity. Take for example, the Web servers and database computers required to maintain the popular online fantasy world *Second Life*. Considering the power consumed by those machines along with a player's PC, a recent estimate put the energy use of a *Second Life* avatar on par with the average real person in Brazil.

Still, silicon chips are remarkably energy-efficient. Compared to crude "electrical" devices such as the heating coils used to bake our daily bread, the power consumption of solid-state electronic products like cordless phones is a bargain.

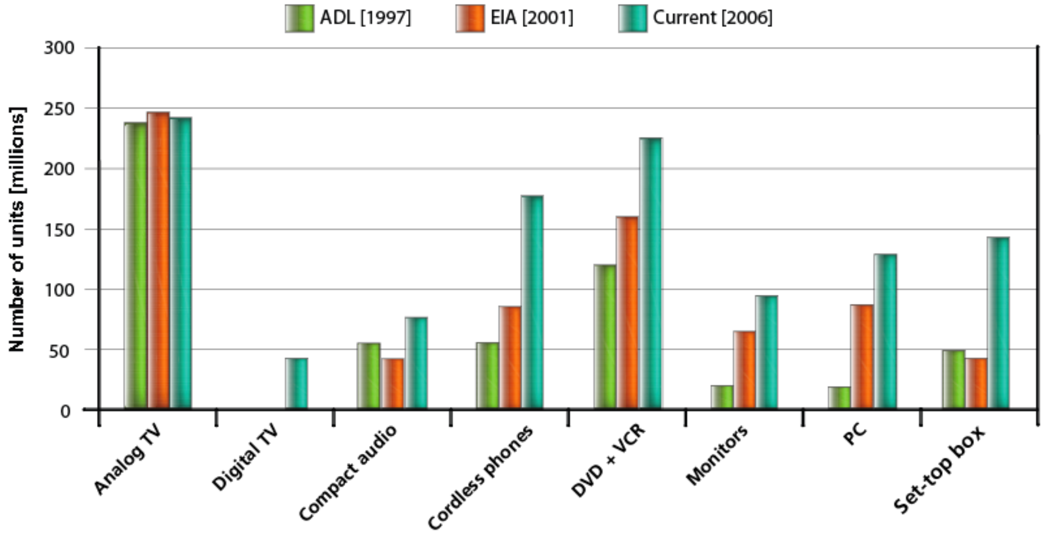
PART OF THE SOLUTION

Chips also can help to save energy everywhere from office space to outer space. Intelligent buildings that use digital thermostats and electronic controls to increase the efficiency of lighting and heating-and-cooling systems offer the promise of reducing the energy footprint of commercial buildings in the U.S. by nearly 30 percent. Using electronics to improve the efficiency of electric motors around the world could also reduce CO_2 emissions by 200 metric megatons in China alone, which is as much as the Netherlands produces annually. And in the sky, satellites already use a variety of electronic sensors to predict weather patterns so that energy-producing resources can be allocated more efficiently.

Chips are also driving efficiencies in one of the most notorious consumers of fossil fuels—the car. Until the 1960s, a radio was the only significant piece of electronics in an automobile. Today, an array of onboard microprocessors enable cars to burn less fuel with techniques such as optimizing gear shifting in automatic transmissions or controlling the number of cylinders that fire in the engine. Or, even more dramatically, computers and communications can keep people out of their cars altogether by enabling telecommuting.

TOO MUCH OF A GOOD THING

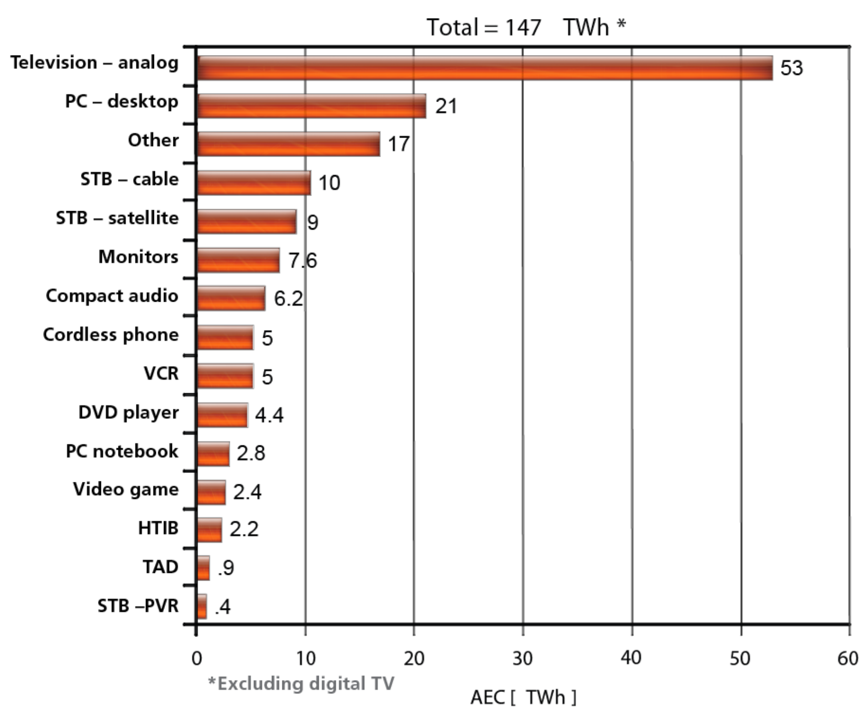
However, the problem has become a numbers game. The appeal of electronic gadgets has hooked consumers as well as business and government users around the globe. Today, billions of people use a dizzying array of electronics technologies and products, and it seems neither life nor commerce could function without the Internet.



Gadgets galore—More people around the world are using more electronics than ever before

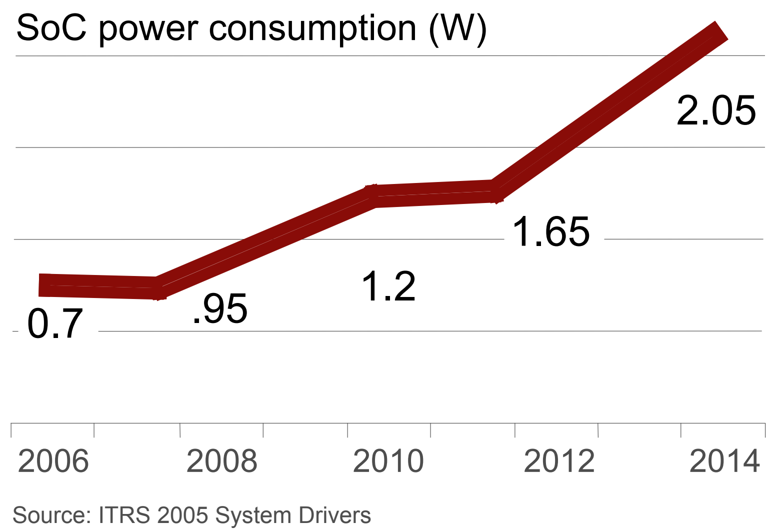
The power consumed by these devices quickly adds up. A typical desktop computer consumes anywhere from 60 to 250 watts, depending on its configuration, while a 17-inch LCD display uses around 35 watts. Then consider the systems that are not typical. Adding a high-end graphics card used to create the lifelike images enjoyed by computer gamers can easily double the power consumption of a system. At full throttle, the latest ATI Radeon HD 4870 X2 graphics card can consume a hefty 250 watts on its own.

Now multiply this by the billion PCs currently in use. Then add to this the billions of people around the world still waiting to get their hands on a mouse. Forrester Research predicts a dramatic growth in PCs, particularly in emerging markets, with a worldwide compound annual growth rate (CAGR) of more than 12 percent between 2003 and 2015. This means that the number of PCs in use will rise to two billion by 2015.



It all adds up—Power consumption of consumer electronics

Another consideration is the number of transistors that electronics companies are squeezing onto each silicon chip. Integrated circuits in the early 1960s typically contained only tens of transistors. By comparison, it is not uncommon for today's high-end chips to employ more than a billion transistors. In June 2008, for example, NVIDIA released its new GeForce GTX 280 graphics processing unit (GPU) containing 240 processor cores—and packing a whopping 1.4 billion transistors. Similarly, Intel recently introduced a quad-core microprocessor code-named Tukwila, which integrates more than two billion transistors. While these smaller and more densely packed transistors use less power individually, the skyrocketing numbers cause chips to consume more power and generate more heat.



Power surge—Rising power consumption of system-on-chip integrated circuits affects most modern electronic products–consumer and industrial

DATA DELUGE

In addition to ubiquitous electronics visible everywhere from living rooms to trading floors to airliner cockpits, there's another power hog lurking behind the scenes—data. International Data Corporation (IDC) estimates that approximately 160 exabytes (an exabyte equals a thousand billion gigabytes) of digital information were created, captured, and replicated worldwide in 2006. This includes all the zeroes and ones that make up the photos, videos, e-mails, Web pages, instant messages, phone calls, and other digital content flowing around the world. One way to grasp this huge number is to imagine three million times the information contained in all of the books ever written; or picture twelve stacks of books, each reaching from the earth to the sun. Now consider that the total amount of data in the world is currently believed to be doubling every eight months.

All this data has to live somewhere. Around the world, data centers—sometimes the size of city blocks—house countless computers, storage devices, communications networking equipment, and Internet servers. Whether it's online gaming or online flight reservations, when called upon to store and retrieve data, these electronic devices not only use enormous amounts of energy, they also give off tremendous amounts of heat, which in turn requires huge outlays of energy to cool the data centers. IBM, for example, must cool eight million square feet of servers.

Despite how things appear to casual Internet users, none of this storage and retrieval is free. When someone types a query into a search engine such as Google, huge numbers of servers sift through mountains of data stored in data centers around the world. In fact, each Google search consumes an average of 4.5 watts of electricity, and Google is easily processing 400 million queries a day. This equates to 1.8 billion watt-hours of energy being used daily to handle basic search queries alone. On top of this, Google is processing petabytes (a petabyte equals a billion gigabytes) of data on a daily basis while performing other activities, such as indexing billions of Web pages.

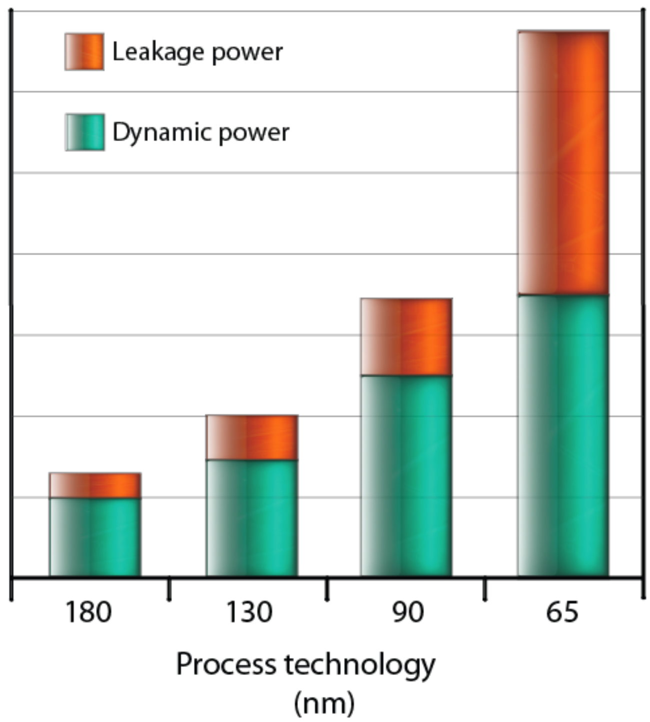
Typical data center—Half of its energy to run computers and the other half to cool them

To put this in perspective, it is estimated that data centers accounted for 61 billion kilowatt-hours of electricity, or the energy consumed by approximately 5.8 million average U.S. homes. This places an additional load on the nation's power grid of around 7 gigawatts, which is roughly equivalent to the total output of 15 power plants. In fact, unless something is done to reduce the energy consumed by data centers, it will be necessary to construct an additional 10 power plants by 2011 solely to support data center operations.

With all this need for power, it's no wonder Google has built a huge data center close to the hydroelectric power of the Columbia River, transforming a factory formerly used for extremely power-intensive aluminum smelting. As a dramatic signal of Google's recognition of future data center power and cooling needs, the company recently filed a patent for floating data centers, which according to the patent application would be "anchored in a water body from which energy from natural motion of the water may be captured, and turned into electricity and/or pumping power for cooling pumps to carry heat away."

SOMETHING STRANGE HAPPENED ON THE WAY TO THE NANOCOSM

Another factor influencing the growing energy consumption of electronics is the physics of making things tiny. Not long ago the size of the components on a chip was measured in microns, or millionths of a meter. But in order to give customers the increasing power and functions they demand—and at the same price point—semiconductor makers have had to dramatically shrink the size of the components so that they can fit more circuitry onto the same tiny sliver of silicon. Consequently, the components on today's advanced chips are often measured in nanometers, or billionths of a meter. Unforeseen physical effects found in these Lilliputian manufacturing processes give chip designers a whole new set of headaches.



A small problem—As the components on chips become tinier, the percentage of energy wasted through leakage grows

One of the biggest challenges is power leakage. For example, at 90 nanometers, the insulating layer on the chip's gates becomes so thin that electrons easily find an escape route. As a result of this electric current flowing unproductively, unless engineers take pains to design in power-saving techniques, today's chips can consume almost as much power while idling as they do operating at full throttle. This not only wastes huge amounts of electricity but also makes the devices run hotter, which can affect reliability and require the use of heat sinks or other expensive packaging, or noisy, energy-consuming cooling fans.

Compounding the energy waste of today's chips is the fact that most microprocessors and their support chips are, on average, being used only 10 to 20% of the time. The rest of the time they are idling, but they are still consuming power. And similar to the way a V8 consumes more gas than a 4-cylinder engine, the bigger the processor, the more power it consumes, even when it is not actually doing anything useful. Consequently, of the $250 billion spent powering computers worldwide in 2006, only about 15% of that power was actually spent computing—the rest was wasted idling.

Furthermore, it is estimated that 40% of the energy used to power the electronic systems in the typical American home is consumed while these devices are turned off. This is because most of today's TVs, set-top boxes, and other electronic devices are never really "off," but simply powered down in a type of sleep mode, which continues to draw power.

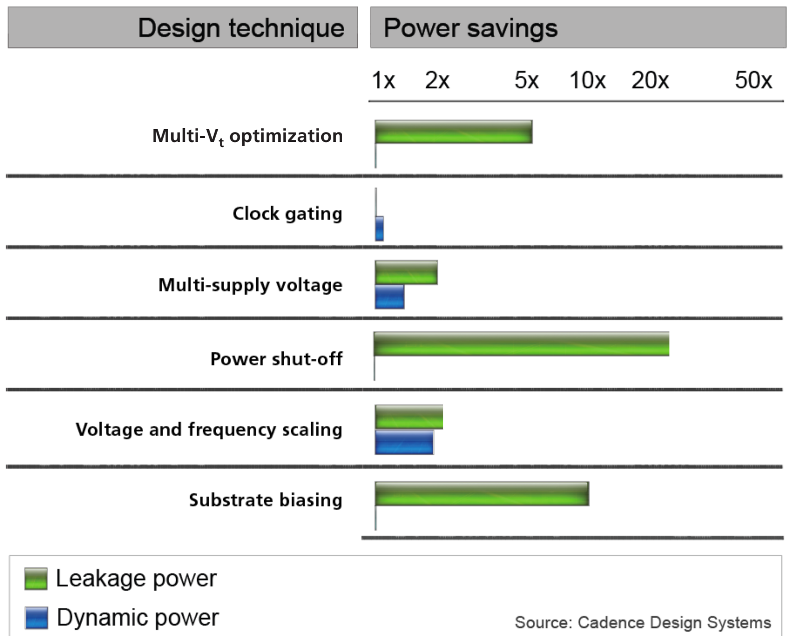
GREEN SILICON

While the television news may depict the problems of oil consumption or global warming with snaking lines of traffic or belching smokestacks, the glowing LED on a TV set-top box or a web page on a smart phone might equally well represent culprits behind today's voracious hydrocarbon consumption. The bottom line is that the vast majority of today's electronic products waste electricity.

A key part of the solution lies in making electronics energy-efficient at their very core—the design of the silicon chip. For example, using the latest electronic design automation (EDA) technologies from Cadence, engineers can easily solve a seemingly simple but exceedingly complex problem—e.g., shutting off power to parts of a chip when they are not in use. A practical example is a GPS (global positioning system). An engineer can design the logic so that it shuts down the graphics engine once the map is drawn, and then momentarily turns the power back on long enough to refresh only the parts of the screen that change as the user moves about.

Other advanced Cadence design technology builds energy-efficient chips by choosing cells consisting of either high-speed, high-power transistors or low-speed, low-power transistors, depending on what is required at each point in the circuit.

In some cases, designers optimize the system with energy-efficiency as the primary goal, balancing incremental performance gains against increasingly large hits in terms of power consumption. This sometimes involves very complex power management techniques that dynamically adjust the operating voltages within the chip to minimize energy consumption under different usage scenarios.



Reducing power consumption—power savings of various chip design techniques

Recognizing the importance of energy-efficient semiconductor design as one of the electronics industry's most pressing challenges, Cadence has taken the lead in developing end-to-end solutions for low-power design. In addition to making it easy to implement advanced power management, these solutions also include advanced verification technology—software that verifies a design will work as intended when it is implemented in silicon—that can handle the added complexity of these power-saving techniques.

Cadence is also spearheading industry initiatives such as the Power Forward Initiative (PFI), which establishes a standard for taking the power-saving concepts of designers and ensuring they are effectively implemented throughout the design and verification of chips and entire systems. Other strategies extend to the chip's packaging and its impact on the power characteristics of the overall system design.

As opposed to conventional techniques to save power—such as keeping whole systems active to implement energy-wasting sleep or stand-by modes—engineers can use these advanced technologies and methodologies to "design-in" energy efficiency at the level of transistors and wires on silicon. These green silicon designs have already been proven to reduce power consumption 20 to 40 percent. Saving power in this way not only helps companies protect the environment and its resources but also enables them to differentiate their products in an increasingly competitive market—through enhanced energy efficiency, reduced heat, and greater reliability.

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