

NANOoze

THE ENERGY ISSUE

*Thin, flexible solar panels
have been developed using
nanotechnology*

**SOLAR ENERGY AND
QUANTUM DOTS**

**ENERGY-EFFICIENT
GRAPHENE**

ALL ABOUT BATTERIES

**KILOWATTS, MICROWATTS,
LIGHT BULBS AND FIREFLIES**



nanooze.org

Welcome to Nanooze!

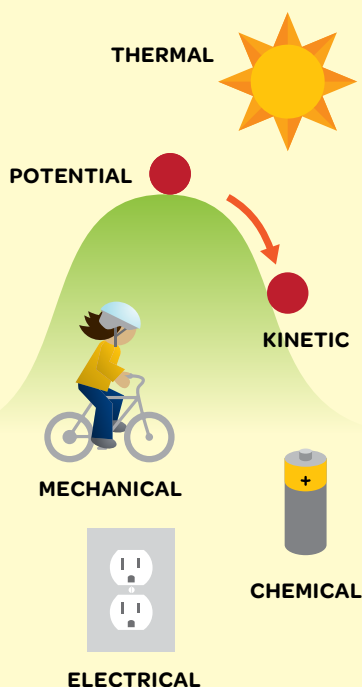
What is a Nanooze? (Sounds like nah-news.) Nanooze is not a thing, Nanooze is a place to hear about the latest exciting stuff in science and technology. What kind of stuff? Mostly discoveries about the part of our world that is too small to see and making tiny things using nanotechnology. Things like computer chips,

the latest trends in fashion, and even important stuff like bicycles and tennis rackets. Nanooze was created for kids, so inside you'll find interesting articles about what nanotechnology is and what it might mean to your future. Nanooze is online at www.nanooze.org, or just Google "Nanooze"—you'll find interviews with real scientists, the latest in science news, games and more!

How can I get Nanooze in my classroom?

Copies of Nanooze are **FREE** for classroom teachers. Please visit www.nanooze.org for more information or email a request for copies to: info@nanooze.org.

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ENERGY IS ALL AROUND US

Different forms of energy power our world. Nanotechnology can help us make, store and use energy more efficiently.

THE ENERGY ISSUE

Energy is about as important as anything. It powers our digital gadgets, our cars, all sorts of things. It also powers us.

There are different forms of energy—kinetic, potential, mechanical, chemical, electrical and thermal—and they all have some nanoscale component. Nanotechnology is also involved in helping to generate, store and use energy. The whole world is concerned about energy efficiency. It is never good to waste anything, but wasting energy has a lot of consequences, including important stuff like global warming.

Nanotechnology can help make energy or actually convert energy. Solar power is energy that is derived from sunlight. Sometimes we use sunlight to generate electricity, other times we are trying to generate heat, or thermal energy. Batteries take chemical energy and convert it into electricity. Rechargeable batteries do the same thing by taking electricity and storing it in a battery as chemical energy. That way we don't have to throw out the batteries when we are done, which is a waste, and we also avoid putting some nasty battery chemicals into our landfills.

This issue is all about energy and how nanotechnology helps to make, store and use energy. It isn't science fiction or a story about things that might happen in 100 years. It is about now.

Learning about nano stuff is fun but it can be complex, so it helps to keep these four important facts in mind:

1. All things are made of atoms.

It's true! Most stuff, like you, your dog, your toothbrush, your computer, is made entirely of atoms. Things like light, sound and electricity are not made of atoms, but the sun, the earth and the moon are all made of atoms. That's a lot of atoms! And they're incredibly small. In fact, you could lay one million atoms across the head of a pin.

2. At the nanometer scale, atoms are in constant motion.

Even when water is frozen into ice, the water molecules are still moving. So how come we

can't see them move? It's hard to imagine that each atom vibrates, but they are so tiny that it's impossible to see them move with our eyes.

3. Molecules have size and shape.

Atoms bond together to form molecules that have different sizes and shapes. For instance, water is a small molecule made up of two hydrogen atoms and one oxygen atom, so it is called H₂O. All water molecules have the same shape because the bonds between the hydrogen atoms and the oxygen atom are more or less the same angle.

Single molecules can be made up of thousands and thousands of atoms. Insulin is a molecule in our bodies that helps to control the amount of

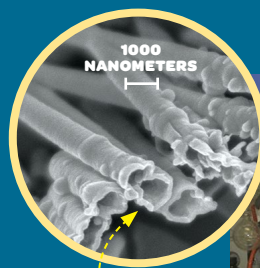
sugar in our blood. It is made up of more than one thousand atoms! Scientists can map out the shapes of different molecules and can even build most types of molecules in the lab.

4. Molecules in their nanometer-scale environment have unexpected properties.

The rules at the nanometer scale are different than what we usually encounter in our human-sized environment. For instance, gravity doesn't count because other forces are more powerful at the molecular level. Static and surface tension become really important. What is cool about nanotechnology is that we can make things that don't behave like we expect. **Things are really different down there!!**

Q&A

with Chemical Engineer Jodie Lutkenhaus



Jodie's team is experimenting with tiny polymer microtubes



Jodie checks the resistance of a battery electrode with her students

What was your childhood like? I grew up in a suburb of Fort Worth, Texas. I was the youngest of two and my mom and dad had bachelor's degrees in chemistry and physics, respectively. My mom worked in quality control and my dad worked in the aerospace industry. Science and engineering was always discussed at home. I remember flipping through Discover magazines and watching PBS documentaries with my parents. If I ever wanted to know how something worked, I could just ask.

In high school I got interested in particle physics. School was not challenging me, so I would check out laymen's books from the library on the topic. I couldn't get enough of it. I was also very interested in literature, reading everything from Russian classics to beat poetry.

Did you imagine that you would become an engineer? I originally wanted to be a physicist, but my parents encouraged me to do chemical engineering for better job prospects. I enjoyed chemistry, physics and math, so I thought it to be a reasonable suggestion. Now my research has led me back to polymer physics, which is the study of a polymer's structure and properties. A polymer is a really long chain of atoms, comprising a "macromolecule." Plastics are an example of a polymer in everyday life.

What prompted you to get your PhD? At an undergraduate internship at IBM, I saw that the PhD's had more interesting work. Those with bachelor's kept the production line going. Those with PhD's were solving the problems or diving deeper into the process. It helped that my sister also was pursuing her PhD in chemical engineering, so I knew I could do it!

I also pursued undergraduate research during my time at UT Austin. I worked in a lab that studied semiconductor processing and photoresist development. I enjoyed

that work very much and got to know the graduate students. They also encouraged me to pursue a PhD.

I met my husband at MIT while I was studying for my doctorate. Now he and I are both professors in chemical engineering. You can imagine the conversations at home.

What's the most surprising thing about being a professor that you hadn't anticipated? I knew I'd be doing teaching, research and service. What I didn't expect was all the writing I'd be doing. Each of these pursuits requires a firm grasp of technical writing. I also didn't expect to wear so many hats for my students. Many of these students are away from home for the first time, make their first B or C, encounter a rough patch, get a traffic ticket—you name it—and they need extra contact beyond just a classroom lecture. To them, I am a mom, a psychologist, a troubleshooter, a career counselor, a proofreader and a cheerleader.

What is a typical day in your life at work? I teach in the morning and then I meet with my graduate students afterwards. After lunch, I might work on a paper or a proposal. If we have visiting professors in town, I might meet with them and attend their seminars. Late afternoon, I hold office hours or lab meetings.

There isn't much time to think if it isn't planned, so I usually reserve two mornings a week to work at home and think without disruption. I'll download a pile of journal articles and read them all at once. After reading a few, I start to see where the major research questions lie in that particular area and how my lab might make a difference.

When I was younger, a typical day would have been much more disorganized or unplanned, but as time became limited, I couldn't keep up with the demands. I tackled my disorganization

with a time-management counselor. I was so disorganized, I even missed my first meeting with her! Now I keep a meticulous schedule on my computer and phone, even scheduling breaks for fun throughout my work day.

What excites you about your research? The science or the applications? Both! I love using my imagination to predict how things could work. I love that I can dream up ideas, test them out, and discuss them with others. For example, the first time I saw flexible displays, I thought, "How will that be powered? Batteries aren't flexible!" And that's when I started to dream up ways to achieve just that. That's led to one of the major research areas in my lab, which is to identify polymers that could act in a flexible battery reliably and safely. It's such a hard problem because you have to balance performance with functionality, and the two are often not mutual. I enjoy working on hard problems because I believe that is where my lab can make the biggest impact.

How do you explain nano to your friends outside of work? Nano is anything teeny-tiny. Thinner than a hair.

What do you do for fun? I have two kids, so when I am not doting on them, I am sewing. Most recently I sewed a pair of Angry Bird pajamas for my oldest son.



Jodie and her family

YOU ARE MY SUNSHINE

Solar power is one of the best ways to make electricity. It's clean and doesn't consume any nonrenewable resources, like oil and coal. We can take energy from sunlight and convert it to electricity. We can also just take sunlight and make thermal energy, also known as heat.

In the last 10 years a lot of solar power units have been built. The biggest private system was installed by Apple to power their data centers in North Carolina. The 100-acre site can produce 42 million kWh of renewable energy each year. A kWh is a unit of power that is equal to 1,000 watts used for an hour; an average home uses about 6,000 kWh per year. So this solar power plant could provide power to 7,000 homes without consuming any oil, gas or coal!

EFFICIENCY

The challenge is that solar power could be more efficient—more sunlight could actually get converted into electricity. The current technology captures about 15%-20% of sunlight energy. Only a few of the photons (little packets of light) that strike a solar panel are eventually converted into electrical current. If more sunlight could be captured and converted to electricity, then the amount of electricity generated for each square foot of solar panels would increase. Right now it takes more than 500 square feet of solar cells to power a house in Arizona. And that is a place with a lot of sunshine.

FLEXIBLE SOLAR PANELS

Scientists are working on developing thin, flexible solar panels, like the one shown here. Nanotechnology could help make this solar technology thinner and more efficient.

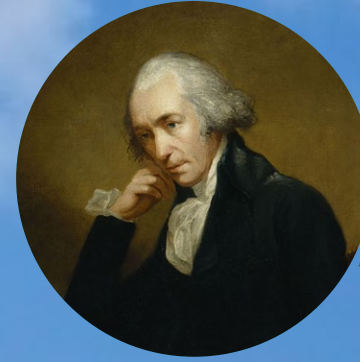
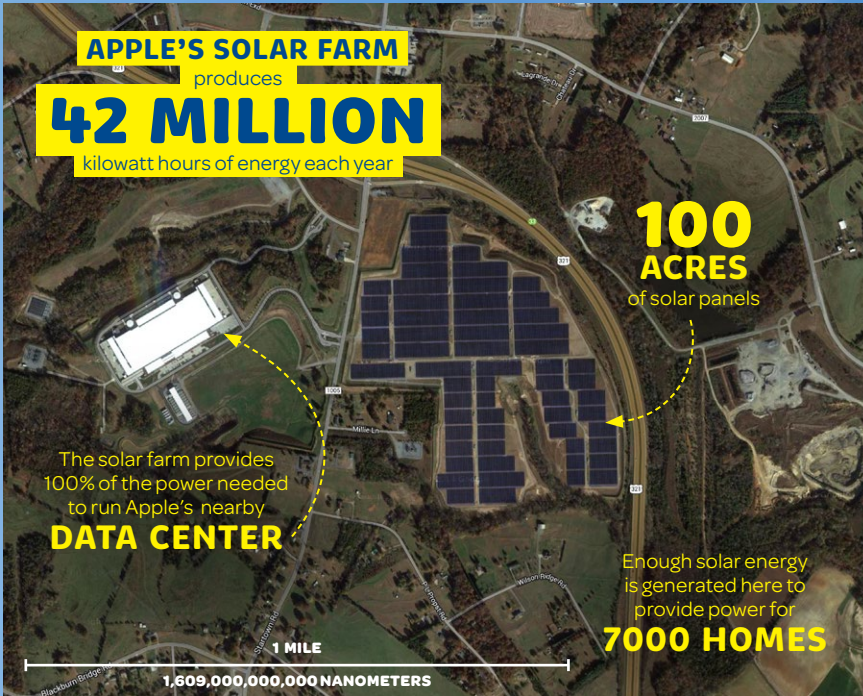
QUANTUM DOTS

But here comes nanotechnology to the rescue, with new materials that are making things better. One new material is called a *quantum dot*. Quantum dots are sometimes called artificial atoms. Made of chemicals like cadmium and selenium, these tiny particles are only a few nanometers in size. They are so small that each dot contains only a thousand or so atoms. Together they form a semiconductor, the same stuff used to make computer chips. Semiconductors are materials that sometimes conduct electricity and other times act as an insulator.

Quantum dots are so small that they don't have any space to store energy. They can produce three excitons for every photon, meaning that they should produce three times as much electricity as the materials currently used for solar cells. That would help a lot in making new sources of safe energy. The challenge is making them cheaply and also figuring out how to use them in solar panels. Scientists are working on it!



Emily Maletz / Nanooze



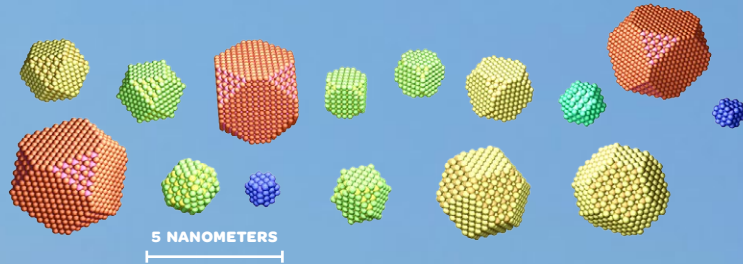
Public domain / Wikipedia

JAMES WATT 1736-1819

A Scottish inventor and mechanical engineer. His designs helped make the steam engine much more energy efficient. The term watt was named after him.

MORE FARMS ON THE WAY

This solar farm is in Maiden, North Carolina. Apple is currently constructing two more solar farms in nearby towns.



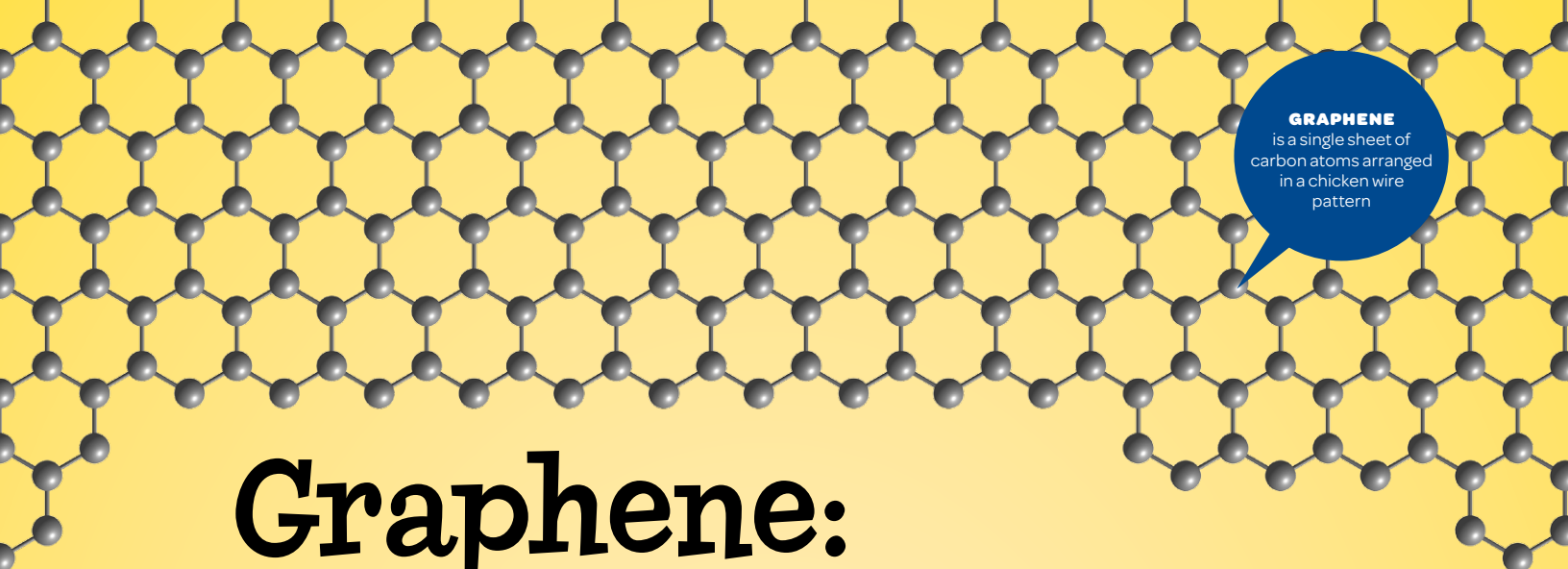
QUANTUM DOTS

Quantum dots are tiny crystals of a few hundred atoms. Scientists are experimenting with using them in solar panels. Quantum dots could help make panels much more efficient because they can produce three times the amount of energy as the materials currently used in solar cells.



SOLAR PANEL EFFICIENCY

Solar panels on the market today have efficiency ratings of 8%-20%. This means that out of all the sunlight that hits the panel, only 8%-20% ends up getting converted to electricity. This is why solar panels take up so much room. Scientists are working on ways to make solar panels more efficient.



GRAPHENE
is a single sheet of carbon atoms arranged in a chicken wire pattern

Graphene: It's Hard to Resist!

Energy is important for pretty much everything we do. The big challenges are making energy, transporting it and then using it efficiently. Nanotechnology offers the opportunity to do things at the molecular scale with nanometer-precision. For energy generation, transport and use there are a lot of nanotechnology solutions.

CARBON AND GRAPHENE

One area of current interest is the use of carbon in the form of buckyballs, carbon nanotubes and graphene. Carbon is one of the most abundant atoms on Earth and is found in all forms of life.

In buckyballs, carbon nanotubes and graphene, each carbon atom is bound to three other carbon atoms, creating a molecular structure that looks like chicken wire. It is the arrangement and shape of these carbon atoms that makes them unique materials. In this particular chemistry, carbon has unique electrical properties and most of the time it acts as a semiconductor.

Graphene is a single layer of carbon that is only one atom thick and it is super lightweight. In fact, a square meter (or 10^{18} nanometers square) weighs only about 0.77 milligrams. So if you had a sheet of graphene that was the size of a small tabletop, it would weigh less than 20 grains of salt!

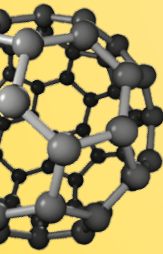
GRAPHENE AND RESISTANCE

Graphene exhibits almost no resistance to movement of electrons. Resistance is one of the factors that contributes to the efficiency of electrical transmission. So the lower the resistance the less electricity is lost over the distance that the electricity is being transmitted. It is estimated that the electrical transmission loss in the US averages around 6.5%. That might not seem like a lot but it adds up.

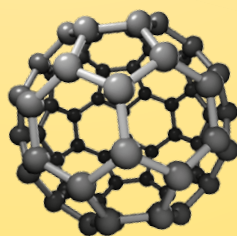
Graphene is a potentially amazing material for energy transmission.

In general, it is about 35% less resistant to the flow of electrons compared to copper. At the nanometer scale, resistance increases—the thinner the wire the higher the resistance. Think about a water hose and how much harder it is to move a volume of water through a thin garden hose compared to a thick fire hose.

So as things get smaller, the type of material matters even more. In the future, use of nanoscale materials like graphene might help make energy transmission more efficient, letting us use more of those electrons to power our stuff.



BUCKYBALLS
are carbon atoms arranged in a sphere



This type of buckyball is about **1 NANOMETER** in diameter

CARBON NANOTUBES
are super-strong tubes made of carbon atoms, they are only a few nanometers wide

ELECTRIC CARS
would not be possible
without high-capacity
battery technology



Batteries Included

Batteries are really important because they are the way in which we store electricity to power all sorts of things. What is important in a battery is the amount of charge that it will hold (for a given size and weight) and how many times it can be charged. In your average cell phone the battery is about 25% of the weight and about 20% of the volume. That is a lot of battery compared to the phone. Wouldn't it be nice if batteries could be smaller?

LEAD-ACID BATTERIES

Batteries work by converting electrical energy into chemical energy and then reversing the process. The size of the battery depends on how much energy is required and what types of chemical reactions are used. The battery in a car with a gas or diesel engine is pretty big and heavy because it uses acid and lead to create chemical energy.

We don't usually care about the weight of these batteries since we hardly ever carry them, and all they do is crank the engine to start it. In electric cars, the batteries are a lot bigger and weight is a concern since the battery provides energy to the engine to move the car that carries the battery.

LITHIUM-ION BATTERIES

Lithium-ion batteries, like the ones used in your laptop computer and in electric cars, can store about 150 watt hours per kilogram. Lead-acid batteries, like the kind in a nonelectric car, can only store about 25 watt hours per kilogram. An electric car made with lead-acid batteries would have to be HUGE!

One problem with lithium-ion batteries is that they degrade over time and can't be recharged as many times. You might notice this with rechargeable batteries at home. Over time they just can't be recharged, so eventually they need to be replaced.

ALONG COMES NANOTECHNOLOGY!

Nanoscale materials can be used to build better batteries. Scientists have used nanowires, which are very thin wires composed of a single element, to create better batteries. Nanowires made of germanium—a semiconductor material similar to silicon—used as a component of lithium-ion batteries can increase the number of cycles that the battery can be recharged. The benefit is a battery that can last twice as long as conventional lithium-ion batteries.

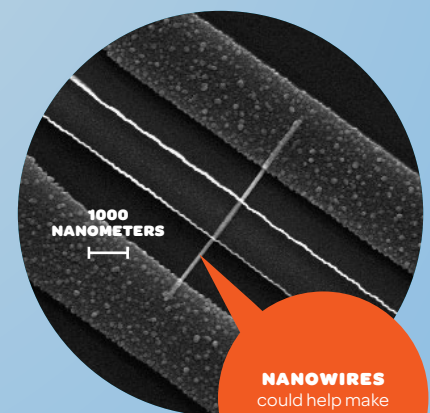
LITHIUM-ION BATTERIES

Rechargeable batteries, such as the ones in cell phones, digital cameras and battery-operated tools use lithium-ion technology



LEAD-ACID BATTERIES

Most standard car batteries and household one-time-use batteries use lead-acid technology



NANOWIRES
could help make
better batteries

What's a Watt?

Measuring Energy Big and Small

There are different ways to measure a given amount of energy that is being used for a particular job. Look at a standard light bulb and you see that it is 100 watts; that is, it consumes 100 watts of electricity to make light. A watt is the measure of work that is done when one ampere moves across a potential difference of one volt. While we think about watts when it comes to light bulbs and other things that use electricity, you can also describe any kind of work in terms of watts.

GENERATING WATTS

A person on a stationary bicycle can generate about 100 watts of power. That means if you had a generator and hooked it up to the bicycle, the rider would have to expend that much energy peddling to light up a regular light bulb. Look at your electricity bill and you might have used 500 or so kilowatt hours. As with other things that are measured by kilos—or 1,000—500 kilowatt hours is like keeping 5,000 100-watt light bulbs on for an hour, or 50 100-watt light bulbs on for 100 hours (about 3 hours a day for a month).

MICROWATTS

If a kilowatt is 1,000 watts then a microwatt is 1/1,000,000 of a watt. A firefly uses 40 microwatts of energy each time it flashes. It would take about 1.5 million fireflies to equal the energy consumption of a 60-watt light bulb.

BUILDING BETTER BULBS

Conventional 100-watt light bulbs are being discontinued. They waste too much energy; that is, they generate a lot of heat in addition to light. New light bulbs use light-emitting diodes (LEDs), which are much more efficient. LEDs are semiconductor devices made possible by nanotechnology.

NANO POWER

Can we think of powering something even smaller than a firefly? How about a sperm cell? Sperm move around using a flagellum, which is a whip-like structure that helps the sperm to swim. It is about 10 micrometers or about 10,000 nanometers in length. To move around, the sperm needs to use energy by breaking down adenosine triphosphate (ATP). The flagellum uses around 2×10^{-18} watts (that's 0.000000000000000002 watts), which it can get just by breaking down a few ATP molecules.

NOT SO FAST...

That is not a lot of energy to spend moving itself around, but sperm don't move very fast. In fact, they move about 8 inches an hour or 0.0001 miles per hour. Does that seem really slow? To a nanometer-sized object it is the equivalent of moving about 10 times your length in a second, or 56,000 nanometers per second. Hmm. That's like running a 100-meter dash in five seconds. As of this writing, the world-record holder for the 100-meter (that's 100,000,000,000 nanometers) is Usain Bolt, who did it in 9.58 seconds in 2009, almost twice as slow as these nanometer-sized speedsters.

A firefly uses
40 MICROWATTS
of energy each time it flashes,
that's **40,000 NANOWATTS!**

INCANDESCENT BULB



ENERGY INPUT
100 WATTS

only 10% of energy input is converted to light, 90% is lost as heat



LIGHT OUTPUT
1600 LUMENS

LED BULB



ENERGY INPUT
20 WATTS

more than 50% of energy input is converted to light



LIGHT OUTPUT
1600 LUMENS