ure

▲ Concept car from Volkswagen was designed to carry two people around cities and suburbs. Weighing 640 pounds (290 kilograms), the vehicle, which at present exists only as a prototype, gets some 240 miles to the gallon.

consumed in actual driving. Today's gasoline spark-ignition engine is about 20 percent efficient in urban driving and 35 percent efficient at its best operating point. But many short trips with a cold engine and transmission, amplified by cold weather and aggressive driving, significantly worsen fuel consumption, as do substantial time spent with the engine idling and losses in the transmission. These real-world driving phenomena reduce the engine's average efficiency so that only about 10 percent of the chemical energy stored in the fuel tank actually drives the wheels. Amory Lovins, a strong advocate for much lighter, more efficient vehicles, has stated it this way: with a 10 percent efficient vehicle and with the driver, a passenger and luggage—a payload of some 300 pounds, about 10 percent of the vehicle weight—"only 1 percent of the fuel's energy in the vehicle tank actually moves the payload."

We must include in our accounting what it takes to produce and distribute the fuel, to drive the vehicle through its lifetime of 150,000 miles (240,000 kilometers) and to manufacture, maintain and dispose of the vehicle. These three phases of vehicle operation are often called well-to-tank (this phase accounts for about 15 percent of the total lifetime energy use and greenhouse gas emissions), tank-to-wheels (75 percent), and cradle-to-grave (10 percent). Surprisingly, the energy required to produce the fuel and the vehicle is not negligible. This total life-cycle accounting becomes especially important as we consider fuels that do not come from petroleum and new types of vehicle technologies. It is what gets used and emitted in this *total sense* that matters.

Improving existing light-duty vehicle technology can do a lot. By investing more money in increasing the efficiency of the engine and transmission, decreasing weight, improving tires and reducing drag, we can bring down fuel consumption by about one third over the next 20 or so years—an annual 1 to 2 percent improvement, on average. (This reduction would cost between $500 and $1,000 per vehicle; at likely future fuel prices, this amount would not increase the lifetime cost of ownership.) These types of improvements have occurred steadily over the past 25 years, but we have bought larger, heavier, faster cars and light trucks and thus have effectively traded the benefits we could have realized for these other attributes. Though most obvious in the U.S., this shift to larger, more powerful vehicles has occurred elsewhere as well.

DAILY USE OF PETROLEUM WORLDWIDE

At present, consumers use 80 million barrels a day (MBD) of petroleum (a barrel contains 42 U.S. gallons). Two thirds of this goes to transportation.

53	29	19	5
MBD for transportation overall	MBD for land transport for people	MBD for land transport for freight	MBD for air transport for people and freight

TIMESCALES FOR NEW TECHNOLOGIES

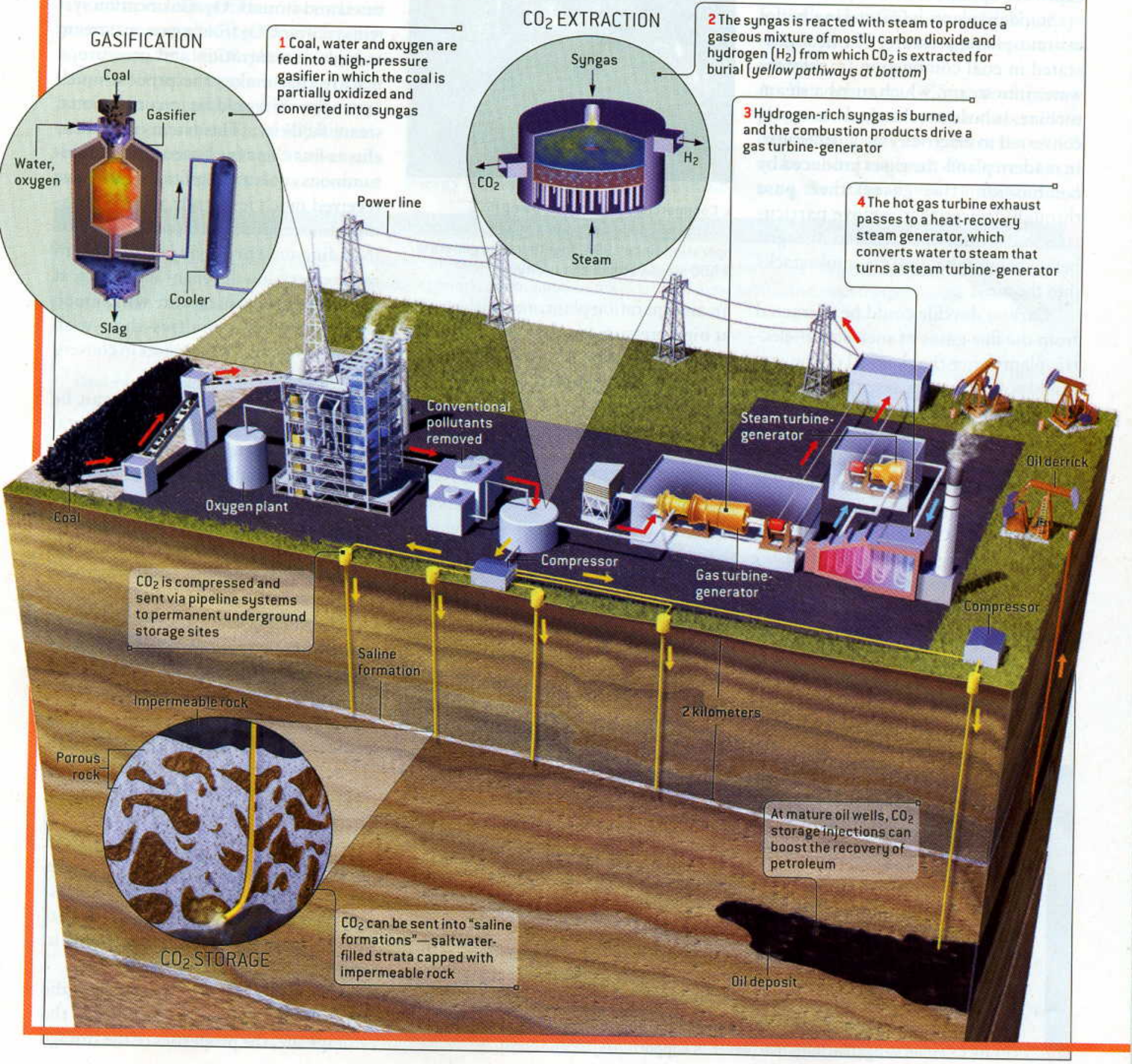
New designs for vehicles may eventually bring down overall energy consumption for transportation in the U.S., but they do not offer a quick fix. Estimates from M.I.T.'s Laboratory for Energy and the Environment indicate how long it might take for new technologies to have a significant impact.

	IMPLEMENTATION PHASE			
VEHICLE TECHNOLOGY	Market competitive vehicle	Penetration across new vehicle production*	Major fleet penetration†	Total time for impact
Turbocharged gasoline engine	5 years	10 years	10 years	20 years
Low-emissions diesel	5 years	15 years	10–15 years	30 years
Gasoline hybrid	5 years	20 years	10–15 years	35 years
Hydrogen fuel-cell hybrid	15 years	25 years	20 years	55 years

** More than one third of new vehicle production*　*† More than one third of mileage driven*

EXTRACTING AND STORING CARBON DIOXIDE

To slow climate change, the authors urge power providers to build integrated gasification combined cycle (IGCC) coal power plants with carbon dioxide capture and storage (CCS) capabilities (*below*) rather than conventional steam-electric facilities. Conventional coal plants burn the fuel to transform water into steam to turn a turbine-generator. If CCS technology were applied to a steam plant, CO_2 would be extracted from the flue exhaust. An IGCC plant, in contrast, employs a partial oxidation reaction using limited oxygen to convert the coal into a so-called synthesis gas, or syngas (mostly hydrogen and carbon monoxide). It is much easier and less costly to remove CO_2 from syngas than from the flue gases of a steam plant. The hydrogen-rich syngas remaining after CO_2 extraction is then burned to run both gas and steam turbine-generators. The world's first commercial IGCC project that will sequester CO_2 underground is being planned near Long Beach, Calif.



1 Coal, water and oxygen are fed into a high-pressure gasifier in which the coal is partially oxidized and converted into syngas

2 The syngas is reacted with steam to produce a gaseous mixture of mostly carbon dioxide and hydrogen (H_2) from which CO_2 is extracted for burial (*yellow pathways at bottom*)

3 Hydrogen-rich syngas is burned, and the combustion products drive a gas turbine-generator

4 The hot gas turbine exhaust passes to a heat-recovery steam generator, which converts water to steam that turns a steam turbine-generator

CO_2 is compressed and sent via pipeline systems to permanent underground storage sites

At mature oil wells, CO_2 storage injections can boost the recovery of petroleum

CO_2 can be sent into "saline formations"—saltwater-filled strata capped with impermeable rock

NANOTECH SOLAR CELLS

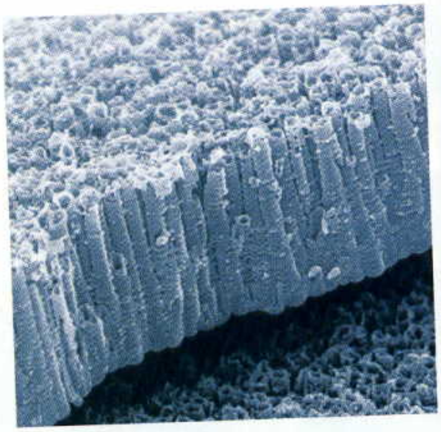
Materials engineered from the atoms up could boost photovoltaic efficiencies from pathetic to profitable

Essentials

50¢: the price to beat for a one-watt solar cell

REALITY FACTOR

4



▲ Titania nanotubes made at Pennsylvania State University boost the light-harvesting abilities of solar cell dyes 10-fold.

Five gigawatts—a paltry 0.038 percent of the world's consumption of energy from all sources. That, roughly, is the cumulative capacity of all photovoltaic (PV) power systems installed in the world, half a century after solar cells were first commercialized. In the category of greatest unfulfilled potential, solar-electric power is a technology without rival.

Even if orbiting arrays [see "Space-Based Solar," on page 108] never get off the ground, nanotechnology now looks set to rescue solar from its perennial irrelevance, however. Engineers are working on a wide range of materials that outshine the bulk silicon used in most PV cells today, improving both their efficiency and their cost.

The most sophisticated (and expensive) second-generation silicon cells eke out about 22 percent efficiency. New materials laced with quantum dots might double that, if discoveries reported this past March pan out as hoped. The dots, each less than 10 billionths of a meter wide, were created by groups at the National Renewable Energy Laboratory in Colorado and Los Alamos National Laboratory in New Mexico.

When sunlight hits a silicon cell, most of it ends up as heat. At best, a photon can knock loose one electron. Quantum dots can put a wider range of wavelengths to useful work and can kick out as many as seven electrons for every photon. Most of those electrons soon get stuck again, so engineers are testing better ways to funnel them into wires. They are also hunting for dot materials that are more environmentally friendly than the lead, selenium and cadmium in today's nanocrystals. Despite their high-tech name, the dots are relatively inexpensive to make.

Nanoparticles of a different kind promise to help solar compete on price. Near San Francisco, Nanosolar is building a factory that will churn out 200 million cells a year by printing nanoscopic bits of copper-indium-gallium-diselenide onto continuous reels of ultrathin film. The particles self-assemble into light-harvesting structures. Nanosolar's CEO says he is aiming to bring the cost down to 50 cents a watt.

The buzz has awakened energy giants. Shell now has a subsidiary making solar cells, and BP in June launched a five-year project with the California Institute of Technology. Its goal: high-efficiency solar cells made from silicon nanorods.