

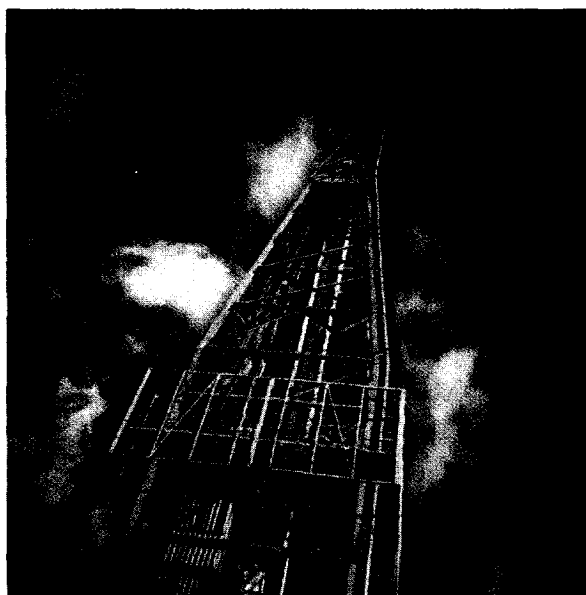
# THE NEW OLD ECONOMY: Oil, Computers, and the Reinvention of the Earth

by JONATHAN RAUCH

*“Knowledge, not petroleum, is becoming the critical resource in the oil business,” the author writes in this firsthand account of how technology is stretching the bounds of finitude*

I ARRIVED on Pompano, an oil platform in the Gulf of Mexico, on a hot day last July, hoping to be on hand when the drillers hit pay. Pompano, which belongs to BP (the former British Petroleum, now merged with Amoco and ARCO), stands in 1,295 feet of water about eighty miles southeast of New Orleans. The nearest land is twenty-two miles away. At nearly 1,400 feet from seabed to drill deck, Pompano is the world's second tallest fixed-leg oil platform (Shell's Bullwinkle platform, also in the Gulf, is fifty feet taller). If it were moved to Manhattan and you were to stand atop it, you would be looking down on the twin towers of the World Trade Center.

Pompano and various other platforms in the neighborhood are served by a little heliport in the marshy town of Venice, on Louisiana's southeastern tip. When drilling activity is intense, as it was in July, dozens of roughnecks gather at the heliport each morning for flights that scatter them around the Gulf. Leafing through the flight manifests, I noticed that the roughnecks were nearly all in their twenties or thirties and averaged not much below 200 pounds (all were men). One man



sitting near me had lost the tip of his left middle finger. At the heliport there were no skinny forearms, apart from mine. The flight to Pompano took about half an hour. At first I saw nothing but water and hazy sky; then someone pointed toward the horizon, and I made out a cork surmounted by a toothpick, and all at once the helicopter was descending on a compressed industrial city, jagged and gray and solitary in a desert of sea.

We piled off the helicopter, and I squinted in the sunshine and tried to take my bearings. To my inexperienced eye the platform was chaotic, a Cubist's fantasy of tanks and trailers and pipes and cranes and control panels and unidentifiable machinery. On the west side a flare boom extended far out over the water; to the east rose a high yellow crane. The helicopter pad was on the south end, above the living quarters and the offices. At the center, overwhelming everything else, was the derrick. Its base was elevated two stories above the deck, and its crown disappeared somewhere in the sunlight above me. I glanced at the drill floor and noticed that the people there were moving but the machinery was not—possibly a bad sign. Then I was rushed away from

the helicopter and to a stairway, which, like most of the stairways on an oil platform, was cantilevered over the edge of the platform, high above the open water and thus away from heavy equipment and from the danger, ever present around oil and gas, of fire or fumes. Newcomers have been known to look down through the grillwork, see nothing but ocean below, and freeze up with dizziness. I did all right on the stairs, but I felt better toward the center of the platform.

An oil platform like Pompano drills new wells some of the time, but it produces oil from existing wells all of the time. Pompano thus conjoins two worlds, one atop the other. Below, always in shadow, is the production deck, which collects and processes 40,000 barrels a day: enough to power America for about three minutes. Twenty-six wellheads pour roaring streams of oil and gas, at pressures as high as 1,300 pounds per square inch, through intestinal tangles of pipes and manifolds and on into a series of tanks and processors that remove water for reinjection into the ground, clean up the oil, and dry the gas. When the hydrocarbons have passed through this digestive system, they are pumped into a subsea pipeline for the journey to refineries back on shore. Pompano processes oil constantly and, as it were, in its sleep, with a production crew of about a dozen. Barring the odd mechanical failure or hurricane, one day in the control room is much like another. All eyes, typically, are on the upper deck, where the drillers work.

Drilling awakens Pompano. The place becomes a swarm of roustabouts and floor hands and mud loggers and perforating teams and completion engineers and geologists and galley hands and medics—at times as many as a hundred people on a surface measuring 230 by 128 feet. They work and sleep in tiny offices and tinier bunks in a prefabricated building where air-conditioning, television, foosball, and a bench press more or less exhaust the amenities. Lunch was beans, rice, cabbage, and sweet potatoes. The office windows, I noticed, looked not outward to the sea but inward, toward the objects of everyone's attention: the drill floor and the derrick.

It must be said that an oil derrick is one of the more majestic artifacts of industrial capitalism. The earliest ones were wooden, but today they are steel lattices that look like the frames of unfinished skyscrapers. Pompano's rises 170 feet above the drill floor. On the monkey board, high in the derrick, a roustabout maneuvers each new 100-foot section of pipe into position below the traveling block and the top drive; floor hands screw this section to its predecessor; and then the driller

sets the top drive spinning, engages the draw works, and commences to stuff the rotating pipe into the earth. Drilling out here costs \$100,000 a day, and the work goes on around the clock. On a good day the pipe descends continuously.

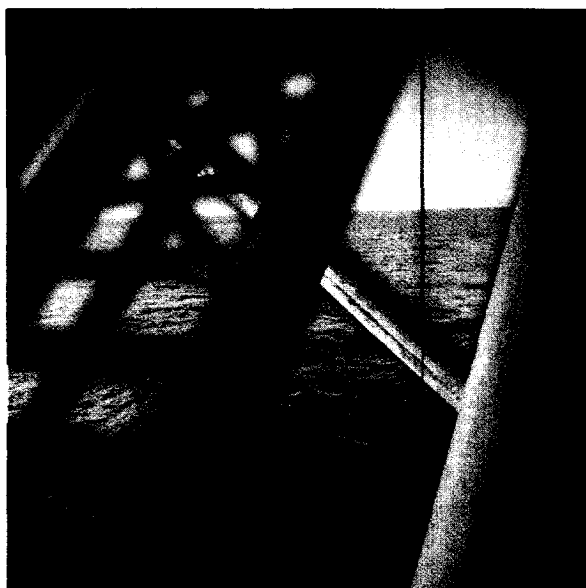
This was not a good day. The drillers had hoped to reach their objective that morning, but something downhole had chewed up two mud motors in succession, and now a seal just above the blowout preventer had sprung a leak. On the drill floor seven roustabouts and the driller were using wrenches and sledgehammers to loosen heavy bolts on the diverter housing. I had no trouble seeing how a roustabout might lose a fingertip. It was a bright, hot afternoon, and the derrick offered no shade; the men on the drill floor were soaked with sweat and spattered with drilling mud. I was standing off to one side, in shade behind the driller's cage, not lifting a finger, and I felt a stream of sweat under my hard hat become a small river behind my right ear. Just about then I heard myself thinking, *Silicon Valley this ain't.*

Yet, in some respects, Silicon Valley this is. The Pompano crews were drilling a well named Margarita, and Margarita was a computer's brainchild. Geologists could not have found this prospect with the computer technology available even four or five years ago, and drillers could not have drilled it as efficiently with the technology available then. Margarita's objective lies under salt, as does much of the oil in the Gulf of Mexico. People in the oil business have been striving to master the salt for years. Learn to see through salt, and then to drill through it

quickly and accurately, and you open new reserves, potentially large ones.

"There's salt in the North Sea, there's salt off Africa, there's salt off Brazil," Doug Stauber told me as we left Pompano later that day. Stauber is one of BP's geologists, and Margarita is his project. The series of mechanical failures meant it would be at least another few days before he knew whether Margarita would succeed. But Stauber betrayed no anxiety. In general, geologists lack the natural demonstrativeness of, say, tax accountants and insurance adjusters, and Stauber's only emotional display had been when he went down to the production deck to give affectionate pats to two of his favorite wellheads—"my good wells," he called them.

*The photographs accompanying this article depict an oil platform in the Gulf of Mexico, off the coast of Louisiana; the Magic Earth facility, in Houston; and the Giddings oil field, in East Texas.*





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In his fifteen years in the oil business Stauber had worked on fifty or so wells, including many of the wells at Pompano. I ventured that Margarita must seem routine. Oh, no, he said. "It's got all my attention."

## THE NEW OLD ECONOMY

**I**N a speech last May, Treasury Secretary Lawrence H. Summers, who is an economist of distinction, reflected on what people are calling the New Economy. The notion is "both palpable and amorphous—more often declared than defined," he said. "But if there is one fundamental change at its heart, it must be the move from an economy based on the production of physical goods to an economy based on the production and application of knowledge."

The New Economy, Summers said, seems to behave differently from the old industrial and agrarian models. "Consider the classic Smithian model of wheat: when prices rise, farmers produce more, consumers buy less, and equilibrium is restored at a lower level of demand." This, Summers said, is a "negative-feedback" economy—one that is bounded by near-term constraints of supply and demand. An analogy, he suggested, might be a thermostat, which will shut down the furnace when your house overheats.

"By contrast," Summers said, "the information economy will increasingly be a positive-feedback economy." In the traditional economy new technologies and products start out expensive and rare, and only gradually become cheap and common; think of refrigeration, the automobile, the long-distance call. In the New Economy additional capacity seems to become available so quickly and inexpensively (think of the microchip) that traditional supply constraints are almost trivial. "In such a world," Summers said, "the avalanche, rather than the thermostat, becomes the more attractive metaphor for economic policy."

If there is a New Economy, its effect might logically be to increase the country's capacity to produce goods without running up against shortages and thereby triggering inflationary pressures. In effect, the economy's speed limits would be raised. Sure enough, the economy produced higher growth in real output per worker, as well as lower unemployment, in the 1990s than in the 1970s or the 1980s, while keeping inflation at a substantially lower rate. That is cause for celebration, but it is also puzzling.

Economists agree that to the extent the economy has changed, "information technology"—the computer and its many offshoots—must have a good deal to do with it. In the three decades since 1970 the power of microprocessors increased by a factor of 7,000. Computing chores that took a week in the early 1970s now take a minute. According to the

Federal Reserve Bank of Dallas, the cost of storing one megabit of information, or enough for a 320-page book, fell from more than \$5,000 in 1975 to seventeen cents in 1999. All well and good. But the computer revolution has been going on for years, whereas the economy's turbocharge came only in the second half of the 1990s. Why?

The Internet might seem to be a reasonable answer, and no doubt it has helped. However, according to Robert E. Litan, the director of economic studies at the Brookings Institution, in Washington, D.C., the Internet is still much too small a factor in America's \$10 trillion economy to account for the productivity surge. Nor, economists say (though this point is disputed), is the New Economy proper—the software, hardware, and dot-com sectors—large enough to have brought about more than part of the surge. Something else is at work, but what? It is not crazy to suspect what I think of as the New Old Economy.

Although at this point no one can prove anything, a story that seems plausible to many economists and business executives goes like this: In the 1980s Old Economy businesses tended to waste much of what they spent on computers and software. Companies in traditional industries would drop a PC on every desk and declare themselves computerized; they

would buy spreadsheet programs and word-processing software and networking equipment that as often as not just substituted new frustrations for old ones. This began to change, however, as software and hardware grew

## OWING TO INFORMATION TECHNOLOGY, THE LINE BETWEEN THE NEW ECONOMY AND THE OLD ECONOMY HAS BEGUN TO BLUR.

in power, and as companies began learning how to use them not just as conveniences or crutches but to change the nature of the job. At first the impact, like a misty drizzle, was too small to show up in the national economic statistics. However, each innovation enabled other innovations, none of them revolutionary but all of them combining in an accelerating cascade. By the second half of the 1990s the aggregate effect on productivity became large enough to register in the national accounts, and the line between the New Economy and the Old Economy began to blur. That is the story of the New Old Economy.

As I say, nothing can be proved, at least not yet. But oil is about as old as modern industries come. If John D. Rockefeller, who lived from 1839 to 1937, rose from the dead today, he would probably need to struggle to get his mind around the Internet. But if you flew him out to Pompano and let him squint up at the derrick, he would know immediately what was going on. Finding and producing oil is still about poking holes in the ground and bottling what comes out, and in most people's minds it has long epitomized dirty industry and the reality of limits to growth. In a number of respects, however, the oil business has begun to behave more like the New Economy than the Old. It is in the midst of the sort of technologi-

cal change that Summers compared to an avalanche; and the bang that started the avalanche came not from the oil fields but from Silicon Valley.

## MAGIC EARTH

**T**HE petroleum industry and the computer have been closely connected for many decades—since the years when a computer was a human being calculating as fast as he could. Along with the space program and a few other endeavors, the oil industry has been elemental in driving computing technology forward, because petroleum geologists' appetite for processing power is insatiable. It is no accident that Texas Instruments, one of the pioneers in the computer business, was born in 1930 as Geophysical Service, a company that provided seismographic data to the oil industry.

There is nothing new about seismic imaging. The basic technology is not particularly complicated. Oil lies deep underground, trapped in the pores of rock at enormous pressures, and rock is a good conductor of sound. Knowing how fast sound travels, geologists can set off booms or pings and then analyze the returning echoes to infer the nature and location of the surface that has reflected them. Submariners have used this trick for decades; bats have used it forever. By the 1930s seismic imaging had established itself as a central technology in the oil business. Geologists would set off a boom and use mirrors to project the resulting vibrations onto photographic paper. Today the surveys use geophones wired to digital recorders, but the principle is the same.

For many years the most that computers could handle was two-dimensional imaging, which showed vertical cross sections of rock. Even 2-D created no small headache for computers. In a typical smallish 2-D survey of twenty or thirty square miles, engineers would lay out a line of hundreds or thousands of geophones and set off a bang. Then they would record the echoes, move the geophones or the sound source, and bang again. (At sea the detectors would be dragged behind boats that detonated air-gun booms every ten seconds or so.) The process would generate several million echo traces—but such traces by themselves tell nothing about the structure of the earth. All the rest must be done by mathematical inference. The computer's job is to construct the mathematical model of the underground structures that seems most consistent with those millions of echoes; each echo must be disassembled into thousands of milliseconds, and each millisecond must be com-

pared with many others and analyzed in several different ways before any sort of picture begins to emerge. With 2-D the picture was crude and, of course, two-dimensional.

Geologists long yearned for three-dimensional imaging, which would let them look inside the earth from any angle, but the computing requirements were staggering. With 3-D the number of possibilities that the computer needs to sort through increases by orders of magnitude. Even a small 3-D survey might easily generate 200 gigabytes of data, and all the data points would then need to be analyzed from every direction simultaneously. In 1975, 3-D seismic imaging came into its first commercial use, but it was too slow and expensive to do anyone much good.

That is what the processing revolution changed. From 1985 to 1995 the computing time needed to process a square kilometer's worth of data fell from 800 minutes to ten minutes. From 1980 to 1990 the cost of analyzing a fifty-square-mile survey fell from \$8 million to \$1 million. Now it is more like \$90,000.



In 1989, according to the U.S. Department of Energy, only five percent of the wells drilled in the Gulf of Mexico made use of 3-D seismic data; by 1996 the figure was 80 percent, and the surveys themselves were more sophisticated. Today that smallish twenty- or thirty-square-mile survey might easily involve 25,000 geophones, 2,000 echo traces per shot, and 30,000 shots—a total of more than half a million floppy disks' worth of data, or more than 800 gigabytes, of which each byte

must be compared and reconciled with thousands or millions of others. Over the past decade seismic analysis has increased its data-gathering and data-processing requirements by an order of magnitude every five years, and no end is in sight. Schlumberger, a big oil-technology company, recently announced a higher-resolution technology, called Q, that gathers several times as much data as anything before and pushes computers proportionately harder.

The easiest way to appreciate the results is to go look at them. A good place to do that is at Magic Earth, in Houston. Magic Earth is what is known as a 3-D seismic visualization facility, one of many that have appeared in the past three years. "Engineers sit in front of this," Michael Zeitlin, Magic Earth's president and CEO, told me one day last spring when I stopped by for a demonstration, "and have an *emotional* response."

Zeitlin has been in the oil business for twenty of his forty-two years. He is originally from New York City, but his manner is all West Coast. We were sitting in a glass cube of a

building, in whose center stood a twenty-five-foot-high metal pod, like a shiny mushroom cap. Zeitlin talked with the rat-atat energy of an entertainment-industry executive, which he could almost be. Hollywood uses digital imaging and supercomputers to bring dinosaurs and typhoons and starships to life; Zeitlin does the same thing for structures deep in the planet, structures that will never be seen by any human eye.

Vision, Zeitlin explained, requires a great deal of bandwidth. To generate the illusion of motion requires fifteen to twenty frames a second. In the 1980s geologists' computers couldn't calculate that fast; in the 1990s they closed the gap, and then some. High-end computers can now take terabytes of seismic data and create vividly colored three-dimensional images of them; and they can generate those images at a rate of up to sixty a second—fast enough to fool the brain into thinking that it is panning through the interior of the planet, seeing formations that are miles underground in much the same way one might see the Grand Canyon from a moving helicopter.

Zeitlin showed me into the pod. On the way to the viewing room we passed the brains of the place, a Silicon Graphics mainframe. At the front of the pod was a large curved screen, eight feet high, twenty-five feet wide, and wrapping 160 degrees, to envelop the viewer. In front of the screen was a conference table, where I took a seat. Behind me was a technician running the computer.

Zeitlin began with some familiar images: a Flintstones car, which we viewed from every angle, and the Matterhorn, which the "camera" (really the computer, manipulating its banks of data to create the image in real time) flew around at the command of a mouse. And then we were underground, about 6,000 feet below West Texas, and the image before me was a translucent cube of planet, colored to show the geologic features of the subterranean landscape. Zeitlin pointed to a blue patch that meandered like a river. It was an ancient channel, he said, cut eons ago and long since buried beneath a mile of sediment. He gave me the mouse, and I found myself clumsily rotating the image, viewing it from above and below and then moving inside it. You can put on 3-D goggles and the image on-screen becomes fully three-dimensional, springing to life like a hologram. You can peel the earth in layers a few dozen feet thick to reveal horizon after horizon of primeval topography. With a mouse you can draw a virtual oil well into the picture, so as to "see" the well long before it is drilled. At certain other visualization facilities the images are projected on the walls and floor and ceiling of the viewing room; wearing 3-D goggles, you can walk through the interior of a formation, as if through a cave.

So compelling is the illusion created by visualization technology that I had to forcibly remind myself that none of it is

either real or even a photographic image of anything real. It is all mathematics—models of the earth built by computers from echoes and algorithms. One forgets, too, that the sci-fi wizardry of a place like Magic Earth is not the computer's most impressive feat in the remaking of the oil business.

That feat occurs in, among other places, an almost bare room in Houston, not far from Magic Earth, where a business called Newfield Exploration Company has its offices. Newfield is a fairly typical independent oil company. It was founded in 1989 and is capitalized at \$2 billion, with revenues of \$400 million, which makes it substantial for an independent but much smaller than the majors. It specializes in buying properties that the majors no longer regard as profitable and finding—as Gary Packer, one of the company's petroleum engineers, puts it—"new fields within old fields." The company is able to do this by buying 3-D seismic data and poring over it, looking for meat that the majors left on the bones.

I asked to see where the magic happens, half expecting to see more supercomputers and giant curved screens. I was led down an unadorned hallway to a room containing a light table, two large-screen monitors, and two middle-aged men in white shirts and ties. Tom Adams is a geologist, and Eric Freeman is a geophysicist, and they were prospecting for oil in Texas. The

monitors buzzed with zebra-stripe patterns. Colored lines showed faults, and here, the men said, pointing, was a "bright spot"—a place likely to harbor hydrocarbons. Newfield was using off-the-shelf desktop software that was

### **ZEITLIN SHOWED ME INTO THE POD AT MAGIC EARTH. SOON WE WERE UNDERGROUND— 6,000 FEET BELOW WEST TEXAS.**

not remotely as powerful as the proprietary program that runs Magic Earth's supercomputer-driven light show. Still, the software allowed Adams and Freeman to examine in detail nearly any small cube of planet they chose, with a wait of only six seconds to bring a landscape to the screen.

I asked to see the computer. It appeared to be a perfectly ordinary PC. It was souped up a little (extra memory and the like), at a cost of maybe \$10,000, plus about \$30,000 for the software. But its brain was a standard Pentium III chip running Windows NT. What supercomputers could not do a decade ago this dime-store computer does under someone's desk. You can buy the technology to peer inside the earth for less than the price of some new cars.

### **MARGARITA**

**D**URING the Miocene and Pliocene epochs, from about 24 million years ago to about two million years ago, sediments flowed down from the plains and highlands of what is now North America and fell into what is now the Gulf of Mexico. The sediments—so Doug Stauber explained one day, as we drove south from New Orleans, past pumpjacks and sulfurous refineries, on our way to Pompano—were rich

with organic material. Under immense pressure deep underground the organic material cooked to become oil, which, being lighter than the surrounding rock and water, tended to flow upward until it met some obstacle—a geologic seal. There it would gradually collect, forming an oil reservoir.

BP built Pompano, in 1994, as a base from which to find and then produce this oil. The platform stands near the edge of the Gulf of Mexico's continental shelf. To the north lies an expanse of relatively shallow water. To the south the seabed drops off sharply into the abyssal plain, where ultra-deep exploration goes on. The territory around Pompano has seen a lot of exploration. Still, Stauber and BP's other geologists in Houston wondered how much oil lay untouched, obscured by salt.

By 1999 the geologists had done enough drilling and seismic surveying to know that much of the rock near Pompano lay beneath salt formations. Underground, salt behaves like a slow-flowing fluid, assuming all sorts of strange shapes; and because it is a hard crystal, sound waves travel very quickly through it. It thus distorts and blurs seismic images, much as a pane of frosted glass obscures the view through a window.

"When we planned the field and did the first drilling," Stauber said, recalling the early and middle 1990s, "we didn't have the technology to make it possible for us to see past the salt with enough confidence to drill." They had taken stabs at drilling through the salt around Pompano, but they had come up dry. "The image basically vanished beneath the salt," Stauber said. "We had hints about the shape of the salt, but nothing underneath it. It was a big volume of blank."

As computers grow faster, they can run more-intricate algorithms, which gradually improve geologists' ability to infer what it is that salt obscures. By 1999 BP's people thought they had a shot at peering through the salt around Pompano. In June of that year the geologists and seismic analysts began the tedious job of re-analyzing masses of raw seismic data going back to 1991, hoping to tease out details that had previously been invisible. Scouring the 180 or so square miles around Pompano required six months, which gives you some idea of the magnitude of the computational tasks involved. The following January, when the results came back, one spot stood out.

It lay about 10,000 feet underground, beneath an overhang of salt, nestled there like a cove at the base of a protruding cliff. It appeared to be a structural trap: a rock formation bent so that oil, if present, could flow in only one direction until it hit an upper seal of salt. Moreover, the image showed what the geologists called a bright spot, a change in the seismic echo's amplitude that suggested either sands through which oil flows easily or oil itself. The geologists decided to drill. Someone on the exploration team suggested calling the hole

Macarena, to go with another called Mambo, but a completion engineer suggested Margarita, and the name stuck. Margarita appeared to have two possible pay zones, at different depths. Steering through the salt and then penetrating both zones with a single well would require directional drilling.

## NEW DIRECTIONS

**O**N a flight to an oil-and-gas trade show last spring I found myself in conversation with the president of a South Carolina company that specializes in laying underground fiber-optic cable. He pulled a binder from his carry-on and opened it to show me pictures of his drilling rigs: machines, he said, that could stand on one side of a wide river and drill right under it, laying cable a mile or two in any direction. "Sort of like what the oil rigs do nowadays," I ventured. He shook his head and said he thought not. Actually, he said, the oil people park their rigs right over their targets and bore straight down.

Most lay people probably suppose as he supposed, and, indeed, a lot of vertical drilling still goes on. But by the mid-1990s many wells, more than 2,700 a year, were directional. Many of the wells in Texas, for example, are directional, and so are many of the wells offshore.

A directional well can run in any direction, though horizontal is most common. It can approach a reservoir from whichever angle geologists deem most promis-

ing. It can twist and turn to cut through any number of reservoirs. Engineers in Brunei recently drilled a **U**, first downward and then horizontally for a production well, and then back up 800 feet at a 167-degree angle, almost vertically, to do some additional exploration, so as to avoid drilling a separate exploration well. As recently as a decade ago a half-mile horizontal reach was considered an accomplishment. By 1997 engineers in the South China Sea could drill a well for Phillips Petroleum that bored 10,000 feet below the surface and stretched five miles horizontally, thus tapping a previously inaccessible offshore field. If oil were discovered beneath, say, Washington, D.C., a rig could be planted on the White House lawn to suck out all the oil in the metropolitan area, much as a mosquito with a flexible fifty-foot proboscis might sit in the middle of a subway car and bite all the passengers. The upshot has been to bring forth new fields amid old fields, and new wells within old wells.

Seventy miles northwest of Houston, in gently rolling farm country that cattle and corn and sorghum and cotton share with wellheads and pumpjacks, lies the Giddings oil field. I drove to Giddings one bright, warm day in early summer to see a crew drilling—or, more precisely, redrilling—the Bush-Bush well, so called because it both begins and ends on prop-

## THE GROWING INGENUITY OF HUMAN BEINGS IS OUTPACING THE EARTH'S GROWING RELUCTANCE TO RELINQUISH ITS TREASURE.





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erty leased from people (nonpresidential people) named Bush. Bush-Bush is one of many re-entry wells that have been drilled in Texas by Union Pacific Resources, an independent oil company that spun off some years ago from the Union Pacific railroad's parent company and made a name for itself with virtuoso horizontal drilling. (The company recently merged with another independent, Anadarko Petroleum.)

Interstate had turned into state highway, and state highway into farm road and dirt road, when the Bush-Bush rig appeared in the distance, a 150-foot derrick creating the nearest semblance of a skyline to be seen among the pecan groves and fields of young cotton. Up close, Patterson Drilling Company's "Mighty Rig No. 11" looked much as rigs in Texas have looked for decades; it was probably not at all different from the rig that drilled this well the first time around, in 1992. Bush-Bush is on its second life, possibly headed for a third—as is, for that matter, the whole Giddings field.

Giddings lies above a limestone formation known as the Austin Chalk Trend, which sweeps across southern Texas (through Austin) and Louisiana. The Austin Chalk is a tough, mercurial formation, full of oil and gas but inclined to give them up only reluctantly and sporadically. "Heartbreak Field" some people used to call the Chalk, and Giddings produced only thimblefuls of oil until the early 1970s. Then the OPEC embargo struck, the price of oil shot up, and people began drilling like crazy, assuming that oil prices would never come down and that the good holes would pay for the bad ones. "We drilled all the smart things and half the dumb things," Nathan Meehan, Union Pacific's general manager of technology, told me.

The vertical wells, when they hit, started out strong, but soon their flow dropped sharply. Then came horizontal drilling, and an insight. The oil in the Austin Chalk lay in thin horizontal or gently inclined strata. The strata were marbled with tiny vertical cracks, through which oil could flow from the surrounding impermeable rock. That was why vertical wells struck oil so capriciously and lost pressure so fast: if you were lucky enough to drill down along a crack, you got oil, but the crack soon drained.

In 1987 Union Pacific tried its first horizontal well in the Chalk. That well became known as "Wrong-Way Loehr" and is remembered, not altogether fondly, as a learning experience. The next attempt worked better, and in 1990 Union Pacific felt confident enough to establish a twenty-person horizontal-drilling team. The trick was to find an oil-bearing

stratum and nose the drill bit along it, taking care to stay within the pay zone's narrow and often irregular boundaries. The horizontal well would act like a channel connecting all the vertical cracks. "It was the equivalent of adding together eight or ten of these vertical wells," Meehan said. Moreover, the team could drill a new horizontal well under an old one and hit oil all over again.

Bush-Bush was one of the early Giddings horizontals, but it had played out after producing perhaps 200,000 barrels—maybe five times what a typical vertical well might have produced. When I appeared on the scene, Union Pacific was drilling a second horizontal well about 500 feet deeper than the first: a new well within an old well. The driller had re-entered the old well and bored down about 9,000 feet, and now was branching off horizontally to run more than a mile to the north. Meanwhile, the gas flare, which burns off waste methane from downhole, was showing a wisp of black smoke: a good sign of oil.

Directional-drilling technology, like seismic imaging, was not new in the late 1980s, when Union Pacific and others began exploiting its possibilities. Rockefeller himself died only two years shy of seeing the first horizontal hole, in 1939. Still, until the late 1980s the use of directional drilling for horizontal wells was negligible. And then something happened. In 1989 a horizontal well could replace, on average, anywhere from two to five vertical wells, but at a cost four to eight times as high. Quite suddenly the balance tipped, and by 1993 the cost premium to drill horizontally had fallen to a factor of two or less, but the productivity advantage remained. The effect was to bring all kinds of previously inaccessible or uneconomical reserves within reach.

What happened in those years typifies change in the New Old Economy. There was no quantum technological leap, no blinding breakthrough. Instead a suite of interlocking technologies improved incrementally, but to revolutionary effect. One of those technologies was 3-D seismic imaging. It was not much good, after all, for people to spend a lot of money drilling fancy trajectories if they did not know where they wanted to go or whether they would find oil once they got there. By the late 1980s 3-D seismic imaging was revealing targets accurately enough to make directional drilling worth considering. Just as important, however, was the parallel emergence of what in the oil business is known as measurement-while-drilling.

What happened in those years typifies change in the New Old Economy. There was no quantum technological leap, no blinding breakthrough. Instead a suite of interlocking technologies improved incrementally, but to revolutionary effect. One of those technologies was 3-D seismic imaging. It was not much good, after all, for people to spend a lot of money drilling fancy trajectories if they did not know where they wanted to go or whether they would find oil once they got there. By the late 1980s 3-D seismic imaging was revealing targets accurately enough to make directional drilling worth considering. Just as important, however, was the parallel emergence of what in the oil business is known as measurement-while-drilling.

If you think about pushing several miles of pipe into the



ground behind a drill bit, it may occur to you that after you get a few hundred feet, you are likely to have some difficulty knowing precisely where your bit is. Not so long ago a driller would point his bit in the indicated direction, bore a few hundred feet, and stop. Then he would push an instrument downhole that amounted to a camera that took a picture of a compass, and then he would pull the instrument out and check his location. Each survey could mean halting drilling for hours at a stretch, and the results were approximate.

Measurement-while-drilling appeared on the scene around twenty years ago. Behind the drill bit rode one or more instruments that kept track of the bit's location and reported back to the surface. Engineers then added a series of sensors to tell drillers and geologists what sort of conditions the bit was encountering as it moved forward; the sensors' capabilities and sophistication have grown by the month. Then the devices acquired brains that allowed them to process data downhole. A high-end downhole tool today may carry the equivalent of three Pentium PCs of processing power—this spinning in high-pressure muck behind a drill bit any number of miles underground in a tunnel of rock at a temperature of, often, 300° or higher.

A few years ago engineers at a rig site would collect the drilling data, known as the logs, and periodically fax it into town. "And someone in the geophysical department would have to review the log and say, 'Oh, yeah, I think there's oil there,'" Ray Newton, of Baker Hughes, an oil-technology company, told me. The process ate up expensive time. Now Baker Hughes and some of its competitors link the log to the Internet. "The rig site becomes a server," Newton said. Geologists and executives in the home office can click on their Web browsers and see what the driller is seeing somewhere in the Gulf of Mexico, or in Prudhoe Bay, or in the North Sea. They can plug into the rig from laptops at the airport. They can instruct the rig to let them know by e-mail or pager when the hole reaches 20,000 feet, or when resistivity suggests oil, or when anything else of interest happens. Rigs recently began talking to Palm Pilots.

Although it would be correct to say that the modern rig and bottom-hole assembly are a drill with a computer attached, it would probably be more accurate to call them a computer with a drill attached. It is not hard to imagine instruments, programmed with seismic data and loaded with sensors, that could sniff their way to oil. No one I talked to thought that robot rigs and robot wells are far off.

To view these technological developments as a series of coincidences is to miss the story. Measurement-while-drilling, directional drilling, and 3-D seismic imaging not only developed simultaneously but also developed one another. That is, improvements in each increased the payoff for improving the others. Higher-resolution seismic imaging increased the payoff for accurate drilling, and so companies scrambled to invest in high-tech downhole sensors; powerful sensors, in turn, increased yields and hence the payoff for expensive directional drilling; and faster, cheaper directional drilling increased the payoff for still higher resolution from 3-D seismic imaging. None of the technologies was anything like new when, collectively, they took off. What was new was the way in which they energized one another, and then chased one another upward in a virtuous spiral. The result has been to create the feeling that technological time is accelerating—and it is.



## MARGARITA

**D**RILLING began on Margarita last June. BP's people decided to attempt two innovations. For one thing, they hoped simply to see the reservoirs, obscured as they were beneath an overhang of salt. For another, they planned to use a tool that they hoped would allow them to bore through salt as quickly as through sediment.

Margarita's finished length, from drill floor to end point, would be more than three miles. The well would stretch about

11,000 feet almost due east of Pompano, and its objective would be almost 10,000 feet underground. Of the three miles that the drill bit would traverse, about a third would be through salt. Staying on course in salt typically requires frequent fine-tuning of direction, and though such adjustments can be made much faster now with measurement-while-drilling, they still slow the process down. In Margarita's case, Doug Stauber told me, standard equipment would be able to drill through about twenty feet of salt an hour, versus perhaps a hundred feet an hour in sediment. As it happens, Baker Hughes in the late 1990s introduced a system, called Auto-Trak, that can adjust direction at full speed. Just behind the drill bit rides a programmable collar, from which sprout three rudderlike fins. Guided by computer (what else?), the fins bulge or retract to point the drill bit in any direction without slowing it down. Margarita's engineers thought that the tool might shave days off the schedule—which, at \$100,000 a day, would amount to more than lunch money. More important, if



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they could drill through salt as quickly and accurately as through sediment, subsalt exploration and development would move a step closer to being cheap and routine.

Sure enough, the drillers got through the salt in five days, instead of the ten to fourteen that would normally have been required. Once past the salt, they had to make a tight turn to set a course that would intersect both their target zones, each about 200 feet in diameter. With some effort they managed to hit both targets—but they did not find oil. They found water. This was more of the salt's treachery. Even under optimal conditions seismic imaging is imprecise, and salt presents anything but optimal conditions.

Stauber and his colleagues could tell, however, from the sensors' logs and from the cuttings that came back with the mud returns, that the hole had nipped oil for a few feet on the way down, just near the top of the upper target zone. The geologists thought they understood what had happened: the computer's maps had put the promising formations a few hundred feet lower than where they actually were. Stauber and the drillers decided to try sidetracking. They would pull back a few thousand feet to the edge of the salt and then make a sharper turn, cutting a new approach about 300 feet to the northwest of the first one. That ought to let them catch the sloping reservoir higher up, where water, they thought, should give way to oil.

## EXPANDABLE EARTH

**I**CAME of age in the 1970s, the era of limits. In 1976, when I was on my high school's debating team, the national topic was "Resolved: that the development and allocation of scarce world resources should be controlled by an international organization." In 1977 the Carter Administration's National Energy Plan said,

The diagnosis of the U.S. energy crisis is quite simple: demand for energy is increasing, while supplies of oil and natural gas are diminishing. Unless the U.S. makes a timely adjustment before world oil becomes very scarce and expensive in the 1980s, the nation's economic security and the American way of life will be gravely endangered.

At the time of the first Earth Day, in 1970, an ecologist and zoologist named Kenneth E.F. Watt said, "We're going to be out of crude oil about the year 2000 or shortly thereafter. What happens then?" He spoke for the times, and to some extent for common sense, when he said, "We in fact live on a small round ball that logic dictates must have limited resources, yet we are proceeding to behave as if there were absolutely infinite resources. There aren't."

Sophisticated observers in those days knew better than to imagine that the oil spigots would suddenly run dry, but they expected that the price of oil would rise steadily, and probably sharply, as oil became scarcer and harder to reach. That was not a fringe view; it was good economics. Concern about oil

prices merged with a related point of conventional wisdom, which was that the economy could no longer expand without bumping into supply constraints, which cause dangerous inflationary pressures. So-called supply-siders of the right blamed the government's tax policies for creating bottlenecks, while intellectuals of the left said that the time had come to adjust public expectations downward; but all agreed that, for whatever reason, the economy's potential for non-inflationary growth had fallen below the level that obtained from the end of World War II to the late 1960s.

The New Economy hypothesis challenges the supply-constraint model and, in effect, inverts it. The notion is that in the Old Economy growing demand soon meets bottlenecks that take months or years to ease as companies invest in new capacity, or as technologists search for workarounds. In New Economy industries, in contrast, the marginal cost of additional capacity falls rapidly toward zero, because the product is informational rather than physical. The first megabyte of data storage, or the first megahertz of processing speed, or the first copy of a new spreadsheet program, is expensive, but before long the cost of one more megabyte or one more megahertz or one more copy is negligible. Production can be ramped up at very little additional cost. That is Larry Summers's avalanche.

Oil, of course, is not information. It is a finite resource that technically becomes more difficult to find with each barrel pumped. If any industry should behave according to the old rather than the new model, it is the oil industry. Yet several ostensible paradoxes suggest that it is not behaving that way at all.

For example, the world has burned about 820 billion barrels of oil since the first strike at Oil Creek, Pennsylvania, in 1859, and 600 billion of those barrels—almost three fourths of the total—have been burned since 1973. Yet the world's proven oil reserves are about half again as large today as they were in the 1970s, and more than ten times as large as in 1950. It is as if using up oil has somehow created more, although obviously that cannot be true.

A second paradox: Each decade produces fewer of the very large discoveries known in the industry as elephant fields. "No field with more than 27 billion barrels—one year of global consumption, at present rates—has been found anywhere since Safaniya, in Saudi Arabia, was discovered in 1951," Gregg Easterbrook wrote recently in *The New Republic*. Today, indeed, a find of merely one billion barrels is considered cause for rejoicing. Yet the average exploratory well yielded four times as much oil in 1998 as in 1980, according to the Energy Information Administration, with the big jump starting about ten years ago.

A third paradox: We know there is less oil in the ground every year. Other things being equal, that should make finding additional barrels more expensive every year. But finding costs have dropped sharply since the 1970s, even in the United States, a region that has been drilled practically to death. According to the Energy Department, the average cost of find-

ing new oil has fallen from \$12–\$16 a barrel in the 1970s and 1980s to \$4–\$8 today. (Oil prices have recently risen quite a bit, of course, but that is because of OPEC's machinations and turbulence in the Middle East. Finding and development costs give a much clearer picture of oil's real scarcity.)

If oil were truly and fully a part of the New Economy, its marginal finding and production costs would be falling toward zero. If oil were truly and fully a part of the Old Economy, its marginal costs would be rising toward unpleasantness. But since oil is part of the New Old Economy, its marginal finding and production costs are falling, though not toward zero—falling because of New Economy technological magic, though not toward zero because oil, unlike information, is a physical substance in limited supply.

Thus the reason the average new oil find grows larger even as the average new oil field grows smaller is that the industry is drilling fewer dry holes and extracting more oil from the new wells it drills. Exploration success rates grew from 23 percent in the 1970s to 29 percent in the 1990s. That increment sounds modest, but remember that explorers in the 1990s were shooting at much more difficult targets. Success rates could rise even as difficulty increased because improvements in seismic imaging gave geologists a much clearer shot—as if a new rifle scope enabled them to shoot targets at 1,000 yards that previously they couldn't hit at 500. Meanwhile, techniques such as directional drilling and enhanced recovery (in which water or gases or chemicals are injected into reservoirs to force out more oil) increased the yield per new well. Thus did the growing ingenuity of human beings outpace the earth's growing reluctance to relinquish its treasure.

It is certainly true that elephant fields are growing scarce. But that is increasingly beside the point. In the Old Economy model of resource extraction, if you needed more of some resource, you invaded and pillaged new reaches of the planet to get it. Every day, however, virgin resources grow scarcer and thus more expensive, while human ingenuity grows more plentiful. In the New Old Economy the cost advantage increasingly tips away from rapine and toward cleverer and more efficient exploitation of existing resources—which, after all, are already discovered, leased, and equipped with infrastructure. Thus forestry is becoming more like high-tech farming, as it moves away from the logging of virgin forest and toward the harvesting of intensively managed plantations, which can produce yields five to ten times as high. Sawmills

are starting to use x-rays and computers to scan logs and extract an average of 10 percent more usable wood from them. The U.S. copper industry was saved from near extinction in the 1970s and early 1980s by, among other things, rapid advances in a process called solvent extraction–electrowinning, which uses chemicals rather than smelters to draw new copper from old mines and also—no less important—from the heaps of waste left behind by old mines. Nowadays almost half of all American steel is produced by so-called minimills, not from ore but from scrap metal, such as junked cars and appliances, construction debris, and so on. In the New Old Economy, intensity displaces extensivity.

Oil is no exception. "Despite the fact that the United States is the most mature hydrocarbon region in the world," the Energy Department reported last year, "11 percent of all the petroleum reserves ever added in the United States (since 1859) have been added in just the last eight years." And where is all this new oil

coming from? Fully 89 percent, the department says, is from old fields. William L. Fisher, a prominent petroleum geologist at the University of Texas at Austin, has found that in theory about 70 percent of the oil in an average reservoir should be recoverable; at present the average well actually drains about half that amount, and often a good deal less. "What we now understand," Fisher told me recently, "is that owing to the complexities of reservoirs, there's a lot of oil unrecovered in existing reservoirs."

In the past an oil well was disposable, like a drinking straw: drillers stuck it in, sucked out

the oil, and then threw it away. Nowadays, in deep water and other environments where drilling is expensive, oil companies are beginning to view wells as being less like straws and more like roads, to be used and reused as new sections of reservoir are opened up and as old sections are redeveloped with new technologies. "When I started, twenty years ago," Mark Vella, a well-completion specialist with Schlumberger, told me, "if you left fifty million barrels behind because of bad practices, it was still commercial. Today you can't do that." Yesterday's scraps are today's meal. And the threshold at which scraps become meals drops all the time, because technology keeps creating new efficiencies.

So technologists are busy looking for a way to separate oil and gas from water downhole, in the well itself, rather than expensively pumping water to the surface only to extract it and pump it back down again. No one doubts that this grail will soon be found. Meanwhile, researchers at Los Alamos National Laboratory have designed a "microdrilling" appara-



tus that replaces heavy rigs and skyscraper derricks with a coiled-tubing system that can be towed around on a tandem trailer behind a large pickup truck. And although it took oil engineers 129 years, until 1988, to learn how to drill for oil profitably in a quarter mile of water, it took them only another nine years to reach one mile—a depth that by last year was considered boring.

Thus is the world I grew up in, the world of scarcity and constraint, stood on its head. “The end of the oil age,” says Julian West, a senior director at Cambridge Energy Research Associates, “is not going to come because we run out of barrels.” West is a good person to ask about the errors of the 1970s and 1980s. “I believe I was the first person to call the peak of UK North Sea production,” he told me in a telephone interview from his London office. “This was in 1981, and I called it for 1982.” And how, I wondered, did he do? “It hasn’t peaked yet.”

It may be as wrong to project today’s optimism into the future as it was to project yesterday’s gloom. “Forecasting with a pencil and a straightedge has had a very checkered track record,” West told me ruefully. But the most common view, and the one that I find most plausible, is that the demand for oil will peter out well before any serious crimp is felt in the supply. Something cheaper and cleaner, perhaps the hydrogen-based fuel cell, will come along, and the oil age will end with large amounts of oil left unwanted in the ground.

It is natural to think of oil the way a miser thinks of gold—as a limited physical resource whose price must rise or at least hold steady. But that is no longer a good way to think of oil, or of any other resource in the New Old Economy. Most people understand intuitively that the essential resource in Silicon Valley is not magnetic particles on floppy disks, or hard drives in servers, or lines of code or bits of data; it is human ingenuity. The oil business cannot be information-based to the extent that the software industry is, but increasingly it is dominated by the same principle. Knowledge, not petroleum, is becoming the critical resource in the oil business; and though the supply of oil is fixed, the supply of knowledge is boundless. In every sense except the one that is most literal and least important, the planet’s resource base is growing larger, not smaller. Every day the planet becomes less an object and more an idea.

## MARGARITA

**T**HE drillers on Pompano began sidetracking on July 18. The results came in on July 20. That evening the Margarita team was at an Astros game and had just settled in for the first pitch when the report arrived from the rig. The group spent the first inning looking over the data and the next three innings celebrating. “The sand”—that is, the oil-bearing sediment—“that we actually found in the well is better than we projected we’d find,” Rick Bartlett, one of Doug Stauber’s colleagues, told me a few days later. The large upper reservoir not only contained oil but would probably exceed expectations. The lower reservoir held a surprise: gas. How much,

and whether there might also be oil in the lower sands, were not immediately clear.

It took several weeks for the engineers to perforate the well liner, install screens to keep sand out, fracture the rock formation, install production tubing, and flush drilling mud and debris and completion fluids from the hole. On September 8 the engineers at Pompano opened the tap, and Margarita came on line. “Looks like it’s almost five thousand barrels a day now,” Stauber said, “and it will go up. For Pompano, that’s a pretty good well, and it’ll get better.” The engineers expected Margarita to yield something like six million barrels of new reserves, at the fairly modest cost of about \$13 million. That was all new oil from an old field; and at around two dollars a barrel, it cost less than half as much to find as the oil from the original Pompano development. Having succeeded with Margarita, the geologists would use the same techniques to go after more.

The great question about the surge in American productivity since 1996 is, Will it last, or is it simply a brief, blessed pop that will disappear forever when the next recession comes? That is essentially another way of asking whether the New Economy and the New Old Economy are real, or are just the Old Economy on adrenaline. In the oil business right now thousands of economists and executives and engineers are asking their own versions of the same question. The industry’s recent rapid productivity advances can be read in at least two ways. It may be that the computer-driven leap to 3-D seismic imaging in the late 1980s triggered a one-time series of follow-on innovations, like a string of firecrackers, which will end before long. Or it may be that the pace of innovation and adaptation has accelerated for good, thanks to the micro-processing miracle and to the oil industry’s rapid merger with the information economy. Either story may be true—or neither. No one will know for some years. But I can tell you how it feels to the drillers on the rigs and the geologists in the 3-D seismic-visualization environments and the engineers building computerized sensor systems that guide whirling drill bits in three-mile mud-filled pipes through hot rock. It feels as though something has changed and there is no going back.

After Margarita was finished, the drillers on Pompano turned to an exploration well called Subsalt. Not an evocative name, but informative. Margarita was 10,000 feet underground, but Subsalt was more like 20,000. Margarita was tucked under a salt overhang, but Subsalt was buried under the main body of salt. The underground salt structure acted as a sort of umbrella, casting a seismic shadow that obscured the formations beneath. Even with the latest seismic runs the image was blurry, and in patches there was no image at all. “There are still areas we can’t see,” Stauber told me. “But it’s a whole lot better than being able to see nothing, which is all we had until January.” The presence of a promising geologic trap, the geologists thought, could now be inferred with enough confidence to justify taking a shot. The drilling of Subsalt began on November 16. ☞