THE HUBER MILLS digital power report

Powering the 21st Century

June 2002/Vol. 3 Issue 6

Published by Gilder Publishing, LLC

Electricity to Oil

Oceaneering stands at the forefront of the technology that meets the future of oil

Colonel Edwin Drake was prepared to go quite a bit deeper when he turned on his steam engine in Crawford County, Pennsylvania, in 1859, but his drill struck oil at 69 feet. Today's oil companies drill as much as six miles for their crude—a first vertical leg through deep water and rock, and then significant horizontal distances beyond that.

That we now drill miles for oil, rather than feet, is hardly surprising. We pump the easy oil first, so tomorrow's crude is usually farther away than yesterday's. What's surprising is this: Over the long term, the price of oil holds remarkably steady. The six-mile oil costs less than the 60-foot oil did, and about the same as one-mile oil did a decade ago. Yes, there have been price spikes and sags, but they've invariably been tied to political and regulatory instabilities, not discovery and extraction costs.

Equally striking: Allowing for differences in the size of the underlying size of the oil pool, the amount of oil pumped out of each individual production rig keeps rising. You'd think the gigantic gushers of the old days would by now have given way to lots of tiny tricklers, and so far as the underlying fields go that's true, but back at the surface, the amount of oil pumped through the individual production rig is now being pushed back up. And getting more oil out of fewer rigs lowers cost a lot, because most of the expense is associated with all the equipment on the surface, not the length of the bore hole.

How do we keep finding still more oil to pump, even as we keep pumping more of it out of the ground? Why doesn't the price rise and rise? To get energy out of the earth you have to project power into it—first to find out where the deposits lie, and then to bring them to the surface. And we keep getting better at doing those things. It is the increasingly intelligent use of energy itself that continuously expands our energy supplies. When James Watt developed his coal-fired steam engine in 1765, his main objective was to provide a better machine for pumping water out of coal mines. Burn a little coal to dig lots more coal was the basic idea, and it worked. Colonel Drake used coal-fired steam to drill for oil. Today, massive diesel-electric trucks and diesel-electric trains move coal from strip mine to power plant. Oil is used to extract oil, too—huge diesel engines power the big drills. But the most important part of oil extraction now depends on electricity.

How? A slew of different companies provide different pieces of the answer. An important one is Oceaneering International, Inc. (OII). Founded in 1964 as a Gulf of Mexico diving-service company, Oceaneering has emerged as a $500M (revenues) provider of services and hardware to customers who need to move stuff about in the harshest environment on the planet: the deepwater seabed.

Seabed Engineering

Putting aside political problems, the Middle East desert still offers the most abundant and the easiest pickings. But in times like these, that's putting aside a lot. Six miles through solid rock begins to look quite attractive when the alternative is to drill under the shadow of feudal theocracies in perpetual struggle with bellicose neighbors and fanatical segments of their own societies.

From Alaska to Turkmenistan, there is still a lot of land surface to explore, and a great deal more oil to find beneath it. But over 70 percent of the earth's surface—and thus as much of the oil—lies under water. Until quite recently, the deep ocean remained an even less hospitable environment than even the most dysfunctional human societies could dish out—worse, even, than outer space. But technology has now changed that picture. In 1954, the world's first "offshore" platform (as distinguished from a mere swampland platform) was deployed in the Gulf of Mexico in 100 feet of water. By the 1980s, "deepwater" wells were routinely built in 2,000 feet of water. Today, petroleum engineers speak of "ultra-deep" drilling—wells that drill beneath more than 5,000 feet of water. An industry-wide collaborative effort called Deepstar is developing ways to drill and work reliably below 10,000-foot depths. In the past five years, deepwater rigs have yielded some 5.4 billion barrels of oil. The forecast for the next five is 20 billion.

The most critical pieces of hardware in offshore oil extraction today aren't the drills or the platforms; they're the semiconductors in sensors, imaging systems, and computers. Smart machines that deploy and maintain drills, pipes, valves, and cables rank next. The hardware used to create the actual conduit from the oil to the surface runs a distant third.

Seeing comes first—it's the dry holes that drive up the cost of drilling astronomically. Land-based oil production begins with satellite imaging to locate promising geological areas, followed by seismic (low-frequency acoustic) imaging, that can look through rock, salt, and sand in much the same way as ultrasound discerns a fetus in a woman's womb. On the seabed, far out of sight of satellite cameras, it's acoustic imaging from the get-go. Long wavelength pulses are generated by an electric thumper (a giant low-frequency "loudspeaker") or compressed water/air guns; a fanned array of detectors (hydrophones) pick up what bounces back; computers then generate a 3D image of what lies up to 6 miles into the earth. Supercomputers then make sense of the cacophony of data generated, just as the visual cortex of the brain does most of the real work of intelligent seeing.

What the images generally reveal in a rich field is a jumble of isolated pools of oil scattered across a several-mile area deep underground. The cheapest way to get to all the pools is often to build something like a hub-and-spoke network of pipes on the seabed. A number of separate bore holes bring the crude out of the rock; the network then channels it to a central node, which feeds the oil up to a production platform on the surface. This way, far fewer production platforms—the most expensive component, by far—can serve the whole field. But this approach depends on a complex array of engineering, piping, networking, pumping, and repairing down on the seabed. In the past five years, the offshore industry commissioned 38,000 km of pipeline; the current forecast is for 67,000 more in the next five years, along with 13,000 km of control cables.

The advantage of doing more on the seabed, rather than on the surface, is that for all its challenges, the seabed is, in many respects, easier than the surface. Hurricanes, icebergs, and killer waves aren't a problem down deep. But you have to deal instead with two other big problems: pressure and power. The pressure doesn't need much elaboration: Either you rely on equipment that can run at hundreds of atmospheres of pressure, or you build immensely strong pressure vessels to isolate the equipment from the crushing weight of a mile or more of ocean on your shoulders. The power problem isn't subtle either: You can't burn fuel unless you bring your own air, and you can't bring enough. Nor can you unfurl solar cells as you would on a space station. Nuclear power works fine for Navy submarines, but nobody in the civilian sector wants to run that regulatory gauntlet. So for power, you end up using electricity. Supplied by an electrical umbilical that reaches all the way back up to generators in a ship on the surface.

Unmanned Underwater Vehicles

For many years, exploitation of the North Sea fields depended on human divers, who worked (limited) depths in huge steel pressure suits and small submersible vessels. At the peak, some 1,400 intrepid divers were employed to keep the oil and gas flowing in the (shallower) parts of the North Sea. But the diver in a pressure suit is a dangerous and expensive anachronism—a human control system inside the robot, because the robot is too dumb, sedentary, and uncommunicative to operate without it. The much better alternative is to leave the human controller at the surface; connect him to a mobile robot virtually, not physically.

As we have discussed before, digital power is now transforming the business of *moving* things. It makes

Authors	Peter W. Huber Mark P. Mills
Publisher	Lauryn Franzoni
Designer	Julie Ward
Subscriber Services	Melissa McNally
Chairman	George Gilder

The Digital Power Report is published monthly by Gilder Publishing, LLC. Editorial and Business address: 291A Main Street, Great Barrington, MA 01230. Copyright 2002, Gilder Publishing, LLC. Editorial inquiries can be sent to: peterhuber@gilder.com or markmills@gilder.com. Permissions and reprints: © 2002 Gilder Publishing LLC. All rights reserved. Reproduction without permission is expressly prohibited. To request permission to republish an article, call 413-644-2138. Single-issue price: $50. **To subscribe call 800-223-0491**, e-mail us at hmpowerreport@gilder.com, or visit our website at www.digitalpowerreport.com

possible altogether new, dexterous robots for use in networked digital factories, keyhole surgery, and intelligent scooters. (*See DPRs for September 2001, February 2002, and March 2002*) The Pentagon uses the new dexterous robots to keep pilots and soldiers at a safe distance from the battlefield. Industrial companies use them to keep employees at a safe distance from toxic chemicals, fire, nuclear radiation, and explosives. And oil companies use them to do what would otherwise have to be done by divers, or else done on the surface. Until 1975, when it went public, Oceaneering still derived most of its revenues as a diving company. But today, divers account for less than 10 percent of revenues—and most of that diving isn't for oil companies. Oceaneering has migrated with the technology. Its divers have given way to its machines.

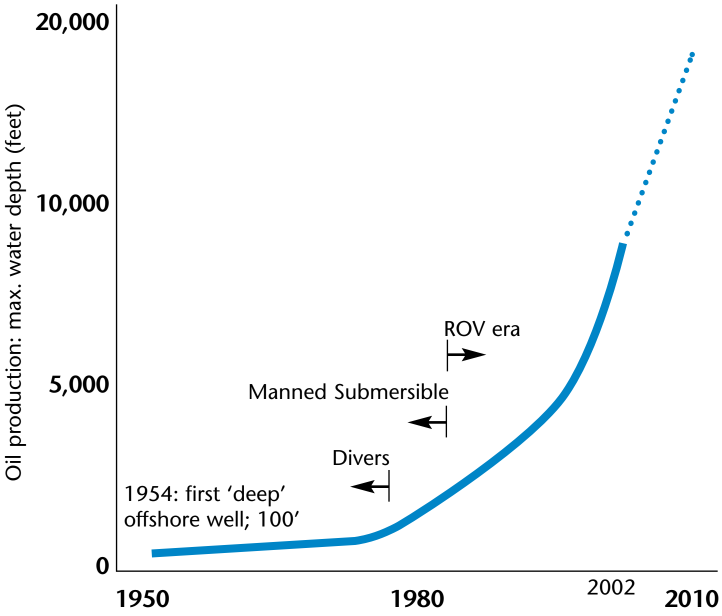
Each industry gets to choose its own acronym for its new-generation robots; the oil industry speaks mainly of Unmanned Underwater Vehicles (UUVs). Most of these are "Remotely Operated Vehicles" (ROVs), which are both powered and controlled via a tether that leads up to a mother ship and human operator on the surface. "Autonomous" UVs (AUVs) comprise a much smaller (but fast-growing) subset—they do surveillance, mostly for the military—and many of them still have a filament-like tether to provide a fiber-optic data link back to the surface. Much of the UUV technology emerged from research and military activities, and from the aerospace industry. One of the first commercial ROVs was built by Hughes Aircraft.

Telecom companies were the first commercial enterprises to adopt ROVs for moving things, not just looking at them—the pioneering cable-laying ROV was the Sea Plow, made by Bell Labs, used from the mid-1960s to the mid-1980s. "Work-class" ROVs now constitute by far the fastest growing segment of the industry, with the oil and gas industry accounting for roughly two-thirds of the ROV market.

ROVs search for oil and inspect underwater equipment—everything from the drilling rig itself to the seabed around the hole. They move and connect gear, pull and connect pipes, and actuate valves. They dig trenches and bury cables. They cut, seal, and manipulate. And ROVs provide extensive "drill support"—they align the drill with the bore hole, provide maintenance, and push back against the relentless forces of current, corrosion, and thermal stress in the deep-sea environment.

Until 1996, Oceaneering purchased most of its ROVs from other vendors. As the market reached a critical size, however, and demand for more powerful, deeper-water systems began to rise sharply, Oceaneering developed in-house ROV design and manufacturing capabilities. The ROV and Advanced Technologies segments of Oceaneering's business, which together generate about half of the company's revenues, grew out of 1992 and 1993 purchases of two businesses that formed the basis of what is now its Advanced Technologies division. The first company acquired was a developer and operator of ROVs for non-oilfield markets. The second, a designer, developer, and fabricator of spacecraft hardware and high temperature insulation products.

Powering the Depths



Power is the single factor that most influences how much can practically be done on the bottom of the ocean—power for motors, well head tools, robot arms, cameras, and sensors. Most of the power is wasted in moving the power-delivery hardware itself. Until very recently, this vicious circle made deepsea engineering prohibitively expensive. Now digital power technologies permit the ROVs from companies like Oceaneering to deliver much more useful power to the workplaces in the ocean's depths.

Since then, Oceaneering has built over 50 ROV systems, and the company now builds all of the ROVs in the fleet that it operates. Oceaneering's ROVs are capable of working in depths of up to 25,000 feet. As of year-end 2001, Oceaneering owned 126 work-class ROVs, and it is now the industry leader in providing ROV services for the most technically demanding deepwater wells. The two closest competitors in terms of fleet size are Stolt Comex Seaway and Halliburton, each with about 100 ROVs.

Like its two main competitors, Oceaneering is in the ROV manufacturing business because ROVs have moved from curiosities to essential tools of the trade.

Deepwater oil recovery is not possible without them; the availability and reliability of the ROVs and their components keep billion-dollar projects rolling and on schedule. With such critical-path technology "you don't want to count on a supplier. If you need a part on Christmas Day to keep working at 6,000 feet, you need the part. And we can count on it from our own operations," notes Dick Frisbee, Oceaneering's VP of Deepwater Technology. Oceaneering's ROV engineers spend lots of time at sea, and bring real-world experience to product design and manufacturing that few other companies can come close to matching.

Oceaneering produces both exploration and work-class ROVs; the latter dominate ultra-deep work. Its Explorer and Deep Ocean Search and Survey ROVs can reach 25,000 feet to perform seafloor geological characterization and searches of every kind. The Magnum is Oceaneering's flagship work-class ROV—the company's fleet currently operates about 100 of these units. The Magnum is designed to work in depths under 10,000 feet—deep enough for the deepest work-a-day wells, which currently reach about 9,000 feet, and easily able to handle the much more typical 5,000-foot depths.

All-electric systems are simpler and at least twice as efficient

Oceaneering's Magellan-class ROVs cover the greater depths that are still primarily the domain of exploration, research, and recovery. Capable of working at, not just visiting, the seabed at 25,000 feet, Magellans won publicity when they helped locate the WWII battleships Bismark and Hood, and recovered the Mercury space capsule, Liberty Bell, from 16,000 feet of water.

The ROV receives high-voltage, high-frequency power via the tether that links it to the mother ship (more on tethers shortly). On the ROV, an IGBT-powerchip AC/DC rectifier powers a 380 VDC bus for the ultra-reliable electric motors, and a 24 VDC bus for the sensors and electronics. The electric motors power a hydraulic system, which in turn powers both multiple thrusters and the manipulators and tools that do the heavy work on the seabed.

The hydraulic systems are still there because until quite recently the power electronics for high-power motors were much too big, and not sufficiently reliable. Rapid advances in digital power technologies have changed that. All-electric systems are simpler and at least twice as efficient. They can be repaired much faster. And they are now proving out to be much more reliable. Oceaneering has made its ROV hydraulic systems remarkably reliable, but Oceaneering's Dick Frisbee readily acknowledge that three-quarters of ROV problems do nevertheless center on the hydraulics.

Oceaneering has teamed with Boeing to develop a new all-electric AUV; an AUV from that program will launch (for the Navy) in the coming weeks. While AUVs are strictly "see" vehicles, Oceaneering foresees the technology migrating eventually to work-class ROVs as well, and the company intends to be there first. Oceaneering has already built and put into the field its first electrically propelled Magnum heavy-duty ROV—able to perform the same tasks as the electro-hydraulic mainstay. Its eight 12-horsepower electric thrusters produce the same total thrust as the original, but the ROV weighs 30 percent less. (An additional 25-hp motor still drives a hydraulic pump to power standard heavy-duty seabed tools.) The electrically propelled Magnum could have been built "considerably smaller" Frisbee notes, but the company opted to use exactly the same chassis, in a configuration that permits electric and hydraulic drives to be simply and rapidly interchanged at sea.

The grabbers, manipulators, and tools will, however, remain hydraulic for some time to come. Above or below the surface, oil extraction relies on multi-ton valves and pipes, and for manipulating components like these, hydraulic systems have one key virtue that still makes them attractive—pressure, and thus force can be amplified simply by increasing the cross-sectional area of a piston. But here too, Oceaneering is developing all-electric options.

Finally, the Magellan and Explorer ROVs carry arrays of sensors and instruments that have much in common with those used in advanced military and medical systems. Fiber-optic gyroscopes for inertial navigation, also found on M1 tanks. Ground-penetrating sonar, which the military uses too, to find caves. Acoustic imaging, to peer through clouds of sediment on the seabed much as it peers through human tissue in a hospital. Survey ROVs typically use multiple sonars: a 3.5 kHz sub-bottom profiler, a 100 kHz side scan sonar, along with a 500 kHz high resolution system. For sea floor geological surveys, the Oceaneering Explorer is uniquely capable of mapping in 5 km swaths with its powerful (up to 2.5 kW) sonar. Like land-based data systems, it has a 55 kWh uninterruptible power supply. Cable-repair ROVs carry sensitive magnetometers as well, to find buried cables. And all ROVs require tilt, velocity, and depth sensors.

If ROVs remain quite myopic, compared to systems deployed on the surface or in outer space, it is because they operate in such difficult conditions. The bottom of the ocean is pitch black, of course; sediment stirred up from the ocean floor can add dust-storm levels of opacity; and power is at a premium. Step by step, however, power and technology are converging to bring better vision to the depths. Low-light digital cameras are being integrated with arrays of light-emitting diodes (LEDs) for illumination—both visible-light and infrared LEDs for close-in observation of marine life. Oceaneering awaits, and has supported development of, ultra-high resolution acoustic imaging—true acoustic cameras, which are now on the near-term horizon. High-power scanning laser systems already used for detailed sea-floor mapping will ultimately emerge as well for real-time vision—they punch a very intense, narrow beam of light through the murky water, and sweep it rapidly back and forth to build a composite image. Oceaneering is also collaborating with the Sandia National labs on developing a mini gas chromatograph. Packaged for subsea environments, it would open up amazing possibilities for detecting hydrocarbon leaks that are completely invisible to all other sensors.

Maneuvering a multi-ton ROV at the end of a multi-ton tether is not easy. Oceaneering's Dick Frisbee talks in terms of "flying" his ROVs, and emphasizes how much work Oceaneering puts into training its ROV pilots. Oceaneering lays claim to the world's most sophisticated ROV simulator (it takes nine Pentium IVs to run it). Designed in collaboration with a manufacturer of helicopter simulators, the simulator matches real ocean conditions but gives operators many hours of flight time.

Power to the Seabed

At this point, *power* is the single factor that most influences how much can practically be done on the bottom of the ocean. Most of the design effort and most of the hardware needed to do something useful in deepwater is centered on getting usable power down to the motors, robot arms, cameras, and sensors. And most of the power is wasted in moving the power-delivery hardware itself. Until very recently, this vicious circle made seabed engineering prohibitively expensive. Now, however, digital power technologies permit companies like Oceaneering to pack much more power through less cable.

A deepwater ROV begins with a cable—a monstrous, cumbersome, unwieldy, beast of a tether. Running two to five miles long, the tether can weigh as much as 16 tons—considerably more than the ROV itself. Deep-ocean robots will almost certainly remain tethered nevertheless. To begin with, it's very difficult to control the ROV without a tether, because it's nearly impossible to communicate through deepwater at any useful speed without a physical link. And in any event, ROVs will require more and more power as heavy lifting shifts progressively from the surface down on to the seabed. If you don't pipe down your power, you have to build a much bigger ROV—big enough to contain a power plant and its fuel and air supply, or a huge bank of batteries. But size gets ruinously expensive on the seabed, as it does in outer space. Smaller structures can withstand the crushing pressure much better than larger ones. The tether is a beast, but the alternatives are worse still.

Size gets ruinously expensive on the seabed, as it does in outer space

So the first challenge in building a better ROV is to build a better tail for it—some two to five miles of tail. The communications channel in the tether is built around familiar fiber-optic technology with up to 400+ Mb/s datastream, that supports real-time, high-resolution video. The power bus, by contrast, is not familiar at all. The power for Oceaneering's ROVs comes from the 60 Hz generators on the mother ship. Oceaneering boosts the voltage to 3600 V and is pursuing even higher voltages, along with higher frequencies. By boosting both voltage and frequency, more power is funneled down less cable. But there are fundamental challenges, too. Electrical conditions in sea water, as well as in and around the cable, may accelerate the corrosion rate of the cable's armor, in what is arguably the electric transmission industry's most complex physical and electromagnetic environment.

In most applications today, the tether leads directly to the ROV. This works, but the vehicle has to drag around its massive tail, which saps power and undermines control. The alternative—already deployed by Oceaneering and others—is to place a way station for power directly on the seabed, or close to it. From a power engineer's perspective, the architecture looks familiar—a high-voltage, high-frequency backbone leading from the power plant (the ship) down to what would be called a "substation" on a land-based grid; the substation then feeds power to the local community.

The main difference is that the land-based substation gets built once, and then sits tight; its ocean-based counterpart is a mobile base. One approach is to let the

ROV serve that purpose, by turning it into a carrier of still smaller ROVs. Another is to deploy a complete power "substation" or "garage" or "Tether Management System" (TMS) from which the work-class ROV is deployed on a separate, shorter, tether—up to 3,000 feet in the current Oceaneering design. Among other designs, Oceaneering produces a TMS with thrusters for use in high-current environments.

From the ship down into the recesses of the ROV, digital power technologies are what make possible the seabed engineering and production without the engineer or the roughneck. They make possible the new parent-daughter power architectures. And by pushing more power through less cable, they create a more favorable balance between the weight of the ROV itself and the weight of its tether. At the same time, ROVs are shedding weight rapidly, as their motors, power electronics, onboard imagers, sensors, and robot arms become much more compact. And they are becoming much more electrically efficient, which slashes the amount of power they use, and thus further reduces the weight of the tether. A 75-kW ROV requires a 16-ton tether to operate at a depth of 10,000 feet. Cut the ROV's power to 18 kW and you cut cable weight in half, and thus achieve 25,000 feet. In the pipeline are utracapacitors and lithium batteries onboard the ROV to further mediate peak power requirements, and thus further reduce the amount of capacity needed in the tether.

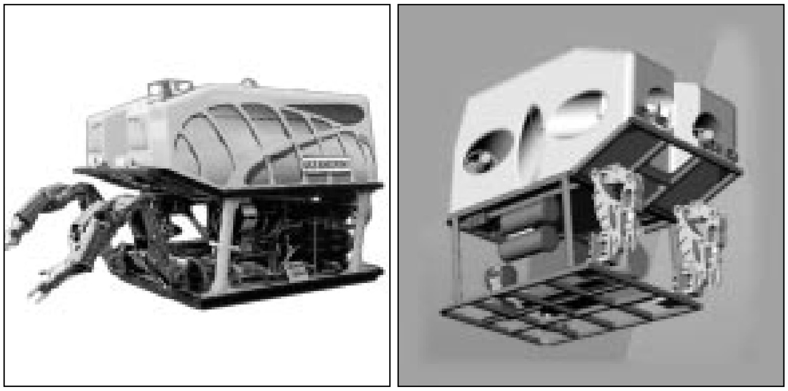
Pure Play

The business press often characterizes it as an industry that followed the deepwater oil companies. deepwater ROVs in fact led it. And now the rapidly maturing technologies of digital power promise to launch a new ultra deepwater era. In 1975, shortly after the Arab embargo, there were only three ROVs in commercial use, and there were still only about 250 operating in the '80s. There are more than 3,000 ROVs today, of which some 600 are the "heavy-lifting" work-class type (the balance are smaller observation-only ROVs). Today, ROVs and ancillary power-related hardware define what will soon be a billion-dollar global business. About 30 percent is in the ROVs themselves; the rest is in their operation. The industry is expected to more than double in size in the next five years.

At least twenty other companies compete with Oceaneering in one segment or another of the underwater contracting business. But just four companies, Oceaneering among them, own two-thirds of the world's ROV fleet. Coflexip Stena Offshore is headquartered in Paris, with its Perry Tritech ROV subsidiary in Florida. The Norwegian-based contractor Stolt Comex Seaway, (OSA on NASDAQ), operates a fleet of 100 RVs and some 40 ships. SubSea Offshore is owned by Halliburton, the global oil and gas services company.

Then there are dozens of companies that build ROVs but don't provide operations and full-scope deepwater services; nearly all are very small, and most of them private. They include Benthos (BTHS), Deep Ocean Engineering, Hydrovision, Seasmart, and International Submarine. At least two large industrial companies have ROV divisions: ECA, a subsidiary of Groupe Finuchem, makes all types of robotic systems. Alstom Schilling Robotics has since 1985 been making manipulator systems for ROVs (including some for Oceaneering's ROVs) and manned submersibles used in offshore oil, subsea telecom, scientific, and military operations; Alstom certainly knows power systems and produces world-class electric ROVs.

Oceaneering remains the largest pure ROV play. With all-U.S. roots, the company has a clear lead in deepwater, serving over three-quarters of the demand for support in deeper than 10,000 feet. Oceaneering is a leader, as well, in the manufacture of electrohydraulic umbilicals that provide high-pressure hydraulics to the stationary control valves and other hydraulically operated equipment on the seabed, to monitor downhole and wellhead conditions, and perform chemical injection. Oceaneering's Space and Thermal Systems division adapts undersea technology for the



The Magnum (left), Oceaneering's flagship work-class electrohydraulic ROV, is able to work in depths up to 10,000 feet. The first all-electric Magnum (right) is 30 percent lighter, more efficient and can ultimately be built much smaller, a combination allowing even greater working depths.

space industry; NASA and its prime contractors are customers. This is an ironic reversal of history—ROV technology emerged from aerospace companies like Lockheed Martin, BAE, and Boeing; Oceaneering is now pushing its armor, automation, interconnection, and remote control technology innovations back the other way.

Oil, Fusion, Sunlight, and Silicon

We first wrote about how technology expands oil supplies in November 1998 on the 25th anniversary of the Arab oil embargo, in a *Forbes* magazine article, "King Faisal and the Tide of Technology" (http://www.forbes.com/forbes/1998/1116/6211235a.html). Jonathan Rauch picked up on our theme in *The Atlantic*, in January 2001 ("The New Old Economy: Oil, Computer, and the Reinvention of the Earth" (http://www.theatlantic.com/issues/2001/01/rauch.htm). Rauch concludes with the following memorable encapsulation of the trends at work here: "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."

Rauch does better than most journalists with a Silicon Valley mindset, who invariably reduce technology revolutions to "computers" and "the Web." Rauch acknowledges the pivotal role of sensors and imaging systems. But even Rauch gives short shrift to the important leg of the triad here, the revolution in power. ROVs represent the paradigmatic fusion of digital power, digital logic, and digital sensors. Work-class ROVs are enabled by technologies centered around the need for power, seeing, working, and communicating. Power for both propulsion and manipulation. The ability to see, navigate, survey, analyze, and control. Working tools to grasp, pull, connect, and cut. Communications to link the vehicle, its arms, and its instruments, to the remote operator.

The inexorable trend is toward less on the surface, and more on the seabed. In time, nothing will remain on the surface but a supplier of electrical and hydraulic power, and perhaps a tanker to haul away the crude. If the well is close enough to land, the tanker, too, will give way to undersea pipes and pumps. This is, by and large, the same technology revolution that sends unmanned General Atomics Predators to do surveillance over Afghanistan. And that leads to Boeing's new X-45, the first unmanned plane designed specifically to fly combat missions (it made its maiden flight on May 22). The main difference between the Predator and Oceaneering's Magellan is one of target selection.

By directing high-grade power toward the capture of more energy, Oceaneering stands at the forefront of lines where technology meets the Malthusian pessimists. All energy-capture and energy-extraction businesses come down to much the same challenge—how to separate the kernels of wheat from the mounds of chaff in our energy-rich but chaotic environment. The pockets of oil lie buried in mountains of rock; the heavy isotopes of uranium and hydrogen are dispersed among the light; wind and sun are fickle and changeable—and in every case, the challenge is to extract and refine.

ROVs represent the paradigmatic fusion of digital power, digital logic, and digital sensors

With the right technology and the right kind of power in hand, it is always possible to extract still more raw fuel from the environment—almost any kind of fuel we like: coal, crude oil, nuclear, or solar. Diesel engines provide the high-pressure hydraulics and the electricity that flow down Oceaneering's umbilicals and tethers, to extract more crude, from greater depths, and the crude then becomes still more diesel. High-power lasers separate heavy uranium isotopes, from light, and the enriched uranium can then be used to generate more electricity, which can fuel more lasers, to enrich still more uranium. Power itself pursues and captures more energy, which produces more power.

Speculators will never tire of investing in impractical technologies touted as "the future of energy." But for many years to come, that future will center on the same old fuels, found, extracted, and refined in new and better ways. The planet's resources aren't contracting, they're expanding, because supplies are determined not by "what's out there" but by how good we are at finding and extracting it. Oceaneering's technology epitomizes the future of oil, and the future of energy. It is a future in which tightly controlled electricity, at the very top of the energy pyramid, sets out to find and extract more raw fuel at the very bottom.

Peter Huber and Mark Mills
June 4, 2002

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	5/31/02 Price	52wk Range	Market Cap
System Integrators	Oceaneering Intl (OII)	5/31/02	31.01	31.01	13.96 - 32.17	762.7m
	Amkor Technology (AMKR)	4/2/02	21.85	14.87	9.00 - 24.79	2.4b
	Emerson (EMR)	5/31/00	59.00	57.85	44.04 - 69.85	24.4b
	Power-One (PWER)	4/28/00	22.75	8.99	5.32 - 24.00	711.2m
Electron Storage & Ride-Through	Kemet Corp. (KEM)	5/1/02	19.63	20.22	13.85 - 22.40	1.7b
	Wilson Greatbatch Technologies (GB)	3/04/02	25.36	25.83	21.20 - 39.00	540.7m
	C&D Technologies (CHP)	6/29/01	31.00	21.71	16.35 - 34.20	563.5m
	Maxwell Technologies (MXWL)	2/23/01	16.72	11.82	5.81 - 22.50	127.1m
	American Superconductor (AMSC)	9/30/99	15.38	7.16	6.50 - 27.65	146.5m
Project, Sense, and Control	Danaher Corp. (DHR)	1/29/02	61.56	69.62	43.90 - 75.46	10.5b
	FLIR Systems (FLIR)	1/9/02	41.64	44.25	15.34 - 59.50	739.9m
	Analogic (ALOG)	11/30/01	36.88	43.26	33.40 - 56.50	571.0m
	TRW Inc. (TRW)	10/24/01	33.21	54.90	27.43 - 55.98	7.0b
	Raytheon Co. (RTN)	9/16/01*	24.85	44.20	23.95 - 45.70	17.6b
	Rockwell Automation (ROK)	8/29/01	16.22	21.94	11.78 - 47.20	4.1b
	Analog Devices (ADI)	7/27/01	47.00	36.62	29.00 - 52.74	13.4b
	Coherent (COHR)	5/31/01	35.50	30.05	25.05 - 39.50	867.8m
Powerchips	Cree Inc. (CREE)	4/30/01	21.53	11.48	10.59 - 33.61	835.7m
	Microsemi (MSCC)	3/30/01	14.00	14.53	12.06 - 40.10	419.5m
	Fairchild Semiconductor (FCS)	1/22/01	17.69	25.15	13.76 - 32.03	2.5b
	Infineon (IFX)	11/27/00	43.75	17.17	10.71 - 35.75	11.9b
	Advanced Power (APTI)	8/7/00	15.00	14.00	6.50 - 15.99	145.0m
	IXYS (SYXI)	3/31/00	6.78	8.15	4.27 - 16.25	218.7m
	International Rectifier (IRF)	3/31/00	38.13	46.97	24.05 - 66.40	3.0b

Note: This table lists technologies in the Digital Power Paradigm, and representative companies that possess the ascendant technologies. But by no means are the technologies exclusive to these companies. In keeping with our objective of providing a technology strategy report, companies appear on this list only for the core competencies, without any judgment of market price or timing. Reference Price is a company's closing stock price on the Reference Date, the date on which the Power Panel was generated for the Digital Power Report in which the company was added to the Table. All "current" stock prices and new Reference Prices/Dates are based on the closing price for the last trading day prior to publication. IPO reference dates, however, are the day of the IPO. Though the Reference Price/Date is of necessity prior to final editorial, printing and distribution of the Digital Power Report, no notice of company changes is given prior to publication. Huber and Mills may hold positions in companies discussed in this newsletter or listed on the panel, and may provide technology assessment services for firms that have interests in the companies.

* *The October 2001 issue closed on September 16, 2001 and was posted at 8 a.m. on September 17, 2001. Due to the markets' close in the week after September 11, our reference price reflects Raytheon's closing price on September 10, 2001.*

More information about digital power technologies
is available on www.digitalpowerreport.com