I find many books about business boring, poorly written, and unoriginal. Most have little applicability to revolutionary discoveries like cold fusion. This is an exception. It won a number of prizes and lavish praise from people like Andrew Grove, chairman of Intel, who wrote: "This book addresses a tough problem that most successful companies will face eventually. It's lucid, analytical -- and scary." The author's main theme is that established corporations are not good at developing what he calls "disruptive technologies," that is, machines or techniques which are inadequate in some ways, yet which have great future potential. A disruptive technology starts out being too small, too slow, or too expensive for the mainstream user. It appeals to people with special needs in niche markets. It then improves more rapidly than the conventional technology, invading the mainstream market "from below." Finally it displaces the mainstream product.

Established companies have difficulty dealing with disruptive technology. This problem is at the heart of the cold fusion dilemma. It is one of the reasons cold fusion has not been aggressively developed by major corporations, and why it will probably not be sold by today's leading energy providers.

Christensen makes a distinction between "disruptive" and "sustaining" innovations. A sustaining innovation makes products more appealing to existing customers. It improves the state-of-the-art in ways that everyone can appreciate. Things are made faster, cheaper, more capable. A sustaining technology is usually more sophisticated than the older version. It takes more expertise to manufacture, and more expensive production lines. The end product may be quite different from previous models. It may be based on different physical principles, but it is functionally equivalent and it fills the same customer needs. Christensen describes the "radical" yet sustaining change from steam to gasoline powered cable-driven excavation equipment: "Where steam shovels used steam pressure to power a set of steam engines to extend and attract the cables that actuated their buckets, gasoline shovels used a single engine and a very different system of gearing, clutches, drums and brakes . . .

Yet the established manufacturers of excavation equipment made the transition, and customers were quick to buy the new machines. Managers in established companies are trained to recognize and aggressively invest in sustaining technology, to keep up with the competition.

Disruptive technology may be cheaper per unit, but it is less cost-effective, slower, less reliable, or less efficient. Established customers have no use for it. Disruptive technology is usually simpler. It may be based on a new breakthrough or on repackaged older technology. To sell disruptive technology you must find new customers. The best place to look for them is in an emerging market. In 1981, Seagate introduced the 5.25-inch Winchester hard disk drive. Christensen compares it to the 8-inch drives that were the industry standard at that time:

The smaller drives were less efficient, slower, and they cost more per megabyte. In 1981 the existing customers for hard disks were minicomputer manufacturers. They wanted more megabytes per dollar, more speed. They did not care how much disk drives weighed or how much space the drives took up. People in the emerging desktop computer market, on the other hand, wanted a low unit-cost, compact, lightweight drive. They were willing to sacrifice speed and cost per megabyte for these advantages. If Seagate had pursued customers in the minicomputer market, it would have swiftly gone out of business. The 5.25-inch drives improved more rapidly than the 8-inch drives, because they were based on simpler
technology. By 1987 the capacity of the 5.25-inch drives met demand in the minicomputer market, although 8-inch drives were still faster and had higher capacity. Eight inch drives had gone beyond the needs of the market, and they had not improved or fallen in price as rapidly as the small drives, so they became obsolete. Companies which had served their customer needs faithfully and stuck with the old eight-inch technology went out of business. They were "held captive by their customers" as Christensen puts it. Companies which entered the 5.25-inch market two years after Seagate also failed, because they could not compete with Seagate's wealth of experience and its base of satisfied customers.

Where established customers see a problem, new customers may see a feature. Hydraulic excavating machines (called "backhoes") were introduced in the late 1940s. They were small and weak at first. They moved only 1/4 cubic yards of dirt with a narrow scoop. Cable excavators moved 1 to 4 cubic yards with each scoop, at a much lower cost per cubic yard. A workman would use a cable excavator to dig the foundations of a house, then others would dig a narrow trench with a pick and shovel from the house to the street, for the water and sewage lines. The cable excavator was too big to dig this narrow trench, but the hydraulic backhoe was ideal. Its small size was an advantage for this job. Hydraulic equipment improved, and by 1970 it could be used for all jobs, large or small. The cable excavator companies went out of business. Christensen describes the situation from their point of view, starting in the 1950s:

Hydraulics was a technology that their customers didn't need - indeed, couldn't use. Each cable shovel manufacturer was one of at least twenty manufacturers doing everything they could to steal each other's customers: If they took their eyes off their customers' next-generation needs, existing business would have been put at risk. Moreover developing bigger better, and faster cable excavators to steal share from existing competitors constituted a much more obvious opportunity for profitable growth than did a venture into hydraulic backhoes, given how small the backhoe market was when it appeared in the 1950s. . . These companies did not fail because the technology wasn't available. They did not fail because they lacked information about hydraulics or how to use it; indeed, the best of them used it as soon as it could help their customers. They did not fail because management was sleepy or arrogant. They failed because hydraulics didn't make sense -- until it was too late.³

Most electric cars accelerate slowly, reach a top speed at 130 kmph (80 mph), and can travel only 160 km between charges. Are these problems, or features? Christensen says that if he were trying to sell electric automobiles, he would look for customers who like these qualities, for example, the parents of teenage drivers. He says if he were managing an electric car project: "Odd as it sounds . . I would direct my marketers to focus on uncovering somewhere a group of buyers who have an undiscovered need for a vehicle that accelerates relatively slowly and can't be driven farther than 100 miles!"⁴ Nowadays, thanks to the Internet, you can uncover this group of people in 0.8520 seconds by looking up "electric vehicle enthusiast" with the Fast Search utility.⁵ The Internet is the ideal medium for selling niche products like Toyota's hybrid electric Prius:

One thing Toyota won't be doing, [Prius project manager] Amstock said, is "shot-gunning" the marketplace with a lot of television advertising about the car. "Those are pretty inefficient dollars." Instead, the company is going to rely on more focused means of reaches the market they think the car will appeal to, consumers who are environmentally conscious and technologically adept. Because of the company's success with its family demo program on the Internet, it is going to it as one of its primary means of reaching consumers.⁶
Electric cars fit the criteria for disruptive technology: they are less capable than gasoline powered models, they appeal to a niche market, they are mechanically simpler in some ways, and they are improving more rapidly than gasoline models. Hybrid electric cars, on the other hand, look like sustaining technology. Their speed is as good as conventional cars, and their range is two to three times better: about 1,100 km on one tank of gasoline. They are not new. The first one was patented in 1905, and hybrid diesel electric railroad locomotives have been the dominant type in North America since the late 1940s. They should appeal to a broad range of customers because they are two to three times more energy-efficient and far less polluting than conventional models. They are more sophisticated technology, not a simplification. They cost somewhat more to manufacture. A sedan slightly larger than a Corolla compact will sell for just under $20,000. (This additional cost will soon be recovered by the savings in fuel, even at today's historically low gasoline prices.) According to Christensen's model, automobile manufacturers should be aggressively developing hybrid electric cars, yet they have ignored them. Toyota and Honda have introduced hybrids in Japan which are scheduled to be sold in the U.S. in 2000, but U.S. automakers have not moved to enter this market.

Christensen describes lively examples of disruptive technology in various industries: mainly computer hard disks, but also steel minimills, hydraulic excavators, motorcycles, and insulin. He finds that most innovations, including disruptive ones, are developed by established corporations. The big companies come up with great ideas and then put them aside. Hewlett-Packard let Steve Wozniak walk out the door with his design for the Apple Computer. The Xerox Parc research institute invented modern graphic operating systems like Windows, but Apple and Microsoft sold them. Startup companies usually borrow ideas from established companies, and they usually begin with less than state-of-the-art technology. The early microcomputers were technically far behind minicomputers. They were inconvenient, slow, and the software even today is nowhere near as reliable as minicomputer software was in 1979.

Cold fusion has also been largely developed by maverick scientists working within mainstream institutions. Toyota and the Electric Power Research Institute (EPRI, working with SRI) have done some of the most impressive cold fusion research, but they put the results aside and canceled or scaled back programs, apparently because managers within these organizations are hostile toward cold fusion. If Christensen's hypothesis is correct, these managers are also puzzled by cold fusion, and cannot imagine what they would do with it. EPRI is a consortium of major U.S. power companies. The first cold fusion generators will probably produce a few thousand watts and they may cost $10,000. Initially, they will be far less cost-effective than conventional generator plants, and they will be built on a scale a million times smaller. If you ignore the future and pretend that cold fusion will never grow larger or more capable, EPRI's management decisions seem correct. A cold fusion generator will be nothing like a gas or wind turbine, which works best when connected to a power grid. Even I cannot see why an electric power company would want one, or what it would do with one. There is no role for a power company in a cold fusion world. A working cold fusion generator at any price, for any market, would be the kiss of death to the electric power industry, just as the first chattering automobiles in 1895 spelled the inevitable, protracted demise of horse-drawn transport thirty-four years later, and the first microcomputers meant the end of most mainframe computers ten years later. Cold fusion cannot help the energy industry. It can only strangle it. The rational response to cold fusion would be to prepare for the orderly liquidation of the electric power industry, the oil companies, and the rest of the energy sector. This would be unthinkable to managers at ExxonMobil. From their point of view, it is like suggesting that if Liechtenstein declares war on the U.S., the Pentagon should immediately begin negotiating a surrender.
Christensen says the managers at large corporations are the smartest and most hard-working people he knows. I have less respect for them, because I was there in 1981 and I knew that small disks would soon outpace the 8-inch ones, and microcomputers would soon replace most minis and mainframes. The trajectory of improvement was obvious to every junior computer operator and technician who followed the trade magazines. The managers at the 8-inch disk companies must have read those magazines. Why didn't they act? Christensen says they relied upon "the best managerial techniques." These techniques work well with sustaining technology, and the "vast majority of innovation" falls in this category. When managers are faced with disruptive changes, their training betrays them.

The book includes a fascinating discussion of how and at what stage to enter an emerging market. Christensen reconciles the opposite views of conventional wisdom: 1) You should jump in quickly; 2) It is better to wait until the pioneers clear the way and resolve the major risks. Christensen found that with sustaining technology, you can afford to wait a few years. Companies that come in late often catch up. But, with disruptive technology, even a short delay can lead to a huge disadvantage. "The companies that entered the new value networks enabled by disruptive generations of disk drives within the first two years after those drives appeared were six times more likely to succeed than those that entered later." The size of the company does not matter much. Small start-up firms and the divisions of larger companies succeed about equally well. It is common knowledge that an early entry to a new market can be beneficial, but Christensen's research shows the astounding magnitude of the advantage: "The firms that led in launching disruptive products logged a cumulative total of $62 billion dollars in revenues between 1976 and 1994. Those that followed into the market later, after those markets had become established, logged only $3.3 billion in total revenue. . . Firms that sought growth by entering small, emerging markets logged 20 times the revenues of the firms pursuing growth in larger markets."10 Anyone thinking of investing in new technology should read this.

Christensen describes several other problems that prevent large companies from successfully selling disruptive technology.

He describes a rule of thumb: "What goes up, can't go down." Once a company sells to the high-end market, it cannot easily back down and introduce cheaper, mass-market models. High-end products for rich customers usually generate a fat profit margin. Companies accustomed to 40% gross margins for 8-inch drives could not bring themselves to accept 25% gross margins from cheaper, slower, low capacity 5.25-inch drives.11 They did not want to cannibalize their own high-end business. On the other hand, companies making the smaller drives were anxious to break into the high-end, high-profit business, so they rapidly improved the small drives.

Large companies are already in business and committed to supporting their customers. Disruptive innovations have no market at first. As Christensen says, "In the tug-of-war for development resources, projects targeted at the explicit needs of current customers or at the needs of existing users that a supplier has not yet been able to reach will always win over proposals to develop products for markets that do not exist."

A large company may not consider a new, small market worth selling to. It might consider a million-dollar order too small to bother with. The size of the organization should fit the size of the market. Large companies have sometimes succeeded in small markets by establishing spin-offs, or autonomous divisions to handle the new product. A famous example is the IBM division in Florida which developed the Personal Computer (PC) in 1980. The chairman of IBM badly wanted the PC. He fought bureaucratic opposition and institutional inertia for many years to get one. He finally financed the project with
discretionary funds and ordered the project manager to report directly to him.\textsuperscript{12,13} This led to one of the most spectacular successes in the history of business. The IBM PC was developed in record time, sales soared, and in a few years IBM took over most of the market. The story has a sad ending. In 1984, PC sales became important to IBM's profits, so managers at corporate headquarters took back control of the business. They stifled innovation, reduced IBM's market share to less than 5\%, and since 1984 they have continually lost money, while Compaq, Dell, Hewlett Packard, and others in the same business have made billions.

Christensen's "disruptive/sustaining" hypothesis is powerful, and worth studying. His examples are illuminating, memorable, and often amusing. But the hypothesis does not explain every case in which great firms have failed. In 1984 when IBM inexplicably began to lose money in PC sales, the PC was no longer disruptive technology; it was the standard. The opportunity to introduce hybrid gasoline electric automobiles has been on the table for nine decades. This would be sustaining technology with broad customer appeal, distinct advantages, a somewhat higher cost, and therefore better profit margins. (The automakers would earn more, the oil companies less.) Yet the automakers have ignored this opportunity.

References
2. In 1979 I managed a Data General computer with a 12 megabyte hard disk. It was the size of a large refrigerator. A repairman showed up one morning to install skids, to prevent the equipment cabinet from tipping over when the disk drive rack was rolled out for maintenance. The disk drive was so heavy that a similar model had toppled over and crushed a technician to death. Today, a 50 gigabyte hard disk weighs about a kilogram.
3. Christensen, Innovator's, p. 73.
4. Ibid., p. 192.
5. The Fast Search utility (www.alltheweb.com) returned 2176 relevant documents in 0.8520 seconds, including many that a product manager would want, such as the Electric Vehicle Association of the Americas (www.evaa.org), and the EV World online magazine (www.evworld.com).
9. See, for example, EPRI manager T. Schneider's forward to N. Hoffman, 1993. A Dialog on Chemically-Induced Nuclear Effects, American Nuclear Society.
10. Christensen, Innovator"s, p. 126.
11. Ibid., p. 81.
13. Christensen, Innovator's, p. 110.