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MISTAKING THE SUNSET FOR THE DAWN: JACK KILBY'S SOLAR BOOM AND BUST

This chapter looks at Texas Instruments (TI), one of the most influential microelectronics companies in the world from the late 1950s through the 1990s. I approach TI through the later career of its star employee, Jack Kilby, who among other things shared the Nobel Prize in Physics in 2000 for his coinvention of the integrated circuit. The theme of the chapter is change, and specifically the awkward politics of change for buccaneering companies reliant on square engineers like Kilby (and vice versa). Change was a constant at TI; the company famously started out in oilfield services, then branched into military technologies, semiconductor manufacturing, and finally consumer electronics. Nor was TI alone in making such major changes to its core business: some of the most well-known names in semiconductor manufacturing—Samsung, Philips, Motorola, Ericsson, Nokia, IBM, Philco, and Toshiba, for example—did not start out in that industry.

As they entered the tumultuous 1970s, companies like these had to decide whether to change again—and if so, in what direction to change. As with NASA in chapter 4, I will draw out ways in which a particular organization's strategies for dealing with change help us to better understand the decade's changes in American science and engineering more generally. Everyone involved in America's R&D system at the time wanted to know how far it would and could change from the early Cold War paradigm, and in what direction. Looking back, we need to know why some systemic changes were pursued and then dropped but others persist to the present. Like the other organizations in this book, TI offers enlightening examples of major strategic changes that were abandoned as well as ones that endured.

Specifically, we will look at a residential solar energy system that TI and Kilby developed in the 1970s and then mothballed in the early 1980s. As an alternative energy source, solar power has long attracted interest from those pursuing "alternative" politics and lifestyles.[1] That was as true in the 1970s as before and after. But for a few years after the 1973 oil embargo, interest in solar power was remarkably widespread across the political and cultural spectrum. Through the rest of the decade, pillars of the national security state like TI, and conservative individuals such as Kilby, attached themselves to solar power. They justified their own—and their patrons' and potential customers'—interest in that technology in terms of cost and national interest, rather than in the environmental or antiestablishment terms that attracted countercultural solarists. If we can understand why companies like TI and individuals like Kilby turned toward solar power in the first place, why they formed some coalitions around the technology but not others, and why they swerved away from solar power later, then we gain some insight into what conditions make square scientists and engineers (and their employers) more socially responsible or less so.

SQUAREST OF SQUARES

One of those conditions, I'll argue, is squareness itself. So before getting to the case study of TI's solar energy system, I first want to show how this chapter's central figure—Jack Kilby—relates to the category of square scientists and engineers. As noted in this book's introduction, the category has fuzzy boundaries and significant internal variability. In earlier chapters I have counted both the acerbic Bill Rambo and the idealistic David Phillips as squares even though they would've disagreed on most of the debates I've discussed. The common characteristics that lead me to label all three—Rambo, Phillips, and Kilby—as squares is their "small-c" conservative presentation of self and their publicly ambivalent or reticent stance toward the politics of the day.

Of course, demographic affinities—their status as white, middle-class, middle-aged men—helped Phillips, Rambo, and Kilby to cultivate a square, broadly quietist presentation of self. None of them were apolitical, but all three expressed their politics quietly, if at all, and their public actions were often only ambivalently related to their private political views. That kind of quietism was a privilege afforded by their demographic status. But demographics aren't destiny. Other white male scientists and engineers used similar privileges to cultivate more provocative public personae instead. Gerard K. O'Neill, who appeared in the previous chapter, is a good example. If anything, O'Neill's background in instrument building meant that he began the long 1970s on the square end of his field (high-energy physics) relative to flamboyant theorists such as Richard Feynman and Murray Gell-Mann. But once he began promoting his utopian visions for space habitation, O'Neill's appearances on the *Tonight Show* and fervent youth following made him rather outlandish relative to his square colleagues. The line that O'Neill crossed, from avoiding the limelight to seeking it, was fluid and contestable yet keenly felt by many squares. One aim of this chapter is to map out where at least some squares drew that line and how they related to those on the other side of it. We'll see that their attitudes toward nonsquare colleagues—or at least colleagues with an outsized public profile or links to the counterculture or the outspoken left—shaped the outcomes of the squares' ventures in the long 1970s.

Jack Kilby is thus the central figure of this chapter because he so thoroughly exemplified squareness. It is hard to imagine someone to whom the label could more aptly be applied. Kilby's public presentation of self was notoriously buttoned-down—to the point that his only biography thus far (a breezy hagiography written by his friend Ed Millis) is entitled *Jack St. Clair Kilby: A Man of Few Words*. There, Kilby is depicted as almost parodically middle American right from the start:

> Life in [Kilby's parents'] household [in Great Bend, Kansas] was probably typical of small-town midwestern U.S.A., but some of the family customs seem quaint by today's standards, or lack of standards. The evening meal, dinner, was a sit-down affair with a white tablecloth and napkins and food brought in from the kitchen. The plates were served by Father Kilby to each family member. This was not just Sunday dinner, or Thanksgiving, but every evening. Conversation during this time was encouraged, but was not to include controversy.[2]

"Conversation encouraged, but not to include controversy" is a better motto for square scientists and engineers than any I could coin.

This is perhaps as good a moment as any to acknowledge that I grew up in a similar milieu to Kilby (the same Midwestern state, in fact), though a half century later. Kilby was of roughly the same generation as my parents, and Millis's picture of Kilby's childhood dinners doesn't deviate much from my mother's recollections of meals among the small-town Midwestern bourgeoisie in the 1940s.[3] So my references to Kilby's squareness are in no way meant as a slight but are rather grounded in a kind of autoethnographic recognition of how his squareness informed the lines that Kilby drew between himself and others.

Once Kilby left Kansas, his adulthood continued in much the same square vein as his childhood. He received a bachelor's degree in electrical engineering from the University of Illinois, interrupted by a stint in India assigned to the Office of Strategic Services (forerunner of the CIA) during World War II. He then took a job with a Milwaukee firm, Centralab, developing techniques for making miniaturized, printed circuits. While there Kilby married another Illinois alum, Barbara Annegers, and they began a family. After eleven years in Wisconsin, the Kilby family moved to suburban Dallas so that Jack could join TI's rapidly growing Semiconductor Research and Development Lab. There they settled into what Millis depicts as unexceptional white Texan suburbia, with Jack immersed in photography and woodworking in his spare time and Barbara becoming an accomplished ceramic artist. That life, however, was compartmentalized from Jack Kilby's work: "People that he worked with for years knew very little about Jack and his home life."[4]

At work, meanwhile, Kilby's name and identity became entwined with TI's thanks to his sudden burst of inventive activity in the first two months after he arrived in 1958. Although his coworkers were all on holiday that summer, Kilby had yet to accumulate vacation time.[5] He thus had the semiconductor lab to himself and could concentrate on solving the microelectronics industry's most pressing problem: the "tyranny of numbers."[6] This crisis arose from the growing number of components (transistors, capacitors, inductors, resistors) in high-performance circuits, especially those made for the military. With discrete components soldered together, failures at the solders became all too frequent and the circuits were uselessly short lived. In the late 1950s the military services and their vendors were exploring ways to "integrate" circuit components to eliminate this problem, and a number of people proposed variants of the eventual solution—monolithic integrated circuits with components and interconnects all made from a single chunk of material—at about the same time.[7] Kilby's tinkering in 1958 led to the first realization of at least some aspects of what became the standard form of integrated circuit—though a long patent battle has resulted in the convention that Kilby "coinvented" the integated circuit with Robert Noyce, then of Fairchild Semiconductor in California.

In part because of that patent dispute, TI has put a great deal of money and energy into enshrining Kilby's 1958 breakthrough in historical memory, down to securing a Texas State Historical Marker commemorating the "demonstration of the first working integrated circuit," unveiled by the state's governor in 1988. (I've heard a TI veteran caustically note that Fairchild's equivalent California state historical marker is for the less punchy "first commercially practicable integrated circuit."[8]) As a result, there is a curious asymmetry between Kilby and the aggressively extroverted Noyce. What they both did in 1958 has been retold many times; but of their lives *after* 1958, only Noyce has been memorialized as *The Man* *behind the Microchip*, the title of Leslie Berlin's biography.[9] No scholarly—or even full-length—biography of Kilby exists, even though he (unlike Noyce) later won the Nobel Prize. In my experience, historians of microelectronics usually have some vague knowledge of Kilby's achievements at TI in the 1960s—for example, ushering the first handheld electronic calculator to market—but not to nearly the same degree that they are familiar with Noyce's post-1958 contributions.[10] This isn't to say that Kilby *deserves* more attention; my point is simply that TI's campaign to secure priority for its intellectual property, plus Kilby's squarely taciturn profile, means that his later life is a cipher compared to his actions of 1958.

Thus, it is not well known that Kilby was a salaried employee of TI for only slightly longer than he was an employee of Centralab—roughly twelve years. Technically, his departure from TI in 1970 was a leave of absence, but there is little indication that he ever intended to go back, and in fact he never did. Millis ascribes Kilby's exit from TI to mounting managerial duties and a consequent disengagement from the technical puzzle solving that he enjoyed.[11] To recoup that creative outlet, Kilby set himself up as a consultant and independent inventor, free to define his own priorities with no pressure from management. The break with TI was not complete, however—Kilby still filed monthly reports to Fred Bucy, a TI vice president (later CEO), and he negotiated a generous deal in which TI paid him a retainer in return for right of refusal on his inventions. He also represented TI on numerous committees, particularly national commissions assessing military policy toward microelectronics research, development, and manufacturing. TI reaped real gains from Kilby's influence over those committees and the insights that he acquired from them. Those factors, plus the reputational advantages of associating Kilby's name with TI, were probably why the company supported Kilby's new venture. Certainly, Bucy did not pursue commercialization of Kilby's inventions for the first few years, so it is unlikely that is the reason that he was kept on retainer.

It's difficult to place Kilby's post-TI venture in historical context. Was he simply an engineering consultant who tinkered on the side? Was he a relic of an archetypal character in American technology, the Edisonian *inventor*? Or did he represent the dawn of a new figure, the disruptive *innovator*? The conventional story has long been that independent inventors became scarce after World War II, but Eric Hintz has shown that companies like TI maintained fruitful relationships with independents throughout the postwar years—so Kilby may have seen his continuing relationship with TI in that way.[12] Yet the 1970s were also a point at which the US corporate R&D system was shifting. Research managers at companies like TI were increasingly aware that they struggled to commercialize in-house inventions, and they therefore needed to externalize some of their R&D efforts. By the end of the decade the microelectronics and biotech industries had established an enduring model for such externalization: fund university researchers, industrial consortia, and small start-up companies and then absorb any intellectual property that they developed.[13] But as Matthew Wisnioski has argued, that model was accompanied by a rhetoric of making "every American an innovator"—that is, encouraging radically decentralized innovation that (with the right policies) could be made to flow into industry.[14] It's possible, then, that TI management saw Kilby's invention shop as an experimental model for externalizing and then capturing innovation.

In any case, Kilby's departure from TI left him in limbo. He continued to be that squarest of squares: a white, straight, suburban, Midwestern-turned-Texan, fairly conservative (but publicly politically reticent), decidedly patriotic, military veteran and family man. But for almost a quarter century he had also been that postwar icon—the *company man*—only now he was without a company. Like NASA after Apollo 11, Kilby had already done the thing that he would always be most famous for—and now he had to find something else to do.

TINKERING AND TEACHING

For the first few years, Kilby's new venture did not yield much. True, he generated a reasonably impressive list of patent disclosures, but not for anything world-changing: a reliable flashlight, a robbery immune cash register, a battery charger, a thermal printer, a display for electronic clocks and watches, and a portable paging system with visible display (of the sort widely adopted in the 1980s).[15] A few of Kilby's projects, though, speak to a more visionary outlook. For instance, an "electronic checkwriter" that he patented in 1975 (filed in 1973) foresaw digital handling and storage of financial transactions on a personal, portable device, thereby paving the way to the "checkless society" that has come into being only in recent years.[16]

More intriguingly, Kilby invested significant energy, time, and money in developing a personalized, interactive electronic teaching machine. Here is how he described the device in 1974:

> Basically the unit consists of a conventional audio cassette playback device, a group of twelve switches and integrated circuit logic to compare the student's answer to an answer recorded on the tape. In operation the student will listen to a question which has been recorded on the tape. When the question is over, the machine will stop. The student then sets his answer on a bank of switches.[17]

This teaching machine seems to have been important to Kilby: there is much more correspondence about it in his papers than about his other inventions of this period. Indeed, Millis speculates that Kilby's attachment to the teaching machine helps explain why he left TI: he invented an early version in 1964—on his own time—that TI nonetheless refused to let him patent in his own name.[18] As Millis notes, TI did eventually market a tremendously successful teaching machine, the Speak & Spell, which Kilby's device closely resembled in appearance (though the Speak & Spell's digital signal processing capability was radically different from, and more pathbreaking than, Kilby's invention).

Electronic teaching machines are the kind of technology that exemplifies the common interests that still could have united American scientists and engineers of the long 1970s even when they were divided by cultural and political affiliations. On the one hand, teaching machines were a vibrant site of countercultural activity, particularly in the San Francisco Bay Area. In fact, the Portola Institute, publisher of *The Whole*

Earth Catalog, was founded primarily to stimulate educational computing.[19] The trivial distance (a quarter mile) between Portola and Douglas Engelbart's group at SRI (Stanford's former contract research arm) aided Engelbart's team in developing technical aspects of personal computing such as the mouse and the graphical user interface. Yet proximity to Portola also encouraged Engelbart's group to indulge in countercultural visions of human potential liberated—and human cognition augmented—by forming a close pedagogical relationship with a computer from childhood onward.[20]

Engelbart's group and the Portola Institute both played an important (if sometimes exaggerated) role in the emergence of personal computing as we know it today. They were by no means alone, though, in the enormous hope that they invested in educational computing. Similar technologies were also a focus of attention among the conventional liberals in the Johnson administration's Office of Education.[21] And they were a hobbyhorse of a few conservative inventors like Kilby, possibly because of growing interest from their patrons in the US military. For instance, Eugene Kleiner (one of the cofounders, along with Robert Noyce, of Fairchild Semiconductor) founded an educational computing company, Edex, in 1962 before selling it to a defense contractor, Raytheon, in 1965. Other military–industrial firms like Litton Industries and Hughes Aircraft entered the field around the same time.[22] By the time Kilby left TI, however, the Mansfield Amendment had forced some square educational computing researchers—for example, the Artificial Intelligence Group at MIT's Media Lab—to shift from military to civilian funders (and consequently toward a more child-centered line of work).[23]

Perhaps because of such widespread interest in the technology, Kilby thought that there was a ready market for his teaching machine, and he tried to persuade a number of companies to develop and market it: Westinghouse, Xerox, Singer, Telex, IBM, Bell and Howell, McGraw-Hill, and Sintra. He also hoped that William Magruder—whom we encountered in chapter 4 running Nixon's New Technology Opportunities program—would connect him to people in the federal Office of Education who might be interested.[24] The Office of Education and several of the companies that Kilby contacted (e.g., Sintra and Bell and Howell) already had or would later have educational computing projects—yet none wanted to collaborate with Kilby or license his invention.

HOW TO TRAIN YOUR ELECTRICAL ENGINEERS

So Kilby's efforts in educational computing did not lead directly to anything (though one can speculate that they gave some impetus to his friends who later developed the Speak & Spell). Yet the teaching machine did mark the start of Kilby's growing interest in bringing his technical expertise to bear on educational innovation. By the early 1970s he had become particularly focused on incorporating hands-on experience in fabricating integrated circuits into undergraduate electrical engineering curricula. Kilby's efforts in this area were stimulated in part by his correspondence with a former TI colleague, Jay Lathrop, who had moved to Clemson University's electrical engineering department in 1968 to be closer to his elderly parents.[25] One of the recurring topics in their letters was Lathrop's attempts to introduce integrated circuit fabrication into his department's curriculum. Around the same time, Kilby developed ties with the electrical engineering department at Texas A&M University, where he promoted a similar incorporation of training in integrated circuit fabrication into the undergraduate degree program. Eventually (1978–1984) Kilby would serve as a Distinguished Professor of Electrical Engineering at A&M, and today that department still hosts the TI Jack Kilby endowed chair.

Kilby's dive into reforming undergraduate electrical engineering pedagogy later facilitated his move into solar energy. His efforts in this area also tell us something about the attitudes toward his peers that he brought with him when tackling a new technological arena—in particular, his greater regard for peers who were allied with military–industrial coalitions rather than civilian ones, and his low regard for peers who sought out the limelight. So it's worth delving into this aspect of

Kilby's post-TI career even though that means skipping slightly ahead in time.

The background for Kilby's new interest in academic electrical engineering was that by 1970 integrated circuit technology had stabilized as *the* platform for mass-produced microelectronics. That is, although Kilby and Noyce's 1958 invention was later taken as a (literal) landmark, through the 1960s other microelectronics technologies were still more practical than integrated circuits for many applications. From the early 1970s onward, however, it was obvious that integrated circuits would predominate in most commercial microelectronics products, whereas alternatives to the integrated circuit would endure only in niche applications.[26]

That realization had two consequences relevant to Kilby's perspective on education. First, companies like TI increasingly wanted to recruit college graduates who were already familiar with integrated circuits and how to make them. At the same time, academic electrical engineers (many, as we saw in chapter 3, former employees of companies like TI) wanted to keep up with industry and make their research relevant to their corporate peers. After 1970 it was obvious that they could do so only if they had ready access to integrated circuit fabrication equipment. Until then most academic electrical engineers made do by scrounging time on industrial equipment, but in the 1970s more and more universities founded microelectronics centers to house their own tools, with which they could train students and facilitate faculty research.[27] The ICL at Stanford, founded in part to advance Optacon development, was an influential early model for such centers. Kilby wanted A&M to set up something along those lines; to that end he corresponded with people who were trying to establish similar facilities, such the University of Minnesota's Microelectronics and Information Sciences Center.[28]

Second, everyone could now see that innovation in microelectronics primarily meant innovation in silicon integrated circuit manufacturing—and that "innovation" in that context largely meant continued miniaturization of components and integration of greater numbers of components onto a single chip. Whichever firms managed to push miniaturization and integration furthest would dominate the market. Various governments therefore initiated projects in the 1970s to boost the capabilities of their nations' semiconductor firms in miniaturization and integration. Japan's Very Large Scale Integration (VLSI) project, announced in 1975, is the most famous and perhaps the most successful of these, but a number of other countries moved in the same direction, especially after Japan's effort was launched.[29]

In the United States, the Pentagon started playing a similar role much earlier, in the 1950s. The US military took that early lead because integrated circuits were suitable for the unusual and extreme requirements of battlefield technologies long before they were practical for most civilian customers. At TI, contracts with the US Air Force and coordination by an Air Force grant officer, Dick Alberts, made it possible to move from Kilby's single, kludgy prototype of 1958 to mass production of integrated circuits in the 1960s.[30] That transition to mass production allowed economies of scale, which meant that over the course of the 1960s, integrated circuits did become cheap enough for increasing numbers of civilian customers. By the beginning of the long 1970s, companies like TI were even incorporating integrated circuits into *consumer* products such as watches. That is, the integrated circuits market civilianized, and it did so at exactly the same time that military support of semiconductor R&D became more controversial, both on university campuses *and* among some of TI's corporate competitors. Indeed, the two trends were to some extent interrelated. Yet Kilby and TI remained committed to the Pentagon's patronage and mission—a commitment that informed Kilby's approach to both educational innovation and solar power.

Opposition to military support of semiconductor R&D took two main forms, both of which Kilby disdained. First, there were semiconductor manufacturers who thought that the military market came with too many burdensome strings attached. Under Robert Noyce, Fairchild had been one of the first semiconductor manufacturers to step away from military contracts for this reason.[31] Other Silicon Valley firms then followed suit—to Kilby's dismay. As he put it in a 1978 report to Fred Bucy,

> DoD continues to pursue the VHSI [Very High Speed Integrated Circuit] project. . . . [A] problem is Bob Noyce, perhaps supported by a few of the smaller West Coast houses. I gather that he feels that people capable of working on the program are in short supply, and that the DoD effort will divert them from more productive tasks. Noyce has always felt that DoD support of R&D has been unproductive, and that industry—or Noyce—could do a better job of directing it. His view is a short term one, and ignores the fact that the supply of trained people can be increased and that the needs of the military are not being well met by the present semiconductor industry.[32]

Thus, for Kilby, it was the duty of the semiconductor industry to ensure that the needs of the military *were* met, even if that meant incurring some extra costs.

Second, *classified* academic research was the subject of intense and broad-based opposition on many American campuses in the late 1960s. Even many academics who had enjoyed military patronage joined that opposition, with the result that many universities banned on-campus classified work. Yet, if anything, the national security state became *more* stringent in classifying microelectronics R&D over the course of the 1970s. Many of Kilby's monthly memos to Fred Bucy raised concerns about the Pentagon's export controls on semiconductor products and manufacturing know-how, because these had the potential to undermine TI's profits. Kilby was unmoved, however, when universities voiced similar worries about restrictions on the open flow of information. As he told Bucy in 1981,

> I am chairing a NRC [National Research Council] panel on the "Impact of VHSIC," a study requested by the DoD. Most of the areas are quite straightforward, but we do have a few problems on the impact of information restrictions on the universities. I am not very sympathetic to the university position. The universities who are complaining got out of classified work ten years ago. If they really want to work on military systems, even if the systems are built on silicon they should be prepared to accept some restrictions. A major part of the problem is caused by delusions of grandeur on the part of the faculty. Many of them feel that with their new microelectronic capabilities that they can build anything. They will not be asked to build VHSIC chips. They should be able to contribute in the rather basic research area, but this is not covered by the VHSIC regulations. It is unfortunate, but the problem has become a matter of principle.[33]

Again, Kilby clearly believed that the military should get to pay the piper and should therefore get to call the tune—and that universities that had allowed antiwar students to run riot should have to bear the consequences.

The person whose "delusions of grandeur" that Kilby had in mind was almost certainly Caltech's Carver Mead, one of the leaders both in VLSI research and in the emergence of academic microelectronics centers. Mead was closely associated with Noyce and was a regular consultant for Intel, the second and ultimately more famous firm that Noyce cofounded. So it's possible that the patent dispute with Noyce colored Kilby's views of Mead. But Mead was also a charismatic promotor of his own ideas—that is, a type of not-very-square academic that Kilby disliked. As Kilby reported to Bucy in 1980,

> I have been asked to serve as Chairman of an NAS panel to review the impact of the VHSIC program for DoD. We have had several meetings, and at the last heard from Carver Mead, who seems to represent the only real opposition to the program. From a technical standpoint just what Mead is proposing is not too clear, but he is very explicit on one point. He feels that vertical integration in the semiconductor industry is bad, and very much wants DoD to build a state-of-the-art fab facility, or silicon foundry. The fact that DoD (ARPA) has already agreed to fund one such facility at Stanford does not seem to deter him. Mead seems to have a messiah complex, and feels that he alone has seen the light and fought the good fight.[34]

Two months later, Kilby expressed relief that "the Carver Meade [*sic*] situation has quieted down . . . [probably because] Meade felt that he had achieved his purpose of securing recognition by all as the father of VLSI, declared a triumph, and withdrew."[35]

Obviously, Kilby's skepticism may have been colored by the rivalry between Intel and TI and the differences in their business strategies (with Intel, like Mead, rejecting vertical integration and TI embracing it). Yet, the fact that Kilby nominated Gordon Moore, Intel's very square cofounder, for membership in the National Academy of Engineering suggests that his dislike of Mead and Noyce was more about personality than corporate or personal rivalry.[36] In any case, whatever his feelings, Kilby couldn't simply dismiss Mead's contributions to both research and teaching related to integrated circuits, but he also couldn't pass up the chance to one-up Mead. As he told Bucy in 1981,

> Carver Meade [*sic*] had the annual meeting of his disciples a couple of weeks ago. . . . To his credit, the courses that he started at a half dozen schools have attracted a great deal of interest, and something over a thousand students have been exposed to the course. . . . Texas A&M is still very enthused about the TI program, and is making a major commitment of capital equipment to enhance it. Their spending will be concentrated on CAD equipment and on testing, which will let them do a better job of designing circuits and evaluating them.[37]

"Better" here almost certainly means better than Mead, because Kilby had earlier explained,

> We have chosen to structure the course somewhat differently than the Carver Meade [*sic*] course, with more emphasis on the basic principles of IC design and less on VLSI. It is intended to be a two semester course, which should give enough time to do a good design and have time to evaluate it and find any errors, which I think is a significant lack in the Meade [*sic*] course.[38]

I'm offering these extended quotes not to slight Kilby *or* Mead, but rather to convey the emotionally loaded language that Kilby used in talking about Mead. One of the arguments of this book is that the turmoil of the 1970s generated strong emotions, even among the most ambivalent square scientists and engineers. Affect tells us something. As we'll see, Kilby's visceral reactions to outspoken and avowed agents of change like Mead and Noyce similarly defined his vision for solar power—he wanted to prove himself a better engineer than such people. But his attitude toward the likes of Mead and Noyce also *limited* his vision for solar power, in that he couldn't bring himself to cooperate with such people.

BORN OF NECESSITY

Let us, then, examine that vision in detail. As far as his papers indicate, Kilby had given no thought at all to solar energy before 1973. He would, of course, have known the basic physics and engineering underlying most solar energy systems, but I can find no indication that he viewed solar energy as a locus for his own inventing activity prior to the OAPEC oil embargo in the fall of that year. Nor should that be surprising—the 1973 embargo was a wake-up call for many. Although there is a debate whether a real embargo was ever put in place and whether the "energy crisis" was orchestrated by the oil industry, there can be no denying that most Americans experienced precipitous increases in gasoline prices combined with severe gasoline shortages in late 1973 and into 1974.[39] In the short term, the Nixon administration scrambled to respond with a mix of price controls and rationing. Eventually Nixon announced Project Independence, a long-range plan for conserving energy, finding new sources of energy, and making existing sources of energy (e.g., oil from the North Slope of Alaska) more accessible. Recall that we saw in chapters 3 and 4 how the embargo, Project Independence, and the ensuing reorientation of the RANN program toward energy caused researchers at Stanford and NASA to suddenly prioritize alternative energy and energy conservation. Kilby and TI were no different.

With his attention primed by the embargo, Kilby hit on an idea at the beginning of 1974 for how his expertise in semiconductor physics could help solve the energy crisis.[40] Over the previous few months he had been in regular correspondence with Lathrop about the latter's pedagogical reforms at Clemson, so when inspiration struck Kilby naturally reached out to his friend and colleague. Lathrop seems to have been positive toward Kilby's idea from the start, and so in early May Kilby offered Lathrop a substantial consulting fee to come to Dallas to collaborate on the project over the summer.[41] Then, sometime before the fall of 1974, Kilby and Lathrop brought a third collaborator into the project, W. Arthur "Skip" Porter, an electrical engineer at Texas A&M. Porter's 1970 PhD dissertation had been on dislocations in single crystal silicon, and it was his expertise in silicon's material properties, as well as his labs at A&M's Institute for Solid State Electronics, that attracted Kilby and Lathrop.[42]

Porter's expertise was necessary because Kilby's system obtained its purported competitive advantage as much from silicon's material properties as its electrical characteristics. Most silicon-based solar energy systems were at the time constructed from large sheets of silicon. In such a system, photons from the sun excite electrons in the silicon, which then travel through a circuit to create an electric current. Making the sheets was costly, difficult, and quite energy intensive—disadvantages that Kilby proposed to overcome by processing silicon with a seemingly simple eighteenth-century technique for making shotgun pellets: a "shot tower." In such a tower—here provided by Texas A&M—a metal or semiconductor is melted and poured through a sieve, creating droplets of molten liquid of a specific size. As the droplets fall, surface tension causes them to form highly regular spheres. By the time they reach the bottom, the droplets have frozen into tiny solid spheres.

Obviously, you can't get much solar energy out of a ball of silicon approximately 250 microns in size. (TI presentations depicted a dozen or so of the frozen droplets lying on the head of a pin.[43]) The *efficiency* of such a small pellet, however, is significantly higher than that of a thick solar panel because almost all of the pellet is close to its surface. In a conventional solar panel of the 1970s, much silicon went to waste because solar photons could not penetrate deep enough to encounter most of the bulk material. With Kilby's pellets there was no bulk material, and hence little wasted silicon. So Kilby imagined combining millions of the pellets in a single modular panel to give an exceptionally high efficiency.

Instead of wiring each individual pellet into a circuit and generating electricity directly, Kilby thought to bathe them in a liquid, the molecules of which could be dissociated by photovoltaic energy. A few such liquids were discussed over the course of the project, but hydrogen bromide was the most commonly used. Photons striking the silicon pellets would create an electric potential, which in turn would break down the fluid medium: for example, hydrogen bromide would decompose into hydrogen and bromine.[44] The hydrogen and bromine would then be siphoned off and stored, and when electricity was needed they could be recombined in a fuel cell (an energy conversion device with a chemistry similar to controllably burning rocket or combustion engine fuel—hence the name). Electric current would flow out of the system, and the recombined

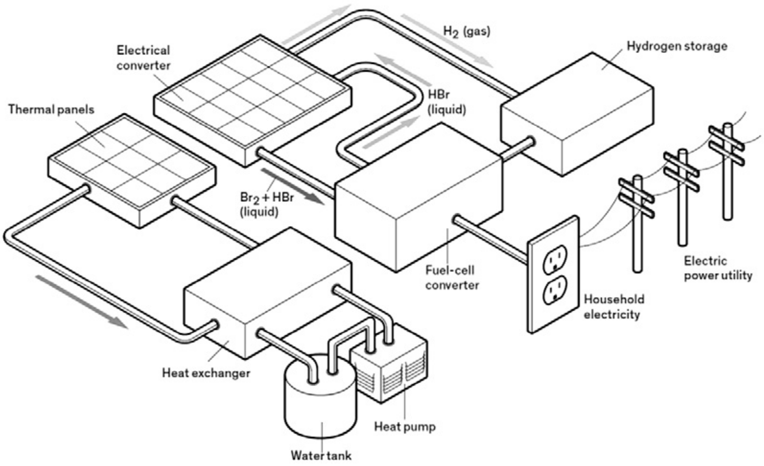

Figure 5.1

Schematic of the Texas Instruments Solar Energy System. *Source*: Image courtesy of Josh McKible.

hydrogen bromide would flow back into it to be reused again. As figure 5.1 shows, the system also included lower-tech thermal panels for generating and storing heat.

The most obvious benefit of this system is that the times when electricity is generated can be separated from the times when the sun is shining. Hydrogen bromide could be broken down by photovoltaic energy during the day, then recombined in the fuel cell to create electricity whenever doing so would be cheaper than drawing from the electrical grid. Kilby and his colleagues also claimed a few other advantages, though these were more disputed. In particular, they believed that the tiny shot pellets would "provide a couple of orders of magnitude more power per pound of silicon than anything I have seen proposed so far."[45] Manufacturing silicon shot also looked, initially, to be cheaper and less energy intensive than traditional photovoltaic panel manufacturing, during which the silicon must be brought to its (very high) melting point several times. Kilby's system also embedded the silicon in a series of narrow tubes instead of large flat panels. Because the tubes operated independently from each other, Kilby claimed that a defect in one of the tubes would not diminish the system's overall efficiency by very much, whereas a defect in one part of a monolithic silicon solar panel would make the whole panel nearly useless and dramatically lower the efficiency of the entire system.

In April 1975, Kilby formally presented his idea to TI's Fred Bucy: "I was glad to have had a chance to go through my scheme for solar energy conversion yesterday. As I am sure that you could tell, I am very enthused about it."[46] From that point on, Kilby kept Bucy regularly updated on the team's progress—a sign that TI was indeed interested in the technology. Then in July of 1975, TI agreed to fund Kilby's team through the rest of the year and to "assume full responsibility for development and exploitation of this program" at the beginning of 1976, with the proviso that Kilby could

> continue parallel development efforts after December 31, 1975, for a period not to exceed two years and for a cost not to exceed $60K per year which cost will be advanced by TI and will be considered as support advances under the existing TI/Kilby agreement. Any inventions and patents obtained on these inventions resulting from work done during the parallel development efforts will be exclusively licensed to TI at no additional cost to TI.[47]

In return, Kilby received a substantial increase in his monthly retainer plus an extra consulting fee, plus a guarantee of payments for the use of his patents (patents that TI also promised to shepherd through the patent office), plus royalties if the system went into production.

I'm outlining TI's agreement with Kilby in some detail to highlight its unusually generous nature. As Kilby himself noted, this agreement was quite different from his earlier ones with TI, not just because TI was actually interested in the invention but also because it envisioned that he would continue to have a role with the technology in tandem with TI's in-house efforts. The solar energy system agreement differed from earlier ones because TI and Kilby

> both felt that this idea was of real importance, and that it needed special attention. I then proposed to continue the work at the universities [Clemson and Texas A&M]

> until summer [of 1976], at which time the project could be moved into TI and a small facility established for it. This plan was accepted by TI and is now well under way. The additional effort has moved the idea along, and no major flaws have been uncovered. I really believe that by the end of the summer [of 1976] we will have a rather convincing demonstration of the concept.[48]

This shows, I think, that solar energy struck Kilby's imagination—*and* TI's business planners—in a way that none of his earlier inventions had. TI saw an opportunity for profit—an entirely new, booming, and untapped market to move into. Kilby likely saw solar energy partly in the same terms—he was in no way averse to making money off his idea. But the enthusiasm of his correspondence also shows an affective commitment that probably went further than just dreams of hefty royalty payments.

MANY WAYS TO BE SOLAR

Most likely one factor motivating both TI and Kilby—though possibly for different reasons—was the fact that they were not alone. By 1975 ideas for commercial solar energy systems were becoming abundant, to the point that it had become possible to speak of a solar energy "industry." TI, with its expertise in the material—silicon—at the heart of most of those solar energy systems, did not want to miss the boat. Kilby, I believe, also wanted to show that he had come up with a better technology than other inventors of solar energy systems.

The industry that Kilby and TI were attempting to join—or, really, to help create—was fractured and complex, however, in ways that Kilby and TI never entirely mastered.[49] The different parts of that industry could've provided grounds for coalition forming that might have sustained the technology through rough times. Kilby and his colleagues did seek coalitions with certain kinds of solarists—but they rejected making common cause with promotors of solar technology who did not resemble the square engineers that Kilby and TI were used to dealing with. In particular, Kilby and TI never showed any interest in allying with the growing cohort of (mostly) young people for whom solar energy fit neatly into a vision of socially relevant science and technology. These were the kind of people who, for instance, entered the UCSB MSI program for combined “tangible” (i.e., pecuniary) and “esoteric” (i.e., idealistic) reasons. Indeed, several of the MSI program’s student projects concerned solar energy.

For many young, reformist solar enthusiasts, one of solar energy’s main selling points was its potential for decentralization: one could use solar power to “get off the grid,” to run your commune or farm as you saw fit without being at the mercy of giant, faceless utilities. Another—overlapping—group of reformist solarists were attracted to the technology because it seemed cleaner and more environmentally (and politically) friendly than coal, oil, or uranium. For some solarists these motivations were mutually reinforcing, but for others they were quite distinct though not mutually exclusive. At least for a time, different kinds of reformist solarists could cooperate even if their interpretations differed. Supporters of the appropriate technology movement associated with E. F. Schumacher, for instance, no doubt appreciated that (some) solar energy systems could be constructed with a small environmental footprint, but they were also happy to work with farmers who cast the technology more as a means to save money and preserve their autonomy.[50]

Some of these idealistic scientists and engineers formed their own start-up companies or science-oriented communes. Indeed, the line between company and commune was sometimes blurry, as exemplified by the colorfully named New Alchemy Institute, founded by Nancy Jack Todd, John Todd, and Bill McLarney in 1969. The New Alchemists ran experimental farms—which they called “arks”—on Cape Cod and Prince Edward Island, where they developed technologies for alternative energy and sustainable agriculture and architecture.[51] The New Alchemists were well-known in environmentalist circles: they hung out with the likes of Schumacher and Stewart Brand, and Prime Minister Pierre Trudeau visited the Prince Edward Island ark. Their example shows that moderately countercultural alternative energy promoters were capable of knitting themselves into quite influential coalitions. Yet it’s very difficult to imagine Kilby taking such coalitions seriously or countenancing anything done by someone calling her- or himself a New Alchemist.

Other idealistic solarists joined government agencies that were developing their own solar technologies or that were tasked with evaluating solar energy systems developed by others. We'll see that Kilby and TI had little choice but to interact with some of these agencies, particularly JPL and SERI (the latter part of the Department of Energy and the former under contract with that department). Indeed, the director of SERI, Denis Hayes, exemplified this kind of idealistic solarist, having been one of the lead organizers of the first Earth Day in 1970.[52] It's no surprise, then, that Kilby was dismissive of SERI and everyone associated with it.

Not all idealistic solarists were young. Schumacher, for instance, was born in 1911. More closely intersecting with Kilby's orbit was the autodidact labor organizer turned tech entrepreneur Stanford Ovshinsky, who was born in 1922. Kilby would've already known about Ovshinsky's discovery of switching behavior in amorphous (i.e., noncrystalline) semiconductors in the late 1950s, something that many mainstream microelectronics researchers refused to accept. But Kilby also would've known Ovshinsky for his relentless, flamboyant promotion of that discovery and of the company, Energy Conversion Devices (ECD), that he built around it. No doubt Ovshinsky, with his left-wing politics and working-class roots, had to promote his ideas in ways that a more establishment figure like Kilby did not.[53] But of course for Kilby such promotionalism was one more reason to shun Ovshinsky.

Ovshinsky's announcement in 1977 that ECD was going to market easily manufacturable solar panels powered by thin (and hence light) sheets of amorphous semiconductors—perhaps even printing them roll-to-roll like a newspaper—put him in direct competition with Kilby and TI's similarly easily manufacturable solar energy system. Unsurprisingly, Kilby's assessment was that Ovshinsky was a fabulist:

> Ovshinsky and ECD continue to make the news. He has been talking to the *Wall Street Journal* and the financial community about his work, and has said that they are now building square foot amorphous cells with 7% efficiency. . . . We have

> checked with some of his people, and it would seem that these stories are incorrect. . . . I think that the stories have been triggered by his need for more money. ARCO [Atlantic Richfield, an oil firm] has told him that they will cut off his funds at the $8 million level, which he will reach by the end of the year. He will probably find another sponsor. Anyone who has been able to raise $75 million on pure promises should not be underestimated, but it looks like a good chance to sell short.[54]

Again, as with Kilby's dismissal of Hayes and environmental solarists, Kilby's intense dislike of Ovshinsky reflected a worldview in which those who came to solar energy from the left or who promoted it too flamboyantly (by Kilby's standards) were probably technically incompetent and certainly not worth engaging with.

The TI program did engage, however, with some *square* solarists, especially those with backgrounds in the military–industrial complex whose fortunes had become more precarious thanks to the decline in defense R&D funding. Some of these people had developed expertise during the early Cold War that now became plausibly relevant to terrestrial, civilian alternative energy: in areas such as expertise relating to solar panels for spacecraft; silicon for microelectronics (but now adapted for photovoltaic energy); advanced airfoils used in fighter jets (but now adapted for wind turbines); construction of large movable structures that (like the dishes used in satellite tracking stations) could follow the wind or sun; and superconducting materials for transmitting power over long distances. Especially after the oil embargo and the announcement of Project Independence, many of these people could see clear incentives to repurpose their military–industrial expertise for alternative energy R&D.

A *few* of these people came to share some of the more countercultural interpretations of solar energy and to advocate that civilian, rather than military–industrial, networks take the lead in developing solar technology (much as Noyce advocated for civilian primacy in development of integrated circuits). We've already seen some examples in this book of such idealistic awakening among former participants in the military–industrial complex. Estimating their numbers would be impossible, but nothing in my exploration of this topic makes me think that such converts were a very large proportion of the square solarists. And nothing in Kilby's papers gives any indication that he thought highly of such people. Quite the contrary—former military–industrial colleagues who collaborated with countercultural solarists or advocated civilian control of solar innovation were, in Kilby's view, not very good engineers. In particular, one such former TI colleague, Paul Maycock, became something of an obsession for Kilby, Lathrop, and the TI team. As director of the Department of Energy's photovoltaic program, Maycock worked closely with Hayes and SERI; hence, Kilby and colleagues frequently expressed concern that Maycock was somehow spying on the TI program on behalf of his new allies.[55]

By contrast, Kilby had few qualms about solarists who remained (in his view) square enough: people for whom solar energy offered a means to make money and perform a patriotic duty, who either saw solar energy's environmental and decentralizing potential as secondary or rejected those interpretations of solar energy entirely, and who avoided association with countercultural solarists. As we'll see, he had deep doubts about the competence of engineers who advocated for civilian primacy in solar innovation; but he had far fewer qualms about the competence of solarists who remained rooted in the military–industrial complex. Some of these people were inside government, and others worked for aerospace firms like McDonnell Douglas (which at one point claimed to have built the "world's largest functioning solar thermal plant").[56] Indeed, one of the distinctive features of the military–industrial complex was the revolving door between government and industry, a fact that allowed firms like TI or McDonnell Douglas to quickly—but often only superficially—attach themselves to federal support for solar energy.

Kilby was also willing to entertain collaborations with square engineers in nondefense companies, so long as those companies didn't approach solar energy in a green or countercultural way. In the latter half of the 1970s there was an abundance of such companies. The trade magazine *Solar Engineering*, for instance, published monthly "stock listings of solar-related companies," featuring firms from an astonishing variety of industries: utilities, chemicals, microelectronics, aerospace, glass, mining, construction, scientific instruments, and others. The oil industry, in particular, was well represented—most of the major oil companies had in-house solar power efforts and/or partnerships with solar power start-ups, such as Atlantic Richfield's funding of ECD.[57] In that context it is worth noting once again that TI was originally an oilfield services company and was still active in that business in the 1970s. Even if Kilby was associated with the part of the company that had little to do with oil, he would've had connections in that industry, if only from being an influential high-tech figure in one of the world's great oil capitals. Later, we'll see that oil firms were prominent among the potential partners—as well as the respected competitors—that he had in mind as the TI project unfolded.

THE AMORPHOUS CRYSTAL BALL

Kilby's orientation toward the square parts of the nascent solar power industry, and away from its more countercultural corners, was not simply a matter of whom he preferred to work with or whose judgment he trusted. It was those things; but those preferences were also baked into the design of the technology itself. The TI effort—initially dubbed Project Illinois, after Kilby's alma mater, and later the Texas Instruments Solar Energy System (TISES)—was not designed for a farm, a commune, or an apartment building but rather for use in a single-family home. Moreover, the system's cost would've been high; in 1983 it was projected that the average system would cost $8,390 when TISES first reached the market in 1988—that's roughly $21,500 in 2019 dollars.[58] Thus, as the consultants Booz Allen Hamilton put it, "'High-end' new home market is the likely entry for TISES"—that is, mansions of approximately 3,000 to 5,000 square feet.[59]

In one sense, this reflected a tried-and-true strategy: develop a new technology at high cost for initial marketing to the wealthy, then use their purchases to achieve economies of scale that drive down costs and make the technology affordable for middle-class consumers. Kilby and TI's own experience with integrated circuits was a successful instance of this strategy, with the military playing the role of the wealthy early adopter. Yet in a number of respects this strategy was a poor fit for the TISES, because Kilby and TI consistently promoted the system in terms of cost savings. People who buy mansions often aren't very worried about saving on their electricity costs and show "generally lower concern with energy efficiency."[60] Unlike many countercultural solarists, mansion owners aren't very attuned to breaking the influence of the utility or fossil fuel industries. But they do want a home that they and others will regard as beautiful—whereas every indication is that they would've regarded the TISES as exceptionally ugly. Finally, though mansion owners aren't usually seen as an environmentalist constituency, there are plenty of wealthy environmentalists. TI could've chosen to market TISES as a means for mansion owners to compete with each other to be seen as helping the planet, yet there is no hint whatsoever that TI even considered that possibility.

So why did they market TISES to mansion owners but only on the limited selling point of cost savings? The answer lies in Kilby and TI's "sociotechnical imaginary," of which the TISES formed a part.[61] In the outline of that concept offered by Sheila Jasanoff and Sang-Hyun Kim, a sociotechnical imaginary is made up of the combined features of a technology and the social order in which it is embedded; specifically, those features that the parties to that technology and social order deem most salient. The collective imaginary guides technological choices in the present—a social group steers the technology one way or another on the basis of the group's understanding of the technology's features and those features' affordances for the social order in which the group is embedded. But the imaginary is also about the coproduction of the technology with a *future* social order: groups try to steer a technology to make certain preferred social arrangements more likely to come into being, just as they try to steer the social order to make certain preferred technological achievements more likely to take root.[62]

For Kilby and TI, the salient features of solar power were its lower cost relative to embargo-era oil and its potential to make the United States energy independent, and *not* its potential to undermine powerful utilities and fossil fuel conglomerates or ameliorate pollution or allow communes to be self sustaining. Kilby's imaginary for solar power guided design choices and preferences regarding what kind of people to market to or to collaborate with (and vice versa). Those design choices had a basis in certain features of the technology; but, crucially, Kilby's imaginary also encouraged or even required him to *neglect* other aspects of the technology. The logic behind accentuating some technological considerations and ignoring others was underwritten by Kilby's projection of a particular future social order. In that imagined future, TI's system would be at the center of an energy-independent society made possible by square scientists and engineers like Kilby. In Kilby's future America, no credit for the country's energy transformation would go to leftie environmentalists like Hayes or self-promoters like Ovshinsky; and the influence of such people would be so limited that any resistance to TISES from that direction could be safely ignored.

We can be fairly certain that Kilby and TI's vision of the future was defined by cost and national security factors rather than environmental or countercultural considerations because they commissioned quite explicit roadmaps for how to make TISES part of that kind of future. In late 1976 or early 1977, TI asked consultants (probably from Booz Allen Hamilton) to construct scenarios narrating three paths for bringing TISES to market: "Texas Instruments [develops TISES] alone," "Texas Instruments takes a partner," and "development with governmental support."[63] Such scenarios were at the time a relatively recent business innovation, having been developed in the 1950s at RAND and other think tanks as a means of projecting the social (dis)order that would be coproduced with various nuclear weapons designs and strategies. As Bretton Fosbrook has shown, by the early 1970s the technique had leapt from the community of defense intellectuals into the corporate world, particularly via Royal Dutch Shell.[64] TI, with its connections both in oil and in the military–industrial complex, was the kind of company in which scenario planning was adopted early and earnestly.

For scenarios to be persuasive, though, they must be plausible; and the grounds of plausibility are rooted in the audience's sociotechnical imaginary. *None* of the TI scenarios referred to solar energy's environmental or other countercultural or anticorporate affinities. We can infer, then, that Kilby and the TI team simply did not see the plausibility of the scenarios as hinging in any way on those factors. The *only* advantage of solar energy presented in the scenarios was its price relative to embargo-era oil—so the only plausible future that Kilby and the TI team could imagine was one in which people chose TISES overwhelmingly on the basis of price. Presumably they understood that there were constituencies for solar power that were more motivated by environmental or countercultural concerns. But in Kilby and TI's sociotechnical imaginary, solar power systems designed with those considerations in mind would secure such a small market share that the scenario writers could ignore them.

One thing that the scenarios could not ignore was TI's need for approximately $30 million to $50 million ($134 million to $224 million in 2019 dollars) in funding to bring the technology to market. Given that scale of investment, the "TI alone" scenario seems to have been dismissed fairly quickly. One reason that that scenario was deemed problematic was that it imagined the TISES technology leaking out to competitors. In that scenario a character, transparently based on Paul Maycock, moves from TI to ERDA and uses his inside knowledge to convince ERDA to give contracts for TISES-like solar power systems to other companies. Whatever its basis in reality, that plot device was plausible to TI managers. Thus, they decided that to develop the technology fast enough to keep ahead of competitors who were privy to TI's secrets, the project would need more money up front than the company itself could risk.

Based on the scenarios, therefore, TI sought a partner with deep pockets, preferably one that would impose few conditions on TI and that could not use its partnership to put itself in competition with TI. The latter requirement eliminated manufacturing firms such as General Electric, but not nonmanufacturing firms such as oil companies. In any case, in the strained economic conditions of the 1970s, almost the only entities with deep enough pockets were either governments or oil companies with large cash reserves from the post-1973 spike in prices. Thus the scenarios quickly narrowed TI's choice down to three partners: Royal Dutch Shell (Exxon and other oil majors were thought to have already advanced far enough in solar power technology to compete with TI); the US Department of Energy; or the Saudi government/royal family. With respect to the latter, the scenario recommended pursuing Prince Mohammed Al-Faisal because:

> He had been technically trained in the US . . . and had just raised $100 million from a group of friends to tow icebergs from the Antarctic to the coast of Saudi Arabia to serve as a source of fresh water. His project had been held up for the development of a technique for coating the icebergs, and the money was available for other ventures.[65]

The author of the scenarios believed that TI would have the most access to funds with the fewest strings attached if it partnered with the prince. The author also noted the risks of Saudi funding (e.g., the possibility that a war in the Middle East would end the partnership with TI) and thus recommended that TI first weigh those risks before deciding (by February 15, 1978) whether to find a private partner or "initiate solicitation of DOE funding."

THE MILITARY–INDUSTRIAL–SOLAR ENERGY COMPLEX

That plan was apparently put into practice, because in January 1978 TI indeed initiated solicitation of DOE funding. Partnering with an oil firm or Saudi Arabia was not taken off the table completely, but those options were temporarily put aside. The problem with seeking help from the DOE, though, was that neither Kilby nor his TI colleagues had much respect for that organization. As the scenario author put it,

> The solar photovoltaic program at DOE has recently been redirected to an early attainment of its goals through a technically unsound approach. This approach has been strongly identified with Dr. [Henry] Marvin, as being personally developed and sold by him. . . . Any alternate programs seeking substantial funds will

> be personally viewed as a competitive threat by Dr. Marvin. . . . DOE personnel generally have a poor understanding of the requirements for commercialization of technology.[66]

The "development with governmental support" scenario also claimed that DOE personnel were likely to view TI as "a difficult company to work with" because "none of the DOE personnel had enough industrial experience to appreciate the importance of trade secrets."[67] Note that this latter point neglects that two of Kilby and TI's DOE bogeymen, Paul Maycock and Hank Marvin, did in fact have industrial experience (Maycock with TI and Marvin with General Electric).

It's reasonable, therefore, to assume that the scenario's objections to DOE were rooted in something other than department personnel's inexperience or "unsound" technical expertise. Most likely the problem was that Kilby and TI just didn't view civilian government agencies as trustworthy partners. That stance wouldn't be unexpected for rather conservative engineers working in the military–industrial complex and living in a very conservative part of the country. But ideology isn't exclusive of other explanations. In particular, Kilby and TI simply had more and better contacts—friendships, even—with Department of Defense personnel, and as a consequence were used to much more generous contracts and intellectual property arrangements than they believed they would get from a civilian agency like the DOE.

The scenario author therefore recommended that TI short-circuit the regular civilian staff of the DOE and instead try to negotiate directly with the department's more Pentagon-friendly leadership. At the time the scenarios were written, the Secretary of Energy was James Schlesinger, previously Secretary of Defense from 1973 to 1975. Schlesinger's deputies—the people the scenario recommended that TI negotiate with—were Dale D. Myers, a former NASA and Rockwell engineer, and Robert D. Thorne, an AEC employee since 1955. These were all square men with national security credentials that TI could trust. In the end, yet another DOE administrator, John Deutch, took the role originally envisioned for Myers or Thorne. Because Deutch was a former civilian systems analyst for the

Pentagon, a member of the Defense Science Board and the Army Science Advisory Panel, and "an influential member of the DOE management" with the ear of the Secretaries of Energy and Defense, his credentials would've been just as reassuring to TI.[68]

The final link in the chain was George Heilmeier, the director of DARPA from 1975 to 1977. Heilmeier had also worked in other Pentagon roles since 1970, and before that he was an influential research manager at RCA.[69] In December 1977 Heilmeier joined TI as Chief Technical Officer, and the *next month* he journeyed back to Washington to begin lobbying the DOE to support the TISES program. Upon his return he reported,

> during my visit to Washington on January 30th, I had planned to see Greg Canavan [an Air Force officer, probably involved with fusion research at Los Alamos National Laboratory], White House Fellow in the Department of Energy, to get an informal view of how the current DoE solar energy program was perceived by the highest levels of the Department. When John Deutsch [*sic*], DoE R&D chief, learned of my impending visit from Canavan, he directed that the meeting be a one-on-one (Deutsch and Heilmeier). During our discussion, Dr. Deutsch made the following points:
>
> - DoE has more money than good ideas.
> - He is extremely unhappy with the content and management of the DoE solar energy program. The technical sophistication of the managers is low, and he doesn't feel that they have a strategy (few truly innovative ideas).
> - He feels that the current DoE projections of $.50/watt by the mid-80's [*sic*] is unrealistic given the strategy of simply mass producing cells based on current concepts.
> - He stated that the current DoE patent policy is as flexible as that of DoD in *theory* but not in practice. He feels that overly restrictive patent practice by DoE may be inhibiting industry, but he would like to have some examples to make the case. Deutsch has been requested by Secretary Schlesinger to take a strong role in DoE patent policies including decisions on waivers.
> - Deutsch has $25M in the budget under his *direct* control for "ARPA-like" program. None of these funds have been committed.[70]

These notes showed that Deutch shared TI's low regard for DOE's civilian solar power experts and that he was willing to use his authority to cast the department's solar energy activities in a Pentagon mold, both in terms of funding ($25 million for “ARPA-like” program) and in terms of intellectual property protections for military–industrial firms like TI.

The Heilmeier-Deutch summit soon achieved the result envisioned in the scenario: a four-year, $18 million contract with the DOE, under which “The government received a royalty-free license for its own use but TI retains patent and licensing rights in the commercial arena.”[71] An internal TI memo made clear that this was Deutch’s baby: “When discussing TI’s solar energy program with the press, please be sure and give John Duetsch [*sic*] the credit he deserves for creating a suitable contractual environment in DOE for the pursuit of this technology.”[72]

In carrying out the contract, however, TI had to interact with ordinary DOE personnel who—as the scenario had forecast—did not necessarily agree with Deutch’s support for TI. There were two main points of contact between TI and DOE: Hayes’s SERI and JPL (which we saw in chapter 4 had a large DOE contract). Exchanges with these organizations did provide some benefits for TI. In particular, the TISES team welcomed the opportunity to keep tabs on developments across the industry: which types of systems (photovoltaic, photothermal, etc.) and which materials (cadmium sulfide, amorphous silicon, etc.) were in vogue and how far their competitors had progressed.[73] But the DOE contract also required TI to present results and cost calculations to SERI and JPL that had the potential to reveal the company’s secrets; and DOE support came with occasional reviews of the project by department personnel who were wont to ask uncomfortable questions.

For instance, in 1979 Pete Johnson, the leader of the TISES group, attended a DOE briefing where “none of the participants attacked the concept or approach,” yet where two rather stubborn objections were raised:

> 1. Paul Maycock questioned if the value of storage . . . for residential PV systems and if the “trouble and expense we go through with hydrogen storage and a fuel cell are worth the penalty we pay in efficiency and cost. . . .” He is focusing on the near term too much and the questioning doesn’t represent his convictions as much as it does his personal need to raise a counterpoint. . . .
> 2. Satyen Deb (SERI) seemed to be particularly concerned about corrosion of the silicon exposed to the electrolyte on the front side of the array. Even after telling

> him that the front metal protects the silicon and where it doesn't, the silicon self passivates and in our experience no further corrosion of the silicon takes place, he seemed to have a fixation on silicon corrosion.[74]

Neither of these is an outlandish question, yet in dismissing them TI again refused to countenance DOE's civilian solar power expertise.

With respect to Maycock's objection, fuel cells were—indeed, still are—a finicky technology that can be made to work in very controlled and expensive systems such as spacecraft but have largely proven uneconomical to mass produce. Yet the technology's problems are consistently obscured by a discourse that Matt Eisler dubs "fuel cell futurism," which is rampant in the military–industrial and petroleum sectors and which has had the effect (intended or not) of diverting resources away from less futuristic but more plausible energy technologies.[75] Another SERI reviewer pointed out some of the flaws in this way of thinking in May of 1978:

> There is a serious question regarding fuel cell life. The more conventional H-O [hydrogen-oxygen] fuel cells have been made to last for five years, but these are very expensive devices. They [the TISES team] have made a very good start on developing an H-Br [hydrogen-bromine] fuel cell. It requires three membranes which causes it to be expensive. There is need for a sulfuric acid flush to get the bromine out of a part of the cell and it is very questionable in my mind that this device could be made with long life at low cost.[76]

The same reviewer also noted that

> The metallized silicon balls implanted in glass have to withstand corrosive hydrobromic acid solution and while there is some evidence that this system might be stable in the short term, there is a serious question regarding a 30-year life which the analyses are based on. . . . [A] major concern is the safety of such a system since bromine gas [which is toxic and causes chemical burns] would be generated and required to be manifolded through the installation. This represents a serious threat. Also, if hydrogen is stored as a gas, it is a hazard and the ability to store hydrogen as a metal hydride has not been completely developed.[77]

In other words, DOE people were pointing out that TISES's underlying technologies, at least in their late 1970s form, (1) posed an environmental and health danger and (2) were too unproven and futuristic for civilian markets, even if their use in national security technologies such as spacecraft inspired confidence among military–industrial engineers.

These were just the kind of objections where TI's team thought it knew better. As Pete Johnson brusquely told reporters, "Corrosion is not a problem of note."[78] TI could have chosen to deal with these objections by redesigning the technology; but instead, it sought to go around the DOE's civilian staff and fall back on familiar military–industrial allies who were more likely to give TI the benefit of the doubt. An example of this that even Kilby found somewhat outlandish involved Dick Alberts, the Air Force procurement officer who had funded TI's initial foray into integrated circuit manufacturing in the early 1960s. In late 1978 Kilby

> met Dick Alberts in Washington. Alberts was with the Air Force in the early sixties, and was directly responsible for giving us the Air Force money for the early integrated circuits work. He is now with the Research Triangle Institute, but is being considered—or has been offered—the job of head of the photovoltaic section of DoE [i.e., the job then held by Paul Maycock]. If he takes the job he would be in a position to provide the other $35 million we will need to finish Project Illinois. To encourage him to take it I told him something of the project, and asked him to keep it in confidence. He was quite enthused, and will be of substantial assistance if he takes the job.[79]

Note the explicit assumption that the person "directly responsible for giving us the Air Force money for the early integrated circuits" would "be of substantial assistance" if he wrested the DOE photovoltaic program away from its current civilian leadership.

In the end, Alberts didn't take the job, but he did offer a suggestion for how to obtain Pentagon support for TISES:

> Sometime during 1980, the Illinois Project will need to begin a manufacturing methods program. My early guesses at the cost were about $35 million. While it is of course possible that this money could come from DoE, another possibility is becoming apparent. The MX [nuclear ballistic missile] program as it is presently configured will have 4600 firing sites, each of which will need about 100 Kw of electrical power. Although this could be supplied by individual diesel generators, there is a feeling that some form of solar power would be desirable. Conventional solar cells and storage batteries for this purpose would cost something over $2

> billion. Because of the need for storage, Illinois type systems would be ideal for this application. I certainly realize that it would be too early to make any firm commitments for systems of this type, and also that it is unlikely that the MX will ever be deployed. Nevertheless, there is about $200 million for MX R&D in the current budget, and increases are planned for the future. I would therefore like to nose around SAMSO [Space and Missile Systems Organization] a bit and see what I can find out about the possibilities. An old friend of Dick Alberts now heads the group, and Alberts would be willing to set up the initial contacts.[80]

Kilby himself viewed the possibility of using TISES to power MX missile sites as "improbable" yet worth exploring precisely because "DoD is interested in the program to help offset the environmental opposition that they expect to encounter."[81] Once again, Kilby and his network could see their solar energy technology only in terms of *opposition* to and from the environmental movement, rather than as a point of cooperation with it.

SUNSET FOR TISES

The problem with the strategy of relying on trusted military–industrial networks (and rejecting civilian solarists) was that Kilby's military–industrial allies were only superficially, if at all, supportive of solar power. Most defense intellectuals and national security administrators believed that greater domestic oil production and a more robust military and diplomatic posture in the Middle East should be the United States' primary responses to the energy crisis. To the extent that they thought that the crisis necessitated development of non–fossil fuel energy sources, their preferred technology—by far—was nuclear power.

Thus, officials who had moved to the DOE from the Pentagon, NASA, or the AEC frequently disparaged solar power, often by making invidious comparisons to nuclear. Perhaps the clearest example came from Robert L. Hirsch, the assistant administrator for Solar, Geothermal, and Advanced Systems at ERDA. As reported in 1976,

> In an extraordinary act, the federal official in charge of the development of solar energy has questioned the fundamental goals established for his office and the thrust of the programs under his direction. He also has drawn attention to the

> public expectations that have been generated by the solar program and the possibility that they cannot be fulfilled. . . . Hirsch confessed: "To a degree I get the feeling that people are reluctant to speak up, like the situation with 'the king that had no clothes.'"[82]

In *The Sun Betrayed: A Report on the Corporate Seizure of U.S. Solar Energy Development*, Ray Reece claims that Hirsch sought to slash SERI's funding and eliminate other solar programs out of fear that they would supplant nuclear energy.[83] That's perhaps speculative but certainly plausible. Most high-ranking officials at ERDA and the DOE came there from the *Atomic* Energy Commission, the world of nuclear wargaming (i.e., RAND, TEMPO, or the other think tanks we saw in chapter 2), or one of the nuclear services of the military (nuclear-armed missiles as well as nuclear-powered vehicles such as submarines). It would have been surprising if people with those backgrounds were *not* more friendly to nuclear power than solar energy.

It's unclear, then, why Kilby and TI would think that these people would help bring the TISES technology to market. One possibility is that they were misled by their own experience with integrated circuit technology. There, military customers such as Dick Alberts had been instrumental in helping TI get over the initial barriers to achieving the economies of scale needed to move to the much larger civilian market. Pat Haggerty, former president of TI, perhaps had that progression in mind when he projected in 1979 that "inherent in the work that Kilby has started is an industry that may be as large as the automotive industry and there certainly is a place for TI within it which will be the general size of General Motors. I mean it will have that sort of potential when it goes." The statement is an accurate description of what happened—via Pentagon assistance—with integrated circuits. In this instance, though, Haggerty was inaccurately forecasting the outcome of Kilby's solar energy work.[84]

Perhaps Kilby and TI knew that military–industrial support for solar power was thin but thought that they could convince their allies that TISES was no threat to fossil fuels and nuclear energy. As TI's 1978 proposal to the DOE put it,

> It is now taken for granted that alternate energy sources must be developed if the future energy requirements of the world are to be met. It is also frequently assumed that solar energy must play an important part in the very long term. . . . All [alternate energy sources] will be marginal competitors to the conventional energy sources in the foreseeable future. No universal replacement of coal or nuclear energy is likely to be found in our lifetime or in that of our children. Although the costs of coal and nuclear energy will increase, they will do so at a fairly slow rate, and may actually decline in constant dollars. . . . Since no universal replacement for the present energy sources is likely to exist, each of the new technologies [such as TISES] must be tailored for a specific application. To be successful, a technology must serve at least one market that is large enough to justify the costs of its development.[85]

That is, solar power will be needed "in the very long term" but only to meet "future energy requirements," and *not* for environmental or ideological reasons. Thus, for the "foreseeable future," supporters of nuclear power and fossils fuels had nothing to worry about because systems like TISES would find only niche applications.

Perhaps Kilby thought that his military–industrial allies would help clear the solar field of countercultural solarists, leaving TI's system dominant. That had been one subtext of the Heilmeier–Deutch summit; a more brazen opportunity to cull Hayes and company came in 1980 with the election of Ronald Reagan. TI president Bucy was well connected to the Reagan campaign and was reportedly offered a job in the new administration. Thus, he asked Kilby for advice that he could funnel back to the presidential transition team. Kilby was probably a Reagan backer as well. At the least, his politics trended in the same direction as many of Reagan's voters, such that by the 1990s his friends could say that "like so many Texans, Jack didn't like [Bill] Clinton."[86] Certainly he was not averse to answering Bucy's request:

> You asked about government officials who should be considered for replacement by the new administration. [Kilby named two Pentagon officials.] In the Department of Energy things are considerably more serious. All of the people who have been involved with the solar program should go. The list should start with Tom Stelson, Assistant Secretary for Conservation and Solar, and would include Fred

> Morse, in charge of the residential applications, Paul Maycock head of the Photovoltaics Branch and Denis Hayes, Director of SERI. . . . In general it is my feeling that the level of competence of the people within DoE is a couple of notches below those in DoD.[87]

All the DOE solarists should go! Radical advice, yet in the end the Reagan administration's actions went substantially further than Kilby called for. We've already seen that JPL's federally funded solar programs were axed in 1982; even earlier, in June 1981, Hayes was fired and SERI's "budget [was] cut in half and its staff by a third."[88] That year the administration "proposed to cut the Federal budget for renewable energy sources from the 1981 fiscal year's $576 million to $193 million for 1982—a reduction of 67 percent. Another 50 percent cut is rumored to be in the works for the 1983 fiscal year."[89]

It's likely that such deep budgets cuts were not quite what Kilby had in mind. I surmise that he would have preferred that DOE continue to support solar power R&D but that Hayes and Maycock be replaced by military–industrial stalwarts such as Alberts to ensure that the DOE supported the "right" solar R&D. Indeed, the withdrawal of federal funding meant that the "development with government support" scenario that TI had been pursuing suddenly became unsustainable. This left Kilby and TI with the two other scenarios: go it alone or find a partner. Going alone, however, was even less feasible than a few years before thanks to TI's falling profits. In the late 1970s, TI management had thought—like many leading semiconductor companies—that it would be easy to make money embedding its chips into its own consumer products such as watches and calculators. And like its competitors, TI soon learned its error the hard way. Corporate profits were *halved* from 1980 to 1981, and the stock price nearly so.[90] TI's semiconductor division, in particular, went from a $170 million profit in 1980 to a $50 million *loss* the next year. And that was only the beginning: in 1983 "TI announced its first quarterly loss ever—$119 million, or $5 per share. Stock prices plummeted from $157 to $107 in a single day. Toward the end of 1983 TI pulled the plug on its disastrous home computer venture, swallowing a $145 million loss."[91]

These staggering and unexpected losses *could* have lent renewed urgency to TISES: as TI's consultants put it in 1982, "Increased competition and a slowdown in profit growth in traditional businesses has led TI to explore new large market opportunities."[92] But the double blow of huge losses in other divisions plus the withdrawal of federal support meant that TI *had* to find a new external partner if it wanted to continue with TISES. Yet TI's troubles and the federal retreat from solar power R&D would have made most potential partners wary. Thus, throughout 1982 Kilby and Pete Johnson fruitlessly pursued joint ventures with several foreign governments (Saudi Arabia, Japan, the United Kingdom, and West Germany) as well as companies from a variety of industries (oil, chemicals, utilities, venture capital). They also looked into a few outliers, such as Weyerhaeuser and Georgia Pacific (primarily known as wood and paper products companies) and Siemens and Hitachi (non-US electronics giants).[93] None of these entities, however, was interested—solar energy had lost its shine.

The standard explanation for the solar energy industry's collapse is that the price of oil sank to a point where TISES and similar systems were no longer competitive with fossil fuels.[94] It is true that in the mid-1980s the price of oil fell to (in real dollars) its 1973 value. It was as if the oil shocks of the long 1970s never happened—and therefore alternative energy technologies inspired by those shocks lost their justification so long as they were justified on the basis of price alone. Moreover, that decline in price was due in part to greater oil production in places like Alaska and the North Sea. That is, there seemed to be evidence of vast new oil and gas fields opening up, and therefore less urgency to solarists' claims that "alternate energy sources must be developed if the future energy requirements of the world are to be met."

When Kilby came up with the TISES idea in the early 1970s, a near future governed by resource scarcity seemed plausible in light of events such as the 1972 publication of the blockbuster *The Limits to Growth* report or the 1973 OAPEC embargo. By the early 1980s that vision had been replaced; now, the foreseeable future was one of resource abundance.

In 1983, TI's consultants explained the consequences of the switch from scarcity to abundance thus:

> Rapid increases in energy costs and concerns about energy supply have let [*sic*] to projections of multibillion dollar markets for non-traditional energy technologies. Prompted by these market forecasts, government support and market place initiatives, many firms have undertaken efforts in PV, synfuels, storage and other new energy sources. However, more recent events have changed the energy situation, requiring a careful reassessment of energy technology programs
>
> - Slower oil price increases in response to reduced usage—reducing the pressure for substitutes
> - Slow progress in the development of alternative technologies—delaying the time of economic cross-over
> - Reduced government support for energy technology development—increasing the cost to stay in the game at a time of economic pressure on most firms[95]

That, in turn, meant that the "many firms" that started solar and other alternative energy projects in the 1970s tried to sell off those projects in the early 1980s. The companies that TI sought to interest in the TISES system were probably looking at similar offers from other firms. An example quite similar to TI is the electronics giant RCA, which on the advice of the same consultants as TI's (the defense contractor Booz Allen Hamilton) sought offers from Siemens, Exxon, Shell, Texaco, Total, and Standard Oil of Ohio for its solar unit.[96] In the summer of 1983 Solarex, a photovoltaic company largely controlled by Amoco, purchased the RCA solar program.

In that kind of buyer's market, TI was unable to find anyone to give it satisfactory terms for a joint venture or even for outright purchase of TISES. Thus, in September of 1983 TI cancelled the TISES project and dispersed its approximately sixty employees to other parts of the company. This seems to have been a significant blow to Kilby. He immediately ended his leave of absence from TI and officially retired from the company on October 31, 1983. TISES was the last thing keeping Kilby invested in his formal connection to TI. Thus, with the project's cancellation he seems to have been anxious to end the TI chapter of his life.

In any case, soon after the cancellation Kilby and TI's lawyers drew up a new agreement because "due to the recent change in circumstances involving the TISES program, it is desirable to clarify our relationship."[97] Under the new terms, Kilby had two years to grant his own licenses to the TISES patents that TI had helped him obtain, but again that led to nothing. As he complained to his University of Minnesota colleague, Ray Warner,

> About a month ago TI decided to abandon the solar energy project there. I have told them that I would like to terminate my arrangements with them by the end of the month. If they are willing to release the patents on the project, I may see if I can do something else with the idea. If they are not, it will die. It may be just as well, as this is not a very good time to be peddling a solar project. We need another middle east crisis, I guess.[98]

Maybe so. That assessment certainly reflects how Kilby became interested in solar energy in the first place, and how he and TI framed the technology. But they could have framed TISES in other ways that did not rely on a Middle East crisis causing a national security panic and driving prices up.

In particular, they could have presented TISES as contributing to a more environmentally sustainable and more decentralized and democratic future. In this chapter I've offered a particular set of reasons why they didn't: namely, that those reformist solar futures were embedded in networks of countercultural, civilian, or charismatic solarists whom Kilby and TI spurned. Instead, Kilby and TI sought to advance their technology with the aid of military–industrial networks that they knew and trusted. They believed that they could effect a wholesale transfer of elements of the military–industrial complex over to civilian solar energy: personnel (e.g., Heilmeier and Alberts), technologies (e.g., fuel cells), management techniques (e.g., scenario planning), and legal frameworks (e.g., for intellectual property agreements with the Departments of Defense and Energy). Their experience with a similar civilianization of integrated circuits seemed to lend plausibility to their forecasts for solar energy. That plan failed, however, in part because their military–industrial allies were committed to fossil fuels and nuclear power and ultimately dismissive of solar power.

Kilby and countercultural solarists like Denis Hayes wanted many of the same things. But they pursued the common elements of their visions separately, or even antagonistically. Neither group was able to offer a vision for solar power that could withstand the decline in the price of oil and the ascendance of neoliberal policies. The two camps were never able to establish a sufficiently large common ground where the enthusiasm and inclusiveness of the one would complement the military–industrial savvy of the other. Perhaps even if that common ground had been opened up, the solar industry still would have dwindled in the 1980s. But we'll never know, because many square solarists like Kilby couldn't overcome their distrust and dislike of less-square solar energy promoters and the future social order that those people appealed to.

The Squares

US Physical and Engineering Scientists in the Long 1970s

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