

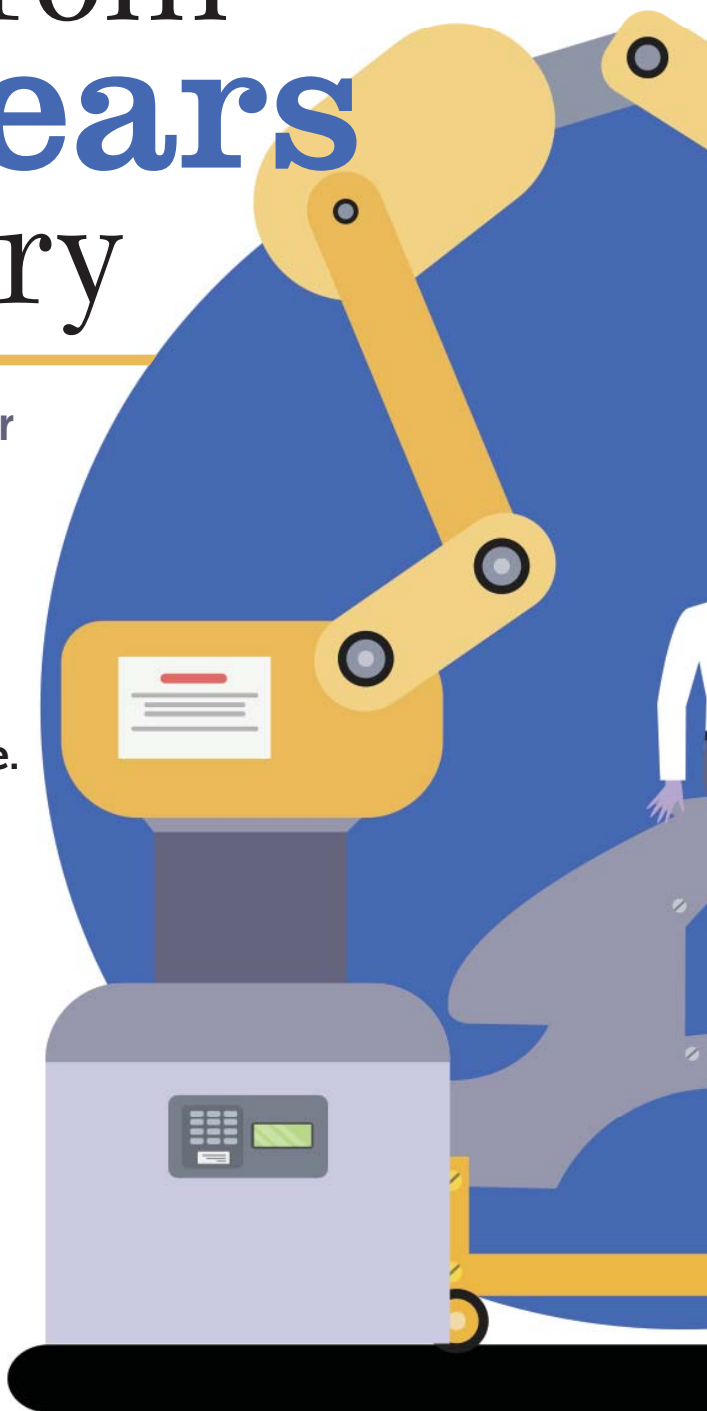
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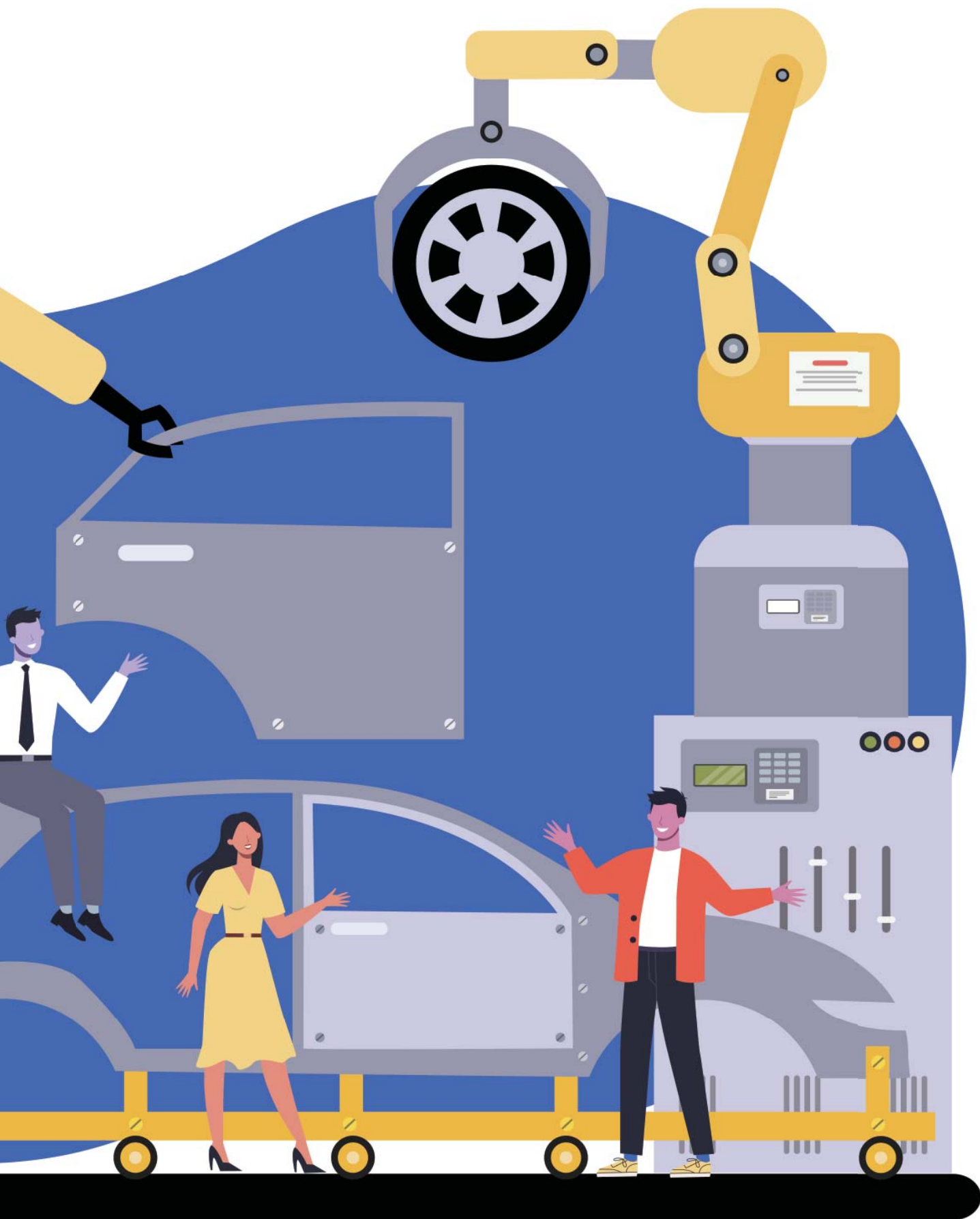
Lessons from **35 years** in industry

Mike Tamor

**Physicists working
at private-sector
companies must
learn quickly and
adapt as needs evolve.**



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he way I started my industrial career is virtually unheard of today. I earned my PhD in solid-state physics at the University of Illinois at Urbana-Champaign in 1982 and was hired directly by the Ford Scientific Research Laboratory in Dearborn, Michigan. The early 1980s marked the end of the era of great industrial research labs whose departments bore academic names. Through them, corporations sought to “own” the R&D pipeline from fundamental discovery to product execution.¹

The near disappearance of corporate basic research does not mean that no one does physics in industry anymore, nor that the capabilities and outlooks of physicists are not valuable, even to a century-old consumer-products company. Rather, it means that physicists in industry must learn to operate differently from their forebears, and they must learn quickly. A physicist leaving academia today is expected to pick up in a matter of months the knowledge and skills I had many years to absorb.

Here I attempt to capture a few key lessons that might ease the jarring transition from academia and promote, even in some small way, a successful industrial-physics career. In that regard, I hope this article will provide some useful guidance to younger physicists starting or considering careers in industry. The lessons are best understood in terms of my own career path, which could be viewed more as three careers because each position differed significantly in the nature of my research and the scope of my responsibilities.

Career 1: Materials scientist

Although the automobile industry has not been seen as high tech since the 1920s, it is rich with new technologies and innovations. I was hired by John Reitz (1923–2014), coauthor of the well-known textbook *Foundations of Electromagnetic Theory*, into the physics department of what was then the Ford Sci-

tific Research Laboratory. On my arrival in Dearborn, I was given a modest equipment budget, the able assistance of one-half of a lab technician, and a partially renovated lab that had once been occupied by Albert Overhauser, best known for his theory of dynamic nuclear polarization. With a silicon micro-machining facility nearing completion, my assignment was to “do something with silicon.”

The search for relevance began immediately. My absurdly vague mandate morphed into a materials-characterization project to help find a more robust replacement for mercury cadmium telluride in thermal imaging systems. (At that time, Ford was making thermal imagers and seekers at its aerospace division in Newport Beach, California.) Although none of the alloy and superlattice systems we studied proved suitable for IR detectors, the work led to interesting physics. For example, in some disordered materials, the Hausdorff dimension describing transport of electric charge could become temperature dependent.²

In those early days, my only responsibilities were to build up the lab and get results. Although I had to justify equipment budgets and present progress reports, I did not have to manage many people or write proposals. Even so, I had opportunities to influence major corporate decisions.

The electronics content of vehicles was growing rapidly in the 1980s. But denser packaging and improved aerodynamics made finding cool, dry locations for system control modules increasingly difficult. Auto manufacturers worried that silicon-based devices were reaching their limits, and gallium arsenide, with its wider band-gap, was emerging as a potential solution to the temperature problem. Suspicious of that simplistic argument, I conducted a study of the limitations of silicon-based electronics in the automotive environment and the prospects that other semiconductors could overcome those limits. The study identified packaging and connections as the real challenges and concluded that with modest changes to circuit design and materials choices, the anticipated—and extremely expensive—shift to wide-bandgap semiconductors was unnecessary.

In 1985 “diamond fever” broke out. Although immediately overshadowed by breakthroughs in high-temperature superconductors, vapor-deposited thin-film

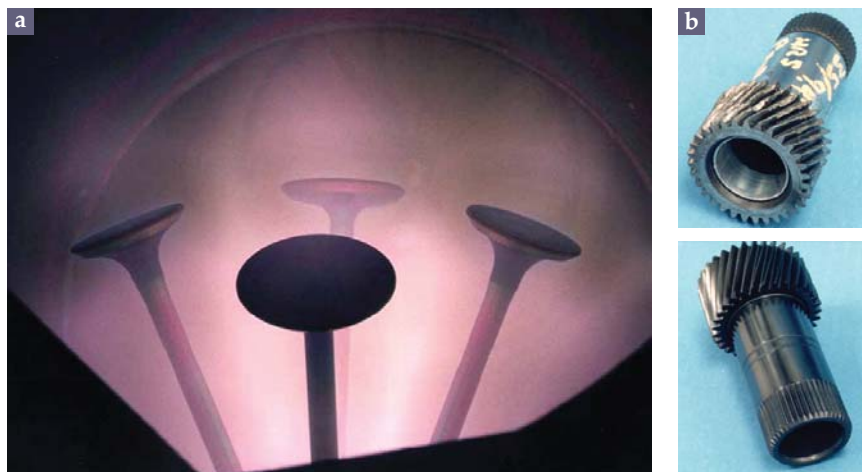
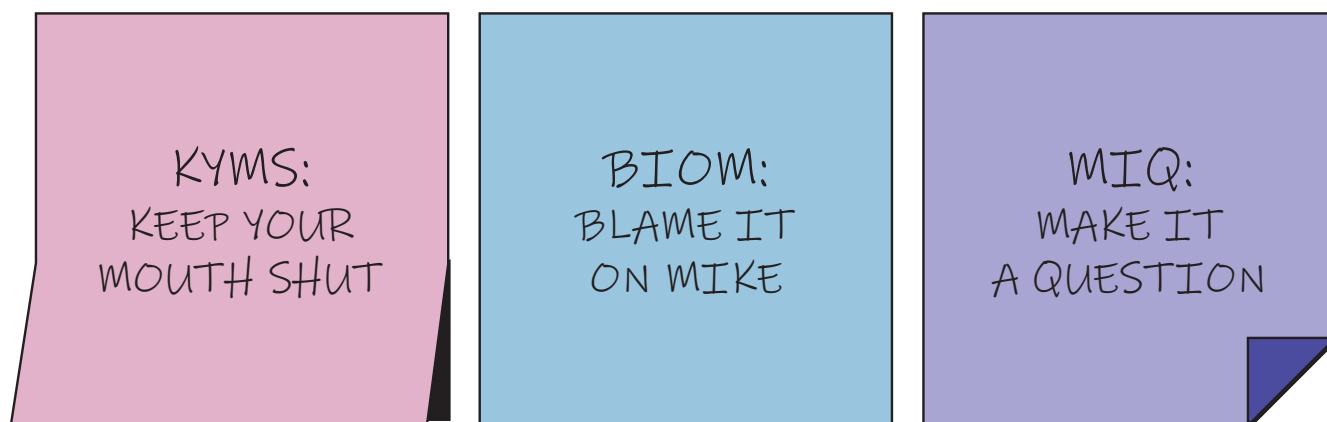


FIGURE 1. DIAMOND-LIKE CARBON (DLC) thin films greatly reduce friction and wear. (a) These engine intake valves receive a conformal plasma coating of silicon-stabilized DLC. **(b)** A transmission sun gear (top) that failed a durability test shows wear and spalls. A DLC-coated sun gear (bottom) that passed an extended durability test shows essentially no wear. (Photos courtesy of Ford Motor Company.)



diamond was promoted as the solution to all friction and wear problems and as the ultimate high-temperature semiconductor.³ In response, I assembled and led a team of scientists and technicians exploring synthesis, properties, and applications of crystalline diamond and amorphous diamond-like carbon thin films. Figure 1 illustrates how the silicon-stabilized diamond-like carbon films we developed improved the performance of engine components and tools. Although leading that larger team entailed greater management responsibilities, the learning curve for managing like-minded scientists was easy compared with what was to come.

Career 2: Power-train researcher

My leap into advanced propulsion-system research began almost by accident. After attending a seminar on the complexity of the design space for hybrid-electric vehicles—a novelty in 1993—I proposed an optimization method that combined an adaptive energy management strategy with scalable, physics-based models of system-architecture options. The goal was to maximize efficiency while minimizing system cost.

The resulting lash-up of Visual Basic models and the existing Fortran-based vehicle simulation program worked well as a design platform. In the early 1990s, conventional engineering wisdom held that a hybrid vehicle was in essence a short-range electric vehicle with a small “range-extender” engine that would run at a single, optimal operating point while the battery delivered the varying power for driving. The headline finding of the self-optimizing model was that the recommended system have a large engine that would generally follow the driving load, and that the battery—the costliest part of the system—could be surprisingly small.

When I presented the results to the engineering team, it was clear that a physicist with no vehicle experience flying in with counterintuitive recommendations had little credibility. If I was going to convince them to accept my findings, I had to be all in. To my managers’ horror, I asked to transfer into the power-train laboratory. I was expecting to be assigned a nonleadership role, but to my horror, the “reward” for finding an optimal design that maximized fuel economy while meeting essential performance criteria was to be placed in charge of the engineering team and, later, all research on hybrid-electric and fuel-cell vehicle technology. The new position entailed significant managerial responsibilities for budgets, personnel, and reporting to funding agencies.

FIGURE 2. RESPECTFUL COMMUNICATION is critical to working in industry. Notes in the author’s office served as reminders that a more successful approach involves listening to others, taking responsibility for missteps, and making an effort to understand other perspectives in a disagreement.

My transition from working with a small group of PhD scientists to leading a growing engineering team was a near disaster. In graduate school, physicists are trained in hand-to-hand combat. Every assumption, every method, and every step are subject to scrutiny and occasional shaming. As one colleague put it, a successful seminar was one in which the speaker did not leave in tears. It is a tacit—and usually wrong—assumption that such grilling will not be taken personally.

Although that meticulous combativeness might be good for scientific integrity, it can be a social and professional disaster. Engineers are accustomed to working in teams, often large ones, and they rely on tested tools and methods to achieve predictable, robust outcomes. Antagonistic dialog that many physicists understand as a customary means of communication comes off to engineers (and most other humans) as arrogant, insensitive, and often insulting. (For more about the value and dangers of arrogance, see the Commentary by J. Murray Gibson, *PHYSICS TODAY*, February 2003, page 54.) Navigating that transition required a conscious and systematic revision of my communication habits.

As a constant reminder, I posted a few simple rules in my office (see figure 2): KYMS, or keep your mouth shut until others have said what they need to say; BIOM, or blame it on Mike, meaning be prepared to share responsibility for discouraging missteps and dead ends; and MIQ, or make it a question, a reminder that any disagreement can be rephrased as a question. It should come as no surprise that the rules can apply to any social interaction.

Career 3: Sustainability guru

Historically, the mobile and stationary energy economies have been essentially disconnected; things that move run on oil, whereas those that don’t rely on a menu of other energy resources. Early in the development of hydrogen fuel-cell vehicles, researchers pointed out that they could not be considered “zero emission” if making their fuel produces carbon dioxide. Of particular concern was black hydrogen made from

coal-fueled electricity. The same holds for charging battery-electric vehicles.

By 2010 it was clear that moving to a carbon-neutral economy would entail making every vehicle electric where practical and providing renewable chemical fuel for the remainder—mainly aircraft. The strategic need to map out the role of a carmaker in an emerging, highly integrated energy economy brought me to my third career in energy systems and sustainability. The transition can best be described as a switch from a conventional leadership role—the “commander in chief” of four departments comprising more than 200 engineers and technicians—to one of “convincer in chief” with only two direct reports.

The fun part of my transition was the opportunity to dive deep into other sectors of the energy economy and their regulatory systems. The challenge was to integrate into corporate strategic planning the findings from multiple studies of personal vehicle usage, the electricity grid’s evolution, prospective renewable fuel pathways, and government policy choices. In a large organization, that is not as simple as it sounds. Understanding how decisions are really made, no matter how arcane it might seem, is essential. Having a real effect on strategy requires identifying who is making key decisions, what they need to know, when they need to know it, who else must be convinced to bring the decision makers on board, and what form the findings and recommendations should take for each audience.

It is true that I enjoyed the rare privilege of (usually) choosing my own research directions. However, the choice was not made in a vacuum and was never based on pure scientific curiosity. Rather, each of my three careers began with the identification of a void in corporate understanding of the underlying science, technology, or potential business impact of an important area of development. The task at hand, then, was filling that knowledge void and building new capabilities so the company could respond as needed.

The capacity to adapt to changing needs is certainly not unique to physicists, but they do seem to use it often. A few examples of technologies that arose from Ford’s “physics” labs as a result of that mindset include applications of neural-network

computing, x-ray tomography, acoustic profilometry, autonomous vehicles, applications of simulated annealing, human-machine interfaces, virtual reality, and big-data analytics. I believe adaptability is what makes physicists so valuable to industry and is the hallmark of a successful industrial career. In other words, the best way to get a new and better job, in reward or advancement, is to invent that job and start doing it!

My career and those of many of my friends and colleagues have consisted of distinct phases. As a new hire, your boss tells you what to do and how you will do it. Then, after achieving a degree of confidence-building success, you will advance to a stage where your boss tells you what to do and you figure out how to do it. With a broader understanding of the business’s needs and greater confidence in your abilities, you can graduate to where you tell your boss what you are going to do and how you are going to do it. If you join the ranks of the most successful industrial researchers and ascend to the final phase, you tell your bosses what they are going to do and how they are going to do it.

Figure 3 illustrates the direct mapping of my own career path and responsibilities in the four phases. Although the wording may sound a bit silly, the progression reflects an increasing understanding of the enterprise’s needs and direction combined with the development of managers’ and colleagues’ confidence that you can and will continue to deliver on those needs. Figure 4 shows that organizational authority is not a measure of career progression or business impact. In fact, your technical contribution is often enhanced by deliberately shedding managerial responsibilities.

Words of wisdom

Described with deliberate and, hopefully, humorous overstatement, here are a few important lessons learned over the course of 35 years in industry. The first set relates to expectations for your role. Corporations don’t have physics departments and don’t hire physicists to “do physics.” Physicists are technology stem cells—they’re expected to mold themselves to fit specialized roles that inevitably arise. It is startling to see how often physicists are the first to dive into new areas and develop them until the areas have new names and the pioneers get matching

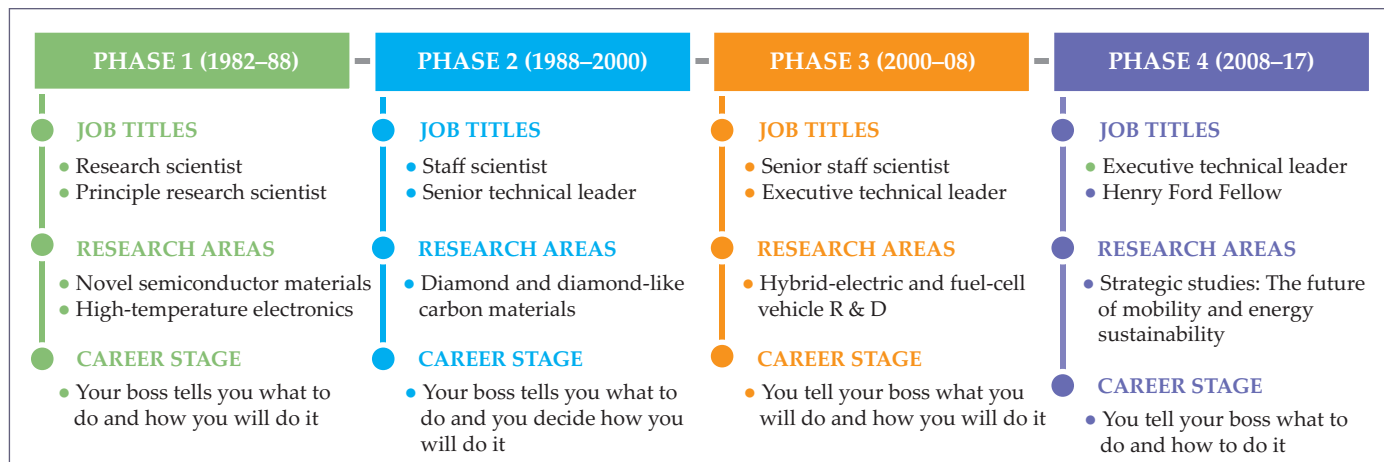


FIGURE 3. THE CAREER PATH of an industrial physicist can be divided into four phases. Here, the author’s career illustrates the evolution from a new hire to a high-level executive.

job titles. In other words, a successful industrial physicist is unlikely to be called a physicist at work.

Physicists are trained to revere new knowledge. The two happiest moments in a scientist's life are when they realize they know something nobody else knows and when they convince an appreciative but skeptical audience that they're right. But in the business world, new knowledge is not an objective. (Don't take it personally.) The job of the physicist is to initiate the process of converting that knowledge into new competitive capabilities; where the knowledge came from might even be irrelevant. New capabilities are the real objective.

But capabilities have no value unless they are applied, which leads to another lesson: Focus on decisions. The competitive advantage of a new capability is lost without a timely decision to use it. But who makes the key decisions? When and where do they make them? What data will they need? Just ask! At the same time, it is essential to find out what customer experience, rather than what physical product, the company seeks to deliver. When should we deliver it? Will we know how to deliver it by then? What must we learn now to be ready in time? Figuring out what data are needed to make decisions and what must be learned before they can be implemented is the essence of outcome-based research.

As for behavior, I have shocking news: Physicists can be arrogant. If asked how you know something, answers such as "it's trivial" or "conservation of momentum" may be amusing to other physicists but are highly offensive to engineers and incomprehensible to management. As I mentioned above, a simple and disarming strategy is to recast every statement in the form of a question. Everyone enjoys feeling respected for their expertise and opinion, even when you are in the process of showing that they are mistaken.

Next, and closely related: The physicist is not Moses. Findings handed down will not be immediately understood, applauded, and implemented. A useful aphorism is that engineers design to the edge of the page, whereas physicists make the page bigger. Because engineers rely on deep discipline and validated tools to ensure quality and consistency of results, they can understandably be nervous about new principles and functionalities. You must join the team and be prepared to teach and reteach what you have learned.

That leads to another lesson: Communication is everything. Think of an Olympic event in which half the points are awarded for technical merit and the other half for artistic merit. Being right—getting perfect technical marks—is of no value without conveying the potential benefits, or the artistic merit. There is no trade-off; you must be excellent at both.

The challenges of communication with management are as great as those with engineers. Management is rarely interested in how smart you are—at least, not in public. Just because executives may have difficulty understanding your work or

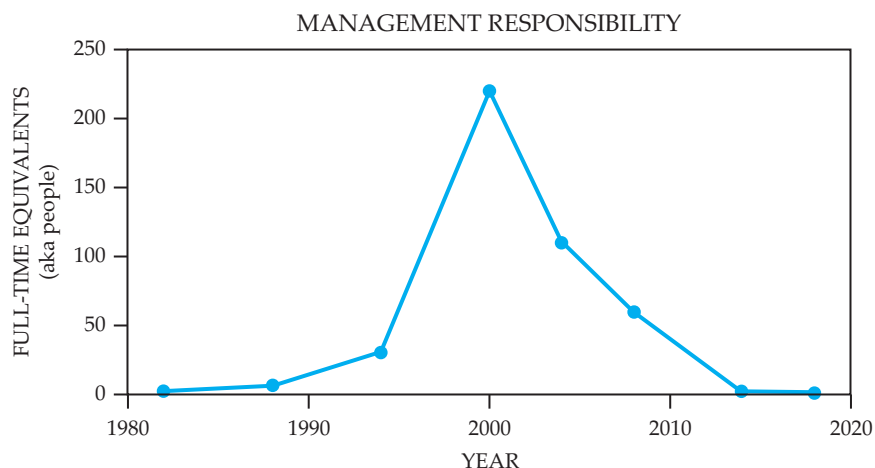


FIGURE 4. MANAGERIAL RESPONSIBILITIES are not always a measure of career advancement. As evidenced by this graph of the author's reports over the course of his career, being responsible for fewer people can free up time to make big-picture contributions.

immediately appreciating its implications does not mean that they are unqualified or unintelligent. In a large organization, there are many routes to senior positions. Executives are intelligent people, and they can be taught! Your greatest success will be marked by an executive lecturing on what you taught them, often without attribution, and sometimes back to you.

Finally, be patient and build trust. When engineers and executives see that you understand their needs and have a record of delivering on them, your influence and freedom to take initiatives will increase accordingly.

When it comes to professional success in industry, you might ask, what's in it for me? Although the money is usually quite good, don't count on being the next tech billionaire. In modern, flat organizations, it is difficult to use promotions as rewards. Most companies have internal recognition programs for patents and technical achievements. Some are quite generous, but others are more symbolic. Technical societies, including IEEE, SPIE, and Optica (formerly The Optical Society), offer prestigious recognitions, and the American Physical Society recognizes important contributions to industrial and applied physics. But there is no Nobel Prize, Fields Medal, or equivalent for industrial physics.

Your greatest pride and satisfaction will come from positive societal impacts that the new functionalities you develop bring to the world. The scale of those impacts can be large: Replacing a million gasoline-powered vehicles with hybrids avoids 30 million tons of carbon dioxide emissions over the vehicles' lifetimes. When approached, or reproached, by environmental activists, I can honestly say, "I gave at the office."

REFERENCES

1. A. Arora et al., "The Changing Structure of American Innovation: Some Cautionary Remarks for Economic Growth," National Bureau of Economic Research working paper (May 2019, rev. August 2019).
2. M. A. Tamor, *Phys. Rev. B* **36**, 2879 (1987).
3. R. Pool, *Science* **249**, 27 (1990).

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