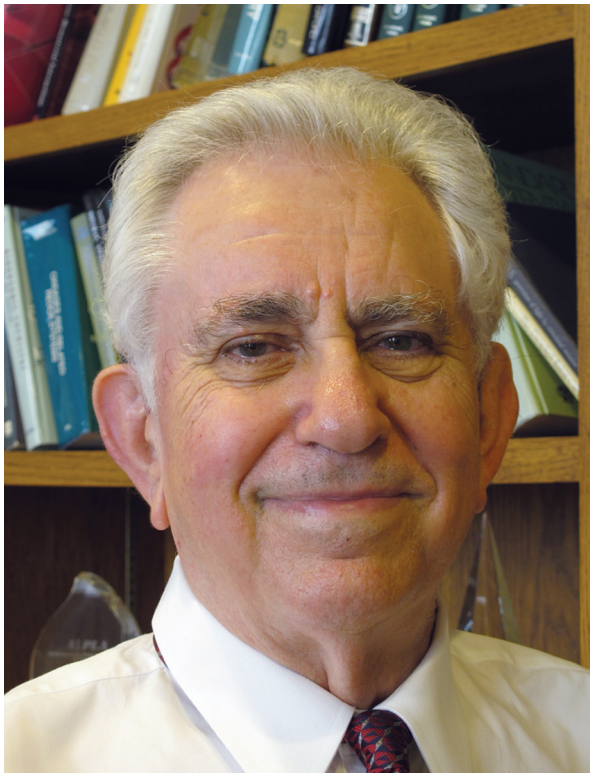

Adam Heller

A Conversation with Adam Heller

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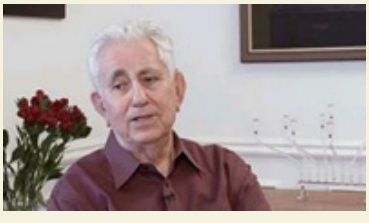

Watch a video of this interview online.

Abstract

Adam Heller, Ernest Cockrell Sr. Chair in Engineering Emeritus of the John J. McKetta Department of Chemical Engineering at The University of Texas at Austin, recalls his childhood in the Holocaust and his contributions to science and technology that earned him the US National Medal of Technology and Innovation in a conversation with Elton J. Cairns, Professor of Chemical and Biomolecular Engineering at the University of California, Berkeley. Dr. Heller, born in 1933, describes the enslavement of his father by Hungarians in 1942; the confiscation of his family's home, business, and all its belongings in 1944; and his incarceration in a brick factory with 18,000 Jews who were shipped by the Hungarians to be gassed by Germans in Auschwitz. Dr. Heller and his immediate family survived the Holocaust and arrived in Israel in 1945. He studied under Ernst David Bergmann at the Hebrew University, and then worked at Bell Laboratories and GTE Laboratories, where he headed Bell Lab's Electronic Materials Research Department. At GTE Laboratories, he built in 1966 the first neodymium liquid lasers and in 1973 with Jim Auborn conceived and engineered the lithium thionyl chloride battery, one of the first to be manufactured lithium batteries, which is still in use. After joining the faculty of engineering of The University of Texas at Austin, he cofounded with his son Ephraim Heller TheraSense, now a major part of Abbott Diabetes Care, which produced a microcoulometer that made the monitoring of glucose painless by accurately measuring the blood glucose concentration in 300 nL of blood. He also describes the electrical wiring of enzymes, the basis for Abbott's state-of-the-art continuous glucose monitoring system. He discusses his perspective of reducing the risk of catastrophic global warming in a wealth-accumulating, more-energy-consuming world and provides advice for students entering careers in science or engineering.

Elton J. Cairns: Hello. Today we're here under the auspices of the *Annual Review of Chemical and Biomolecular Engineering*. I'm Elton Cairns, Professor of Chemical Engineering at the University of California, Berkeley. We're going to have a conversation with Professor Adam Heller of the University of Texas at Austin, in the Chemical Engineering department. Professor Heller is very well-known as a scientist, technologist, inventor, and entrepreneur. It's a real pleasure to be here with him today to hear more about his highly varied and very interesting and exciting career in these various fields.

So, Adam, can you tell us a little bit about your early years and the development of your interest in science and research?

Adam Heller: I was born in Cluj, Romania in 1933 to a pretty well-to-do family. My father was a textile merchant, and he and his partner had one of the biggest stores in that part of the world, known as Transylvania. I had a fairly happy childhood and fairly happy family.

When I was 9 years old, my father was taken to slave labor by the Hungarians, sent to the Ukraine under horrible conditions where only one out of six people survived. He suffered horribly and survived, but because his heart was damaged died young.

When I was 10, we were deprived of all of our property, and the schools I attended were closed. We were incarcerated under inhumane conditions in a brick factory where my father was twice so badly beaten that he was carried out in a stretcher. We stayed in brick sheds—there were 18,000 people in those—where the Hungarians who ran the camp had one single business: loading them onto cattle wagons and sending them for gassing in the German concentration camp of Auschwitz.

EJC: What an experience. Was your family allowed to stay together?

AH: My father had a friend and he succeeded in convincing the Nazis that we were of some value, and that they could get some money for us. And we—along with 380 Jews—were not shipped to Auschwitz, but to Budapest. And then there were negotiations on whether we should be sent for gassing or whether we should be sold. And fortunately, we were not sent to gassing, but we were sent in a group of 1,684 Jews to another German concentration camp: Bergen-Belsen, where the negotiations continued.

EJC: Who would pay the money?

AH: There were not many takers. However, as the end of the war approached, in December 1944, the price dropped. And because the price dropped, we were released to Switzerland at a low price. Presumably there were some monies changing hands, coming from the American Joint Jewish Distribution Committee, in the shape of tractors that were given to the Germans. It's quite a story, and several books were written about it. You may find them if you search for Kasztner's Train.

In December of 1944, when I was 11 years old, we arrived in Switzerland. We got some clothing; we got some food. I was emaciated—I had lost about half my weight. And we continued, in the fall of 1945, to Palestine. I was on a troop carrier that returned troops from the war to Australia and New Zealand. And they dropped my family and me off in the port of Haifa. So I arrived in Israel—at the time the British Mandate of Palestine—in the fall of 1945. And that's where I got my education.

EJC: How much time did you miss from school as a result from all of this?

AH: Well, the first place I came to in Israel was a Kibbutz in Northern Israel. They put me in the sixth grade, although in Hungary I completed only half of the fifth grade. When I rejoined my parents in the outskirts of Tel Aviv, they allowed me to skip the seventh grade, and I went straight

into the eighth grade. I caught up with the children of my age group. Then I went to a wonderful high school where I got my physics foundation and chemistry foundation.

EJC: At this point was this the beginning of your intense interest in science?

AH: Absolutely. I had absolutely great teachers there, who worked for practically nothing. Later, I found out that the school was so poor that it couldn't even pay my teachers.

Then I went to—like all the young Israelis—to serve in the Israeli army. And at the time I was interested in a medical career. When I was in boot camp and they learned that I wanted to be a physician, they sent me to the medical corps to work in the pathology institute of a military hospital. There I very quickly discovered that at the time, medicine was not yet science. And I saw—being in the pathology institute—mistakes. I decided that I'd rather be a scientist working toward better medicine.

I applied to and I was admitted to the science corps of the Israeli army. And that allowed me to go and study at the Hebrew University in Jerusalem. Initially I wanted to study biochemistry, but very quickly I found out that the foundation of biochemistry is really chemistry. And then I found out that for chemistry, I needed physical chemistry; and for physical chemistry, I needed physics; and for physics, I needed mathematics. So I studied all of the above.

Eventually, at the Weizmann Institute I wrote a first Master's thesis in chemical kinetics with a great physical chemist—Ernest (Ernie) M. Grunwald—who was on a sabbatical from the United States. On his way to Israel he passed through England where people don't drive on the right side of the road. And he didn't look at the traffic coming, and he arrived in Israel with his arms and his legs broken. So I was the arms and the legs of Ernie Grunwald, and it couldn't have been a better experience of learning physical chemistry.

EJC: You must have developed a very close relationship with him.

AH: Indeed. Exceptionally close. He taught me how to analyze results, how to measure, how to pose a question, how to answer it. It was an exceptional experience. He was sitting in a chair with his arms and his legs in casts, and I was executing his work. What a way to learn!

EJC: A very unusual opportunity and—to some degree—burden.

AH: I wrote my Master's thesis, but there was some jealousy. The Hebrew University didn't want to recognize a Master's thesis that was done at the Weizmann Institute. So my thesis was rejected. I went to my organic chemistry professor—Ernst David Bergmann—and he said, "No problem. I like your thesis. And you will just work with me for a little while, and this will be part of your PhD thesis." So I became the student of Ernst David Bergmann.

And Ernst David Bergmann was one of the greatest scientists and technologists of Israel. The Weizmann Institute has a chemistry building named after him. The Israeli armament development authority has its major facility named after him. He worked very closely with David Ben Gurion—who was the first prime minister. He was also the founding director of the Weizmann Institute.

What I learned from Bergmann is something that at the time was not acknowledged: that there is no boundary between good fundamental research and good applied research and engineering. The boundaries don't exist. You have a continuum. You do one well, you do the others well. At the time, the notion was that there is such a thing as fundamental research that stands on its own, and there is applied research that is aimed at products and services. But, of course, the boundary doesn't exist.

EJC: Unfortunately, that view is still somewhat popular around the world.

AH: In some places. My opinion is that there is nothing—but nothing—that is more important than uncovering a new truth in science or in engineering. The next best thing that one can do is create a product or a service that serves people. The next best thing is to educate people who can uncover truths or create people-serving products. The next best thing one can do is to provide data for those people who can use them to uncover new truths or to create new products. And I have a pretty poor opinion of people who say that they work on applied science but are looking for its application.

EJC: I guess it was around this time of your graduate work that you met your lovely wife, Ilana.

AH: Indeed.

EJC: Can you tell us a little about that?

AH: In the second year of my studies, when we were in a biochemistry class—that's where I got to know her. I also was her commanding officer for a while in the summer and in the weekends when we were training. And I was fortunate to meet her.

EJC: How many years have you been married?

AH: I met her in 1953, I believe. And so we have known each other for 61 years. We have been married for 58 years.

EJC: That's an enviable situation. After you finished your studies in Israel, can you tell us about your early career following your graduate studies?

AH: Well, let me go back. Bergmann very much believed at the time that, other than performing experiments, one can also calculate their outcome. You can derive properties, reaction rates. You can mathematically derive synthetic routes. One of the best centers for computational chemistry was in Paris. So he sent me to work for a year with Bernard Pullman, at the University of Paris, where I did such work.

Immediately after I got my PhD, I put my knowledge to use. I knew some computational chemistry, I knew synthetic chemistry, I knew physical chemistry, and I used these to develop organic liquid scintillators for fast nuclear counting. I got a patent and published five papers—most of them in the *Journal of Chemical Physics*—and sold the patent to Nuclear Enterprises in Scotland. This provided Ilana and me much needed money because we were exceptionally poor at the time.

In 1958, our first child was born. That was three years before I completed my PhD thesis. Ilana was working on her PhD thesis. By the way, when I was in Paris, Ilana was with me, working at the Institut Pasteur with Jean Dausset, who later got the Nobel Prize. So Ilana was a pretty good scientist on her own.

But in 1958, our first child—a daughter—was born, and she was sick. She didn't have valves in her urinary system, and she was misdiagnosed—terribly—as being allergic to cow's milk. Because of the misdiagnosis, she then developed a chronic kidney infection, had high fevers, went into convulsions, was treated with dihydrostreptomycin, which made her deaf. It also damaged her brain. We didn't know about her missing urinary valves until much later, until we came to the United States. In Israel, initially, we were told that she was retarded. Later, also in Israel, it was discovered that she was deaf.

Ilana and I came to Berkeley in 1962 where I was to work with Andy Streitwieser. At the time, Andy Streitwieser was doing theoretical chemistry. I thought that I can do better computational theoretical chemistry with Andy than I had done in Paris.

EJC: I guess I just missed you at Berkeley? I graduated just before you arrived for your postdoc.

AH: We published a paper with Andy on computational chemistry, but my main conclusion at the time was that I am getting my hypotheses back in numerical form. And very quickly, while I was still at Berkeley, switched to working on plasma chemistry with Andy. This was 1963, when the first lasers appeared. They were Maiman's solid-state laser and Townes and Schawlow's gas masers and lasers; liquid lasers didn't exist. I started spreading the word, based on my work on liquid scintillators, that I know how to make a liquid laser.

And somebody, somehow, heard about it at the world's greatest hub of physical science and technology, the legendary Bell Laboratories. It was, at the time, the mecca of science and engineering, particularly in anything that has to do with electronics and communication. I got a phone call from a colleague at Bell Labs asking me, "Are you spreading the word that you know how to make a liquid laser?" And I said, "Yes." Pretty soon, I had a couple of colleagues from Bell Labs interviewing me. I got a job offer as a postdoc in Murray Hill, New Jersey, to work on liquid lasers. I start working there in the department of Field H. (Stretch) Winslow with Ed Wasserman.

Unlike others, I understood the core principle. There were no liquid lasers because people tried to make liquid lasers in solvents like water or alcohol or acetic acid, all of which had protons. But because they had protons, they had high-frequency vibrations. The high-frequency vibrations coupled with the excited electronic states, and the electronic energy was transferred to the vibrations. I showed this, while still at Bell Labs, by taking neodymium—which was *the* lasing ion, lasing in glasses and in solids—dissolving it in water, measuring a quantum efficiency of 10^{-6}, putting it in D_20, and increasing the quantum efficiency by three orders of magnitude. Not good enough, but substantial.

EJC: You got rid of the protons?

AH: Yes.

At the time—this was now 1964—my daughter needed a school in New York. She had to go to the Lexington School for the Deaf. I had to look for a job in New York. I went to work for GTE Laboratories in Bayside, New York. It was there that I would build the first neodymium liquid lasers. On these, I have had the greatest exposure one could have had, that you could imagine. It was written up by all the newspapers, all the magazines. The American Institute of Physics had a press release.

EJC: So it was a big deal?

AH: It was a big deal at the time, in 1966.

EJC: I guess that was just before we actually met, I think. You were at GTE when we first met.

AH: Exactly. Now, the solvent that I used was selenium oxychloride. Then we went to phosphorus oxychloride, and we tried to dry the phosphorus oxychloride to remove all the hydrogen present as hydrogen bound to the oxygen, tried to get it out as hydrochloric acid. And, in desperation, I added sodium to the phosphorus oxychloride—expecting it to blow up.

EJC: Were you disappointed?

AH: Well, it did not blow up. Sodium was, at the time, the best agent to reactively remove hydrogen chloride. Well, the sodium just sat there very quietly and didn't blow up or even react. It developed a passivating layer. Because it developed a passivating layer, I asked, "Maybe I can make a lithium chlorine battery and a sodium chlorine battery?" So I electrolyzed sodium chloride, using sodium tetrachloroborate and tetrachloroaluminate as the dissolved electrolytes in phosphorus

oxychloride. And lo and behold, I made sodium chlorine and lithium chlorine batteries. And in these you were deeply involved; you were the guru at the time of these batteries. That's the way we met.

EJC: I remember your visit to Argonne National Lab.

AH: And I remember, I think we met in Stockholm at an ISE meeting?

EJC: Yes.

AH: And it was at this ISE meeting that you invited me to visit Argonne.

EJC: Yes.

AH: Nobody at the time believed me, that one can make a practical battery of an oxyhalide solution and lithium or sodium. I went from agency to agency. There were no takers.

EJC: Well, it was a far-out idea at the time.

AH: There was one exception: The acting director of chemistry of the Office of Naval Research, Harry Fox.

EJC: I remember that name.

AH: Harry Fox invited me to come to see him in Washington, and listened to me—without saying anything—for about 30 minutes. And then he said, "Write a proposal for me no longer than four pages double-spaced. Did you hear me?"

EJC: You wouldn't hear that now.

AH: So I wrote a proposal—not longer than four pages, double-spaced. And he gave me $25,000.00. The $25,000.00 was substantial, but this wasn't terribly much. But it was enough for my management at GTE Laboratories to be convinced that there is something there. Because until that, they wouldn't support it at all.

With that $25,000.00 I hired Jim Auborn. Jim Auborn, being the great scientist and engineer he is, looks at the system and takes chlorine, bubbles it into the phosphorus oxychloride, measures quantitatively how much chlorine there is, puts in it a lithium electrode, and lo and behold he derives far more coulombs than he could from the amount of chlorine that he added; the capacity greatly exceeded the amount of added chlorine.

EJC: So, of course, there was another reaction going on.

AH: So we very quickly discovered that we were reducing the phosphorous oxychloride. Then he looked at other oxychlorides and we came up with the lithium thionyl chloride battery, which was the first important product that we put into production. That was in 1972.

EJC: So this, of course, had all kinds of defense applications.

AH: It went into defense applications, medical applications, computer applications, and it was produced just about by all major battery manufacturers of the world.

EJC: Did GTE hold the patents on this?

AH: GTE tried to get the patents, but Blomgren—at Union Carbide at the time—had an experiment where he dissolved in nitrobenzene thionyl chloride and he discharged it. He had it in his notebook, so the patents went in part to Blomgren and in part to GTE. We wrote the first papers because he had nothing to publish.

EJC: And wasn't the army laboratory near Washington, DC also working in this area?

AH: Absolutely. They gave us money for this work. And when we reported it, they got very much involved, very quickly. The people who funded us also got involved—their paper was published immediately after ours.

EJC: It was a very active field at that time.

AH: It became very active. What's gratifying is that, today, after 42 years, the battery is still in production. And it's still used in those applications where you need a very long life; it has a shelf life now proven to be 20 years. If you need a huge energy density, it has the highest.

EJC: So it has a unique combination of characteristics that no other battery can match.

AH: And that's why it is still being used. We then moved on to demonstrate electroluminescence in inorganic oxyhalides. In 1970, my daughter could no longer benefit from her special school in New York, and we had to move to Massachusetts. At GTE Labs in Waltham we experimented with electroluminescence. I thought, in the absence of radiationless relaxation—when energy doesn't flow from excited ions to vibrations of the solvent—then maybe we can have electrochemical reactions that emit light in the oxyhalide solutions. And, indeed, very quickly, we found that all of the rare earths are electroluminesced. But that wasn't important.

What was important was that my colleague Heinz Gerischer, at the time the director of the Fritz-Haber-Institute in Berlin, was also interested in electroluminescence. He came to visit us in Massachusetts and spent a few days with us. This was just a short time after the oil crisis, precipitated by the Arab oil embargo, in 1973. And he was teaching me the elements of semiconductor electrochemistry and telling me that we can make a semiconductor liquid junction solar cell. At GTE, I couldn't do much work on these—my responsibilities were totally different and mostly lighting product related.

But a short time later, in 1975, my daughter no longer needed the school in Massachusetts. So I could return to Bell Laboratories. And then I really started to work seriously on the semiconductor liquid junction solar cells. And over five years we published a series of papers on efficient, more than 10 percent efficient, electrochemical solar cells.

EJC: Yeah. I remember that work very well. During this time, did you maintain your connection with Heinz and collaborate on the semiconductor work?

AH: I came to Berkeley and gave several seminars at the invitation of Charles Tobias.

By 1981, after we made hydrogen efficiently, and after we converted sunlight efficiently to electrical power, I recognized that, in the practical sense, we cannot compete with the silicon p-n junction solar cells. The high assembly costs and sealing costs of the photoelectrochemical solar cells were inevitable, making them much more expensive. And because I saw that I can't help society, I quit.

EJC: So, what came next?

AH: I became a manager. Bell Laboratories decided that I should head a small but exquisitely great organization called the Electronic Materials Research Department.

If you asked me, "What's the claim to fame of the Electronic Materials Research Department?" I would say that the claim to fame was my colleague King L. Tai. King L. Tai was an absolutely unique colleague. He came to the United States without higher education, worked as a lab technician and as a junior scientist, and eventually—well before he retired—he was one of the few Bell Labs Fellows.

King built the technology of the dense interconnection of silicon chips. How do you connect an array of silicon chips so that they talk to each other rapidly? And in an integrated array, how do you transmit rapidly information from chip to chip? This required multilayer metallizations and multilayer interconnections, a totally new world of materials technology, including the flip chip technology where one made 10,000 solder joints simultaneously.

My job was to not interfere with his wonderful work, but to assist him, to promote him, to coordinate his work. I also had other colleagues like George Celler and Bob Frye, who worked on high-voltage silicon chips, laser annealing, silicon-on-silicon. . .all of these in our department.

It was the culture of Bell Laboratories that, in addition to being a manager, one continued to work as a scientist and engineer on one's own projects, not on somebody else's in the department you headed. I was my colleagues' supervisor and helped them, but was not their competitor, nor did I tell them what to do. Being head of the Electronic Materials Research Department, I was also reading the literature in the field and was tracking the science and technology of superconducting computers.

I saw a paper by two electrochemists whom you probably know—John Albery and Phil Bartlett—saying that there is an enzyme called glucose oxidase, which is a flavoprotein, having a catalytic redox center surrounded by thick, electrically insulating glycoprotein. When they used an organic metal electrode, electrons nevertheless appeared to tunnel from the metal to a redox center deeply buried in the insulating protein, well removed from the organic metal surface. We knew, however, that electron tunneling beyond a few angstroms was extremely slow.

EJC: A low-probability event.

AH: Terribly low. So I started to look into it. And with my postdoc, Yinon Degani, we quickly established that the organic metal dissolved, and it was reacting and decorating the protein with redox centers. Then we took the enzyme, exposed its inner protein, bound to it redox centers and lo and behold. . .

EJC: It worked.

AH: . . . we could tunnel electrons back and forth by multiple hops, from redox center to redox center. Wow. Ephraim, my son, was at Yale School of Management at the time. Earlier, he got his first degree from Harvard in theoretical physics, then worked for a management consulting company, and was now in Yale School of Management. And he decided that he was going to look into applications of the electrical connection between enzymes and circuits, and quickly came up with diabetes management. Diabetic people must monitor glucose concentrations in order to maintain their health.

EJC: So, of course, that could have a huge impact. So many people are afflicted with diabetes.

AH: We'll come to that.

This was now 1987–1988. And however much I loved Bell Laboratories, I knew that this work needed to be done at a university. I really loved Bell Laboratories. I never worked with such fine colleagues in my life—and never ever will again—as those I had at Bell Laboratories.

EJC: It was a unique laboratory.

AH: I got myself an Engineering Chair at the University of Texas at Austin (UT).

EJC: And this was a big decision, a very big change in your professional life.

AH: Indeed. And my colleagues at Bell Laboratories were kind enough to keep my position open for more than a year. And after a year, Al Cho—who was my boss—asked me, "Will you come

back?" And I said, "No." Until then, I was still coming to Bell Laboratories for a week every month.

So I stayed at UT, where we did perhaps the most important thing that helped people. We developed redox hydrogels, the only known electron-conducting aqueous phase, in which biochemicals like glucose and enzymes dissolve. We coated with the enzyme-loaded electron-conducting hydrogels electrodes, creating a technology for the transduction of biochemical fluxes to electrical currents.

EJC: Yes.

AH: Let me jump now to September of 2014. Based on the electrical connection, the electrical wiring, of enzymes, Ephraim and I founded a venture called TheraSense. TheraSense came out with a series of products, which we will discuss. The latest product, FreeStyle Libre™ of Abbott Diabetes Care, the company that acquired TheraSense. It is based on our electrical wiring of glucose oxidase to an electronic circuit. It came out in Europe two months ago. It's a dollar coin–sized device that has a needle so small that its insertion and removal from the skin causes little pain. You stick in your skin, and when you pull out the needle, it leaves behind a tiny polymer strip that you don't feel.

EJC: So this adheres to your skin?

AH: The coin adheres to the skin, the miniature glucose concentration-to-current transducing strip is in the skin. In the coin, there is a short-range transmitter. If you swipe over it a device that looks like a cell phone, you get your glucose reading and you get your history for the past eight hours. And you don't have to calibrate it. You don't need to draw blood anymore. You use it for two weeks between replacements.

EJC: A significant advance.

AH: Abbott underestimated how much people would want it and has a long waiting list.

EJC: So they couldn't make it fast enough?

AH: No. In November 2014, Abbott had to temporarily halt taking new customers because it could not keep up with demand. Production is being rapidly expanded.

EJC: That's incredible. What a success!

AH: Considering that it is designed to replace 16 billion blood withdrawals annually, it's quite important.

EJC: It's amazing.

AH: So let's go back to 1988. I come to the University of Texas. We build the technology for electrically connecting enzymes to circuits via redox hydrogels. . .

EJC: So who owns the patents on this?

AH: The University of Texas.

EJC: But some of your work started at Bell Labs, right? Do they have a patent interest?

AH: No. At Bell Labs, we decorated soluble enzymes. But the hydrogels with the redox centers came later. And they were necessary, because the redox center modified enzymes were still soluble. Now the redox centers are not in the enzyme, they are part of the hydrogel—the polymer, swelling in water to a hydrogel. The reason that they pair with the enzyme is that the enzyme is a polyanion,

and the hydrogel is a polycation. So they stick together. And they couple electronically. These and other patents of UT were acquired by TheraSense and became the foundation of a large part Abbott Diabetes Care.

EJC: So now Abbott owns the patents or licenses the patents?

AH: Both. Abbott exclusively licenses and also owns many of the patents because, over the years, I continued to consult to TheraSense and then to Abbott. Ephraim and I always aimed to assure that there will never be a fight and the relations of Abbott and UT will be harmonious. Ephraim proposed and negotiated the deal—the University was paid a modest royalty, irrespective of where the product was conceived or developed.

So let me now talk about TheraSense. The first glucose monitor that we wished to develop was a FreeStyle Libre™–like continuously glucose monitoring system that I just described. But the venture capitalists said that it was too risky. So my son Ephraim decided to switch to a painless glucose monitoring system, still requiring a blood sample, but requiring at least ten times less blood than any existing glucose monitor at the time.

People were pricking their fingers, getting large blood drops. It was painful: get a strip, touch it, get a blood sample, measure the glycemia (the blood glucose concentration). Five percent of the people of the world are diabetic. One percent of the people need these measurements. If they don't do it, they go blind, they lose their kidneys, they develop neuropathy, their legs are amputated. It can become a horrible disease, if they don't monitor their blood sugar.

Ephraim observed that if he pricks his skin in the arm, he can painlessly get a much smaller sample of blood. By pricking his finger, he got, painfully, a large drop of blood. So he asked me, "Can we make a sensor for such a small sample of blood?" I knew that it could be done if I used a small enough microelectrode.

But with a microelectrode, I would get only an extremely small current, requiring expensive electronics. The better alternative was to switch from an amperometric to a coulometric measurement. In a small sample, coulometry works to my advantage because I can rapidly electrooxidize all the glucose.

We recruited some wonderful people. Ben Feldman developed this microcoulometer. Phil Plante made it manufacturable. And that was the product that, after four years, the company put on the market. It increased the company's value to $1.2 billion, which Abbott paid for TheraSense.

EJC: Spectacular growth for TheraSense.

AH: But Abbott bought more than the painless blood glucose monitoring coulometric strip technology: It also bought the continuous monitor, which we had to keep on the back burner. Its first version came out only in 2008. It was the Abbott Diabetes Care FreeStyle Navigator.

EJC: Spectacular achievements over a relatively short period of time. It's really something to be proud of.

AH: So that's the story. What else can I tell you?

EJC: Well, I think that many of our readers know that you have been a recipient of the National Medal of Technology and Innovation, presented by the president. This is quite an honor—among many—for you. And I think the people that are reading this would be interested in hearing a little bit more about your visit to Washington and the ceremony associated with the award.

AH: It certainly was the highlight of my professional life—to be in the White House, to spend time with the president. And it's indeed pretty rare for an individual to get that medal. It's occasionally given to companies. I feel that it is absolutely wonderful, considering that I come from Cluj,

Romania, and passed through a concentration camp. And the two are maybe related, because today—at the age of 81—I'm still thinking that I need to pay for my survival, when everybody around me died and I survived. How do I pay back society for being allowed to be alive?

So, indeed, we are thinking about our next contribution to society. You and I know that Ephraim and I are trying to help people with Parkinson's disease. And it's the continuation of the recognition in the White House. Now that I was allowed to survive, I was honored by the president of the United States. What can I do next to pay society for this? I am doing my best.

EJC: Well, you've done such outstanding work already. It's very interesting to hear from you that you feel that there is more debt to pay. So, Adam, before we finish our conversation, I know that you've seen a number of changes in the field of chemical engineering. And we would be interested in knowing a little bit about the changes that you've seen and where you think the field of chemical engineering may be headed in the future.

AH: First of all, the fundaments of chemical engineering. You are one of the great electrochemists; Charlie Tobias was one of the great ones. Our field is expanding, growing, and developing. John Prausnitz contributed as much as anybody to thermodynamics. The basics are developing. We gain deep and new understanding. What we also see—and you have seen so well as an associate director of Lawrence Berkeley National Laboratory—that we are doing a huge amount of quasi-engineering that leads to nowhere. We are doing it only because the money exists. And that's a plague of part of chemical engineering R&D because it doesn't lead to new understanding or to people-serving products and services.

A lot of it is politically motivated. We see huge efforts at reducing carbon dioxide emissions. And it's a true tragedy that people are not taught that increased energy use is a direct result of growth in global wealth. The GDP per capita has increased 18-fold and the population of the world increased 14 fold in the past 100 years, resulting in a 250 fold increase in global wealth. Global poverty has decreased dramatically, and will continue to decrease. As people get wealthier they live in larger and better built homes and drive more cars. Just the cement and steel industries generate 13% of all CO_2 emitted. So as people and governments get richer, they consume more energy. There is nothing that you can do to stop it. One can't stop Asia and Africa from using more energy, nor can one stop people from having large families. The commendable and profoundly important substitution of fossil fuels by renewables and energy conservation have not stopped or slowed the rise in atmospheric CO_2.

Considering that people will seek to increase their wealth and to have large families, resulting in continued rapid and massive growth in wealth and thus more energy usage, and considering that we already spend heavily on renewables, what are the alternatives? Well, we don't discuss the alternatives as much as we discuss renewables and conservation because the alternatives are offensive to well-meaning purists. We need to discuss more the limiting of global warming by controllable and reversible processes that when nature-caused and uncontrolled in the past had caused in the ice-ages, such as fertilizing of the Southern Oceans with short-lived forms of iron to induce photosynthesis by marine organisms and transiently reflecting sunlight by stratospheric sulfate aerosols.

EJC: So, where do you think our field is headed in the coming decades? Chemical engineering especially—I think—has changed quite a lot in the past 30 years. And it is certainly going to continue to change.

AH: There are some wonderful things that are happening. You see absolutely wonderful things happen in chemical engineering: providing, at a lesser cost, better materials; relying increasingly on natural product based feedstocks and inexpensively converting them to environmentally friendly

chemicals. You see wonderful things in electrochemistry: shrinking down power sources, making electrical car batteries the way you are doing it. Sooner or later we will have a long-lived, moderate temperature, high-power-density fuel cell that uses methane instead of hydrogen, followed by one that uses higher boiling hydrocarbons. I think in electrochemistry, that's the greatest challenge that I can imagine.

And you and I know that this will come. It's up to the next generation. So pretty soon—on a historical scale of 100 years—there's no question in my mind that we will drive liquid hydrocarbon fuel–based fuel cell powered cars.

EJC: So, you and I—as educators—see many young, bright students coming through our educational system. To end this conversation, I'd like to ask you what you think these young students should be told about entering a career in science and engineering and being successful in their careers.

AH: For those few of our students who are thinkers, they should think. When I was mentored at Bell Laboratories by my executive director, William P. (Bill) Slichter, he taught me that I am not here to tell people whom I am coaching what to do, but to let them think. There's nothing more important that you can do. The minute that you let them think, they are on their way. But you and I know that the thinkers among our students are few—if I look at my own colleagues, I would certainly say fewer than 1 in 20 are able to think in depth about new directions.

EJC: That's my impression also.

AH: So what should the rest do? The rest should think how they can bring benefit to society. And when you go to work, the toughest test of whether you are bringing benefit to society is to go to work for a venture because the venture will sink if it doesn't bring benefit to society. In a large organization, you will survive even if you don't bring benefit to society. I guide students joining large organization join their fastest-growing part—not on one of the branches that are about to die. Each company has a fast-growing branch.

I like ventures. I like small companies. I like small organizations that are dynamic, where a small group of people makes decisions and has authority to carry out decisions, and where each member is held accountable for the decisions and their execution.

EJC: Well, that's a valuable thought and advice. And I think we should conclude our very interesting discussion.

AH: Wonderful.

EJC: It's been a great pleasure to meet with you today.

AH: Thank you, my beloved friend, Elton. It's such a pleasure to sit here with you and tell you stories.

EJC: Thank you, Adam.