INTERVIEWER: Today is December 16, 2011. I'm Bill Lattanzi. And today, as part of the MIT150 Infinite History project, we're speaking with Vladimir Bulovic, professor of electrical engineering, the director of MIT's Microsystems Technology Laboratories, and a MacVicar Faculty Fellow, an award that recognizes MIT faculty who have made exemplary and sustained contributions to the teaching and education of undergraduates at the Institute.

Welcome, Professor Bulovic, and thank you for speaking with us.

BULOVIC: My pleasure to be here.

INTERVIEWER: You've said in other interviews, you're trying to train the next generation of leaders, and that at MIT, we know how to do this. And I'm sure there's a lot of interest. How do you train the next generation of leaders? What's the method?

BULOVIC: It's very easy, actually, at MIT. You start with extremely good material, which is our students. In many ways, universities pride themselves by being able to provide exceptionally good education. And yeah, indeed, as faculty, we try to offer the best class we can. MIT, I think, excels in that.

But that's, I don't think, most of the education a student gets when they get to MIT. I think most of the education a student gets is from their peers-- the fact that, on the undergrad level, it's really the dorm room, or it is the dining hall, that most of the experiences that will shape you will be given to you. And the good thing about it is that you're surrounded by incredible other young people, full of enthusiasm, who see the future that, maybe a little vaguely, but certainly with you, in conversation will discover what needs to be done next.

So we start with extremely good raw material. And then the best we can do is excite them, show them what makes us excited about the world we see ahead of us. We have maybe a little more perspective than they do. We've seen more as faculty. But they are the ones who need to do the work. So they're the ones who will inherit it and take on and define the next set of milestones. For us, it's to tell them the few first few we see and see if they can achieve them, and then learn from them as well on what is it that we might have been missing.

And their usefulness and charisma and daring of exploring new things, often you find that that's a great inspiration of what you should really be thinking of as a faculty.

INTERVIEWER: So you find young people coming out with a fresh eye inevitably are seeing things in a new way?

BULOVIC: Yeah, often a very misguided way, which is wonderful, because once in a while you stop and say, well, maybe it's not so misguided, maybe this is not an entirely crazy way to think about it. And in that, you inject a little bit of your own wisdom that you might have gained through the years and realize, oh, maybe I never would have thought of doing that, but since it's adjusted, let me try.

On the undergrad level, I see that. On the undergrad level, I see that real enthusiasm. On the graduate level, there is already a semi-formed personality of someone who already has a great deal of investment, or at least passion, that they feel they want to make the best solar cells, they want to make the best light bulbs, they want to save the world in this or that way. And that's wonderful.

What I often love to do-- well, what I think is important to do with individuals like that is maintain their enthusiasm with a dose of reality, if possible. I often start by challenging their notions, not to be contrarian, but only to point to the practicality of some of the challenges. If I'm going to talk about solar cells, I'm going to go ahead and save the world with solar technologies, right? That's what I want to do. Well, that's a great idea. I'm a director of the Solar Frontiers Center. I truly believe in it as well. But it will take me a long time to make enough solar cells to truly make a difference.

And you can ask how long will it be? Well, if I put down solar cells as fast as I could put down roads, it will take 10 years, 11 to reach 10 percent of electricity needs of US. So give me 100 years of deploying solar cells, and maybe I'll be able to reach that goal of truly making a difference, and only if you have a battery technology that goes with it, that doesn't exist as of today. So that doesn't mean that I want to quelch their enthusiasm, but I do like to give them that dose of reality so that the next thing they think of will solve the battery issue, or will solve the deployment issue that right now truly is the Achilles heel of the technology.

And what you often find is you pose a problem like that, and the students just fly with it. They come up with extremely innovative ways of completely rethinking the whole concept of why is this done or that done.

INTERVIEWER: They're problem solvers. You lay out a big vision, and then start solving problems?

BULOVIC: In many ways. I'm an electric engineering professor. So the students I see are very much hands-on students. All of that is rooted in theory. So often, what I find are the best solutions are the ones that are willing to go ahead and try out stuff. But at the same time, students who step back and ask themselves, how come the world is this way? and jot stuff on paper, do a bit of analysis, model, and then recognize that the first experimental was faulty or not complete for some reason based on the numerical work they've just done, and then propose the second thing to do, implement it again, get partway there, fail, in some respects, only to again learn what to do yet again. So that persistence and discovery is extremely important.

INTERVIEWER: In the humanities, Samuel Beckett says his method is-- or character says-- fail, try again, fail better.

[LAUGHTER]

BULOVIC: Yes, exactly.

INTERVIEWER: So you've said also that it's key for students to know the difference between science and technology. And I wonder if this taps into what you're talking about now. And I just want to ask the simple question, what's the difference? And why don't students know it?

BULOVIC: I think many of the faculty don't know it, and I think much of the world doesn't know it. I mean, it's pervasive to recognize that we don't really appreciate where one stops and the other one starts. And the way I look at my work is very much too trifling to do. I like to make something that is useful, broadly useful. Yet I'm a nanoscientist, I'm a nanotechnologist, a electrical engineer, for goodness sake, and yet I'm willing to use the word "science" in what I do. That's because it's integral to everything that we do. It's all about how the world is done on the nanoscale that will enable me to give you a yard-by-yard square sheet of something. Is it a solar cell, or a display, or a sensor, or whatever it is?

And so, being able to link the two and recognize when one starts and the other one stops, there's no clear boundary. I mean, I need to know the basic science. And when I'm down on using my pencil and scribbling stuff down or typing a code to model this, that's science. And then I go ahead and try it out. Well, am I now doing engineering or technology? Well, not really. I'm just testing the science.

I'm generating a test bit to examine the idea. And then what next? Well, the next thing to do is actually to make something that actually works and test does it work very well. So am I doing science or engineering? Well, often both. Often at that point, I'm turning on my little LED to see the light bulb glow. And I say, well, it's glowing. This is great. I can give this to someone else to start using it. But it's not glowing quite bright enough. It's not quite as efficient. Why is that? Well, now I'm back in science.

So it's this feedback that enables you at the end to make something truly worthwhile, at least in my own experience. And if it ever becomes just purely one or the other, it's a wonderful endeavor. It's a truly wonderful endeavour just to have it pure as well, except you, in the technology end of the things, you're then taking on already solved problem and you're trying to scale it. And development is a very challenging issue, but a challenge of a different kind than understanding how to develop it.

And if you're in a step before, which is go ahead and give me the basics of why these things work, beautiful as well in so many ways, yet not really practical for truly making a difference in that encapsulation of just being pure science without it seeing a link to how to link to the technology. In many ways, I play right in that cusp of the two. And I do see the feedback across the technology and science being extremely important in order to advance.

INTERVIEWER: It sounds like the borders are so porous that it shouldn't matter as much which you think you're working in. But are there problems if you mistake the one for the other?

BULOVIC: I think the best thing to do is to have a buddy, and have a buddy that you can trust and that understands the complementary part that you don't. I, at least in my own experience, have fantastic time working with chemists. My very close friends are Tim Swager and Moungi Bawendi in the Chemistry department, who both make chemicals, that then I can imagine how to use.

I would not have the slightest chance of knowing how to even start making the chemicals that they make. But we do get a vial of either a powder, of polymer, or molecules from Swager, or we get a vial of little glowing quantum dots, and we go ahead and now, say, OK, there's this nanomaterial. It's magical. They made it. What is it? You do optical characterization, and you go ahead and check out where the light gets absorbed, what kind of light gets emitted. Then you start saying, well, what can I do with this that really makes a difference?

So you work with Tim Swager and say, well, you tell me that this polymer is extremely sensitive to chemicals, like TNT, dynamite, great. I know how to actually make a really good solid-state, thing you can hold in your hand chemical detector. As a matter of fact, you told me a way to start it. Make a tin of film, go ahead and expose it to TNT, and it's going to stop glowing.

And this stopping of the glowing is because of the chemistry that Tim Swager does in it. And then I start thinking, you know, there's a phenomena in optics known as lasing. If I can go ahead and use that very same glowing material and make a laser out of it, a laser's an amplifier of optical events. And you tell me your film is going to slowly stop glowing in presence of TNT. Maybe I can amplify it if I make that film into an optically pumped laser.

And indeed you can, we found out. And this way, you can actually increase the sensitivity detection of that dimming of the flow a thousandfold, so that you can actually make a thousandfold more sensitive detector, even more sensitive than a dog's nose, which is our best detector there is, in sniffing out, actually, explosives, for example. Now, the reason why I cited it as one of the many, many examples, it's that interplay between his materials. I would have no idea how to make something that's chemically sensitive, but I do know how to manipulate the electrons and photons and think about stimulated events that utilize concepts in physics and concepts in conventional optoelectronics to then connect to this nanoscale of material space, and then make, at the end, a product or an item that has never been seen before, or has never be quite performing to the level.

INTERVIEWER: So this seems like a perfect example of the kind of interdisciplinary work that goes on at MIT. It seems more than other places, and seems increasingly vital in the 21st century as different fields kind of converge on one another. So I'm wondering, is my perception right that that's a hard thing to do at most places? And what is it that makes MIT different?

BULOVIC: Well, I do emphasize to people two things about MIT whenever I think about what really makes us truly different. And this is when I get the graduate student who's thinking about Stanford, Princeton, Caltech, or MIT. And you say, well- at least I do-- all those places are great, and all of those places can really give you a good education, and in many ways, your primary education, especially as a graduate student, is very much linked to your research group. So all these places have great research groups. You'll do great.

One difference at MIT is that we're all connected via corridors. And that seems like a small thing, but there's another element to that. And that is that all our buildings were built in about the same time. So in some respects, they all look equally drabby or equally good. You never have a sense that you left your own environment.

You start in my office. You can walk down the corridor and take a left, go down, take a right. You're now in the chemistry wing, looks just about the same. There's no psychological barrier to opening a door and feeling like you're in someone else's turf. You're indeed with yet another colleague who happens to have an interesting thing to tell you. And his door is open. That's the second thing that really matters. Hence it's very easy to knock and say, hello, and introduce.

And I've never found a lack of ability to develop a relationship at MIT. I always found that, if I asked and suggested, there was always a reciprocal response from the other faculty member. This is a very open campus, very, very open in both the way we interact with our students and interact with other faculty members. Everyone goes by first name. There's no professor this or that. I go by Vladimir with my students, and they clearly expect me to reciprocate by calling them by their first names.

That, I think, puts a level of collegiality and a level playing field, whatever. I can't rest on my laurels. There are plenty of brilliant people on this campus, but you wouldn't know it by looking at their office that they're any more special than anyone else just down the hall. And they wouldn't act as if they're any more special either. They will actually just engage you in a conventional conversation, tell you all that you would like to know as long as you reciprocate in the same way.

INTERVIEWER: I don't think I've ever been in an institution with more open doors, literally open doors, than MIT. You can just walk into any building at any time. And I too have sensed this lack of hierarchy and pure interest in the content. People are more interested in the content, it seems, than position.

BULOVIC: I also found that, if I look at presentations of people who, let's say, want to represent a center, there's a true joy in a director presenting their colleagues' work. It is not as if people are necessarily favoring their own little research and saying, this is the best thing to do. I find myself, at least as I'm presenting, as I run these different centers, I find it just joyful to be allowed to present my colleagues' work, which is just brilliant in so many ways. And emphasizing the brilliance of it makes me feel proud to be able to have a chance to share it.

So I guess the other thing that really distinguishes us is that we truly do take true pleasure in our colleagues' achievements. And that, I think, at the end, breeds the collegiality that's truly unsurpassed.

INTERVIEWER: Related to that, just-- I think you may have just answered this. But what is your chief pleasure then in teaching?

BULOVIC: Well, there are two products that we make as an institute, as a university, only two. One is knowledge, new ideas, new patents, new papers. And the other one is people who are capable to take those ideas and actually push them forward or generate new ideas thanks to the fact that we managed to show them how to get to the first one. So my joy is when I see an aha moment, when I say something in a classroom and a student then back says, oh, that's what you meant. Yeah, that's what I meant.

It's a small thing, and it's not like it's going to change your life tomorrow. But at that moment, your life just got a little broader, and you got kind of a picture of where I was heading. And a few times, you get questions from the students. They also say, I can't answer that because I never thought of it that way, but you know what, I'll come back tomorrow because that's a really good thing to ponder. And you come back tomorrow, and you kind of try to -- and say, well, I thought of it and it's just this, or maybe I thought of it and that's a really good line of research to pursue. Sure, let's think about it more.

So my joy is in recognizing, for undergraduates, it's recognizing those aha moments. With graduate students, typical graduate student in my group stays for about five years, and I like to emphasize that, with them, as I start, that first two years, more likely or not, I'll be saying a lot of stuff, and I'll be telling them a whole bunch of things, and the latter three years, two and a half, it's their job to teach me, because at that point, they are nearing being the world experts in what they're doing. By the five years' mark, they are the world experts. I mean, that's their goal. They should be. In that little discipline, little subfield of a little subfield, they should be the best in the world doing that.

And hence, I cannot match their understanding of what it truly is, but I'll revel in being able to talk to them about it, because, I mean, how often do you get the chance to be next to world experts in things that I care about? Because, indeed, we grew together. So my joy is in seeing that.

Now, the next step beyond that, if my students are able to get jobs and actually make a difference in the world, I revel in that as well. I mean, in many ways, what I value, again, is that exportation of knowledge, and people who are capable to take that knowledge to fruition of some sorts. And it can mean either generating that little idea we had, or generating jobs that are carrying out the little idea, starting little companies that can actually make a difference to someone, or if we have a big idea, saving the energy footprints of this or that village by introduction of this or that technology. There are many ways to take joy out of it, but it's all about advancement. It's all about advancement of people and knowledge.

INTERVIEWER: Yeah, and you mentioned spin-off companies. I know you've been involved with a lot. I know you've got a million different things going on. So what's the process that leads to a student or grad student spinning a startup company out of your lab? And how do you participate in that?

BULOVIC: Well, we need to have a good idea. I mean, we do have a lot of patents that we filed within MIT. I think at this point, I have maybe 50 issued patents by the United States, maybe more than that internationally. But it's all the same idea. So patents are good, because those allow you to have something to bargain with as you want to start the company.

How does a student start the company? Well, let's start with a good idea. And we started, for example, QD Vision was the first company we started from my group. Before that, I had the chance of participating and observing being a graduate student who was assisting others start companies. So my own project adviser, Steve Forrest at Princeton, was very entrepreneurial, is still very entrepreneurial. And one of the things that I was working on as a graduate student was organic light-emitting devices. And I had the chance to see what it means to try to launch a technology.

We started with no patents. We had just a few demonstrations. It was a very hot and very interesting field to be in, a whole bunch of really neat science, but also nifty technologies-- LEDs that are transparent, that look just like a piece of glass. And, indeed, *Minority Report* is a movie, has used some of those ideas to kind of show really cool TV displays or displays you can flex.

So they're as thin as a sheet of paper, just a variety of simple gizmo-like things you can imagine. But underlying all that is how the molecules get electrically excited. So I realized that in my own graduate research, I could go ahead and develop these ideas, or go ahead and patent it, or go ahead and then make a few gizmos, then we'll go ahead and show it to some people that might care about it. We'll have to process a thought on, how valuable is this for the world? Is this truly groundbreaking? Is this earth-shattering in some way? Is this going to interest anyone?

And even if it does interest someone, is the market big enough for anyone to actually care to invest in this? And is this something that could sustain one job or 50 jobs or 1,000 jobs? And after that little economic thinking on how far can you go, then you say, well, how can I raise the money? Well, I can go and try my best to get a few grants, and maybe in a year I'll get another grant. And I'll have two guys run this thing, and eventually that might blossom. Or I can go ahead and say, well, if this is such a great idea, and let's say the market is $100 billion in display technologies, well, maybe I can go and ask for $10 million from a venture capitalist, because he wants to get $100 million.

If he gives me $10 million, he wants tenfolding return on his money. So I can say, well, there's $100 billion. So come up with that technological landscape that, indeed, is rich enough to be able to support initial fruit of the development that you have from your lab. With that, come up with a really enthusiastic student. And this is not just technically savvy, but someone who has a vision to see where the economic benefits of this technology, and be able to speak to it in a way that would enable others to see that vision, because you have nothing in your hand except a little gizmo, and you're selling an ability to change the world. Well, the only way you can do that is if you have that power of persuasion in your words and in your ability to paint that picture for people where this can go, and provide a technical roadmap that spells out, step by step, what needs to be done.

So often what we do, if a student would like to start a company, first thing to do is to recognize we need a team. We need a technical lead, maybe the student. We need a technological development team, which is maybe, again, this one student, and then have a faculty member like myself, have a good advisor from Sloan School or from the angel community around Boston, put the package like that to four or five people, walk into an office of VC, present it, but present it in a way that will tell you that in five years you'll get somewhere.

And often, it ends up with a concrete job for the students, and it will never be any better than that, because they are the most enthusiastic people to fly this technology. They're the ones who invented it in the lab. They're the ones who saw it from the seed, growing into a sapling, growing into a true thing that can actually change the world. So you have all your needs. You have enthusiasm, brilliance of students, and you have the financial support from the back. My job then just becomes to stand on the side, observe, and once in a while give a suggestion that might help out a tad more. But really, at that point, it goes into students' hands that are now PhD doctors that know what they're doing.

INTERVIEWER: So again, it's this emerging theme of integration, where the idea is just one piece of it. Communication is as important, yeah?

BULOVIC: Very much so.

INTERVIEWER: I want to go back to the QD Vision idea, which as I understand it is a much more efficient light bulb, basically.

BULOVIC: Yeah.

INTERVIEWER: And it works with something called quantum dots.

BULOVIC: Yes, invented by my colleague, professor Moungi Bawendi, in Chemistry.

INTERVIEWER: So what are quantum dots? And in layman's terms, how do you make a light out of dots?

BULOVIC: Well, if you have ever drank Gatorade, you might have found, once in a while under sunlight, it appears to be glowing almost. And it actually is. What's glowing inside that is molecules, little items that we call molecules. And we're not scared of molecules. We think, well, molecules, that's usual stuff.

Well, they're one nanometer in size. Those are nano items, that you optically or electrically excite them and they glow. So many nano items are surrounding us everywhere. Car paints are also made of nano items. That's a use of nanotechnology that happens to be molecules. They happen to be coloring our cars. Pigments on inkjet printed paper, another example, again, one nanometer-size elements. And we don't even think of it as one nanometer-size elements. We think of it as a print.

Stained glass windows, those are nano balls of metal inside pieces of glass. In that case, they happen to have a particular color absorption and reflection property that allows you to make a stained glass. So these are all little nano items. So among them are possibilities to take a chunk of stone, and stone in this case would be phosphite, cadmium selenide, zinc sulfide-- these are crystals that come as big little chunks of stone. And I'll take a chisel and chisel out just the tiniest little stone. No, we don't really chisel anything out, but imagine doing that.

And now we have a little chunk of stone that is 30 atoms across, let's say. So that little item is so small. It's 30 atoms. So you say, well, if I'm an electron, it might seem like a big enough box for me to roam. It is, but even electrons like more than just 30 atoms to roam across.

And it turns out that I can-- I can't, but my colleague, Moungi Bawendi, can. He can choose the size of the box he makes. He can make these little chunks of stone using chemicals. He mixes up chemical A and chemical B. One contains, let's say, cadmium. Another one contains selenium atoms. You stick them in a pot of hot oil. Cadmium falls off. Selenium falls off. They swim in this pot of hot oil. Cadmium meets selenium. They bond. They form a tiny little crystal. And you keep on cooking this, and more cadmium adds in and more seleniums add in. And now I'm going to cool it down. And what I'm going to be left with is a solution with a whole bunch of little crystals. If I cooked the solution for a long time, the crystals will get big. If I cooked the solution for a short time, they would only manage to be very small ones. So what can I do with those?

Well, they're just of the size that electrons can be inside them, clearly, because everything's made of atoms that had electrons in them. But the size of the box is a little bit too small. And this is manifested in a following way. It's manifested by giving you small crystals.

They'll be blue in both their absorption and their glowing luminescence. Big crystals, they'll be red in both their absorption and luminescence. And the crystals in between, they'll be the colors that are in between those. So if you're a little bit bigger than blue crystal, you'll be green. A little bit bigger than the green crystal, you'll glow yellow, orange, red.

As you change the size from, let's say, three nanometer crystals, 10 atoms across to nine nanometer crystals, 30 atoms across, so that's the brilliance and simplicity of it, where you can ask next is, how come different-sized crystals have different color? I just told you they do, but how come? Well, there's one thing that is true that we never tell people, and that is that electrons really are waves.

We think of electrons as particles, but they're really waves, just the same way as the photons are both waves and particles. The two happen to be exactly the same in many ways. And so if electron is a wave, it needs to resonate. It needs to bounce back and forth off the walls of this particle. Give me the small particle, and the wave of the electron will be very, very short, which means its energy will be high. If I make the electron that sits in a bigger box, its wavelength will be longer, which means its energy would be less.

And this leads to the higher energy, small particles; bigger energy, larger particles. Another analogy that Moungi Bawendi would say, he'd say, when you play violin and you pluck a string and you hear a sound, now go ahead and press down the string and make the length of the string a little shorter, pluck it down. You'll hear a higher note, same thing. Give me a smaller box, you'll pluck the note and you'll find that the color of light coming out is blower.

INTERVIEWER: So we're going to have sheets that can project any color, like a television?

BULOVIC: So yes. So now take these little quantum dots, and ink them over a surface, and ink this area here blue, and this area green, and this area red. These areas will contain many, many quantum dots, because areas are maybe only 20 microns across. 20 microns is, like, 1/5 of the thickness of your hair. But those 20 microns will contain thousands of dots. So ink an area with some green, some blue, and some red, and you can optically excite them to get, again, colors coming back at our eye, or you can maybe put electrodes on top and the bottom of these sheets of quantum dots and electrically excite them. And when you electrically excite them, they'll flow.

And a good example of that, I'd like to emphasize or point out, is a pickle. So a pickled cucumber, pickle, if you go ahead and put two electrodes in a pickle and you apply enough voltage, like 110 volts, you'll start observing a yellow glow coming out of it, because you're exciting sodium atoms inside the pickle. Sodium is from sodium chloride from the pickle ink of the pickle. Sodium is about a nanometer in size or less, and so here's a nano item glowing, electrically excited by the electrodes. Same thing here, except rather than needing 110 volts, we slice the pickle really, really thin, and so to generate same kind of fields, you only need about five volts, or three volts to excite the very thin layer of dots that you can say is akin to sodium inside the pickle.

INTERVIEWER: So is the idea then that the dots can be used in any place you need illumination, from a regular light bulb to a television screen to the screen over Times Square?

BULOVIC: In many ways, yes. I mean, the quantum dots themselves are the ultimate, in many ways, light source, as long as optically or electrically excited. But the beauty of them is they can tailor for you the spectrum of light that you will see. They'll give you warm light or cold light, all by choosing a different amount of mixtures of the reds, greens, or blues.

INTERVIEWER: And when can I buy this at Home Depot?

BULOVIC: So today, you can buy light bulbs, but these are light bulbs that are optically excited. So essentially, what you can do today, you can go ahead and look at the most efficient lighting that's available, which is LED lighting, that starts with a blue light that excites a yellow phosphor. And that's what's right now available at Home Depot, blue light with yellow phosphor. And combined, your eye thinks it's looking at white.

However, it's a very cold white. It's missing the red hues. And so what we've done-- actually, what QD Vision has done, inspired by work done at MIT, is to take the red quantum dots, add it to this blue-yellow light bulb, and take away some of those blue extra photons, excite the red quantum dots. All combined, now you have a little bit less blue, you still have the yellow from the phosphor from before, and now added to that is this beautiful red extra peak, giving you an overall spectrum that looks very much like an incandescent light bulb that uses only about 1/5, 1/6 of the energy. So dramatic energy savings at the same quality of light. And as the LEDs keep going down and down and down in cost, give it a couple of years, and it's going to economically seem a no-brainer to invest in LEDs, as opposed to even fluorescent light bulbs that happen to be issues with mercury disposal, packaging, and so forth.

INTERVIEWER: While we're on the spin-off company area and the tough science, your one other spin-off company you have, Kateeva, I have read focuses on the development of printed organic electronics.

BULOVIC: That's right.

INTERVIEWER: Now, to me this sounds like an all-cotton iPod.

[LAUGHTER]

BULOVIC: Exactly. I don't know how you knew that. That's exactly it.

INTERVIEWER: So I'm guessing it's not that. But I was wondering if you could explain what it is.

BULOVIC: Sure, it's an all-cotton--

[LAUGHTER]

BULOVIC: For my graduate work, I worked on organic LEDs, as I mentioned earlier. And all those are are, again, those electrified pickles sliced really thin. In this case, though, you use organic molecules to give you the glow. I mentioned before, the nanometer-scale items that can be optically or electrically excited. The organic LEDs make beautiful displays. And there are demonstrations. Companies like Sony, Samsung, LG have demonstrated 11-, 15-, 17-inch displays. The only little problem with them is that the cost may be 10 times more than conventional screens.

As a matter of fact, you look at the screen and you say, this is so simple, how can it cost so much? I mean, the only thing you have is a piece of glass, some electrodes, a little bit of electronics, and then just this film of molecules and the top electrode, and you're done. It should cost a lot less than a liquid crystal display, which is the standard today, which has, on top of everything, polarizers, liquid crystal that's liquid, these rotating plates-- I mean, just a whole bunch of color, just a whole bunch of things. Yet it's cheaper still today to make liquid crystal displays, because technology has been around for about 20 years in commercial use for really good ones.

OLEDs, organic LEDs, invented about 20, 25 years ago, but commercially really available only for a few years. And so you look at the big Achilles heel of that technology and it's patterning, being able to actually give a very well-defined pattern of particular molecules with a well-defined thickness over extremely large areas. And the reason for it is that, in my OLED, my whole OLED, the entire device consists only of 100 molecules in thickness. To kind of get you a sense, it's 0.1 microns, which is 1/1,000 of a thickness of your hair, roughly.

So take your hair, slice it 1,000 times lengthwise, that's the thickness of the whole OLED screen. So you can put it on anything you want. But out of those 100 molecules, it's the middle 10 molecules that are glowing. So if I'm going to give you a technology that's going to make TV displays made of OLEDs, I'm going to give you a technology that's able to put down accurately with a 10-molecule accuracy films of molecules over very large areas. That's a big challenge in the organic led manufacturing industry.

And then, on top of that, I would like to have molecules that glow red over here. 20 microns away, I would like to have molecules that glow green. And then 20 microns away, the blue ones, and then repeat that over and over again. And you know what else? I do not want any of my pixels that make my TV screen to look bad. I want all of them to work exactly right. As a matter of fact, all the three million pixels and subpixels, every single one better be absolutely perfect for me to buy your display.

That's a very tall order, because if I'm going to give you any electronic technology-- I'm going to give you a Intel Pentium chip. There are plenty of really bad transistors in that Pentium chip, but there are redundant circuits that make sure that, in a case there is a misdoing of one of the transistors inside that billion-element chip, there are other circuits that pick up the slack and work, compensate for the error. Or you can give me a solar cell. You look at a solar cell, light gets absorbed. You don't know that sections of that solar cell don't work very well.

But stuff you stare at, displays, you're looking at every element I made. And so what Kateeva has, it has likely a solution to this really challenging problem on how to print organic electronics in general, specifically thin films for organic displays, over very large areas as needed. You can think of it almost like making a saddle plotter for, in this case, not just posters, but for electronics.

INTERVIEWER: I'm sorry, a saddle poster?

BULOVIC: Saddle plotter. So if you look at the inkjet printers, they print 8 and 1/2 by 11 sheets of paper. But whenever we make posters, we go to this thing that's called saddle plotter. And what it is, it's an inkjet printer that's this wide and this narrow, so it looks like a saddle. And you feed a very large sheet of paper through it, and you print the whole poster that's now 2 by 4 feet, or 6 by 10 feet, however big you want to make it.

So inkjet printing over that large area is now doable. So we are thinking that's just optics. Can I give you an inkjet printer that prints electronics? And so the tools that Kateeva is making are indeed very large. They can handle 2 meter by 2 meter pieces of glass, if you want, which is as tall as me and as wide as me. So in that sense, it can generate an ability to deploy electronics on nearly any surface in a format that might be desirable by simply on-the-fly programming at how you want to make it.

INTERVIEWER: So that would radically drive down the cost of the LED television screens.

BULOVIC: Absolutely, but--

INTERVIEWER: They'd be everywhere. Will we have that *Minority Report* future where screens are everywhere?

BULOVIC: A *Minority Report* future is today. We have stuff like that in the lab. Before *Minority Report* was filmed, we had the transparent and flexible displays. And then one day, I was visiting UDC, Universal Display Corporation, a company that got started on organic LED research back when I was a graduate student. And we heard that the crew from the next Tom Cruise movie was coming to talk to us. So they did. I did not know which movie it is. The next thing I knew, that next year *Minority Report* came out, and they had ideas that were very similar to what we were talking about back in the late '90s, which was transparent displays and flexible displays and light-emitting surfaces. So, nifty.

INTERVIEWER: It is nifty. As we're talking, I'm thinking about a statement you made, that we live our lives at the nanoscale. And I get a little of what you mean, but I'm a little confused. When I get up in the morning and I drink my cup of coffee, I'm living at the 12-ounce scale, at the eight-ounce scale.

[LAUGHTER]

INTERVIEWER: I think. Aren't I?

BULOVIC: Well, it's a fantastic question. I mean, I think we are creatures who consume macro quantities of nanoscale. It is indeed the way that the water dresses the insides of your body, but those water molecules, the way they interact with the insides of your body that makes a difference for the way our neurons fire, or makes a difference for the way that the digestive system works. It is leaching of ions from our bones into our system that controls the firing of our neurons. And I know very little about biology, but I do appreciate the fact that it's the ion channels that make a difference.

And all that ion channels do is let sodium or potassium go in and out, and that change causes a change in potential. That little change in potential causes our neurons to spaz. And that spazzing of the neurons sends a signal, an electrical signal, to our brain. And our brain says, whenever that particular neuron is spazzing, I must be looking at a green light at that section of my eye. And these million signals come to the eye, and then we see an image, because those signals were then translated to spazzing.

So at the end, I need to ask, what happens when that single photon hits that single molecule inside my eye and opens up that ion channel that's made of not single molecule but maybe four molecules? But it's that nanoscale that, at the end, that will govern the way that I will respond. And yes, I am experiencing macroscopic nanoscale response all at once. And yes, it's incredible that our brain is able to go ahead and manage all this input all at once. I marvel at the fact that I can ignore the fact that my jacket and my shirt are touching my body as I'm speaking to you. But it's happening all the time. I'm sensing all those things, except my brain knows to just focus on this one thing, looking at you and talking to you and tune out all the other parts.

So we always deal with macroscopic amounts of information, but at the end, the way it's translated to us is via a nanoscopic-type event. And an appreciation of a nanoscopic-type event will allow me to understand how to modify, how to make it look different, how to make it appear different.

INTERVIEWER: So do you have moments when you're walking down the street that the world is like seeing the Matrix? You suddenly see things in nano form?

[LAUGHTER]

BULOVIC: No.

INTERVIEWER: Or imagine it to be so? Would you like to?

BULOVIC: Well, I guess the only thing I ever done is try to understand the world around me. So I teach a class, 6.007. It's electromagnetic energy from motors to lasers. And it was a fantastic learning experience. A colleague of mine, Rajeev Ram, co-developed it with me, and Rajeev taught me an amazing amount of stuff in the process. But the challenge to us was to try to relate to a student in the course of a semester everything that we might experience in the process of living our life.

Now, both of us are electrical engineers, and we wanted to essentially give you applied electromagnetics, but not by telling you Maxwell's equations and by telling you this is how you go about solving the cylindrical coordinates. That's not real. I mean, it's real, but it's not real from the perspective of actually seeing an iPhone and saying, everything in this iPhone is electrical engineering, every single bit of it. I mean, I'm going to show you how the antennas work. I'll show you how the display works. I'll show you how the microphone is made. I'll show you how the accelerometer works, figure out how the picture twists around when you turn the phone around. I'll show you how to make a battery. I'll go ahead and then connect it to the whole system and tell you how the two communicate.

That's what matters at the end. And so your Wii controller now that you swing around to play your game, you realize that, oh, that has an accelerometer. And all the darn accelerometer is is just a little piece of silicon that has a little spring on it that happens to move left and right and change the capacitance between the left contact and right contact as it's swung back and forth, which is interpreted as me moving my hand. We spend time talking about, again, everything from motors to lasers, so there is launching of magnets, there is liquid crystal displays, there is tunneling in touch scans.

So I find that as you tell the story of the class-- and the class is taught in 50 stories. We have 50 lectures. And it's fairly rigorous. At the end, you need to understand both electricity and magnetism, electrostatics, electrodynamics, and quantum mechanics, all in the same work.

But at the end of that, you realize that, I needed to spend a class talking about how we see. And the fact that, if I'm going to trick you into seeing yellow, there's no yellow pixel on my TV display, so how come my TV can make a yellow image? Well, it's the way our brain works, so you have to explain that. Or how do I make a 3D image when I go to that movie theater? Oh, well, all you need is a polarization rotator, a quarter-wave plate, a polarizer, and go ahead and do a different polarization for left and right, circular polarized light for the left and right right.

So that sounds really complicated, but at the end, all it is is I'm saying I'm sending a different image to the left eye and the right eye. And my brain sees those at the same time and interprets a three-dimensional image. And here are seven ways, or let's say four different ways you can do it based on the tools we just learned last class. And while you're at it, you might as well make a hologram.

So it's not a big deal if you start in very small steps and recognize that it is that nanoscale, again, in my head. That is what you need to know.

INTERVIEWER: I'm starting to see the romance of it now. It is like seeing *The Matrix.* It's seeing what's really going on at the most basic level of reality. So I'm wondering when that moment happened for you. What was the moment that you fell in love with the nano world?

BULOVIC: I'm not sure I ever had a definition of it being a nano world until I needed to express it as a professor. You know, what I do? And I realized sometime, as I joined MIT in 2000, that I need to say what I do. And I think I do nanostructure materials. I imagine uses of nanostructure materials in optics and electronics.

INTERVIEWER: But as a boy, there must have been a time before you realized this is what it was.

BULOVIC: But it has always been, why does it work? It's, why does a flashlight work? Or it's been, how come the radio works? That's really what got me excited as a boy. And as I moved to the United States and recognized I can actually spend time thinking about the details of what happens on a nano scale, that was remarkable to me. I think one of the first experiences, eye-opening experiences was, as an undergraduate, I helped put together one of the first atomic scanning tunneling microscopes that we had at Princeton.

And professor Antoine Kahn, who I worked as an undergrad in his lab, he let me participate and just let me help out. And what it was, I mean, what scanning tunneling microscope is is a really sharp needle that you can bring in the vicinity of a surface and image individual atoms with this very sharp people.

INTERVIEWER: Scanning--

BULOVIC: Tunneling microscope.

INTERVIEWER: Scanning and tunneling at the same time, OK.

BULOVIC: Yes. So the scanning simply means you're rastering the needle across the surface. Tunneling is this really cool thing we cover in 6.007, which is, electrons can jump through air from one surface to another if the gap between the two surfaces is very, very small. And the jumping through the air allows you to-- so if I put some positive voltage on the tip that's scanning a negative voltage on my surface, I can have electrons jump from the surface to the tip, as they like to go to the more positive end. And I can observe when is it that I see current.

If my tip is very close to the surface, I will see the current. If my tip is far away from the surface, I will not see the current of electrons jumping, because the gap is too big. So what I can do is, if I can control the motion of my tip, I can tell you exactly how the texture of the surface looks, when it has the bumps, and when it has the valleys. And if I can do that, and I can do it with enough accuracy, what's been shown in 1980s is that you can do it with the accuracy of seeing individual atoms.

So to me, that was mind-blowing. You can actually see individual atoms. Before that, it was all hypothetical. And now the mystery becomes like, well, what happens when I put another atom on top of these atoms? What's going to-- It's easy to get hooked. If you can recognize that it is not mysterious, it is not something far out there, it's right here in front of you, and you can press a button or move a needle and actually see another atom, it becomes real. And before that, it was just a picture in some textbook.

INTERVIEWER: You mentioned coming to America. Where were you born?

BULOVIC: I was born in Belgrade, Yugoslavia, now Serbia. I got here in 1984, and I finished high school in the United States, and then started college and graduate school.

INTERVIEWER: You were involved with Princeton and Columbia both, yeah?

BULOVIC: I was. I was at Princeton as an undergraduate. I went to Columbia, stayed for a couple of years, and then got my Master's degree, and then decided to come back to Princeton to complete my PhD degree. And every one of those places I had one of those-- every experience is a set of chances and circumstances. And in a similar fashion, my own journey was very much luck of being surrounded by brilliant people and being surrounded by tremendous opportunities and recognizing that I could go ahead and try out some stuff.

INTERVIEWER: Those are both New York City-central areas. Was it difficult to leave the center of the universe when you came here to Boston?

BULOVIC: No, no, no. New York is a very, very, very busy place. When I moved in to my Columbia housing, I mean, you deal with little bugs and cockroaches and stuff. That's OK. That's all right. But it's a very lonely city, unless you have a circle of friends to actually go to. So I found myself very much, again, focused on my laboratory and finding the community of people around there. New York can be very distracting. It can pull you in very many, many different directions, but that is not necessarily the best thing to do as you're thinking about the world.

And I get plenty of inspiration just talking to my students in my lab. I don't find myself needing to stimulate myself by yet another amazing experience in New York. You do those whenever you want to go to an opera or you want to go to a play, but that's once in a while. You don't need to live in a city for that.

INTERVIEWER: True, true. So how about your kids, are they into science? And do you want them to be?

BULOVIC: I don't want to influence the way they eventually turn out. I want to make sure I give them all the chances that they choose to take.

INTERVIEWER: How many children do you have?

BULOVIC: I have four.

INTERVIEWER: And what are their ages?

BULOVIC: Well, my youngest is six. I have a six, eight, 10, and 12, easy to remember. I started with a girl, then there was a boy, girl, and a boy. So we have a bit of everything, which is wonderful. It's just wonderful to see the dynamic between them, as friends, as colleagues, as people who teach each other.

This morning I was-- well, I get excited about math and science in general, just like applied math. So this morning, I was in my elementary school that my kids go to. I do it on Wednesdays. I go in the third grade, because I have a third-grader, I have a fifth-grader. So Wednesday, I was, for example, teaching, and what I do is I show up, I have a little PowerPoint presentation.

And the PowerPoint presentation can be about anything, so we did calendars, and we learned that if you take the 4th of April, the 6th of June, the 8th of August, the 10th of October, and the 12th of December-- so 4, 4, 6, 6, 8, 8, 10, 10, and 12, 12 on a calendar-- all those happen to be Monday in 2011. Add to that 9, 5, 5, 9, 7, 11, 11, 7. All those also happen to be Mondays, and the 0th of March, the last day of February.

So now you can ask me day of the year, and I can tell you what day of the week was that particular day of the year, because I have a crutch for every one of the--

INTERVIEWER: And then you could interpolate between.

BULOVIC: And you can. And you know what, these are third-graders, and the whole point of showing them that is to then ask them to do addition, to ask them to tell me, since the 12th of December is a Monday, well, what's the 19th of December? Hm, oh, it's a Monday too. Well, how do you do that? Or to ask them, April has 30 days, and what if it rains? What if it rains two inches of rain every one of those days? How much rain would it be? Or what if you slept for eight hours every day, how many days in April did you sleep? I mean, it's all about very simple things, but it tells them that they can actually use the math in very practical ways.

So the reason why I'm telling you that story is that, after my 10 minutes of doing a little PowerPoint-- and it has to be a penguin or a piece of cheese or an exploding pumpkin. It has to be something to draw them into the story. You give them little worksheets. And again, my wife does a brilliant job in putting together these stories about fairies or knights or pirates that are all based on the theme we just covered. A pirate wants to find the treasure, but he can only find the Tuesdays of this week.

That being said, we ask, well, let's do the worksheets. And then I can, by looking at my fifth-grader, who sits next to my third-grader, and he goes ahead and asks her questions so she can answer it as he tries to tutor her through it, now that's a joy, seeing that happen, seeing that exchange, recognizing they actually care about these few little things I tell them. It can be anything. It doesn't have to be math. It doesn't have to be science.

I just want them to be passionate about the next thing they do. And they're beautiful artists. They draw beautiful pictures. And if that's what they want to do, that's what they should do. They're awesome at writing stuff. Again, that's what excites me about my kids.

INTERVIEWER: So how often do you teach at the elementary school?

BULOVIC: Well, I go about every week. So every Wednesday morning is third grade this year. And every Friday morning is the fifth grade.

INTERVIEWER: Have you had days where you've gone from third-graders to fifth-graders, up the scale?

BULOVIC: Well, yes. I do remember, maybe a year, year and a half ago, I started with a fourth grade math morning, followed by probably another graduate class, followed by, I think I gave a talk to the graduate students. And then in the afternoon, I was asked to give a talk to the MIT Corporation. So it was wonderful to start by the inspirational talk to the very youngest, and then end up recognizing that the most important talk of the whole day, yes, I enjoyed very much talking to the Corporation, but the most important talk of the whole day, I think, was that very first one, where I was trying to do my very best to inspire those fourth-graders into saying, ah, science is really cool, or math is really cool, where the world around me can actually be quantified and measured in some way.

INTERVIEWER: So thinking about kids maybe is a good transition to thinking about the future. And so I have a few questions about the future, and I want to start with the future that used to be. So my question is, look, it's almost 2012, where is my solar-powered house?

BULOVIC: Oh, just wait a few more years. I mean, it's coming, it's coming. Really. No, really.

INTERVIEWER: We'll come to the artificial leaf?

[LAUGHTER]

BULOVIC: So it is not that far away, actually. The remarkable thing about solar technology, generally speaking, it has taken a remarkably fast path in being more and more affordable. And we are still-- and we because I'm a scientist that works or a technologist that works in that area. We are maybe still a factor of two or three away from being practically applicable. And you can say, well, that maybe is a little too long. Well, it'll take, I don't know, five, six years to reach cost parity with an average price of electricity.

But even today, it makes a lot of sense to install solar, if you're willing to wait for payback. And the best way to put it is that, if you look at the cost of electricity in the United States, in North Dakota, it's less than $.05 a kilowatt hour. If you happen to be an industry who's spending the electricity simply because all the coal fields are there, coal-burning power plants are there, it's easy. If you are in Hawaii, it's $0.26 a kilowatt hour, because you need to burn petroleum, because there is no coal, there is no natural gas. The easiest thing to do is to burn petroleum.

Well, I would like to replace all of that with solar or wind or something renewable so I don't spoil the planet. Wonderful, but I can't, because I mentioned before, it's going to take about 10, 11 years of deployment of solar if I can pave them as fast as roads-- and I don't quite know how to do that yet-- to reach 10 percent of the electricity needs of US.

Well, if that's the case, I can say, well, all right, can I go beyond 10 perfect one day? Well, I can't without batteries. If I don't have a way to store the sun energy, I can't really go ahead and go beyond 10 percent, because I'll destabilize the grid. I need electricity at night, and the only way I can get that is by burning either coal or natural gas today. Hydro, nuclear is an option as well. But coal and natural gas in the US is the primary source.

So I need those batteries. And without those batteries, 10 percent really is my ceiling where I want to be. Good. So my goal is to replace 10 percent of US electricity with solar. I do not need to be at the cost level of North Dakota, because there are places in the US that are paying a lot more than that. And those are the places I should really aim for-- California, some places in northeast.

If I can be at about $0.14 a kilowatt power, I can reach 10 percent of US electricity needs. And I can say, how can I make a solar cell that's $0.14 a kilowatt hour? And then you start getting into economics, and you start realizing very simple things, like, well, the guy who reads the meter and gets me the bill, he needs about $0.03 of those $0.14 a kilowatt hour for distribution. That leaves me $0.11.

I'm going to make a really good solar cell, though, so maybe I can make it. So out of $0.11, how much of it will be to the installer guy who actually needs to mount this on my roof, or put it in the field and wire it? He actually needs about a little more than half of my remaining $0.11. Oh, I'll give him $0.06. So he gets $0.06 a kilowatt hour. I have $0.05 a kilowatt hour left for me to do my magic in the lab and build me my solar cell.

How much this is that per meter square or yard square? So per meter square, how much does that come out to? Well, that depends, because I don't have the money to really invest in it, so I need to borrow it from a banker. Oh, but the banker will lend me the money either at a six percent interest rate if I'm really good, or more realistically, historically it's 10 percent interest rate. Ooh, so $0.05 a kilowatt hour, 6 percent interest rates, how much money is that? About $100 to make a meter square solar cell.

How about if he lends it to me, a little more realistically, at 10 percent interest rate? $60, that's all I have. To make my solar cell that's a meter square, how much is a piece of glass? I have only $60 as my budget. $20 is a piece of glass. Oh, I need two pieces of glass. That's $40 just for two pieces of glass.

I'm left with $20 to do all my magic. And you know what, I need to pay someone to do it. He'll take at least $10 for salary per meter squared, so I'm left with about $10 to make a meter square of a nanostructured large-quality device. That's really, really hard. That's nearly impossible. But we do manage.

I mean, there are companies that can do that today. First Solar can do it with cadmum telluride thin films, nanostructure, it's goo that gets put down. It's not scalable, because there's not enough tellurium in the world to really meet the needs. So we need different technologies.

And so, looking at these kinds of thinkings, we realize, well, maybe that's not necessarily the right way to think about it. Maybe the way to think about it is to say, if I look at what's most expensive in this whole business, it's installation, among other things. Installation costs a lot. Well, why does it cost so much to install something? Well, maybe because it's heavy. Maybe because someone needs to carry it and put it down. And indeed, actually, if I give you a 2x4 foot solar cell, it's a good 40 pounds in weight. And labor laws say that anything installed repetitively shouldn't be heavier than 50 pounds.

So I can't make them bigger than 2x4, because if I could, I'd make a really big one and just unroll it, because if I can do that, I can reduce installation. All I would need to do is just staple this thing to the roof, whole job done. Prefabricated stuff, like prefab homes, cost half as much as homes built in a field. So this is one way to really cut the cost of solar down.

All right, so I'll make it rollable. Well, if I can do that, what kind of substrate would I use? What kind of surface would I put this on? Well, maybe paper, maybe silicon foils, maybe aluminum foils. Oh, every one of these I just mentioned, plastics, they can't sustain high temperatures needed to make a good solar cell. So I can't do solar cells, unless I can invent a new type of solar cell that can go on top of it.

How about solar cell made of molecules, quantum dots, polymers? You can take raspberry juice and a little bit of titanium dioxide, the stuff from suntan lotion, you can make a solar cell.

INTERVIEWER: Raspberry juice and suntan lotion?

BULOVIC: Yes, there's a website that I can refer you to. They actually do this. There are a variety of things like that. I'm making a class I should teach in the spring called Nanomaker, that we tried it this semester with freshman. I teach freshman seminar. And it worked great. Katey Lo, a post-doc, developed it, together with, again, Rajeev Ram and another post-doc, Joe Summers.

And it's great, because we use face paint to make LEDs, raspberry juice to make solar cells. But to come back to solar cells, you can imagine using a variety of very simple things, car paints. One of the first organic thin-film solar cells was made using essentially a red car paint and a blue car paint. And you evaporates these molecules, and you get large-area coverage, and it's extremely cheap from that perspective. But more powerfully, it's room-temperature processed, so you put it on any surface without ever having to use high-temperature steps.

So working with Karen Gleason from chemical engineering, she developed a way to use chemical vapor deposition to coat paper with electrically conductive material. And what we do then is take that conductive paper, take it to my lab, evaporate my red car paint and blue car paint, evaporate the top electrode, and make a solar cell that's on paper. That's all it is. It's a little solar cell paper.

Earlier this year, we've chosen the right kind of materials, like in molecules, that do not absorb any of the visible light. They only absorb infrared and UV light, but nothing invisible. And we made solar cells out of those. And how'd they look? They look like nothing. They are transparent. They look like pieces of glass.

INTERVIEWER: I think I've seen this on the web. And this is a company you're thinking of rolling out which is basically just a transparent sheet you put on the windshield. What's the progress of that? When can I buy that at Home Depot?

BULOVIC: Give it a few years. Any idea made in the lab-- and we demonstrated this the first time in March this year. Any idea made in the lab takes typically three to five to 10 years to commercialize.

INTERVIEWER: So I'm afraid of running out of time. And I want to bring it back to MIT, but before I do, all of these things, it makes me think about this idea that, at least when I was young, they used to say, 90 percent of all the scientists that have ever lived are alive today, because of the scientific revolution and the explosion of the population. And we have this huge explosion of technology that we're living through.

And it seems like there are two schools of thought. One is that all of these wonderful inventions are going to save us and bring forward a new age of humanity that's much better than we have now, and one is that we're not going to get there because all the other things that we're inventing and using and despoiling are going to send us to our doom. And I wonder how you feel about the role of technology and the struggle between scarcity and post-scarcity, the boom. Sometimes they call us the boomsters versus the doomsters.

BULOVIC: Ooh, ah, I like that. I haven't heard it that way, but I like that. Well, we could go back to not thinking about things. We can just sit down and go back to where we used to be. The invention of food supply improvements, crops that bear more fruits, was in some ways what saved the humanity and allowed us to grow to as big as we are now. So advances in agriculture, fantastic, but that came from science.

I think anything that we do, you can use or misuse. And at the end, what we need to do is recognize what are the true challenges. I think, often, even when you look at the world of solar and you say, solar cells will save the planet from warming, I'll challenge that, because I'll say, you know the desert? That desert reflects 40 percent of the incoming light, just by itself. And maybe even 60 percent of incoming light gets reflected off the desert. I'm going to take my solar cell and put it in it, and I'll absorb 90 percent of the incoming light, and 10 percent of that will be, indeed, electricity. But the other 80 percent will warm up the desert twice as much than it would have gotten warmed up if I just left it alone without putting solar cells in it.

So I mean, that sounds like solar cells would just doom the world to overheating. Yeah, true, unless I put aluminum foil around my solar cells to compensate for the reflectivity, and hence have simply highly reflective areas that reflect that energy back, and areas that will absorb the light that will be my solar cell. One option. Other option is deploy the solar cell over oceans, or use the dead zones of the ocean so you don't kill any fish. But you can look at all the dead zones of the ocean.

There are a lot of very simple things you can do that make a huge difference. Secretary Chu of DOE was suggesting, you know, one really big thing for us to do as a country would be to paint our roofs white. Absolutely. I put my students a very simple question. I say, is there anything we can do to save the planet from overheating?

Well, we can. We can take aluminum foil and make rafts and put them on the ocean surfaces-- again, over the dead zones. And you can balance energy and energy out just simply that way. Oceans are 90 percent absorbing incoming light. Aluminum foil is 88 percent reflective. Cover enough, in 50 years, you can produce enough aluminum foil to cover enough of the ocean to balance the present misbalance of the energy in and energy out, as an example.

I mean, there are very many different ways to promote a technology, but I feel like, the doom versus boom, it's all about having the cognizance and awareness of what the big challenges are. And the best we can do as educators is point to students what the big challenges are, and they'll come up with solutions.

INTERVIEWER: As you've been talking about, in translating it into action is as hard as coming up the technology, or harder. You do this at MIT. You have an energy-efficiency project. You have classes that basically change, in some way, the infrastructure at MIT almost every year. So how does that work with the administration? We've got a really smart microcosmic example of what change is like. I imagine that would be difficult in any organization.

BULOVIC: Well, I don't run MIT. But but I had the privilege of being involved in whole bunches of ways with MIT changing itself, especially in the energy area, starting with the Energy Initiative. I was one of the young faculty who was asked to participate in the Energy Research Council that formed what's now known as MITEI. But in that discussions, one of the things we very quickly realized is that, every university teaches, every university offers classes. And we are good, Stanford is good, so are dozens of other really good universities. So we can't distinguish ourselves that way, by saying that we're doing something special. We are just contributing to the common knowledge.

In the same way, you can say we have really smart students, just like any other university does. So what is it we can do that can truly make a difference? And we came up with what is now known as the Walk the Talk taskforce of the MIT Energy Initiative, where if we're going to actually tell our students what needs to be done, why not just let them do it? And again, the brilliance of our campus is that we don't have a particularly beautiful campus. There's some really pretty places. Killian Court is gorgeous. But most of the campus today is somewhat old, especially the buildings built in the '60s, '50s, '40s.

It wouldn't hurt that much if we chose to install solar collectors, if we chose to install new LED lights, if we chose for students to evaluate the performance of campus and make suggestions on what can be done. Use campus as your lab, and in that way, try to improve it. Now, we can't let students run helter skelter. So we have an amazing facilities department here, actually, facilities that for the first time that I've ever observed. Well, in many ways, I don't think many of us appreciate them, because I walk in my office expecting my lights to turn on, my heat to be on, expecting that I have all the commodities that they provide and I just take for granted.

So they, on the other hand, recognize that there's this humongous intellectual capital we have on campus, and we have figured out a way to connect facilities with academics, allowing us to run classes, essentially projects, where students can go ahead and try out stuff, figure out that a chemical hood in a chemistry lab, if you leave the sash open, the amount of energy that is sucked out, the warm air from the lab that's sucked up the chimney and that you need to replenish by warming up cold air from the outside, that amount of energy, just single hood, is comparable, I think, to about two, or is it four, household energy uses in New England. So leave the sash down after you're done using your hood is the message.

And so we went to-- I didn't go. My colleague, Leon Glicksman, led this with undergrads. And they went to the chemistry department chair and pointed this out. The chemistry department chair, with his brilliance, said, we'll have a local competition. We'll measure the energy use of each hood, and the lab that uses the least energy because they leave their sashes down after they're done will get, I don't know, sandwiches or pizza, whatever it is. But it saved a lot of energy in the process, and hence recognized that action, local action, can make a lot of difference, or just simply local awareness of your actions can make a huge amount of difference.

INTERVIEWER: Turning this now a little to the social aspect of life at MIT, MIT can be a very intense place. We've lost two undergrads this year to suicide. And I wonder if you have any thoughts about why that is, or how you combat this kind of high-stakes game that the students sometimes find themselves playing, where personal worth is wrapped up with academic achievement. Or I don't know what it is. I mean, you would know better than me.

BULOVIC: Well, no, I think you voiced it quite well. I'm not a psychologist, so I don't understand this. I mean, I have my little notions of why the world is the way it is, and it's extremely unfortunate whenever anyone dies, especially a young student. I think the world we live in puts a great deal of pressure on students. And maybe more and more what I see is that students come to MIT, receive their education as what I like to say as bingo sheets. There is a bunch of boxes you need to get checked off.

So I need to have two sports, seven AP classes. I need to have a debating team, and I need to be a straight-A student. So check, check, check, check, check. I do that, I'll move to the next stage, which will be called a graduate school. I'll be there for five years. I go check, check, check, check check. And then I'll be able to live a life and have a good salary.

And that's not what life is. I mean, life is, especially when you come here, when you get to the graduate experience, certainly, it's a sense of discovery. You need to find out what is it that you're good at. And how can you really change the world? Grades do not matter in the graduate experience.

On the undergrad end, the one thing that we do have, both as a challenge and as a benefit, is that we have students that are all similar in some ways. I mean, they're all highly motivated, highly motivated to do stuff, to use their hands, to make things. I guess I have this little thinking. I'm thinking, when I was an undergrad at Princeton, my electrical engineering class was 20 students. And every year, there will be another 20 that come in.

So let's imagine it's 1 percent of all the students that go to Princeton, MIT, Caltech, Harvard, these top-tier schools, as I've understood, let's imagine 1 percent of them are just truly out of this world, just true brilliant people like you've never seen before. Well, at Princeton, you'll see one of those guys every five years. And it'll be an oddity. They'll be someone that you haven't had a chance to really see except maybe. They will be the standard.

MIT, introductory class, chemistry, bio, physics, electrical engineering has a few hundred students, 300, 400, 500 students sometimes. In that class, there are three or four of those truly outstanding people. They set the norm for the rest of us. And as a consequence of it, well, I feel a little diminished.

Although I might be a very good student, and I'm surrounded by peers who are really good students, all of us don't feel like we're living up to the potential we should be at, as opposed to simply recognizing that we are really good, we are here already. I mean, for goodness sake, you made it into MIT, and it's an amazingly good place to be at for point of view of being, one, surrounded by peers who are really smart, you can learn a lot from; two, the opportunities, especially hands-on research opportunities that are truly second to none.

And anything you do will be good enough when it comes the time to leave this place, will be good enough to get you to be really, really productive in the world outside. At the end, that is what matters, rather than comparison of, you know, I got this C here, or I got the B+ here. That's not going to change the world, your little B+. What's going to change the world if you're missing, so that we can't have your contribution down the line when we really, really need you?

So yeah, I mean, I feel like that message, I do mention it once in a while to my students, just to emphasize that it's also really good to fail once in a while, just to get a sense of what it means to not live up to the standard you aspire to. And many of the students here never failed. They are very, very, very good at what they do, and once they come over and recognize that they're just average compared to their peers, that's a fairly unsettling experience. So I do not know how to teach people how to fail, but maybe it's the thing we need to emphasize more and encourage. Maybe since it's pass/fail the first semester, maybe we should encourage them to try to fail one class and see how it feels. I mean, I know.

INTERVIEWER: Do your job, try to fail.

BULOVIC: Yes.

INTERVIEWER: Yeah, that's very good. So maybe that's the answer. I was going to ask you, if there's one thing you could change about MIT, what would it be?

BULOVIC: I'm not sure I would change anything about MIT. I mean, I feel like the amazing thing about MIT is the flexibility, that it can adapt to the change of circumstances, to the needs of people. We are surrounded by brilliance in so many ways, understated brilliance, which makes it that much more comfortable to be around. Yeah, I guess the one thing I would change is, if I could avoid stress on students, I would do it if I knew how to. And maybe all we need to do as faculty is to keep repeating it, telling them that it's good enough that you're here. Don't be lazy. Don't be a slacker. Have a good time. But at the same time, don't be stressed about it.

INTERVIEWER: That's great. My last question is a fill-in-the-blank. And it's, MIT is--

[LAUGHTER]

BULOVIC: After what I just said, extraordinary, in so many ways.

INTERVIEWER: Just do it in a sentence for me, just for fun.

BULOVIC: Sure. Well, MIT is a hubbub of ideas and innovation. I think MIT is the place that will redefine of what tomorrow will bring.