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Majumdar puts materials in the context of energy systems

Interviewed by **Anke Weidenkaff**

Four years ago, the US government launched an agency that would transform the country's landscape of energy. Focusing on high-risk research that would radically change the way energy is produced, stored, and distributed, the Advanced Research Projects Agency-Energy, under the direction of materials scientist Arun Majumdar, funded over 275 projects. By the time of his departure in 2012 for the position of vice president for energy at Google, Majumdar saw many of these funded projects lead to start-up companies. *MRS Bulletin* caught up with Majumdar at the 2013 Materials Research Society Spring Meeting. Interviewed on the stage where he would next give his plenary address on the new industrial revolution for sustainable energy, Majumdar said of his time as director, "What makes me proud is the fact that we enabled a lot of pioneers."

***MRS BULLETIN:* From your experience in ARPA-E, what are the most impactful consequences of the shale gas revolution**?

ARUN MAJUMDAR: I know there's a lot of euphoria about the abundance of shale gas, which is understandable; however, we must also be aware that there is uncertainty or error bars about the known reserves and the changes in production rate over time from the wells. The price of wholesale natural gas is really low, which is not sustainable in the long run. With the abundance and low price of natural gas and the high efficiency of the natural gas combined cycle engines, it is the cheapest way to produce electricity at about 5 cents/kWh. Natural gas as an inexpensive feedstock is also triggering the petrochemical manufacturing industry, which is good for our economy.

The transportation sector is also being affected. Private companies are installing liquid natural gas (LNG) refueling stations every 200 miles or so on major trucking routes, and long-haul trucking companies are transitioning to to replace diesel tanks with onboard LNG storage systems. They're doing so for business reasons; the payback period for any additional cost is about 2–3 years for both LNG refueling stations and the trucks. For passenger cars, the key question is can we store enough compressed natural gas (CNG) for a range of 200 miles or so, at a sufficiently low additional cost so that it pays back in about five years? ARPA-E started a program called MOVE—Methane Opportunities for Vehicular Energy—to create technologies to reduce the cost of natural gas storage in the form factor required for light-duty vehicles so that you can refuel at home, because the infrastructure to create CNG refueling stations is very expensive. We have about 160,000 gasoline stations around the country, and to create a similar infrastructure for CNG would cost about a hundred billion dollars. If you make it economically viable to fill at home in a way that would meet your cost reduction and storage needs, then you bypass the infrastructure problem. However, one should not lose sight of the fact that there could be leakage of natural gas, not just in production but in pipelines and distribution and use at the endpoints. Some studies say it is less than 2%, some say it's 9%. I think the jury's still out, but it's fair to say that if it's more than 3% or 4%, it could have a worse effect on greenhouse gas emissions than the CO_2 that it saves.

What are the most impactful opportunities for energy storage?

There are two kinds of storage: one is the transportation side where energy density does matter, and the stationary side where it is perhaps not as much of an issue. I want to mention significant innovation that is happening on the stationary side, which doesn't get much press. We're seeing elements of the whole class of metal–air batteries to make them rechargeable, reliable, and to increase their calendar and cycle life. Some of the innovations are enabling grid-level storage overseas where power is not as reliable, but we'll see some of that happen in the United States as well. We need researchers to develop the technologies that would reduce cost, and that needs system-level thinking: it's not just materials. Materials in the context of systems is really what the issue is.

Which of the ARPA-E initiatives has been the most successful?

I feel it is too early to expect homeruns from ARPA-E. I prefer to focus on research areas and programs rather than on specific projects. For example, we launched a new program to create nonphotosynthetic routes to make biofuels, which was completely new and there were doubts whether it was even possible within 2–3 years. However, researchers showed that this was indeed possible and thereby launched an entirely new way of making biofuels. On the question of air conditioning, we launched a program to reduce the energy consumption by a factor of two, which is a really big deal and needs new materials that would separate humidity control and temperature control. Wide-bandgap

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semiconductors enable efficient high-frequency switching for power electronics, and when integrated with low-loss soft magnets that operate at these frequencies, the combination would reduce size and cost and increase efficiency of switching power conversion devices and systems. These are the kinds of opportunities that I think are very promising, but it's too early to say which specific projects are going to be successful.

What are the most successful ARPA-E examples of energy efficient innovations?
For light-emitting diodes (LEDs), for example, one of the significant costs is not the LED itself, but the drivers and the packaging associated with it. A key reliability challenge is the use of electrolytic capacitors that are used in these drivers. If we can use high-frequency switches using wide-bandgap transitors, we could then potentially use solid-state capacitors and all integrated on a single chip. The single-chip integration solution is going to be more reliable, cheaper, and longer lasting. That's the kind of thing that we are going to see in the next several years. In buildings, we are likely to see much more efficient cooling systems based on what I talked about earlier. However, in the building sector, technology is necessary but not sufficient. The challenge in the building side is how to introduce that in the actual market. We may need some regulatory signals, such as appliance standards, to introduce that.

Does energy research require a longer time frame than other research sectors to get innovations?
Sure, because the energy sector from innovation in the laboratory to market penetration takes, realistically, 15 to 20 years. It is all about cost and scale—a technology has to scale down in cost and scale up in volume. If it does not, it will never be used. This is not software that you can distribute via the Internet to everyone. Some of it will need large-scale volumes. This is going to take time, and some of it is going to be capital-intensive.

What is the biggest energy challenge facing the United States, and how does it differ from that of the world as a whole?
The global challenge is how do you transition to a new industrial revolution that is sustainable in the long run? In the United States, we already have a developed economy with a grid that needs to be modernized. Parts of the world where a significant population growth is going to happen, who have either no or very limited access to electricity, face a completely different problem. Do you want to extrapolate the 20th century grid of today for them? Probably not; you may want to start off with a clean sheet. In the United States, we had invested significantly in nuclear, and we need do so again if we are to address our climate issues on the electricity sector. In transportation, today we have only one option—using gasoline or diesel as the fuel—and thereby we face future vulnerability if do not diversify our fuel source. In many cases, the developing economies of the world offer the opportunity to leapfrog and start something new that the United States does not allow because of our legacy systems.

Electricity is often touted as the most versatile, clean, and sustainable energy carrier for the future. What are the most pressing needs in this area?
Electricity is clean as long as it is produced in a clean way. In terms of a "smart grid," what we've done so far is to measure various attributes of electrical power via smart meters at end uses and via phasor measurement units in our transmission systems. The end use information is now starting to be used for demand response to shave off some of the electricity demand peaks. What we really want at the end is to have both demand and supply response in an automated way and in real time, which will likely reduce the cost of electricity as well. Furthermore, how do you build security into the system in such a way that it is resilient against malware? The third aspect is that the greatest challenge for renewables is going to be not the cost—wind is already cheaper than coal today—but how do you integrate intermittent sources onto the grid that allow higher capacity utilization and penetration.

Google has invested more than $915 million in the renewable energy sector. How does Google's approach to energy differ from the ARPA-E approach?
ARPA-E is a government agency to create and stimulate innovation in energy technologies. ARPA-E is not in the business of making money, but rather to invest in research that will lead to US competitiveness and a technological lead in the future. Google is a private company, and the investment that you pointed out is not for charity, but rather to get returns. Google's philosophy is to do good for the world and make money at the same time. □