Dr. Arun Majumdar, ARPA-E Director, Talks About Our Nation's Energy Future

IN THE SPOTLIGHT for this issue of *Currents* is Dr. Arun Majumdar, Director of \the Advanced Research Projects Agency—Energy (ARPA-E). On 12 August 2011, Kenneth Hess from the public affairs staff at the Chief of Naval Operations Energy and Environmental Readiness Division (N45) conducted this interview with Dr. Majumdar as he spoke about ARPA-E's top priorities, current work, and interactions with the Navy and Department of Defense (DoD).

CURRENTS: Thank you for taking time to talk to us today. Could you tell us a little bit about your background?

DR. MAJUMDAR: Before I came to the Department of Energy (DoE) and ARPA-E, I was a professor of mechanical engineering and materials science and engineering at University of California Berkeley. My Ph.D. is in mechanical engineering and engineering in general. I was also head of the Environmental Energy Technologies Division at the Berkeley National Laboratory.

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I have been very fortunate to receive funding from the Navy during my research career. I was involved with two Multi-disciplinary University Research Initiatives (MURI) that were funded by the Office of Naval Research.

My background spans the physical sciences, engineering and energy. I've worked in the biological sciences on projects that were funded by the National Institutes of Health. So my science and engineering research and development background includes a lot of areas—more recently the area of nanoscale science and engineering. The last 30 years of my career has concentrated on power systems, power/energy generation, energy and efficiency. I am also a member of the National Academy of Engineering.

CURRENTS: Tell us about ARPA-E. What is your organization's mission and vision?

MAJUMDAR: Our mission is to focus on research and development for transformational technologies, to translate science into breakthrough technologies that will provide the energy and economic security for the nation and protect our technological lead. We seek to reduce greenhouse gas emissions and increase the efficiency of our entire energy sector, as well as reduce our imports of energy. Our vision is to change the world, and make the U.S. globally competitive in energy technology.

ARPA-E is in many ways operationally modeled after the Defense Advanced Research Projects Agency (DARPA). If you recall the history of DARPA, it was created in 1958 in response to the launch of Sputnik when it was felt that the U.S. was losing its technological lead to the Soviets. At that point, we needed some quantum leaps in technology and a group that would take high risks with the potential for high reward. And of course, as we know, out of this came many interesting technologies including stealth technologies. So, as the president said, we are in a Sputnik-like moment right now and that has to do with our clean energy future. We are in a globally competitive landscape. Other nations are playing by our playbook and taking the lead. ARPA-E's role is to "out innovate." That's what we are doing.

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CURRENTS: Talk about some of your priorities for ARPA-E.

MAJUMDAR: Well, we are still relatively new—just two years old. Our number one priority right now is to recruit talent. It is extremely important that we have the right kind of people here, to get the right value system in this organization so that we can achieve excellence in everything we do. We need to invest in ideas that are potentially transformational, to take enough risks, and in many cases, celebrate some failures. It's actually a good thing sometimes to fail and quickly learn from it.

The value system that we are creating in the energy sector is very different from the value system in the defense sector. And that's the difference between ARPA-E and DARPA. We are very closely connected to the private sector, because that's where the energy economies are huge. We want to create value for the nation, the private sector, and the military. So bringing in really talented people is very important. We need to create a culture to generate ideas that are not shy, not conservative. We are interested in taking the risky approach—not just for the sake of risk, but for a potentially high impact. That's what's going into creating this organization, in many ways from scratch, and having it connect with all the stakeholders in the right places including Congress and the White House.

CURRENTS: Let's talk about some of the ARPA-E projects that you see as having potential for transforming our nation's use of energy.

MAJUMDAR: That's like asking which of my children I like the best. It's very hard to do. But let me just say a few things that perhaps would be relevant for the Navy. We have invested a lot in storage—I'm talking about quantum leaps in battery technology—both mobile batteries, where weight is really important, as well as stationary battery systems that can store large amounts of energy for a long time in stationary systems (like the electrical grid). This has many implications for reducing our fuel consumption,

Non-photosynthetic fuel production is potentially a quantum leap in fuel synthesis.

whether it's generating electricity or changing how we use our energy. Storage turns out to be a really important factor in saving energy. Hybridization is an example, as we see in hybrid vehicles. Hybridization really increases the mileage and reduces fuel consumption.

Storage is a basic technology where there is a lot of room for improvement in both performance and reducing costs. Cost is a very important aspect in what we do. Our goal is to create technologies that make clean energy cheaper than traditional forms of energy. We often don't invest in technologies that are seemingly wonderful but just too expensive. It wouldn't matter in the real world.

We're also looking at new ways of synthesizing fuel. Today, most of the biofuels that we know of are photosynthetic-based—plant-based or algae-based—converting light into some sort of chemical bond using photosynthesis.

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The Basics about ARPA-E

RECOGNIZING THE NEED to reevaluate the way the United States spurs innovation, the National Academies of Sciences (NAS) released a 2006 report, "Rising Above the Gathering Storm," that included the recommendation to establish ARPA-E within DoE. The America Creating Opportunities to Meaningfully Promote Excellence in Technology (America COMPETES) Act, signed into law in August of 2007, codified many of the recommendations in the NAS report. Authorized but without an initial budget, ARPA-E received $400 million funding in April 2009 through the American Recovery and Reinvestment Act. In December 2010, Congress reauthorized the America COMPETES Act. ARPA-E is modeled after DARPA–the agency responsible for technological innovations such as the Internet and the stealth technology found in the F117A and other modern fighter aircraft. Specifically, ARPA-E was established and charged with the following objectives:

1. To bring a freshness, excitement, and sense of mission to energy research that will attract many of the U.S.'s best and brightest minds–those of experienced scientists and engineers, and, especially, those of students and young researchers, including persons in the entrepreneurial world
2. To focus on creative "out-of-the-box" transformational energy research that industry by itself cannot or will not support due to its high risk but where success would provide dramatic benefits for the nation

3. To utilize an ARPA-like organization that is flat, nimble, and sparse, capable of sustaining for long periods of time those projects whose promise remains real, while phasing out programs that do not prove to be as promising as anticipated
4. To create a new tool to bridge the gap between basic energy research and development/industrial innovation

For more information about ARPA-E, visit http://arpa-e.energy.gov.

More Insights Into ARPA-E's Programs

ARPA-E PROGRAMS EXPLORE creative "outside-the-box" technologies that promise genuine transformation in the ways we generate, store and utilize energy. Unlike conventional DoE research, ARPA-E funds concepts that industry alone cannot support, but whose success would dramatically benefit the nation. Its high risk, high reward programs aim to substantially reduce foreign energy imports; cut energy-related greenhouse gas emissions; and improve efficiency across the energy spectrum.

ARPA-E is making investments in the following six program areas:

Better Energy Efficiency Through Innovative Thermodevices (BEETIT)

Residential and commercial buildings currently consume 40 percent of the primary energy consumed in the U.S., and they produce roughly 39 percent of total U.S. carbon dioxide emissions. Cooling is one of the major uses of energy in buildings, yet the basic approaches used for cooling have not changed in decades. New, more efficient methods of cooling represent a great opportunity to reduce energy consumption, especially from traditional refrigerants, from buildings. The 16 projects funded through the BEETIT program focus on developing new approaches and technologies for cooling equipment used in heating, ventilating, and air conditioning (HVAC) systems in our buildings, as well as in refrigeration. These projects aim to drastically improve energy efficiency in buildings at a cost comparable to current technologies. The technologies undergoing development in these projects are suitable for new building construction and can also be retrofitted into the existing cooling systems of legacy buildings, which will enable the U.S. to leverage its existing infrastructure.

Electrofuels

Liquid fuels are a ubiquitous component of the Nation's energy landscape. According to the U.S. Energy Information Administration, the U.S. will continue to rely on liquid fuels at a constant level for the next 20 years, even with the increased deployment of plug-in hybrids and electric vehicles. The U.S. transportation sector is almost exclusively reliant upon petroleum-derived liquid fuels, and this dependency comes with a large and increasing economic cost.

Domestically-produced biofuels increase the Nation's energy security, but there remains considerable need for next-generation renewable fuels that can be integrated into the Nation's current fuel refining and distribution infrastructure. Most of the methods for producing biofuels that are currently under development involve converting biomass or waste, or directly producing fuels from sunlight and carbon dioxide, but overall efficiencies from these approaches remain low. The 13 projects that comprise the Electrofuels program intend to explore new paradigms for the production of renewable liquid fuels that are compatible with today's infrastructure–using microorganisms to harness chemical or electrical energy to convert carbon dioxide into liquid fuels, without using petroleum or biomass.

Grid-scale Rampable Intermittent Dispatchable Storage (GRIDS)

The ability to store electricity and shift the power in time is becoming significantly more important as the U.S. increases its use of more eco-friendly renewable power. Renewable electricity generation is most commonly associated with wind and solar power, which when the sun stops shining or the wind stops blowing, is an intermittent and sometimes unreliable and undispatchable source of power. Storage allows energy producers, such as utility companies, to send excess electricity to storage devices. When wind and solar power ramps from available to unavailable or when electricity demand increases, energy can be taken from the storage devices and delivered to users that need it.

Today's electricity grid, the interconnected network that delivers electricity from suppliers to consumers, has virtually no storage. Those storage facilities that do exist use pumped hydropower, a system that pumps water uphill to a reservoir when excess electricity is available and then lets the water flow downhill through turbines to generate electricity when it is needed. While pumped hydropower storage works well on a cost effective basis in many cases, it can only be located in very limited areas of the country. The 12 projects that make up the GRIDS program seek to develop new energy storage technologies that are comparable in reliability and cost to pumped hydropower, and additionally, that are modular and can be deployed in any location in the country. These new technologies will enable the storage of electricity anywhere on the electricity grid

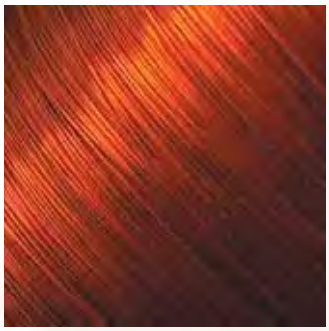
across the U.S., allowing extra energy to be transmitted to geographies that need it the most at any given time. This ability to store and dispatch electricity on a reliable basis will be a key enabler of renewable electricity generation at high penetration while maintaining high reliability in electric supply.

Batteries for Electrical Energy Storage in Transportation (BEEST)

The U.S. transportation sector is almost exclusively reliant upon petroleum-based fuels and this dependency comes with a large and increasing economic cost. The transportation sector is a major contributor to U.S. reliance on foreign oil and air pollution. One way to reduce the impact of these factors is for more people to drive cars that use electricity instead of gasoline, where the electricity is stored in large on-board rechargeable batteries. A major roadblock to realizing this goal is the battery itself. Batteries for plug-in hybrid electric vehicles (PHEV) and electric vehicles (EV) are currently limited to a range of fewer than 100 miles for normal light duty vehicles. This limitation causes "range anxiety" among many Americans and will likely slow EV adoption due to a fear that EVs cannot take them everywhere they want, when they want.

The ten projects that make up the BEEST program are developing batteries for PHEVs and EVs that can make a 300- to 500-mile-range electric car a reality. Successful development of these types of batteries will make PHEVs and EVs valuable to more people and could significantly reduce dependency on foreign oil for transportation. In this program, ARPA-E supports game-changing technologies that range from devices to double the minimum range of today's EV cars, to high risk lithium-air batteries that could allow a car to travel up to 500-miles on a single charge.

Agile Delivery of Electrical Power Technology (ADEPT)



The Office of Electricity Delivery and Energy Reliability, part of DOE, estimates that within the next two decades, 80 percent of the electricity used in the U.S. will flow through power electronics. Power electronics modify the form of electrical energy (i.e., change its voltage, current or frequency) and can be found in applications as diverse as solid-state lighting, intelligent motors, electric vehicles, and a smarter electricity grid. Deploying advanced power electronics could reduce electricity consumption up to 30 percent, or 12 percent of total U.S. energy use. Innovations in power electronics could significantly reduce costs, which would promote U.S. businesses through technological leadership.

ARPA-E's ADEPT program is focused primarily in two areas–creating the world's first kilovolt-scale integrated circuits, and developing transistor switches operating at grid-level voltages that would exceed 13 kilovolts. Bringing the integrated circuit revolution to power applications can improve the performance of nearly every type of electrical component while simultaneously redefining the manufacturing platform for power systems. The development of grid-scale discrete transistors has the potential to create an actively controlled electric power grid where transformers can be reconfigured dynamically. The 14 projects that make up the ADEPT program strive to reinvent the basic building blocks of circuits from transistors, inductors, transformers to capacitors for a broad spectrum of power applications.

Innovative Materials & Processes for Advanced Carbon Capture Technologies (IMPACCT)

Coal-fired power plants generate approximately 45 percent of electricity for the United States. While coal is a cheap and abundant natural resource, continued use of coal as an energy source will lead to increasing levels of greenhouse gases as carbon dioxide is released into the atmosphere. Capturing the emitted carbon dioxide and storing it would enable the continued use of domestic coal resources while reducing greenhouse gas emissions into the atmosphere. The primary challenge is the current cost of capturing carbon dioxide from a coal power plant, which is unacceptably high.

The IMPACCT program seeks to reduce the cost of carbon capture significantly through a combination of new materials, improvements to existing processes, and demonstration of new capture processes. Fifteen high-risk, high-reward projects are underway among a group of universities, businesses, and national laboratories. IMPACCT is pushing the boundaries of carbon capture research through technologies such as new liquid chemistries that dissolve carbon dioxide and a capture system inspired by jet engines that transforms carbon dioxide from a gas into pellets of dry ice. If successful, the IMPACCT program will provide options for the use of America's existing infrastructure without further increases in harmful greenhouse gas emissions.

For specific projects being funded in each of the above program areas, visit http://arpa-e.energy.gov/ProgramsProjects/Programs.aspx.

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We have invested in techniques that are non-photosynthetic—that are still using biology. This is a completely new route for making oil, and may be much more efficient than the photosynthetic approach. Efficiency is cost in this context. This is potentially a quantum leap in fuel synthesis.

CURRENTS: That is exciting. Give us an example of something that you're exploring in that regard.

MAJUMDAR: Sure. There are microbes that live in the deep vents in the ocean which do not have light but still survive. They use different kinds of energy. They grab energy from ions of magnesium or calcium or iron. They use energy from the electrons. They use energy from waste products of oil and natural gas like hydrogen sulfide. Hydrogen sulfide is the "sour" part of "sour crude." It's a waste product, but there's energy stored in the bonds. So if you can convert electricity from wind or nuclear into a liquid fuel for transportation, it doesn't need photosynthesis. There are microbes that live on electrodes. And so we are programming them to make oil.

We have had interactions with many parts of DoD, but our interactions with the Navy have been particularly strong.

There's some basic infrastructure in energy that could use some improvement. For example, power conversion. Electricity is moving at 300 kilovolts or 765 kilovolts, but the outlet in people's homes are at 110. That voltage conversion is very important, including the voltage conversion to go from 110 to AC or DC for our personal computers. There's a lot of opportunity in power efficiency using new kinds of power electronics that are missing from the landscape.

Today, all the transformers we buy for our grid are made overseas. These transformers are not that different from the first transformers invented by Nicola Tesla way back in the late 1800s. I think we can take a quantum leap in that technology. Energy efficiency in air conditioning also has not changed much since the days of Willis Carrier. (Note: Mr. Carrier is credited with inventing air conditioning in the early 1900s.) It has improved, but there's a lot of room for improvement. We have taken some very interesting, radical ideas. I think some of them might work out. Some will not. Some of them will potentially reduce the energy consumption of air conditioning by 50 percent—that is a big deal.

CURRENTS: You have definitely covered some technologies that would be of use to the Navy. That's going to be interesting to our readers. Are there any specific types of collaborations between ARPA-E and the Navy going on now, or areas you see as ripe for collaboration in the near future?

MC2 Cayman Santoro

MAJUMDAR: We have worked very closely with the Navy and DoD to develop some partnerships. One of my mentors in ARPA-E and DoE as a whole is the former Secretary of Defense William (Bill) Perry. He has seen it all in DoD since the days when DARPA was created. He is also the Chair of the Advisory Board for the Secretary of Energy. He has deeper involvement than just ARPA-E. He has enabled many interactions, not just with DoE but also with DoD. We

have had interactions with many parts of DoD, but our interactions with the Navy have been particularly strong.

We have a big summit every year. At this year's summit in March, Secretary Mabus—on behalf of DoD—announced a partnership on a project known as the Hybrid Energy Storage Module. The idea is that if you have power generation, whether it's a ship or a forward operating base, you have fuel being consumed to generate electricity. But if you were able to store the electricity, you could use your generator in a much more optimal way and increase efficiency and reduce fuel consumption. You can size the engine in the right way. So instead of using a big engine because you have a peak of electricity that you need only for a few minutes, you use a smaller engine so you use less fuel—and you use the battery to generate the extra power when you need it. That has implications not only in reducing fuel consumption but also in providing you a sudden burst of electricity when you need it—and you all could think about where that could be applicable.

I think we could be of value to the Navy in many ways, in making your applications much more energy-efficient and giving you new capabilities that perhaps you didn't have. At the same time, it helps us integrate the different components we are investing in—the breakthrough technologies in power electronics, generators. This partnership gives us a way to integrate those technologies into systems and deliver performance and capability. That is very useful to us. So I'm really looking forward to this partnership with DoD in general and the Navy in particular.

Innovations in energy are at the foundation for our national security.

CURRENTS: That's a piece our office focuses on quite stridently—combat capability. We want to do the right thing for energy efficiency, but it has to help the warfighter become more capable.

MAJUMDAR: Innovations in energy are at the foundation for our national security—our national security, our economic security and prosperity, and our environmental security. We want to develop technologies that can address all three, or at least two out of three. These are not mutually exclusive. In fact, they're mutually inclusive. The national security part is very important, which is part of the reason for our engagement with DoD.

CURRENTS: As a director of a federal agency focused on energy solutions, do you have any suggestions for the Navy on the best way to solve our energy challenges? For example, what are we doing right and what can be improved?

MAJUMDAR: It's very hard for me to speak for the Navy. But I think our partnerships so far have been absolutely wonderful. I've had several discussions with Admiral Cullom. I know he's very focused on the energy issue. I've had the honor of interacting with Secretary Mabus as well. Partnerships are something I wanted to build right from the beginning of ARPA-E. It should be part of the DNA of the organization, because national security is one of our goals. I hope that the discussions we're having and the partnerships we are creating together are just the first step in a longer relationship for these two institutions. I'll be long gone after awhile, but the institutions need to live together and that's what I'm really looking forward to. To build a sort of connective tissue now.

Dr. Ely Sachs, 1366 Technologies
Chief Technology Officer, Dr. Majumdar
and Dr. Steven Chu, U.S. Secretary of Energy.

CURRENTS: Anything else you'd like *Currents* readers to know?

MAJUMDAR: Well, I just want to thank the people in uniform and their families for all the sacrifices they're making and for protecting us. Our goal is to find solutions to make them more capable and bring them home safely. ⚓