Testimony of
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Committee on Science, Space, and Technology
U.S. House of Representatives
On
The Future of ARPA-E

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Good morning. Thank you for the opportunity to testify before this Committee. I'm a Senior Fellow at the Manhattan Institute where I focus on the policy implications at the intersection of technology and energy,

I am also a Faculty Fellow at the McCormick School of Engineering at Northwestern University where my focus is on the technology and the future of manufacturing. And I note for the record that I'm as well a strategic partner in a boutique venture fund dedicated to startup companies developing software and artificial intelligence for oil & gas technologies.

Permit me to begin with a brief observation about the report "Rising Above the Gathering Storm" in which the National Academy of Sciences originally proposed the creation of ARPA-E. That report specifically focused on the "long-term energy challenges" and the "need for creative 'out-of-the-box' transformational" research. So, as a predicate for thinking about the future of ARPA-E, it is worth framing the scale of this energy challenge.

As is well known by this Committee, roughly 85% of global energy comes from oil, coal and natural gas. Traditional metrics are inadequate to visualize the magnitude of hydrocarbons our digitally infused industrial society requires. But, for context on the scale challenge, consider that if global hydrocarbons were all produced as oil and stacked up in a row of barrels, that row would stretch from Washington D.C. to Los Angeles, and would grow in height by a Washington monument every single week.

That's today's state of affairs, and that challenge is expanding. When, not if, the world's poorest four billion people increase their energy use to a mere 15% of the per capita level of developed economies, global energy use will rise by an amount equal to adding an entire U.S.A.'s worth of demand. Meanwhile, in the developed nations, we can illuminate the scale challenge looking at just two fast-growing sectors: every $1 billion of commercial airlines put into service leads to some $2 billion in aviation fuel consumed over one decade. Similarly, every $1 billion spent building datacenters leads to $2 billion in electricity use over a decade. The world is buying both at a rate north of $50 billion a year.

We already know how challenging it is to find any means, never mind practical ones, for making "transformational" changes at these scales. Over the past two decades, the world has spent more than $2 trillion on non-hydrocarbon energy alternatives; meanwhile hydrocarbon use has *risen* nearly 1.5-fold and hydrocarbon's share of global energy supply has decreased by only a few percentage points. These realities are what likely motivated Bill Gates – who has given serious thought and significant capital to energy innovation -- to recently state that "there is no [energy] substitute for how the industrial economy runs today."

The scale challenge commonly elicits the proposition that a solution can be found by embracing the spirit of the Apollo program: "If we can put a man on the moon, surely we can [and we can fill in the blank with any aspirational goal]." This popular rhetorical analogy is in fact a profound category error. Transforming the energy economy is not like putting a dozen people on the moon a handful of times. It is like putting *all of humanity* on the moon —permanently. To do the latter would require science and engineering that doesn't exist today.

But in the decades since Apollo, we've seen another, far bigger engineering revolution that has also inspired a similar trope. This is of course the computing-communications revolution – often short-formed as simply, Moore's Law.

It has become a cliché to observe that smartphones are not just far cheaper but also far more powerful than a room-sized IBM mainframe from 30 years ago. Invoking the Moore's Law analogy, the International Monetary Fund, to name only one example, asserts in it's "Riding the Energy Transition" manifesto: "Smartphone substitution seemed no more imminent in the early 2000s than large-scale energy substitution seems today."

But this analogy is also based on a category error. A similar transformation in how energy is *produced* or *stored* isn't just unlikely, it can't happen with the physics we know today.

In the world of people, cars, planes, and large-scale industrial systems, increasing speed or carrying capacity causes hardware to expand, not shrink. The energy needed to move a ton of people, heat a ton of steel or silicon, or grow a ton of food is determined by properties of nature whose boundaries are set by laws of gravity, inertia, friction, mass, and thermodynamics.

In order to illustrate how far from reality this kind of thinking is, consider that if combustion engines, for example, could achieve Moore's Law scaling, a car engine would generate a thousand-fold *more* horsepower and shrink to the size of an *ant*. With such an engine, a car could actually fly, very fast. Or, if photovoltaics scaled that way, a single ant-sized solar array would power an entire office building. Similarly, if batteries scaled like computing, a battery the size of a book, costing less than a dime, could power an A380 to Asia.

But only in comic books does the physics of energy production work like that. In our universe, power scales the other way. The challenge in storing and processing information using the smallest possible amount of energy is distinct from the challenge of producing energy, or moving or reshaping physical objects. The two domains entail different laws of physics.

Of course wind turbines, solar cells, and batteries will yet see useful improvements in cost and performance; so too will drilling rigs and combustion engines. And of course Silicon Valley information technology will bring important, even dramatic efficiency gains in the production and management of energy and physical goods. But the outcomes won't be as miraculous as the invention of the integrated circuit, nor the discovery of petroleum or nuclear fission.

The point of all this is precisely relevant to ARPA-E. An "out-of-the-box" energy revolution can only come from discovering new "transformational" science, new phenomenologies that then lead, eventually, to radically new technologies. That can only come from basic research. It won't come from deploying R&D funds to improve – or subsidize -- yesterdays' technologies. The Internet didn't emerge from improving the rotary phone, nor the transistor from subsidizing vacuum tubes, nor the automobile from subsidizing railroads. Policies in pursuit of an energy revolution require a focus entirely on *basic* scientific research.

To be blunt: there is simply no possibility that more federal funding for wind turbines, silicon solar cells or lithium batteries will lead to a "disruptive" 10-fold gain. All those technologies are approaching physics limits, just as aviation engines have. And while one cannot, by definition, predict what kind of entirely new phenomenologies have yet to be discovered, we do know from history that such discoveries do happen. But history also shows that they rarely if ever emerge from directed goal-specific funding.

I can offer one example of an area where there is a serious deficit in support for research where 'magic' can yet happen, and that is in the basic materials sciences. We already know that metamaterials and quantumengineered catalysts or alloys – areas that will yet benefit from the emerging capabilities of artificial intelligence and exascale computing – hold the potential for "big bang" energy impacts. Radically new materials can profoundly change how energy is produced, transported, stored and used, from the still chimerical pursuit of batteries as effective as fuel tanks to doubling combustion engine efficiencies, to engineered bacteria that excrete diesel fuel.

Returning then to the Academy's *Gathering Storm* report: its recommendations provide a clear roadmap for three things Congress should do in order to fulfill the mission envisioned for ARPA-E.

First, APRA-E should have a clear focus on basic science. While it is often tempting and perhaps more politically comfortable to fund projects with directed and near-term utility, that focus fails the science challenge set out for ARPA-E.

The role of ARPA-E should not be in duplicating private sector R&D, which in any case vastly outspends the government in this area. Nor should it try to bridge the oft-noted "valley" between innovation and commercialization, which again is not only a private sector activity but is already engaged (for better or worse) by many other DOE and federal programs. A vital role for ARPA-E is in the far more challenging gap between foundational science discovery and validating whether a radical new discovery, while clever, is useful.

My second recommendation is that Congress follow the Academy's original plan and place ARPA-E's function within the office of DOE's undersecretary of science. This should be done both as a signal of the commitment to basic research – again, with a focus away from commercial goals like speed-to-market, or incremental cost-reductions -- and as a practical operational insulation from the inevitable 'contamination' by policies oriented towards near-term outcomes.

Third, I support those who propose increasing ARPA-E's budget, but with two caveats. The first, to restate, is that spending must be focused on long-term basic science. I believe the evidence is clear that ARPA-E has significantly drifted towards near-term goals to improve yesterday's technologies. This is not just duplicative but a drift away from critical "transformational" possibilities. My other caveat regards the source of funding. Rather than new appropriations, the funding should follow, again, the Academy's original recommendation to expand ARPA-E "through reallocation of existing funds." The reallocation should come from federal programs at both DOE and other federal agencies where the spending is duplicative of what private markets do.

In order to support these recommendations, Congress should also follow the Academy's original proposals to undertake a review of ARPA-E's performance. Such an audit should focus on how well ARPA-E has fulfilled its primary "basic science" mission as originally envisioned. And, critically, such an audit should be undertaken by an independent panel that is neither run by nor dominated by federal agencies, drawing mainly on private sector and university experts in basic science domains.

I have no doubt that scientists will yet unveil, and engineers will yet commercialize an energy "miracle" – the specific word Bill Gates has used for this goal. But, to repeat and close on my central theme, that will not come from helping private markets make yesterday's tools better.
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