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SOLAR TOGETHER: A PROPOSAL

By Colin McCormick
and David Sandalow

APRIL 2016

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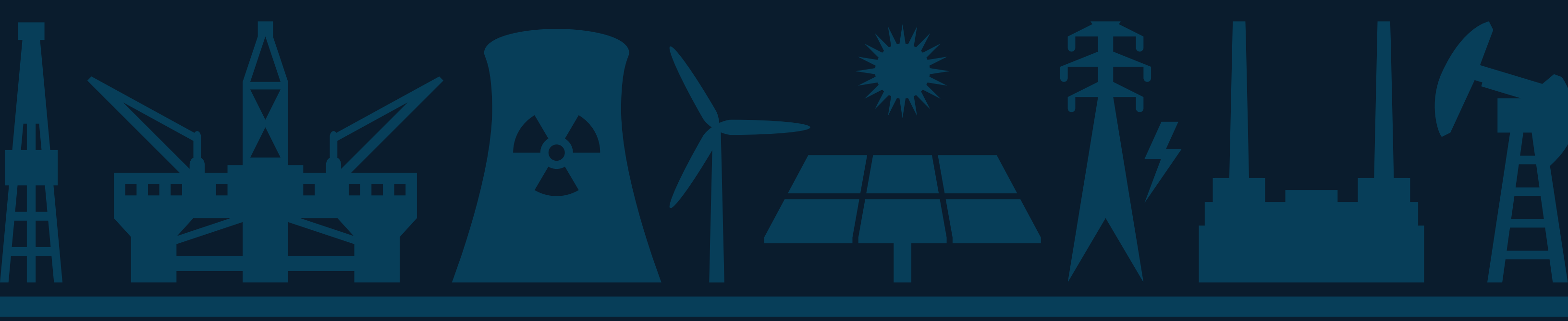

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Colin McCormick and David Sandalow*

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COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

ACKNOWLEDGMENTS

The authors gratefully thank those who reviewed, commented on and contributed to this paper, including Ron Benioff, Jason Bordoff, Travis Bradford, Mary Brunisholz, Steve Griffiths, Richard Nephew, Ken Novak, Stefan Nowak, Matthew Robinson, Varun Sivaram and Lenny Tinker.

This policy paper represents the research and views of the authors. It does not necessarily represent the views of the Center on Global Energy Policy. The paper may be subject to further revision.

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EXECUTIVE SUMMARY

National governments spend more than $10 billion per year on clean energy R&D. These amounts will grow significantly under Mission Innovation, an initiative to double clean energy R&D budgets in five years launched by 20 countries at the opening of the Paris climate conference in November 2015. This new funding could help significantly to cut carbon emissions and energy poverty, although more money alone will not necessarily deliver better results. To realize the full promise of Mission Innovation, research spending must be well targeted and research results must find their way to market.

One way to help channel funds to the most promising research topics is to improve understanding of related work around the world. Although information sharing among government R&D programs can be difficult, governments have demonstrated a willingness to work together on clean energy R&D in several fora including the International Energy Agency's Technology Collaboration Programs.

For clean energy R&D programs to have impact, their results must be commercialized. This is often difficult or impossible with existing funding mechanisms, resulting in a "Valley of Death" that leaves many technically successful innovations on the shelf. The Breakthrough Energy Coalition, a group of 27 billionaires also launched in November 2015, is in part intended to address this problem.

Solar power is an especially important area of clean energy R&D. Although solar power costs are falling and deployments increasing, the industry is still young. R&D on topics such as transparent solar cells and perovskite materials could significantly accelerate cost reductions. National governments spend more than $900 million annually on solar PV R&D programs.

Our review of the solar PV R&D programs in four countries (the United States, Japan, Germany and South Korea) reveals important similarities:

- Each program focuses on cutting the cost and improving the efficiency of PV cells and modules.
- Each supports research on silicon PV technology (the dominant technology in the industry today), as well as on advanced concept materials such as cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and perovskites.
- Each addresses integration of solar power into electric grids.

At the same time, the emphases of these programs differ. More information on these and other programs could help avoid duplication and improve allocation of funding.

We propose **Solar Together**—a program to bring national solar PV R&D programs together with each other and members of the Breakthrough Energy Coalition for annual meetings to review research results and discuss research plans.

- Solar Together would improve R&D results from national programs by improving information available to program managers and researchers.
- Solar Together would facilitate commercialization of government R&D results by establishing a structure that leading investors could use to identify and evaluate the most promising R&D results from many countries.
- Solar Together would be launched as a Clean Energy Ministerial initiative, a program of the International Solar Alliance or both. Its initial home would be the Photovoltaic Power Systems Programme of the International Energy Agency. The International Renewable Energy Agency (IRENA) could also provide support.

The program could serve as a model for similar programs in other clean energy technology areas as well.

INTRODUCTION

In November 2015, at the opening of the Paris climate conference, 20 national governments pledged to double their investment in clean energy research and development (R&D) over five years as part of Mission Innovation. Participating governments span five continents, represent 58 percent of the world's population and together spend roughly $10 billion per year on clean energy R&D.[1] If even part of their pledge is realized, significant new funding for clean energy R&D will be available in the years ahead. This funding has the potential to accelerate deployment of clean energy technologies, reducing both carbon emissions and energy poverty.

A significant increase in clean energy R&D will also bring challenges. One of the most important is to channel new funds toward the most promising areas of research. If new investments complement and enhance existing research, returns will be far greater than if those investments duplicate other research underway. Information sharing and collaboration among participating governments therefore have the potential to increase returns on funds spent.[2] While information sharing and collaboration with respect to clean energy R&D can be challenging, those activities may have especially high payoff now in light of likely budget increases in the years ahead.

Another challenge is bringing the results of new clean energy R&D to market. Technologies that achieve performance goals in the laboratory generally require significant additional investment before they can be successfully commercialized. This is often difficult or impossible with existing financing mechanisms, resulting in the well-known "Valley of Death" that leaves many technically successful innovations stuck on the shelf.[3] The Breakthrough Energy Coalition, a group of 27 billionaires convened by Bill Gates and launched in November 2015, is in part intended to address this problem.[4]

Solar power is an especially important area of clean energy R&D. Although solar power has grown rapidly in the past several years and costs are falling, the industry is still young.[5] Financial and policy innovation will play an important role in the continued growth of the industry, but technology innovation will also be necessary to drive costs down further and promote rapid deployment. R&D on topics such as transparent solar cells and perovskite materials[6] could significantly accelerate cost reductions and improve performance. The importance of solar power was underscored by the announcement in November 2015 of the International Solar Alliance, an initiative of more than 120 countries launched by India and France "with a view to reducing the costs of finance and cost of technology for immediate deployment of competitive solar generation assets in all our countries."[7]

In this paper, we first examine reasons that coordinating clean energy R&D internationally is challenging, paying particular attention to issues of incentives and information. Next, we review the solar photovoltaics (PV) R&D programs of the four developed country governments with the largest budgets in this area. (We are not aware that the goals and technical results of these programs have been described before in a single paper.)[8] After this, we propose a program to improve information sharing among national PV R&D programs and help move the most promising new solar PV technologies more rapidly to market. In brief, we propose that national governments with solar PV R&D programs meet annually with each other and members of the Breakthrough Energy Coalition to share research results and discuss research plans. This would be launched as a Clean Energy Ministerial initiative, a program of the International Solar Alliance or both. We call the new program "Solar Together."

CHALLENGES OF INTERNATIONAL CLEAN ENERGY R&D COLLABORATION

Many national governments invest in clean energy R&D programs, spending more than $10 billion in total per year.[9] Major funders include the United States, Japan, Germany, South Korea, the United Kingdom and China. Figures for total private sector spending on clean energy R&D are not available, however, total private sector spending on renewable energy R&D has been estimated to be approximately $7 billion. Total investment in renewable energy in 2015 was $270 billion.[10]

As the costs of solar and wind technologies continue to fall, a threshold question is whether public funding for clean energy R&D continues to be justified. We believe so, for three reasons. First, markets alone do not deliver socially optimal levels of support for clean energy technologies, because several benefits of those technologies (including lower emissions of local air pollutants and heat-trapping gases) are not fully valued by markets. Second, markets also fail to deliver socially optimal levels of support for early stage R&D, because innovators are often unable to capture the full benefits of their work and the period from investment to payoff often exceeds the time horizon for private investors.[11] Finally, although costs of solar and wind technologies are declining, costs of other important clean energy technologies—such as energy storage and carbon capture, utilization and storage—remain high. Because of these factors, public funds to support clean energy R&D will continue to be justified for some time.

Currently, national governments and their research institutes share some information on clean energy R&D through a variety of mechanisms, including International Energy Agency (IEA) Technology Collaboration Programs (at the program level)[12] and the technical research literature (at the project level). There are also bilateral programs, such as the US–China Clean Energy Research Center, US–India Partnership to Advance Clean Energy and Europe–China Clean Energy Centre.[13]

Despite this, there are many examples of overlap, redundancy and potential duplication among national clean energy R&D programs. For example, researchers in the United States, Japan, China, Korea, the United Kingdom, Italy, Spain and Switzerland are all currently working to develop large-area solar cells based on perovskite materials, which have recently been shown to have enormous potential for solar technology.[14] In addition, publicly funded researchers in the United States, Germany, China and Taiwan are each supporting their own national PV manufacturers in efforts to improve the efficiency of PERC solar cells, a promising design approach for conventional silicon-based PV.[15]

This situation, in which competing research projects are funded by multiple national governments, partly reflects the nature of global scientific research: individual scientific groups compete with each other for academic credit by being the first to publish a new result. In this sense, competition accelerates progress in early-stage research. However, this situation also means that a large amount of this research is not producing original results—and may also mean that other important research topics are being neglected.

These examples lead to a question: while competition can spur results, would collective outcomes be better if duplication could be minimized? In other words, would improved information sharing and collaboration among countries conducting solar R&D programs lead to faster, lower-cost deployment of the technology and more rapid mitigation of carbon emissions?

We believe the answer is yes. With better information, program managers and researchers could target R&D more wisely, focusing on the highest-priority topics and avoiding waste. Evaluations of IEA Implementing Agreements (which establish multilateral cooperative clean energy R&D programs) tend to confirm this hypothesis. Those evaluations find important benefits to the participants, particularly in "intelligence gathering" around technology developments in other countries, leveraging limited research funding and improving intra-industry collaboration.[16]

Why then is collaboration among national R&D program managers challenging?

Reason #1 is incentives. As the examples above suggest, governments often view their R&D investments as benefiting national economic interests by making domestic companies more competitive internationally. While cutting emissions and improving domestic energy systems are also factors, national economic competitiveness is often the most important factor. An example of this perspective comes from the German Federal Ministry for Economic Affairs and Energy (BMWi), which stated in a 2014 report: "By promoting research in the field of energy technologies, the government aims to meet its energy requirements and climate policy commitments. In economic terms, the leading position of German companies will also be increased in the field of modern energy technologies."[17] Program managers are accountable to their political leadership for helping realize these competitiveness goals and may have little incentive to share technical knowledge.

This dynamic is reflected in the restrictions many governments place on the eligibility of foreign researchers to compete for their energy technology R&D grants. For example, the US Department of Energy generally restricts "foreign entities" from serving as the lead recipient of solar technology R&D grants, unless they can demonstrate that it is "in the economic interests of the United States to have a foreign entity serve as the prime recipient."[18] Under the German Research and Development for Photovoltaics program, eligible grant recipients are "commercial companies (headquartered and mainly exploiting their results in Germany)."[19]

Reason #2 is information gaps. Even when governments decide that international research collaboration is in their national interest, lack of understanding concerning the procedures and practices in other countries and the inherent complexity of some research topics can make collaboration difficult. Program managers can work to improve understanding, but this can be challenging. The US–China Clean Energy Research Center, which now has over 1,000 researchers working on several dozen projects, took roughly two years to launch in part for this reason.

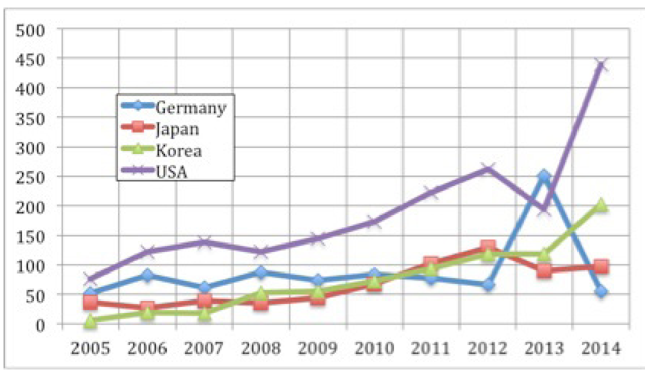
Closely related to this, R&D focus areas and results can be difficult to compare systematically. Research topics are often categorized differently in different national programs, defying direct comparison. For example, the German government funds PV research in the categories of "crystalline silicon," "thin-film technologies," "basic research" and "solar thermal power plants," while the US Department of Energy uses the categories "concentrating solar power," "photovoltaic R&D," "systems integration," "balance of systems soft cost reduction," "innovations in manufacturing competitiveness" and a laboratory-specific category.[20] Subject experts can approximately correlate these categories, but there is a lot of room for confusion and misunderstanding.

Complicating this problem, the highly technical nature of energy R&D requires very specialized knowledge to enable valid comparison. There simply may not be enough trained staff resources available to program managers in relevant ministries to perform this sort of technical comparison work in addition to managing and overseeing their own programs. Cutting-edge research topics also involve many unknowns in the substance of the research work. Two technical projects that appear to be similar may turn out to address very different underlying technical issues. Conversely, two projects with very little apparent connection may eventually be revealed as studying the same technical issue or phenomenon when better understood.

NATIONAL SOLAR PV R&D PROGRAMS

More than a dozen national governments conduct R&D on solar photovoltaics. According to the best available estimate, national governments spent at least $924 million on solar PV R&D programs in 2014. The governments with the largest known budgets for solar PV R&D were the United States, Japan, Germany and South Korea. (The Chinese government also has significant solar PV R&D programs, but does not disclose budget figures.) National government spending on solar PV R&D has grown over the past decade, as shown in Figure 1 below. [21]

Figure 1: Public R&D spending on solar PV technology of four leading countries (in millions of USD)



Source: IEA PVPS Trends reports, multiple years.

In this section we present the principal goals and features of the leading national solar PV R&D programs. The programs are similar in several important respects:

- Each program focuses on cutting the cost of PV cells and modules.
- Each program also focuses on improving the efficiency of PV cells and modules.[22]
- Each program conducts research on silicon PV technology (the dominant technology in the industry today), but also supports research on advanced-concept materials including cadmium telluride (CdTe), copper indium gallium selenide (CIGS), gallium arsenide (GaAs) and perovskites.
- Each program addresses integration of solar power into electric grids.
- Each program uses the international network of testing laboratories (notably the National Renewable Energy Laboratory in the United States, the Fraunhofer Institute for Solar Energy Systems in Germany and the National Institute of Advanced Industrial Science and Technology in Japan) as a method of verifying results.
- Each program is spread across a number of domestic institutions, including energy, industrial and science ministries as well as publicly funded research laboratories.
- Each program participates in the IEA Photovoltaic Power Systems Programme (PVPS), the broadest multilateral R&D framework for PV.

The programs also have some important differences:

- Several programs establish specific numeric targets to be achieved in specific years, while others establish more general goals.
- The emphasis of programs differ, with some more focused on cell- and module-level targets and others more focused on system-level issues.
- The work in each program on advanced-concept materials differs significantly, with each program emphasizing different pathways.
- Only one program (Japan's) includes a major emphasis on recycling.

Key features of four leading national solar R&D programs are summarized below. *These sections contain technical material that may be unfamiliar to some readers. Readers more interested in our proposal to improve information sharing and collaboration with respect to solar R&D may wish to skip to the next section.*

1. UNITED STATES

The primary US R&D program focused on solar PV is the SunShot program, administered by the US Department of Energy (DOE) and launched in 2011. The program has set the following targets for 2020:[23]

Topic	Target (2020)
Utility-scale PV system cost	USD1.00/WDC
Commercial-scale PV system cost	USD1.25/WDC
Residential-scale PV system cost	USD1.50/WDC
LCOE of utility-scale PV system	USD0.06/kWh

Table 1: US SunShot program targets

SunShot has established three areas of focus: (1) reducing the cost of core technology, (2) reducing the cost of grid integration and (3) accelerating technology deployment. The structure of the program combines research at government laboratories with cost-shared, competitive grants to universities and companies. There are seven themed program areas for these grants.[24] Multiple government laboratories participate in these research programs; the primary institution is the National Center for Photovoltaics at the National Renewable Energy Laboratory (NREL).

The recent areas of targeted R&D include: (1) degradation of PV modules (including metallization corrosion, solder joint failure, backsheet degradation and weathering[25]); (2) efficiency of PV cells (including ultra-thin-film c-Si, light trapping with photonic crystals, reducing the CZTS open-circuit voltage deficit and MBE-grown CdTe[26]); and (3) new concepts for PV (including stabilizing perovskite materials, alternatives to lead, dye-sensitized cells, multijunction organic PV, integrated Si/III-V cells and roll-to-roll printing of III-V cells[27]).

Some recent key technical results of the program include: (1) dual-junction III-V/Si solar cells with 29.8 percent efficiency,[28] (2) improvement of up to 30 percent in the accuracy of solar power forecasting using machine learning,[29] (3) dopant-free silicon cells with efficiency over 19 percent,[30] (4) four-junction III-V cells with 45.6 percent efficiency,[31] (5) development of an aqueous solar flow battery[32] and (6) the use of solvents to eliminate annealing during organic solar cell production.[33]

The SunShot program also includes a variety of projects focused on community solar and storage with its Solar Market Pathways program, which works to develop virtual net metering, integrate distributed solar and storage into emergency planning and reduce regulatory costs associated with solar installations. The SunShot program is supporting new research on integrating energy storage and solar PV so that they interface with smart buildings, smart appliances and utility communication and control systems.[34]

DOE's Advanced Research Projects Agency–Energy (ARPA–E) also funds solar PV research, with programs designed to pursue high-risk, high-reward projects. Recent ARPA–E programs include MOSAIC (Micro-scale Optimized Solar Cell Arrays with Integrated Concentration), with the goal of developing micro-scale concentrated photovoltaic (CPV) systems with costs and physical shapes similar to flat-plate PV technology; and FOCUS (Full-spectrum Optimized Conversion and Utilization of Sunlight), with the goal of developing hybrid solar PV/thermal technologies that use the entire available solar spectrum.

Solar-related research is also carried out by the National Science Foundation (NSF) through the Energy for Sustainability program and the Department of Defense (DoD) through the Environmental Security Technology Certificate Program (ESTCP).

2. JAPAN

The primary Japanese framework for solar PV R&D is articulated in "NEDO PV Challenges," a strategy document focused on supporting the mass introduction of solar PV to Japan.[35] Within this framework, the New Energy and Industrial Technology Development Organization (NEDO) has established high-level technology cost and performance targets, with different deadlines:[36]

Topic	Target	Date
LCOE of commercial-scale PV	JPY 14/kWh	2020
Module efficiency, lifetime	22 percent, 25 years	2020
LCOE of utility-scale PV	JPY 7/kWh	2030
Module efficiency, lifetime	25 percent, 30 years	2030

Table 2: Japanese solar technology targets

NEDO has also developed technology-specific subtargets for c-silicon (100 JPY/W, 25 percent efficiency), III-V (125 JPY/W, >30 percent efficiency) and perovskites (<100 JPY/W, with 20 percent efficiency). NEDO's program focuses on four areas: (1) reducing solar PV's levelized cost of electricity (LCOE), (2) enhancing system reliability, (3) enlarging the possible range of applications for solar PV and (4) establishing a solar PV recycling system.

Some recent key technical results of the program include: (1) crystalline silicon cells with 25.6 percent efficiency,[37] (2) triple-junction III-V concentrator cells with 44.4 percent efficiency,[38] (3) triple-junction thin-film silicon cells with 13.6 percent efficiency, (4) thin-film CIS cells with 22.3 percent efficiency,[39] (5) the development of a single-seed cast method for mono-silicon[41] and (6) polymer-based solar cells with over 9 percent efficiency.[42]

NEDO conducts domestic and collaborative international projects to demonstrate integrating distributed solar PV systems with energy storage, such as stabilizing distribution networks with batteries (in Spain),[43] providing customer autonomy during cold-weather grid outages (in Canada)[44] and enabling community-level self-generation and consumption using solar PV and storage (in Germany).[45]

In addition to the program conducted by NEDO, the National Institute of Advanced Industrial Science and Technology (AIST) conducts solar PV research at its Research Center for Photovoltaics, with focus areas including advanced processing, module reliability research, calibration and standards. In 2014, AIST established the Fukushima Renewable Energy Institute (FREA), with a research program that includes thin-film silicon PV technology and advanced III-V concepts,[46] as well as tandem nanowire silicon PV.[47]

The Japan Science and Technology Agency (JST) conducts basic research in solar PV under three programs: ERATO (Exploratory Research for Advanced Technology), CREST (Core Research for Evolutional Science and Technology) and PRESTO (Precursory Research for Embryonic Science and Technology).

3. GERMANY

The primary framework in Germany for solar R&D is the Sixth Energy Research Program, launched in 2011.[48] This program combines direct institutional funding with project-level funding for cost-shared, collaborative research among universities, research centers and industry. Key research centers for energy include those of the Helmholtz Association of German Research Centers and the Fraunhofer Energy Alliance, notably the Fraunhofer Institute for Solar Energy Systems ISE.

From 2010 to 2014, the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Economics and Technology (BMWi) administered a comprehensive solar R&D program known as the Photovoltaics Innovation Alliance. This program was funded at 100 million euros and had the strategic goal of strengthening the photovoltaic industry through collaborative projects.[49] In May 2013, BMBF and BMWi launched the "Research and Development for Photovoltaics" initiative, which focused on PV production technology and systems engineering.

Some recent key technical results of the program include: (1) PERC silicon standard-format solar modules of 306W, p-type mono-crystalline silicon PERC cells with 21.7 percent efficiency and industrial PERC silicon modules with 20.2 percent efficiency;[50] (2) hybrid silicon-perovskite tandem solar cells with 18 percent efficiency;[51] (3) multijunction concentrating PV cells with 46 percent efficiency;[52] (4) thin-film silicon cells on flexible substrates;[53] (5) cadmium-free CIGS thin-film cells with 21 percent efficiency[54] and (6) real-time molecular-scale monitoring of production processes of organic solar cells.[55]

4. SOUTH KOREA

The primary framework for solar PV R&D in South Korea is the Second Energy Master Plan, launched in 2014,[56] and the following Fourth Basic Plan for Technology Development, Application and Deployment of New and Renewable Energy.[57] The latter plan includes high-level technical targets, including commercializing solar PV systems beyond silicon.

The leading ministries involved in solar PV R&D programs are the Ministry of Trade, Industry and Energy (MOTIE); its subordinate office, the Korea Institute of Energy Technology Evaluation and Planning (KETEP); and the Ministry of Science, ICT and Future Planning (MSIP). Key research centers include the Korea Institute of Science and Technology, the Korea Institute of Energy Research, the Korea Research Institute of Chemical Technology and the Korea Electronics Technology Institute.

Some recent key technical results of the program include: (1) a stable perovskite solar cell with efficiency of 20.1 percent,[58] (2) improved perovskite fabrication techniques,[59] (3) ultra-thin, flexible organic solar cells based on nanowires[60] and (4) improved solar cell recycling techniques that do not involve hydrofluoric acid or other toxic chemicals.[61]

PROPOSAL: SOLAR TOGETHER

We propose **Solar Together**—a new program to improve information sharing among national solar PV R&D programs and move their most promising research results more quickly to market. Solar Together would bring countries with national solar PV R&D programs together each year to share information with each other and the Breakthrough Energy Coalition. Participating countries would provide publicly available information on their solar energy research programs, including research areas, objectives and budgets. Participating countries would also establish a system for short-term exchanges of program managers. Members of the Breakthrough Energy Coalition and their staffs would review R&D results for potential investments and give guidance on investment priorities for the years ahead.

Solar Together would be launched as a Clean Energy Ministerial initiative, a program of the International Solar Alliance or both. It would be supported by the International Energy Agency and the International Renewable Energy Agency. The Breakthrough Energy Coalition would be a core member. We elaborate on the backgrounds and roles of key players below.

1. CLEAN ENERGY MINISTERIAL AND INTERNATIONAL SOLAR ALLIANCE

The Clean Energy Ministerial (CEM) is a global forum launched in 2010 that promotes policies and programs to advance clean energy technologies. Twenty-four countries with more than 90 percent of global energy investment participate, sharing lessons learned and best practices. Ministers from those countries meet annually to review progress on roughly a dozen clean energy initiatives launched by participating countries. Member countries participate in some but not all initiatives.[62]

The Multilateral Solar and Wind Working Group is one of the oldest CEM initiatives, dating to the founding of the CEM in 2009. Thirteen countries participate, including the United States and Japan, with leadership from Germany, Denmark and Spain. The Working Group has produced a global atlas for solar and wind energy, a report on the economic value of renewable energy projects and a handbook on capacity building.[63]

The International Solar Alliance (ISA) is an initiative launched in November 2015 by Indian Prime Minister Narendra Modi and French President Francois Hollande. More than 120 countries have signed on. The ISA "will contribute towards the common goal of increasing utilization and promotion of solar energy and solar applications in its member countries."[64] Statements to date suggest a greater focus on immediate deployment than long-term R&D, although the work program of the ISA is still taking shape. In January 2016, Prime Minister Modi inaugurated the interim headquarters of the International Solar Alliance in Gurgaon, India.

Solar Together would be launched as a CEM initiative, a program of the International Solar Alliance or both.

2. INTERNATIONAL ENERGY AGENCY AND INTERNATIONAL RENEWABLE ENERGY AGENCY

The International Energy Agency (IEA) is an intergovernmental organization established in 1974. Twenty-nine developed countries (including the United States, Japan, Germany and the United Kingdom) are members. In 2015, China activated "association status" with the IEA, which also works closely with a number of other emerging economies including India and Brazil. [65] IEA Technology Collaboration Programs provide a mechanism for IEA members and nonmembers, as well as businesses, international organizations and NGOs, to work together on energy technologies. Since 1993, the IEA has operated the Photovoltaic Power Systems Programme (PVPS) as a technology collaboration program to improve collaboration among its members on solar photovoltaics. Membership includes most IEA members along with several industry trade associations. PVPS conducts joint projects in areas such as PV analysis, environmental health and safety, and performance and reliability of PV systems.[66]

We propose that PVPS serve as the initial home of Solar Together, receiving an expanded mandate and additional budget. A core team from governments helping lead Solar Together would meet to consider other institutional arrangements as well.

As one option, the International Renewable Energy Agency (IRENA) could provide support for Solar Together, including some secretariat functions. IRENA is an intergovernmental organization established in 2011 that supports countries in the transition to renewable energy. More than 140 countries are members. IRENA's work program includes preparation of renewable energy readiness assessments, handbooks on renewable energy policies, technology briefs and cost studies. IRENA's staff includes scientists, engineers, economists, diplomats and others with deep expertise on renewable energy systems and planning. IRENA's focus on renewable energy could make it a natural home for Solar Together, although the IEA PVPS program has long experience serving as a forum for governments sharing information on solar R&D.

3. BREAKTHROUGH ENERGY COALITION

The Breakthrough Energy Coalition is a group of 27 billionaires from more than 10 countries committed to accelerating the transition to advanced energy. The coalition was launched in late November 2015 under the leadership of Bill Gates. Members signed on to a statement of principles that includes the following:

—"The urgency of climate change and the energy needs in the poorest parts of the world require an aggressive global program for zero-emission energy innovation."

—"The foundation of this program must be large funding commitments for basic and applied research, and here governments play the key role."

—"Government research, however, is not enough. We must also add the skills and resources of leading investors with experience in driving innovation from the lab to the marketplace."[67]

Members of the coalition pledge to form a "network of private capital" to accelerate the transition to clean energy. They call for "a partnership of increased government research, with a transparent and workable structure to objectively evaluate […] projects, and committed private sector investors willing to support the innovative ideas that come out of the public research pipeline."[68]

In a paper elaborating on these principles, Bill Gates argues that "governments play an indispensable role in supporting energy research," but adds:

> "Promising concepts and viable products are separated by a Valley of Death that neither government funding nor conventional investors can bridge completely. A key part of the solution is to attract investors who can afford to be patient, and whose goal is as much to accelerate innovation as it is to turn a profit."[69]

Gates offers three examples of promising advanced energy technologies, two of which are solar technologies (solar chemical and solar paint).[70]

We propose that several members of the Breakthrough Energy Coalition and their staffs participate as core members of Solar Together. Members of the coalition or their staffs would commit to meet annually with representatives of national solar R&D programs, reviewing recent research results that are presented, transparently, to all members of Solar Together. Technologies with sufficient promise would receive follow-on investment from members of the coalition.

We foresee a structure building on existing institutions and adding new ones to maximal effect. The initial home for Solar Together would be IEA's PVPS program. Using existing channels of communication and procedures to the extent possible, participants would convene annual meetings among members of PVPS and the Breakthrough Energy Coalition. Each national government would have the opportunity to present promising research findings in a fully transparent manner in front of all participants. Breakthrough Energy Coalition members would commit to invest in promising technologies presented there.

Solar Together could also work to develop and update a list of global research gaps in solar PV, based on the published technical literature, company and investor needs, and research proposals submitted to different national governments (whether funded or not). Breakthrough Energy Coalition members and staff could express interest or lack of interest in specific research directions, before that research gets underway.

Finally, Solar Together could establish a formal system for short-term exchanges of program managers between participating countries. These "clean energy R&D management fellows" would work within the host country's research funding agency to help develop R&D priorities and targets, monitor the progress of existing projects and contribute to developing technology roadmaps. In doing so they would both share information about their home country programs and learn about the host country's R&D programs, enabling and encouraging ongoing collaboration. While a number of research agencies fund exchange programs like this for researchers, to our knowledge there are none that specifically target R&D managers with the goal of enhancing international clean energy R&D cooperation.

4. BENEFITS OF SOLAR TOGETHER

Solar Together would have several important benefits.

First, Solar Together would facilitate commercialization of government R&D results by establishing a structure that members of the Breakthrough Energy Coalition could use to identify and evaluate potential investments from many countries. The Breakthrough Energy Coalition emphasizes the importance of such a structure in its statement of principles:

> "Success requires a partnership of increased government research, with a transparent and workable structure to objectively evaluate those projects, and committed private sector investors willing to support the innovative ideas that come out of the public research pipeline."[71]

Without strong ties between the public research pipeline and such stakeholders, promising results from government-funded labs can languish unused and unnoticed. Conversely, without regular interactions between government R&D managers and businesses, R&D funds may be channeled to projects with little prospect for commercialization. As a 2003 IEA report states:

> "[W]hile public sector R&D is important, it cannot directly bring about the cost reductions that will make the technology competitive in the marketplace… [T]here is no virtuous cycle and no substantial cost reductions without market interactions."[72]

In recent years, clean energy investors have often struggled to identify the most promising research, particularly in areas like solar where research centers of excellence are distributed around the globe. A structure such as that offered by Solar Together could enable more efficient and effective scanning for high-value research results, speeding the movement of promising solar PV technologies from the lab to market.

Second, Solar Together would improve R&D results from national programs by improving information available to program managers and researchers. R&D is a process of defining hypotheses to be tested based on the best available information. The more program managers know about results to date and research underway in other national programs, the better job they can do in designing program strategies and allocating funding among different possible research directions.

Experience confirms the benefits of information sharing and collaboration among national R&D programs. Since the 1970s, the International Energy Agency's Implementing Agreements have provided a vehicle for information sharing on topics including R&D programs among IEA Members. Evaluations of those Implementing Agreements have found significant benefits to participants. Those benefits include improving decisions on which R&D topics to pursue and avoiding duplication of effort.[73] The US–China Clean Energy Research Center's Advanced Coal Technology Consortium (one of three components of the Center) has produced around 50 jointly authored technical papers in just over five years of operations.[74]

We do not expect competition among national government R&D programs or individual research labs to disappear, nor would we want it to. Competition can serve as a powerful spur to research results, accelerating the pace of progress. Competition can also lead program managers to be cautious in sharing information. But Solar Together or a similar structure would increase incentives to share information about false starts and dead-end lines of research, saving others from repeating these errors and thereby improving research results globally.

Our proposal is designed to encourage shared learning and minimize unproductive duplication while recognizing the benefits of productive competition. It focuses on the role of program managers, who make decisions about how to allocate research funding among different possible topics, but don't directly conduct research or make project-level technical decisions. Improving information sharing at this level would be particularly valuable, because that is where decisions about allocation of increased funding under Mission Innovation will be made.

Third, Solar Together could serve as a model for similar programs in other clean energy technology areas including carbon capture and storage, biofuels and energy storage.

CONCLUSION

National clean energy R&D budgets are expected to increase significantly in the years ahead as part of Mission Innovation. The potential benefits are enormous. However, more money alone will not necessarily produce better results. To realize the full promise of Mission Innovation, research spending must be well targeted and research results must find their way to market.

One way to improve research results is to improve understanding of related work underway around the world. This will reduce duplication and improve programmatic allocation of funding. Although information sharing and collaboration among government R&D programs can be challenging, governments have demonstrated a willingness to work together in a number of different fora. The opportunity to present research results to private investors could provide an incentive for R&D managers to share information about their programs more broadly.

Limited information is currently available concerning the details of national solar PV R&D programs. Our research indicates that leading programs each conduct research on silicon PV technology as well as advanced-concept materials including cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and perovskites. Yet the emphases and, in some cases, the goals of these programs appear to differ.

A program that brought national solar PV R&D programs and the Breakthrough Energy Coalition together for annual presentations of research results would deliver significant benefits. Such a program would encourage information sharing and collaboration among national solar PV R&D programs and create a clear, well-structured channel for moving their most promising research results to market. The program could be launched as a Clean Energy Ministerial initiative, a program of the International Solar Alliance or both. The IEA's Photovoltaic Power Systems Programme could provide an initial home. Such a program—Solar Together—would improve the results of national solar PV R&D programs, accelerate deployment of innovative solar PV technologies and provide a template for similar programs in other clean energy technology areas.

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8 The IEA PVPS Trends series of reports highlight the program areas and funding levels of national PV R&D programs, but do not describe technical results.

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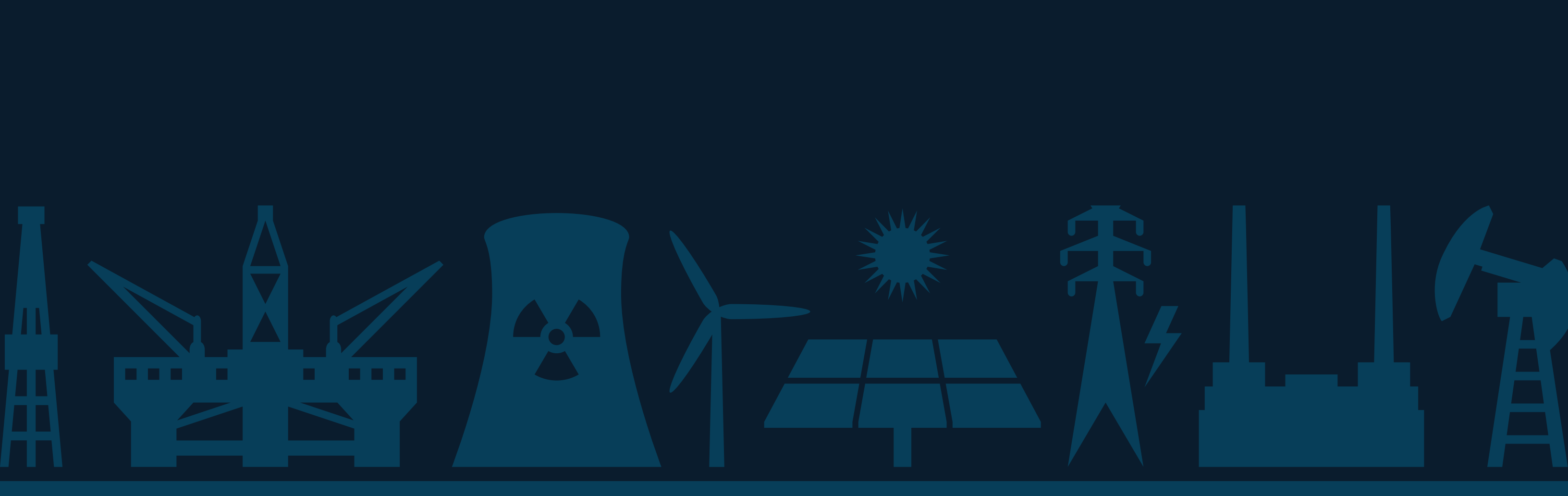

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