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FACILITATING A SUSTAINABILITY TRANSITION IN DEVELOPING COUNRIES

Proposal for a global Advanced Research Project Agency for Sustainable Development

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FACILITATING A SUSTAINABILITY TRANSITION IN DEVELOPING COUNRIES[1]

Proposal for a global Advanced Research Project Agency for Sustainable Development

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Introduction

While the world as a whole has made enormous strides in the past decades in advancing human and economic development, the challenges of sustainability are recognized as being increasingly central to continued progress in human well-being and prosperity. These challenges are enormous in scale, complex in nature, and there also is some urgency in addressing them, partly because of the significant human costs that they already entail and partly because of the potential of future enormous costs (as in the case of many environmental challenges).

While there is no simple way to address these major sustainability challenges, give their scale and the interweaving of the drivers with the very fabric of our economic, social, and human existence, technology has the potential to play a major role in this process (see, for example, UNMP 2005). This is particularly important for developing countries, given that these challenges are pressing and urgent there. Yet leveraging the potential of technology for addressing sustainability challenges in developing countries is not a trivial exercise, given the uncertainties and the complexities of the technology innovation process in general and in relation to the sustainability transition, especially in the developing-country context.

The next section will discuss some of these issues that are salient to facilitating a sustainability transition in developing countries. Following that, we discuss some emerging institutional models and approaches that have been developed to accelerate and make more effective technological innovation. And then we outline a specific proposal for an international technology facilitation mechanism that can help developing countries in addressing sustainability goals by enhancing the development and dissemination of suitable technologies.

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[1] This report has been prepared for the United Nations Department for Economic and Social Affairs (UN DESA) Division for Sustainable Development. The views expressed herein are those of the authors and do not necessarily reflect those of the United Nations or its senior management.

Technology innovation, sustainability, and developing countries

The technology innovation process: an overview

The innovation process is often stylized as having a series of steps (often called the 'technology cycle' – see Figure 1), beginning with basic and applied research, which leads to scientific and technical insights/knowledge that can address a particular need. This is then explored as a technological proof-of-concept in the laboratory, which is a practical demonstration of the initial idea. For example, a material scientist may observe an electrochemical phenomenon during their research and have the insight that it could be used to build a better battery. He/she would then build a one-off working model of the battery in the laboratory and see whether the model functions as expected and/or how it could be fine-tuned in order for it to have the performance attributes, which in this case could be the power density and the charging time, for it to be a potential advance on existing energy storage options.

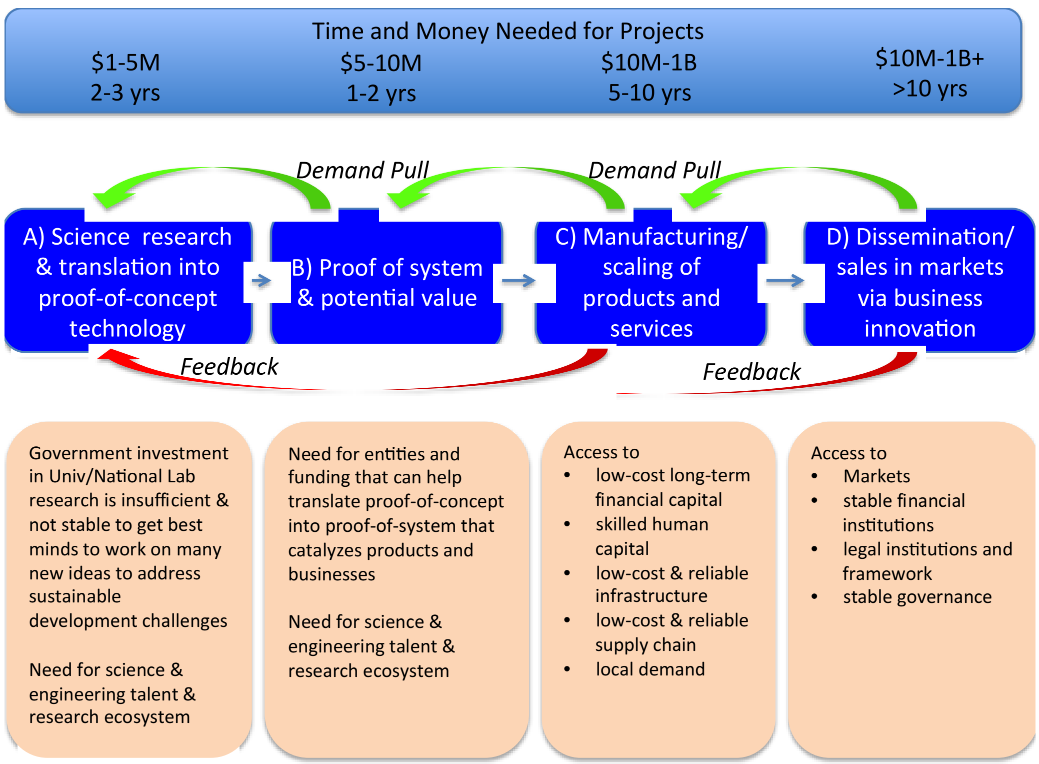


Figure 1: Stages of the technology cycle
(with illustrative figures for time and financial requirements for different stages)

If the proof-of-concept demonstrates potential for real-world application (i.e., the new technology seems to have better performance characteristics and/or lower cost than the incumbent technology for the specific application under consideration) the next step then is to do a more through exploration of the technology through the development of a working prototype/proof-of-system that is a reasonable representation of what the product and associated components eventually would look like. The next step would be an actual demonstration of the prototype or a pilot project that is intended to assess the performance of the technology under actual use conditions.

Once the technology prototype is seen to be performing suitably, then the next step is the development of a product that can be commercialized, which involves taking into account feedback from pilot/demonstration projects, detailed user interactions, manufacturability, as well as market conditions to refine the product characteristics and design. Once the product design is finalized, then the focus shifts to establishing manufacturing infrastructure and then eventual manufacture and dissemination of the product.

Broadly, the amount of funding required increases and the risk decreases as one goes along the technology cycle. Thus, the early stages of the technology cycle, i.e., basic and applied research, are rather exploratory in nature and the likelihood of success in this work leading a specific technology/product is low (although it does lead to advances in knowledge). Given this nature of these activities, that is high risk but with gain in knowledge that is a public good, much of the funding (although not all) comes from the government agencies. And there are numerous examples of forward-looking public investments leading to specific gains as in the case of the DARPA funding of the precursor of the internet and the DOE's funding of horizontal drilling research that has played an central role in the current shale gas revolution. But as one goes along the cycle and the focus is on a specific products that potentially could yield a return, private sources of finance (venture capital for the middle stages of the cycle, i.e., product development and testing, and private equity/commercial finance for the later stages, i.e., manufacturing and scale-up, become available). The scale of needed investments is progressively larger but also the risk is progressively lower.

The importance of the local context also increases as one goes long the technology cycle. Basic and applied research is focused more on understanding and applying fundamental scientific principles and the knowledge derived from this work can have broad application. Therefore the location of this activity in relation to the location of eventual application is not very crucial. But for the results of the research to be successfully translated into a technology, an understanding of user needs is critical, since the technology is intended to address specific needs. In addition to this, an understanding of the conditions and characteristics of the intended market is key to successful product development. And approaches to disseminate the product are very much dependent on other actors in the local ecosystem as well as policies and institutions. Thus the importance of the local context in enhanced the closer one gets to the actual ground-level deployment.

There are some well-recognized gaps in the availability of financing for innovation. First of all, there is a general under-investment in innovation (especially in the earlier stages of the technology cycle, i.e., basic research) by private actors because of their inability to appropriate all the benefits of their investments in the creation of new knowledge (see, for example, Nelson, 1959; Arrow, 1962). [Scientific knowledge is a classic example of a public good, that is a good which has the characteristics of non-excludability and non-rivalry, i.e., the others cannot be excluded from using that good and the use of a good by one individual does not reduce its value to another individual. Other forms of knowledge may allow for excludability (e.g., patents or tacit knowledge) and therefore allow for greater appropriability, which is why firms are willing to invest in latter parts of the technology cycle, where such forms of knowledge are more likely.] Thus if a firm invests in scientific research in a particular area and there is a major advance in knowledge, this advance eventually will benefit other firms also since it is difficult to corral this knowledge and derive all the possible benefits from it. Yet activities such as research that lead to advancements in knowledge provide a social benefit - this then provides a rationale for governments to invest in such activities.

In addition, there also are some finance gaps that occur during the transition between some stages of technology cycle, which also involve transitions from one dominant source of funding to another dominant source of funding. These often are referred to as the "valley(s) of death," in that many technologies die as they traverse this space because of the lack of funding (see Figure 2). The first valley of death pertains to the lack of funding for taking the idea out of the lab (where research funding is available from public and private sources) where the development of the working prototype/proof-of-system is needed. The conventional wisdom is that public sources should not support this step since this is meant to begin exploring the commercial feasibility of the concept; on the other hand, it still is too uncertain and risky for private actors to invest their

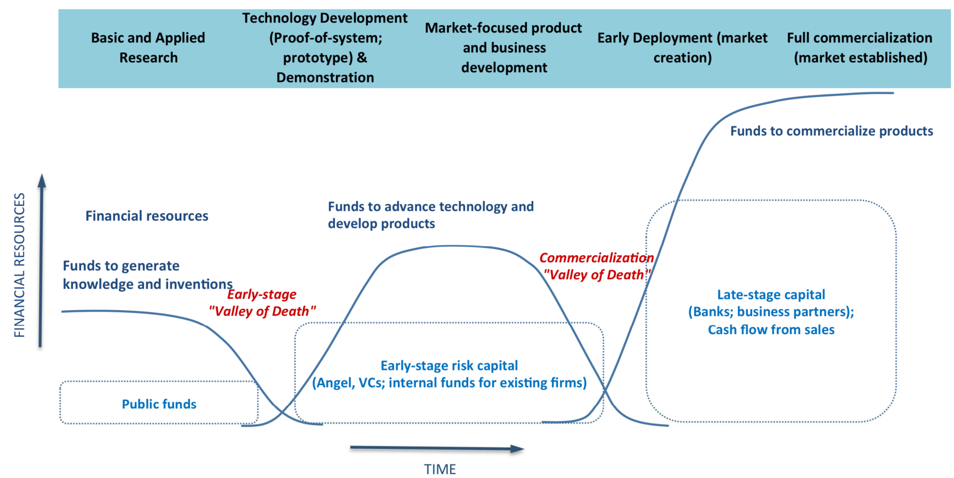


Figure 2: Valley(s) of death in the technology cycle

funds. The second valley of death refers to the space between the availability of risk capital that allows for product and business development and early-market exploration and the commercial capital that is available once the market has been proved. The first valley of death is particularly critical and there have been many public policy efforts to address this gap.

It should be noted that the successful transitioning of a technology from an early stage concept to the marketplace does not only have to overcome gaps in finance but also requires alignment on a number of other dimensions. In fact, the process of technological change is best described as a socio-technical transition, given that producers and users of technology are embedded in a broader social and economic context (Rip and Kemp 1998; Geels 2004). Thus puts the emphasis not just on the development of knowledge but also on the diffusion and use of technology, impacts, and the institutional and societal transformations that are necessary for, and accompany, significant technological change (Geels 2004). With such a perspective, it becomes clear that the focus needs to be not just on the narrow functioning of innovation systems that lead to the development of new technologies but the broader processes that ultimately allow for a shift from one regime to another (Geels 2004). This is also reminiscent of Unruh's notion of 'lock-in' where a prevalent set of technologies and associated infrastructure and practices can impede or prevent the uptake of new technologies, even though they may confer additional benefits for users or add to public goods.

The sustainability transition

In recent years, there has been much analysis and writing on the nature of the sustainability transition. It has now become clear that the sustainability transition is a complex and challenging task and while innovation can play an important role in this transition, there are some key characteristics of this transition that are worth noting (and relevant to the discussion here).

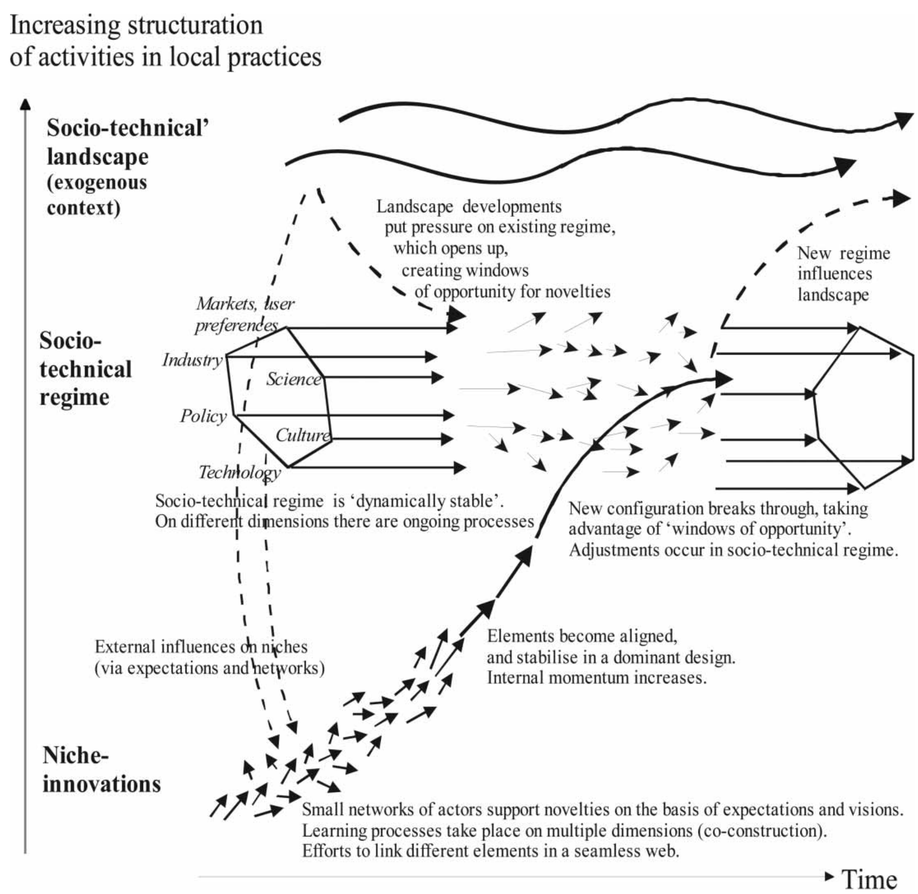


Figure 3: Multi-level perspective on transition (Schot and Geels 2008)

Beyond the general underinvestment in innovation mentioned earlier, the case of public goods such as a clean environment suffers further from another level of underinvestment. Individuals by themselves likely will not pay for such a public good since others may also enjoy the resulting benefit even if they do not pay for it. It also is difficult to coordinate the action of the large number of actors who may all gain from such a public good, and even if one could do so, it may be that different individuals value this good very differently so collective actions again becomes difficult. Therefore business-as-usual, market-driven approaches, which characterize the bulk of technological innovation activities, result in an underinvestment in environmental technologies since the environmental externalities are not fully reflected in the marketplace. On the other side, some actors may also be benefitting from activities that contribute to 'public bads' such as a polluted environment. So a firm that is engaged in the manufacture of some products may be emitting some chemical, which would be termed as an externality of this production. Reducing the emissions of this pollutant would cost the firm money and therefore it has no reason to do so on it own. This lack of adequate signals or incentives to address these challenges leads to situation where the market by itself fails to address these externalities (hence the term 'market failure') that cause public bads.

Therefore we find ourselves in the position that current technological innovation efforts have not addressed the environmental sustainability challenge at the scale and pace required.

Once again, the role of the government is key through both the provision of financial support for technological innovation this area and also facilitating the innovation process through the creation of specific policies and/or institutions. Policy signals to promote innovation for public goods (or reducing public bads), for example, could come in the form of financial disincentives, such as the provision of a pollution tax that then provides motivation to reduce pollution or in the form of legal or regulatory norms that limit the emission of pollutants, which again then creates a market for technologies that help avoid such public bads. Additionally, governments can also support R&D for these technologies as another way to facilitate their development.

But more broadly, radical changes in socio-technical regimes are required for sustainable development (Rotmans and Kemp 2001). Such systems transformations will need to draw on radically new solutions whose translation into widespread use will require significant evolution of organisational and socio-economic structures (See bode et al. 2012).

Smith et al. (2005) highlight that regime transformation depends largely on a combination of two sets of factors – resources (factor endowments, knowledge, and capabilities) and coordination of responses – that together constitute the adaptive capacity for such a transformation. The particular form of the regime transformation depends on how these factors are brought to bear.

A transformation may be said to involve a 'reorientation of trajectories' in response to a stimulus that may come from within or outside the system. In this case, the resulting uncoordinated response is from the within the system, drawing upon the resources within the existing system and changing the trajectory of the system but without a fundamental shift in the regime as such. If there is greater coordination among actors from within the present regime, then the response to the stimulus is categorized as 'endogenous renewal.' But here again since the transformation is being guided by actors from within the system with their interests, values and problem-solving approaches, the changes build on historical paths and are again only incremental in nature. If the response involves resources from outside the system, then a shift in the regime may be possible (termed an 'emergent transformation') as a result of the interactions between actors existing within the system and new ones from outside the system. The lack of coordination here, though, makes the transformation slow and uncertain. But if the regime transformation process not only draws upon resources but also does so in a focused manner with a particular societal objective in mind, then there is a chance for a shift to a radically different regime through a 'purposive change.' (See Figure 4). The participation of actors from outside the regime – whose interests help shape the new regime and resources help facilitate a transformation towards it – is key as is the coordination of these actors and resources. This is not to say that the other transition approaches cannot contribute to radical shifts – for example, an emergent transformation may pave the way for a more coordinated response and eventually purposive transformation.

Given the radical transformation that sustainable development entails, such coordinated efforts that allow for purposive change and eventually lead to regime shifts are likely to play a central role.

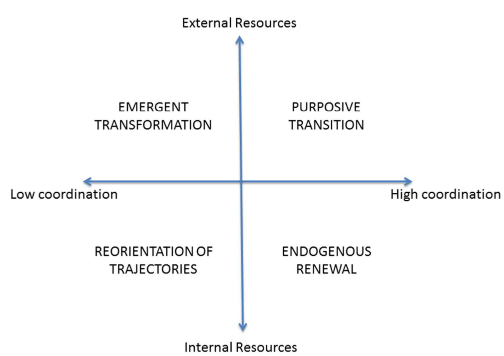
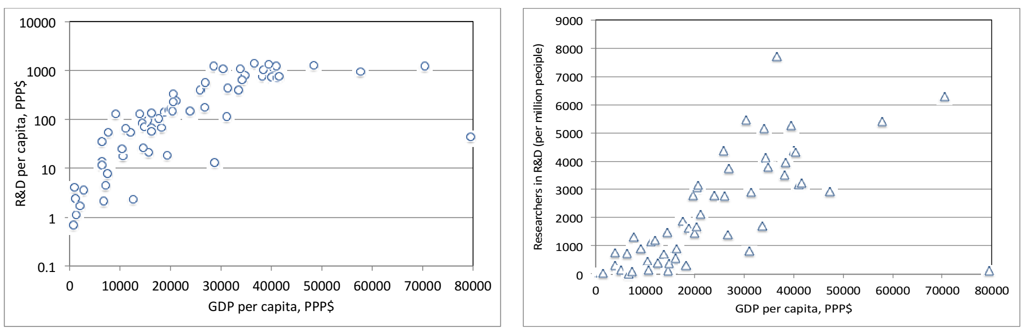


Figure 4: Typology of sustainability transitions (adapted from Smith et al.,2005)

But a socio-technical regime shift cannot happen overnight. New technologies that are introduced into the marketplace have to compete with existing technologies, find favor with users (by offering better performance features or other attributes such as lower cost), and try and become a dominant option in the user space. This kind of technological competition happens every day in the marketplace (as a form of 'endogenous renewal' to use the term just introduced above) but if the new technologies offer public benefit, then there is rationale for a public policy response to manage their introduction as a way of leading to a purposive shift. Since a new technology occupies a niche, an important role of public policy is assist in what scholars have referred to as 'strategic niche management' (Kemp, Schot, and Hoogma 1998). This involves creating support conditions for the technology to survive and thrive in its introductory niche, which could involve providing regulatory support, promoting interactions between various actors, nurturing the technology and assisting in its refinement, and learning from user interactions.

The case of developing countries

While sustainability challenges are most stark in developing countries, these countries also generally have the least technical and institutional capabilities to leverage technology to meet these challenges. Just to illustrate with a few figures, we find that the poorer countries invest far less on R&D in comparison to richer countries on a per-unit-GDP as well as a per-capita basis – in fact, on the latter metric, the difference can be as much as *2-3 orders of magnitude* (see Figure 5). While some developing countries (most notably, China) have been increasing their R&D investments in recent years, overall OECD countries still accounted for over 75% of the global R&D expenditures in 2009 (NSF 2012).



Not surprisingly, then, the number of researchers per million people is also much lower in poorer countries (and this, in a manner of speaking represents the stock of human capita in the country). And lastly, looking at the broader picture of

Figure 5: Cross-national perspective on R&D investments per-capita and number of researchers per million population vs. GDP (2010 data)[2]
(R&D investments from UNESCO, other data from World Bank)

innovation capabilities, we find that the Global Innovation Index (GII), which is a composite measure of performance on a large number of indicators of innovation, taking into account input to innovation (human capital & research, infrastructure, institutions, market sophistication and business sophistication) as well as output measures (knowledge & technology and creative outputs), also indicates a similar strong correlation between GDP/capita and innovation capability (GII 2013). Even major emerging economies, which in recent years

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[2] As the figures show, the data on R&D investments and number of researchers was mostly available for countries with medium or high levels of income. This illustrates even more starkly the facts underlying the trends presented in the graph – many developing countries do not systematically collect such data about their S&T systems.

have made significant efforts to strengthen their S&T system, still lag well behind their industrialized counterparts on innovation indicators.[3]

International cooperative approaches

This combination of sustainable development needs and the (relative paucity of) developing country capabilities, has motivated a number of international collaborative programs, both within and outside the United Nations, to help developing countries implement technologies to address urgent environmental and developmental challenges. Most of these programs, though, are focused mostly on the downstream side of the technology cycle, namely on exploration and creation of markets and diffusion of technologies (see Figure 6). In the area of climate change, for example, a detailed study found that international technology collaboration often does not involve R&D or technology development but rather focuses on facilitating the sharing of knowledge and experiences (UNFCCC 2010).

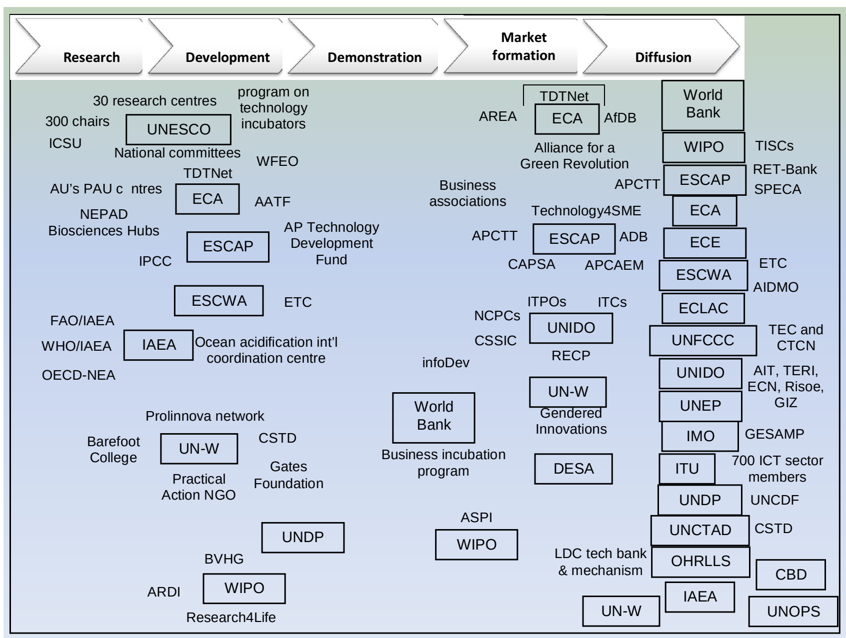


Figure 6: International technology facilitation - UN contributions (boxes) and selected partnerships (without boxes) (Source: UN 2012)

While these are useful in addressing many challenges by leveraging existing technologies, the scale and nature of sustainable development challenges doubtless will require the development of new and improved technologies. Thus a set of international cooperative activities focused on the upstream side of the technology cycle that could deepen and enhance efforts and activities to generate new technologies potentially could make a significant contribution to the achievement of sustainable development goals. This would fill the gap that

3 The 2013 GII ranks China 35th, South Africa 58th, Brazil 64th, and India 66th. Other than South Africa (and Mauritius), the highest-ranking country from sub-Saharan Africa is Uganda, ranked 89th.

developing countries are unable to fill themselves, given their limited technology and innovation capabilities and financial resources.

Furthermore, given that success in early-stage technology development and its translation into commercializable (or disseminable) products is less dependent on proximity to the user context (unlike diffusion, where the local context is key, as mentioned earlier), this also would allow technological and innovation capabilities from around the world to be leveraged. The development of new and improved technologies that offer a performance and/or cost advantage would ultimately also facilitate dissemination of these technologies.

Institutional approaches to enhance innovation

Given the uncertainties inherent in the innovation process, both in terms of research yielding desired technological solutions that can address specific needs, and the translation of a technology into viable product that is disseminated at scale, there have been a number of institutional approaches that are intended to overcome these barriers. Some of the more recent ones include the Advanced Research Project Agency – Energy (ARPA-E), product development partnerships (PDPs) in the health area (e.g., Global Alliance for TB Drug Development, Medicines for Malaria Venture, and International AIDS Vaccine Initiative), and Innovation Prizes. We briefly will discuss these below.

Advanced Research Project Agency – Energy (ARPA-E)

ARPA-E is an organization, launched in 2009, that provides thought leadership, funding and stewardship of breakthrough and potentially disruptive energy technologies. ARPA-E's strategic mission is to enhance U.S. economic, energy and environmental security and ensure U.S. lead in advanced energy technologies. In doing so, it aims to reduce greenhouse gas emissions, reduce energy imports and increase energy efficiency.

The agency is modeled after the Defense Advanced Research Project Agency (DARPA)[4] and focuses on "high-potential, high-impact energy technologies that are too early for private sector or other DOE applied research and development investment … [which] can be meaningfully advanced with a small investment over a defined period of time" (ARPA-E 2013). These technologies potentially could create initiate entirely new techno-economic learning curves (see Figure 7) that are too risky for the private sector to initiate but, if successful in the future, they would create the foundation for entirely new industries (as was the case with the computer networking (which enabled the internet) and GPS, which

[4] The Defense Advanced Research Projects Agency (DARPA) that was established in 1958 (as ARPA) in response to the launching of the Sputnik so as to avoid 'technological surprises.' DARPA aimed to address the problem of transformative innovation by developing an innovative approach to foster and help implement radically new and transformational technologies (Bonvillian and Van Atta 2011). DARPA's program managers help 'bridge the gap' between scientific advances and application through new technology trajectories. In order to do so, they (1) identify directions, (2) seed common themes, (3) build community, (4) validate new directions and (5) not sustain the technology" (i.e., avoid the technology become reliant on DARPA funding). (Fuchs 2010)

were funded by DARPA, and horizontal drilling (which has underpinned the shale gas revolution), which was funded by the Department of Energy).

As with DARPA, ARPA-E takes a project-based approach, focusing on transformational advanced energy technologies. It uses what Bonvillian and Van Atta (2011) refer to as a 'right-left' model in that the ARPA-E project managers begin by zeroing in on what they would like the outcomes to be at the downstream (i.e., right) end of the innovation pipeline, and then fund projects on the upstream (i.e., left) side that could achieve such outcomes. Therefore the research is not open-ended but meant to address specific technology challenges and achieve specific desired outcomes. ARPA-E awards are of two kinds: "focused" programs that aim to address a specific energy challenge; and "open" solicitations, which provide support for ideas that may be game-changers in energy technology (ARPA 2013).

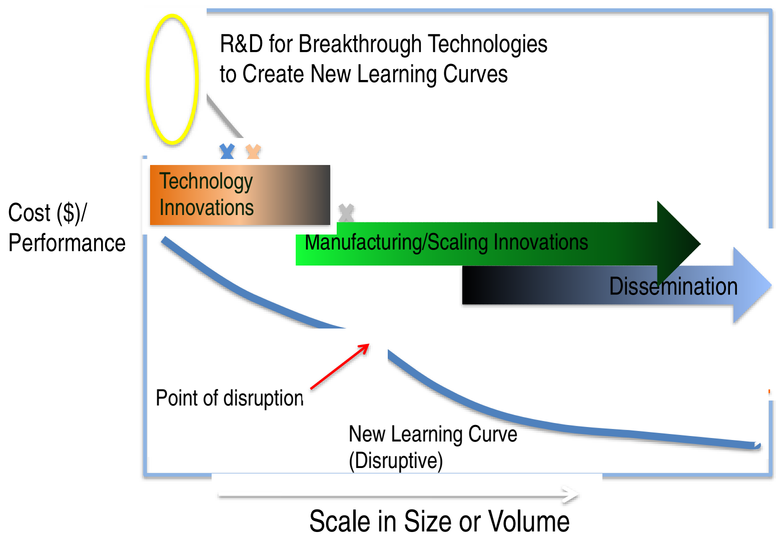


Figure 7: The creation of new learning curves through R&D

ARPA-E's program directors and technology-to-market advisors together play a key role in meeting the Agency's objectives: the program directors, who are technically well-respected and often have academic as well as industrial experience, play a key role in the selection and shepherding of projects as well as providing technical guidance to the awardees; the technology-to-market advisors provide practical training as well as business and market perspectives to the awardees to help their projects succeed and advance technologies into the market (ARPA-E 2013).[5] As with DARPA, the role of the program director is key: it is neither leaving everything to the market, nor is it picking technology

[5] As Fuchs (2010) points out, DARPA program managers are embedded in the ecosystem and yet have a high-level perspective of the field. Therefore they are "in constant contact with the research community, understanding emerging themes, matching these emerging themes to military needs, betting on the right people, bringing together disconnected researchers, standing up competing technologies against each other, and maintaining the systems-level perspective critical to orchestrate … disparate research activities." They also "re-architect social (and professional) networks amongst researchers" in order to "identify and influence new technology directions."

winners (Fuchs 2010) but more to be a part of the system and identify and help realize technology opportunities.

As of Feb 2014, ARPA-E had invested over $900 million across 362 projects through 18 focused programs and two open funding solicitations. Also, 22 ARPA-E projects had attracted more than $625 million in private-sector funding following ARPA-E's investment of approximately $95 million. In addition, at least 24 ARPA-E project teams had launched start-ups to commercialize their technologies, and more than 16 ARPA-E projects had partnered with other government agencies for further development of their technologies.[6]

What makes ARPA-E successful?

The success of ARPA-E depends on four factors - people, culture, funding and leadership – as detailed below.

1. People: Highly selective in recruiting top-notch active scientists and engineers with certain key attributes from R&D community as Program Directors (PDs) for finite time (3-5 years). This creates a sense of urgency and mission because it is not a permanent job! Key attributes include: deep expertise in at least one area of research; entrepreneurial in pursuing research in other areas; ability to see connections and leveraging opportunities between different fields to innovate new technologies; ability to create a community of researchers and provide thought leadership.
2. Bottom-Up Programs: PDs are not told what to do, but rather they take the leadership to create new programs. ARPA-E maintains very high expectations for creativity & thought leadership for PDs to spread their wings and identify "whitespace" to create new programs with audacious but realistic stretch goals via internal debates and external workshops with research community. Programs are sunset when PDs leave.
3. Decision Making: PDs are given autonomy in decision-making based on their knowledge of science and engineering with rigorous technical review and feedback from external community. No non-technical external influence. Empower PDs to make decisions about whether projects should be funded or terminated based on their judgment of technology and teams, but hold them accountable about the success of the program as a whole.
4. Funding Excellence: Fund few top-notch projects with adequate funding so that they can make a dent – no dilution in excellence by funding many. Each program contains 15-20 projects with $30-40M over 3 years, managed by a PD. Each PD can manage 2-3 programs during their tenure at ARPA-E.
5. More than just money: Active program management by PDs with project site visits, technical scrutiny and support, networking within community, stewardship beyond ARPA-E. It is more than just money!
6. Ideas Fail, People Don't: Encourage failing fast and terminate projects if they are dead ends. Create environment with no shame in failing, and encourage researchers to return with better ideas.
7. Success: Define success (project, individual, organizational) early before others define it for you.

[6] http://arpa-e.energy.gov/?q=arpa-e-news-item/arpa-e-projects-attract-more-625-million-private-funding, accessed July 6, 2014.

Product Development Partnerships (PDPs)

PDPs are a new approach in public health that is intended to develop and deliver solutions for specific health challenges – often neglected diseases – that represent major health risks yet traditionally have received limited attention, especially within private sector (Moran 2005; Mahoney 2011). PDPs are intended to overcome key factors that have impeded investments for addressing developing-country health needs: these include high costs and technical risks in R&D, low returns in developing-country markets; and the complexity of delivering solutions in such markets (Grace 2010).

In some sense, a PDP is akin to a virtual R&D organization that outlines a common goal, provides overall project guidance, organizes and manages collaborations among various researchers, provides technical oversight, as well as supporting other activities that can help bring the product to the market. Projects can involve researchers from academic, industry (large pharmaceutical companies, small biotechnology firms), government laboratories, as well as NGOs. On the funding side, PDPs often cobble together support from multiple donors including private foundations, government funding agencies, in-house contribution from industry, and bilateral aid donors and multilateral agencies (Grace 2010; Moran et al., 2010). See Figure 8 for an illustration of a PDP.

While the general approach may be common, PDPs may focus on specific technologies (vaccines, diagnostics, etc.) or disease types (e.g., malaria, AIDS) or both (Grace 2010, Moran 2010) and may take a variety of organizational forms.

A study of PDPs suggests that these approaches result in drug development trajectories that are comparable or faster than industry and significantly faster than public programs (Moran 2005). They also are seen as being more cost-efficient than other comparable programs. Their ability to marshal scientific and technical resources that are required to address specific projects (or parts thereof) as well as their portfolio approach (in projects as well as funding sources) allows for better risk management from both the point of allocating resources to scientific activities as well as of the perspective of the funder (Moran 2010). According to Mahoney (2011), the involvement of PDPs in different aspects of technology development and delivery contributes to their success – these includes R&D, attention to national and international markets, manufacture, IP management and regulatory systems.

In addition, PDP activities also have co-benefits such as strengthening of clinical trial infrastructure for neglected disease in developing countries and better understanding of developing country disease burdens and markets that may stimulate private sector involvement beyond that through PDPs (Grace 2010).

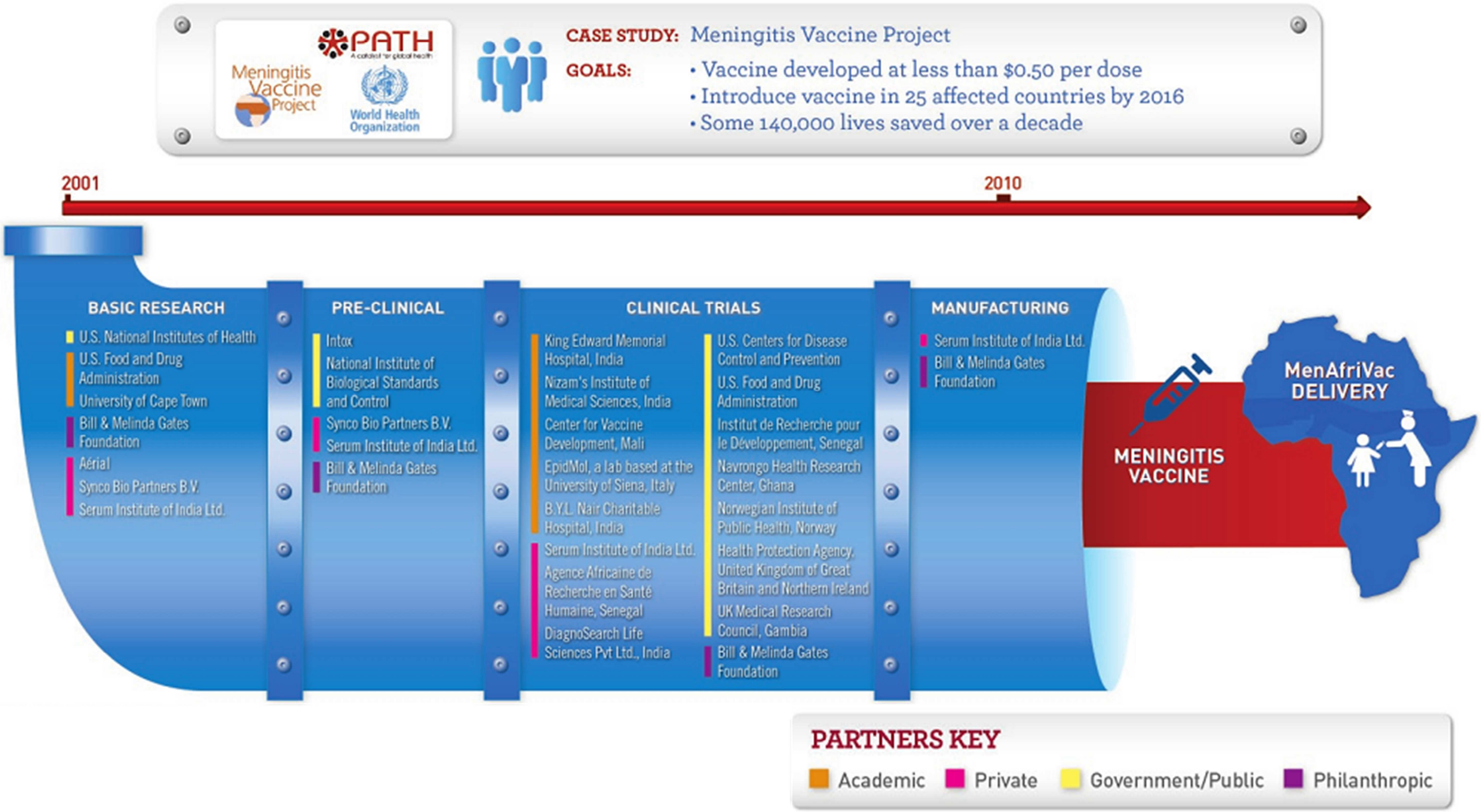


Figure 8: Illustration of a PDP (Source: Research!America)

A significant amount of the funding is now flowing to PDPs in the public health area. In 2007, 23% of the total global funding for neglected diseases flowed to PDPs (and 42%, if NIH as a source of funding is excluded from the analysis, since it contributes only a minuscule amount financially to PDPs), amounting to about $470 million (Moran 2010). [Only a fraction of this amount, though – just over 12% – is invested in activities in developing country organizations (Moran 2010).] As Moran points out, despite their recent emergence as an organizational form on the global stage, PDPs occupy an important role in the global R&D landscape for neglected diseases.

The arrival of the PDP model has resulted in a substantial and positive transformation of the neglected disease pipeline. As of 2009, ten new technologies developed by PDPs had been brought to the market, with an additional 122 candidates in the development pipelines (including 90 biopharmaceutical candidates and 32 diagnostic/vector control candidates) (Grace 2010). This is in significant contrast to the earlier scenario: of the 1393 medicines developed 1975 and 2000, only 16 were for diseases in least developed countries, with only 20 projects on neglected disease during this period.

Innovation Prizes

The concept of innovation prizes is not new: in fact, possibly the most famous innovation prize was the Longitude Prize of £20,000, offered by the British government in 1714 through an Act of Parliament, for a solution that could determine longitude to within 30 miles.[7] But the concept recently has received renewed attention as a way to get a specific desired outcome (McKinsey 2009, Murray et al 2012), driven in part by the success of the $10 million Ansari X Prize for launching a reusable manned spaceship into sub-orbital space twice within 2 weeks. [The prize was launched in 1996 and won in 2004 by SpaceShip One, which was developed by Mojave Aerospace Ventures, which was a joint venture between Paul Allen and Scaled Composites, Burt Rutan's aviation company.]

The overall prize purses have increased dramatically over the past couple of decades, with the purse for large prizes between 1970 and 2009 estimated to have increased more than 15-fold and exceed $375 million at the end of that period (McKinsey 2009), with foundations and corporations accounting for about two-thirds of this total. Much of the increase is attributable to incentive prizes (which we will refer to as innovation prizes), which accounted for 3% of the total purse in 1990 to 78% in 2007, with a shift towards areas such as climate, energy, and environment (McKinsey 2009). [Incentive prizes are intended to induce a specific outcome, in comparison to recognition prizes that recognize some achievement.] Even governments have begun to recognize the utility of prizes to solve tough challenges (see, for example, OSTP 2009) and, in

[7] Although the prize was not formally awarded for a variety of reasons, it did lead John Harrison, a person with only limited education but an interest in developing clocks, to invent a series of very accurate chronometers that met the specifications of the prize and were the precursors of marine chronometers (see http://www.royalnavalmuseum.org/info_sheets_john_harrison.htm).

fact, the 2010 America COMPETES Reauthorization Act authorized Federal agencies to pursue prizes as a way to achieve their objectives. More recently, the UK Department for International Development (DFID) launched a £10 million program on prize-driven innovation for environment and development and Nesta, the innovation charity from the UK, has launched a £10 million Longitude 2014 prize that is focusing on diagnostics for antibiotic resistance.

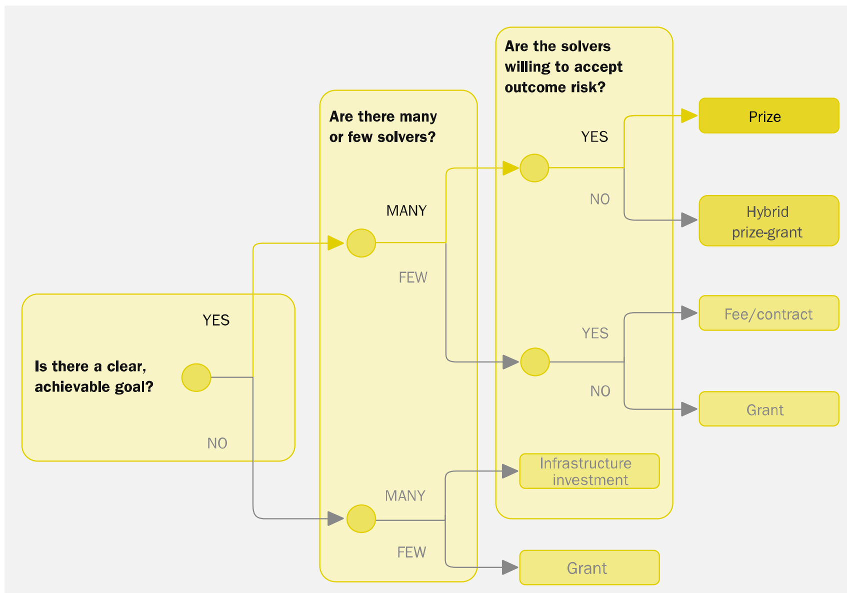


Figure 9: Choice of prize over other instruments for achieving specific objectives. (Source:McKinsey 2009)

Innovation prizes serve as a complement to the tradutional "R&D-push" model of technology development, where actors were offered R&D funding with the expectation that the activities will lead to desired outcomes. Innnovation prizes turn this model on its head by offering a prize on the achievement of a previously-specified outcome, thereby motivating multiple actors to participate in a proiblem-solving exercise whuch might have been ignored by the markets. (See Figure 9 for the decision-tree for choosing an innovation prize.) While ostensibly the main reason motivating particiopation is the monetary award, in reality participation is driven by a number of factors such as publicity, education, reputation-building, passion for the topic, and exploring the viability of alternatives (Murray et al. 2012).

This approach offers a number of advantages, in particular shifting the risk, through its results-based model, from the funder to the performer (since the prize is paid out only if the specified outcome is achieved). This also allows for more audacious and complex objectives. By specifying a performance outcome, innovation prizes can also be technology- or approach-agnostic, thereby pulling in potentially a larger number of participants (potentially from across the world) into the exercise than a traditional approach would. In fact, the US National Research Council, in its report on innovation prizes, specifically notes that main reason for offering a prize is to "attract different parties to contribute to a recognized societal or scientific objective." (NRC 2007) In adidtion, an incentive prize could also induce investments by various particiopants that far exceed the purse itself – it was estimated that the 26 teams from 7 countries that competed for the $10 million Ansari X Prize together invested $100 million and since then, there has been more than $1.5 billion dollars of public and private investments in the private spaceflight industry.[8] In addition, incentive prizes can also draw attention to, and create public awareness about, a particular issue and mobilize talent that may not have turned its attention to a particular problem otherwise. A prize may, in fact, create market where none existed, as is the case with private spaceflight industry spawned by the Ansari X Prize.[9]

In fact, Murray et al. (2012) suggest that innovation prizes should not be seen just a mechanism to stimulate innovation where markets have failed, but "viewed as a novel type of organization, where a complex array of incentives are considered and managed in order to assure that successful innovation occurs."

While these three institutional models are very different, there are some commonalities among them: they all are outcome-oriented, they all have a good view of the eventual 'market' for these technologies, and the institutions themselves play an active role in helping bridge the innovators to the marketplace (through market awareness as well as facilitating formation of linkages with market actors/other disseminators). In such a way, they are serving as bridges between research and application, thereby both increasing the effectiveness of, and accelerating, the process through which new technologies are developed, refined, and brought to the users

Advancing innovation for sustainable development – a proposal

We present here a proposal with three interlinked elements that aim to meet the global gap in the upstream part of the technology cycle (see Figure 10), namely the development of technologies and proofs-of-system that could make a significant contribution to addressing sustainable development challenges and complement existing programs in the downstream part of the technology cycle. In doing so, we propose leveraging emerging institutional models discussed above that take different, yet complementary, approaches to stimulating, facilitating and managing innovation so as to overcome market failures and yet also link up with the markets for eventual impact.

[8] http://space.xprize.org/ansari-x-prize (accessed July 3, 2014)

[9] In fact, Virgin Galactic, a commercial spaceflight company launched by Richard Branson, is planning to use SpaceShip Two (built by Scaled Composites), which is based on the SpaceShip One concept.

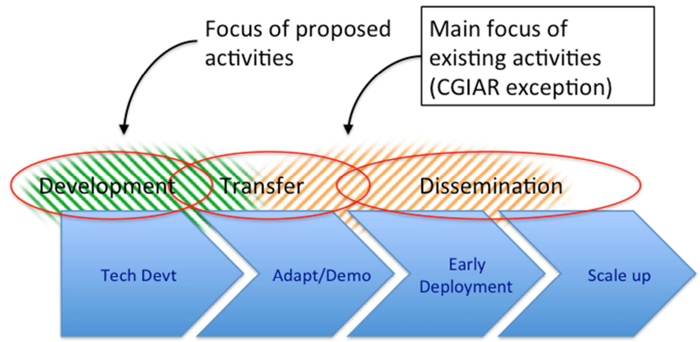


Figure 10: Focus of proposed activities to facilitate sustainable development

The heart of the proposal is the establishment of an organization – an Advanced Research Projects Agency for Sustainable Development (ARPA-SD) – that would provide the overall guidance, thought leadership, and strategic funding for three interlinked activities (see Figure 11):

1. Nascent technology development efforts (within individual academic and industrial organizations) that can contribute to addressing particular sustainable development challenges.

   In this case, the area of application will be clear but there might be multiple avenues to developing a foundational technology that could make a transformational contribution to that area. Thus this element would be building a bridge from science to early-stage technology (as is the case with ARPA-E).

2. Formation of product development partnership (PDPs), which bring together a number of technical and market actors to develop a product that can be disseminated as well as develop a dissemination strategy, again to meet a specific sustainable development goal.

   In this case, the focus is on the development of a specific product rather than a foundational technology. Thus there would be less exploratory work but more of a targeted effort to bring together S&T assets to develop a product.

3. Innovation prizes for particularly challenging sustainable development concerns.

   In this case, while a particular desirable outcome can be specified *ex ante* (for example, the performance and cost specification of a water filter), there may be multiple technological possibilities to achieving that goal. Thus this is a technology- and pathway-agnostic approach that allows multiple actors to engage independently to reach that objective.

The primary role of ARPA-SD would be to provide overall guidance to, and management of, the portfolio of activities envisaged here by virtue of its personnel's understanding of the technology opportunity space in relation to needs articulated by various developing countries.

This would require understanding of both the local 'market' condition under which these technologies would be disseminated (and therefore interactions with local experts with familiarity of the economic, social, cultural and policy milieu of the potential recipient countries that would influence technology dissemination) as well as relevant scientific and technical trajectories (and therefore engagement with a range of scientific and technical communities). Thus the Program Directors (PDs) would have to be rather unique individuals (as in the case of ARPA-E) with impeccable scientific credentials and credibility but also an understanding of, and appreciation for, the application space.

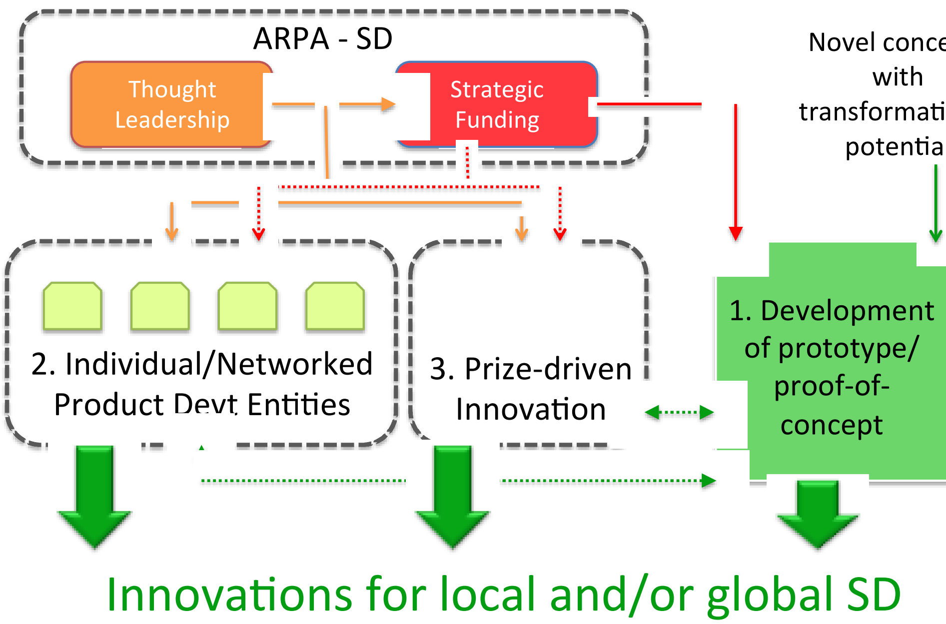


Figure 11: Schematic of interlinked activities under ARPA-SD

For the first institutional element,[10] i.e., programmatic support for development of early-stage technologies, each PD would be responsible for identifying – through engagement, as mentioned above, with the scientific and technical community as well as the dissemination community – program areas that could make a significant positive contribution to sustainable development. For example, a program on next-generation energy storage materials could make an enormous contribution to dissemination of off-grid renewables in developing countries. Box 1 in the appendix outlines the questions that ARPA-E uses in order to select new programs and a similar set of questions could be used to guide ARPA-SD in its decision-making. Each PD may be responsible for ~3 program areas and within each program area, there may be about 10 projects. The tenure of each PD would be ~ 3-4 years, so each program (and projects

[10] The design of ARPA-SD, especially the first institutional element, draws heavily on the ARPA-E experience.

under each program) being managed by that PD would have a 3-year cycle. This will give a sense of both urgency and boundedness to the programs.

The PD then could solicit technical proposals by researchers from across the world, which would then be evaluated for the scientific feasibility, the potential of the proposed team to achieve the proposed outcomes, as well as the potential for such an idea, if successfully translated into application, to make a significant contribution to sustainable development. In addition to having the proposals reviewed by the top technical people in the world, the PD and his/her colleagues would also be involved with this review process.

Unlike most other scientific grant-making, the PD and his/her team would take a hands-on approach with the grantees, from sitting down with them and developing technical milestones, then engaging with them often, shepherding their work, connecting them up to other researchers, and helping them meet their milestones (and understand reasons for missing milestones, in case that happens, and work with them to sort out any problems). But the PDs also have to be willing to terminate a project if it turns out that a team is not able to meet its milestones (or if the concept is not working out). Thus failing, although undesirable, is seen as part of the high-risk/high-reward approach and it is understood that it is better to declare failure on a project early rather than continue on otherwise. The PD would also bring together grantees in a particular program so as to build a sense of community amongst these researchers and thereby promote exchange of ideas and knowledge to enhance the chances of success (which might mean a demonstration of a technology or the development of a prototype, for example).

In fact, success for a project here would be measured not just in terms of publications and patents, although these are necessary for any scientific activity but also in terms of development and performance of a technology/prototype as well as movement towards market (which may include partnerships with firms, licensing, or spin-offs). Ultimately, the success for ARPA-SD has to be measured in terms of its positive contribution to sustainable development.

For the second institutional element, i.e., product development entities, these basically would be entities that organize product development partnerships that aim to solve specific SD challenges by bringing together a constellation of actors from the private and public sector to jointly engage in R&D to develop the appropriate product as well as to take it to market (with each actor providing complementary skills – see Figure 8). Each PDP would be constituted, with guidance from the PDs, for that product and would be disbanded subsequently. As with the previous element, the technical background of the PD as well as the bird's-eye view perspective will be valuable for overseeing the PDP entities in a manner akin to the projects in that the PD and his/her team would take a hands-on approach to managing the PDP, reviewing its progress, and providing guidance to help move it forward. The manager of each PDP would be like the principal investigator of a project under the first element and work closely with the PD for this purpose.

Similarly, for the third institutional element, i.e., the innovation prize element, the PDs would judge the value and the feasibility of innovation prizes to solve specific challenges in their program area. Each prize would be organized as a separate entity, therefore, in a sense, again like a project under the first element, with the manager of the prize process acting like a principal investigator. The manager of a prize would work with the PD, other technical experts, and potential users to clarify what the prize objectives are and then accordingly to design the prize (i.e., develop the *ex ante* technical performance specifications – for example, a water purifier that cleans a specified quantity of water to specified level of cleanliness in specified time at some reasonable cost), which is the most critical part of the prize process. The prize manager also would be responsible for the operation and management of the prize.

The box below highlights key features of the three institutional elements.

Institutional Element	**1. Early-stage Technology Development**	**2. Product Development Partnerships (PDPs)**	**3. Innovation Prizes**
Objective	Develop foundational technologies that can be transformative in chosen areas relevant to SD	Develop products that can directly address specific SD challenges	Develop products that can directly address major SD challenges
Rationale for choice of approach	Specific area of application; early-stage so technological disruption possible	Very specific technological objective/application (e.g., a vaccine); complex product requiring complementary technical assets; reasonably clear technical pathway(s); small number of actors	Well-specified, grand, objective (multi-criteria objectives possible); Multiple potential and widely varying technical pathways; multiple potential actors
Approach	Support applied research projects that bridge science with early-stage technology development; facilitate translation to market through linkages	Establish product development partnerships involving private and public actors for R&D, translation to market, and dissemination channel	Provide well-specified technical specifications *ex ante*; purse and publicity to attract multiple players; facilitate translation to market
Overall vision	Program Directors	Program Directors	Program Directors
Day-to-day management	Principal investigator of project	PDP manager	Prize Manager

Governance and implementation

The ARPA-E experience shows that a few conditions are absolutely essential for such an organization to be successful:

1. The quality of the people (Director and PDs) is essential. These must be people who are active researchers with the highest scientific credentials and respect within the community (while they could be from academia or industry). But they must also have some understanding of (or willingness to understand) the application space.
2. While larger institutional objectives (and even problem areas) may be decided by policy-makers, technical decisions must be taken by the Director and the PDs. To use the succinct phrase from Narayanamurti et al. (2009), the personnel must be "insulated but not isolated."

3. The institution cannot be bureaucratic. It must be nimble and responsive, yet technically solid and robust.
4. A stable source of funding, isolated from political uncertainties, is key. This must be seen as a long-term activity rather than as short-term effort that is only looking for quick, one-time, breakthroughs. This is also highlighted by Foray et al. (2012) in their review of mission-oriented R&D for meeting social challenges.

The objective of this proposal is to significantly enhance the institutional capabilities to develop technologies to meet SD challenges. While much of the motivation for such a proposal comes from urgent SD needs in developing countries combined with their limited technological capacity to address these needs, the contributions of an ARPA-SD should be useful to both developed and developing countries. To reiterate, while the institutional goals would need to be set by policy-makers from developed and developing countries, the problem-solving approaches would be determined by technical experts within the organization. Such an effort could be funded through contributions from private actors (e.g., foundations) as well as developed and developing countries – we already are seeing such partnerships between varied private and public sources (in PDPs, for example).

This model, in a sense, is creating a lean and virtual R&D institution – ARPA-SD – which leverages existing capabilities around the world in a strategic manner that fits with the desired set of outcomes. It does not establish a brick-and-mortar institution and therefore can stay nimble and evolve as SD needs evolve.

While the proposal contains three institutional elements, which are complementary in nature both in terms of approach to enhancing innovation as well as possible outcomes and have the potential for significant synergy and mutual reinforcement, it also is possible to advance on different elements at a different pace.

Appendix 1

ARPA-E Program Creation and Execution Strategy

The ARPA-E program creation strategy operationalizes the technology strategy. The five stages ("Five E's") of ARPA-E's program creation strategy are:

1. ENVISION: analyze the energy landscape for gaps and opportunities and identify whitespace for new programs
2. ENGAGE: engage the technical community to refine a nascent program concept and create a competition for ideas
3. EVALUATE: carefully select projects based on a multistage review process
4. ESTABLISH: quickly and efficiently negotiate technical roadmap, funding and cooperative agreements
5. EXECUTE: Actively manage programs and projects

As part of the program creation process, ARPA-E Program Directors reach out to a wide range of experts, since fundamental discoveries in multiple disparate disciplines often enable a technology only when considered in aggregate. Because balkanization and the formation of silos are common phenomena in science, apparently unrelated but enabling discoveries might not be apparent to practitioners of any one field.

ARPA-E's program creation strategy serves to quickly and efficiently vet technology ideas and convert those ideas into contracted programs. This five-stage process has not only increased the speed and efficiency but has also improved the quality of the merit reviews and subsequent project management. The total process from conception of a new program to contracting awards (the first "4 E's") takes 6-8 months, with contracting down to approximately 3 months. ARPA-E achieves this with a program development process that includes extensive up-front research and workshops co-hosted with other DOE program offices and technical community members. ARPA-E also employs a thorough merit-based peer review process. Further, ARPA-E has embedded dedicated procurement and legal teams, allowing ARPA-E to achieve exceptional speed and efficiency for processing awards from announcement to signing contracts.

1 Envision

Technology investments are carried out through programs. Programs are created through an iterative process that begins with a scan of the energy landscape (including technology, market, and regulatory factors) to identify gaps and opportunities for investment. These gaps and opportunities are translated into program concepts that undergo rigorous internal debate and external review. ARPA-E Program Directors hold technical workshops and coordinate with other DOE offices and federal agencies, as well as groups outside of government, to gather input on untapped technical opportunities. Notably, all ARPA-E programs are vetted in workshops, but not all workshops necessarily lead to programs.

2 Engage

Following the technical workshops and collaborative discussions, a Program Director identifies a possible new program topic. The Program Director defends the new program through consultation and debate involving all Program Directors, producing answers to a standardized set of criteria that justifies why ARPA-E investment is needed (see Box 1). When appropriate, the Program Director refines the program concept, incorporating internal and external feedback, and presents the program to the Agency Director. If approved, a new ARPA-E program area is created, and a funding opportunity announcement

(FOA) is released, soliciting project proposals.

Box 1: Questions to be answered to create new programs

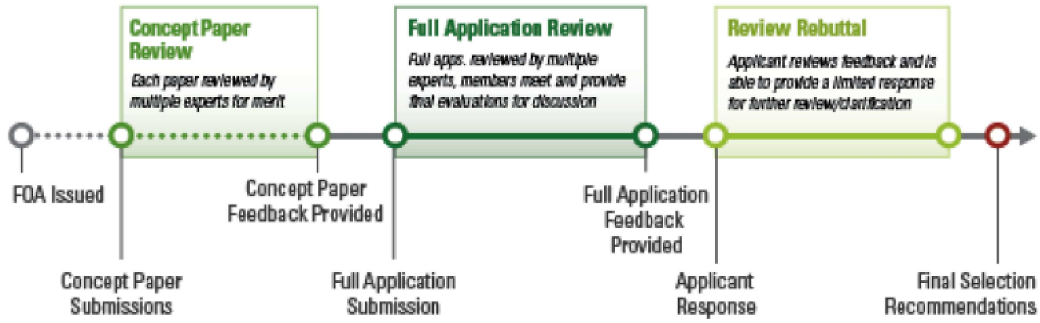
1. **What is the technical problem to be solved and what is the global landscape of this problem – science, technology, markets?**
    a. *What are the major gaps and "whitespaces" in technology?*
    b. *Is the science understood and can it be translated into a technology to address the whitespaces? Do we know the theoretical limits and how far we are from them?*
    c. *Are there multiple competitive approaches to create new learning curves that are both transformational and potentially disruptive?*
2. **How will ARPA-E "move the needle"?**
    a. *Why aren't people investing in this technology concept today?*
    b. *Will ARPA-E investment overcome a key technical barrier that otherwise cannot be overcome?*
3. **If the program is successful, will it matter?**
    a. *Will it address ARPA-E's statutory goals?*
    b. *Will the technology scale in cost and volume?*
    c. *Will it attract private sector investment in the future?*
4. **Who are the potential performers of this research?**
    a. *Does the community of research exist or does it need to be created?*
    b. *What is the approach for engaging and building this community?*
5. **Who are the potential customers and who will adopt this technology?**
6. **What are the external risks to the long-term success of the program?**
    a. *What are the market/regulatory risks that the Technology to Market (T2M) team can help navigate?*
    b. *What are the political/cultural/economic risks that are beyond ARPA-E's control?*
    c. *Would success in the program require other technology advances (either after the program is completed or in parallel) before adoption?*

3 Evaluate

ARPA-E carefully selects projects for funding through a multistage review process. During proposal review, ARPA-E solicits expert perspectives from academia, federal agencies, national laboratories, and industry to ensure support of the most promising technologies. World-class scientists, engineers, and leaders from the technical community bring the most relevant expertise and knowledge needed to vet potential projects. ARPA-E reviewers evaluate applications over several weeks, and then come together for a review panel meeting.

ARPA-E has introduced an innovation in the review process. Before a decision is made about a proposal, a key component of the ARPA-E evaluation process is the opportunity for the applicant to provide a *rebuttal* of the panel reviews. The applicant response period ensures that ARPA-E avoids misunderstandings by asking clarifying questions about the application.

The Program Director is empowered to make decisions of particular projects after integrating the information from the panel reviews and the rebuttal. The Program Director then presents and justifies the decision to the Director of ARPA-E for final selection of awards. During this stage, the Director could potentially change some decisions.



ARPA-E Project Selection Process

4 Establish

Once projects are selected for funding, ARPA-E moves quickly to develop the necessary legal agreements. With dedicated procurement and legal teams embedded within the Agency, ARPA-E has a streamlined agreement negotiation and award process that allows projects to begin promptly. From the time a funding opportunity is announced to the signing of a funding agreement, ARPA-E is able to transfer awards to selected project teams in, on average, three months. This speed and efficiency of this process is critical to ARPA-E's success.

5 Execute

The role of the Program Directors in ARPA-E is to be the best stewards of tax-payer dollars. ARPA-E is a metrics-driven organization, and uses quantitative technical milestones in project management. Technical milestones are developed for each project through negotiation between Program Directors and project teams prior to the initiation of work. As part of active program management, the Program Director works with the project teams to help them succeed. This is achieved through site visits at least 2-3 times a year, where the Program Director engages technically with the project team. In addition, the financial health of the project is closely monitored. If a project fails to meet its technical milestones, the Program Director works with the project team to resolve technical challenges. However, if the idea simply does not work and if the project milestones are missed by a large margin, ARPA-E will discontinue the project. On the other hand, if project shows signs of success, ARPA-E offers support to move the technology toward market adoption. This support includes market sector and value chain analysis, evaluating barriers to bringing the technology to market scale, and exposing project teams to appropriate next-stage investment partners.

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