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Effects of Market Approaches to Green Technologies for the Poor: The Case of Improved Cookstoves

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By

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Abstract

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"Sustainable" or "green" technologies for the global poor have been proposed as solutions to the difficult problem of how to improve the lives of the world's poorest without contributing to climate change or other environmental catastrophes. While such technologies were once the domain of non-profit and government funded initiatives, they are now increasingly developed and deployed through market mechanisms. Using improved biomass cookstoves as a representative technology, this dissertation seeks to assess the social and technological effects of this shift to market-based approaches for development and dissemination of sustainable technologies for the poor.

Chapter 2 uses a Science and Technology Studies theoretical framework to follow the coproduction of the material form of improved biomass cookstoves and the cookstove movement from the 1960s to the present. The chapter shows that during the 1980s, particular conceptions and articulations of the problem that cookstoves were meant to solve led to a definition of technological "improvement" that included fuel efficiency, consistency of performance, and ability to scale quickly. This particular type of cookstove was much more compatible with mass-production than traditional artisanal production, creating social organizations that could mass-produce cookstoves, which then encouraged commercial approaches in order to recover costs. The move to a market-approach was in part driven by and in part the cause of a particular kind of technology, demonstrating the mutual co-production of the social and technological.

Chapter 3 takes one market-based tool, intellectual property, and analyses the effect of deploying it in the realm of green technologies for the poor. Using the contrasting cases of UV Waterworks and the Berkeley-Darfur Stove the chapter identifies some of the salient social and technical characteristics that determine whether such effect is positive. The complex social arrangements involved in developing technologies for the poor mean that tools such as intellectual property can be useful but must be compatible with the organizations involved at the level at which the tool is targeted, each of which may have different orientations and incentives. The type of funding at each level, donor versus investor, appears to be a particularly important variable in predicting positive or negative outcomes.

Chapter 4 examines one specific environmental policy market mechanism, the carbon market, and its role in stimulating technological change, invention, innovation, and dissemination (Schumpeter, 1942) in biomass cookstoves. It shows that carbon credits are thus far improving diffusion of current cookstoves but failing to stimulate innovation in cookstoves with stronger health and environmental impacts. Additionally, the chapter shows that the carbon market is influencing the selection of cookstoves for dissemination. The characteristics selected for are most compatible with centralized, mass production, which is likely to strengthen the shift towards these approaches.

To Nick, who I always love to come home to.
And to my parents for encouraging me to pursue my dreams and inspiring me through their example.

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Chapter 1: Introduction

"The world has a new Energy Champion. Tonight, the US-based Aprovecho Research Center (ARC) and Shengzhou Stove Manufacturer (SSM), a Chinese business, were feted for their mass-production of environmentally friendly cookstoves at the Ashden Awards for Sustainable Energy ceremony, hosted by HRH The Prince of Wales." So reads the June 11, 2009 press release for the Ashden awards, a highly prestigious award annually bestowed on a select few "sustainable energy solutions" from around the globe (Ashden, 2009). Aprovecho and SSM were chosen for the award because of their capacity to "cut carbon and save lives" through the provision of mass-manufactured fuel-efficient cookstoves, over 70,000 of which were distributed in the last year alone. The stoves, each fully assembled and ready-to-use, have been delivered to projects in dozens of developing countries. In accepting the award, Dean Still, Executive Director of the Aprovecho Research Center, described their partnership with the Chinese manufacturer as a key step forward in a process that Aprovecho has been involved in for over thirty years: "We knew how to design good stoves, but we had to find Mr. and Mrs. Shen at Shengzhou stoves to manufacture them. Their traditional Chinese ceramics finally made it possible to mass produce high-quality, affordable stoves" (StoveTec, 2011).

These stoves are but one example among hundreds of what can be termed "sustainable" or "green" technologies for the poor. While such technologies were once the domain of non-profit and government funded initiatives to alleviate poverty and address environmental concerns, they are now increasingly developed and deployed through market mechanisms. Using cookstoves as a representative technology, this dissertation seeks to assess the social and technological effects of this shift to market-based approaches for development and dissemination of sustainable technologies for the poor.

Technologies such as improved cookstoves, which are seen to simultaneously improve the lives of the global poor and environmental conditions, have been linked through the discourse and theory of sustainable development. The theory was perhaps most famously articulated by the report of the Brundtland Commission, *Our Common Future* (1987): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Such development, though frequently challenged as to its precise definition, requires two things. On the one hand, drawing from ideas of sustainability, it demands technological change, a shift towards developing and using technologies that rely on renewable resources and emit less waste. At the same time, according to the idea of "development," as understood in this and most other articulations of sustainable development, these technologies must also enable improvement in standards of living, especially for the global poor.

Technologies that can meet both of these criteria, then, are seen as especially valuable. Variously called "climate-poverty-energy" technologies (Casillas & Kammen, 2010), "win-win" technologies (Simon, Bumpus, & Mann, 2010), "no regrets options" (Smith, personal interview, December, 2010), and technologies with "co-benefits," (Smith & Haigler, 2008), these technologies are particularly powerful symbols. Their example offers proof that, rather than facing trade-offs between rich and poor, environment and economics, we can have it all, given the right technologies. Faith in that possibility has been given renewed weight in the context of climate change, as the global South has often been pitted against the North, the South arguing for their right to develop, the North arguing that catastrophic climate change could result if they do. Sustainable development, green technologies for the poor, offer a way out of this dilemma by demonstrating that the interests of all can be aligned, even that the twin desires of development and climate mitigation can be mutually reinforcing.

Because these kinds of technologies are beneficial in both realms, they have champions in each working to increase their development and dissemination. Yet the ways in which their development and dissemination has been approached has changed over time along with our broader societal understanding of the role of technologies in development and the environment. In both realms, the approach has become more market-based in recent years as markets are increasingly believed to have a role in solving social and environmental problems.

Regarding technologies for development, recent proposals such as the “Bottom of the Pyramid” approach put forth by Prahalad (Prahalad & Hart, 2002; Prahalad & Hammond, 2002) envision the poor as consumers whose needs are not yet being met by products designed predominantly for the global rich, the top of the pyramid. The technological needs of these poor consumers can be best met by corporations who, newly aware of this vast and underserved market, should put their considerable resources to work to develop products that can be sold to them to help them improve their lives. By engaging the private sector in providing these much needed products to the poor, an entirely new set of actors with much greater access to resources can be galvanized to address the problems facing the global poor.

This view contrast strongly with the view that was more dominant among those concerned with technology for development in the past, beginning in the 1970s, that of appropriate or intermediate technology (Schumacher, 1973/1989). The appropriate technology paradigm imagines the poor, not as consumers, but as producers. The problem of poverty was in fact that there was not enough work, and technologies should be introduced to give the poor jobs in production. These technologies would not be mass-produced, but “produced by the masses,” their important role being that their production would provide “millions of new work places in the rural areas and small towns” (Schumacher, 1973/1989, p. 185).

These understandings of poverty and the role of technology in combating it are quite opposed to one another, and adherence to either leads to forms of social organization and material technology that would be seen as unacceptable by the other. Bottom of the Pyramid and other market-driven, commercial, consumer approaches, advocate technologies that are mass-produced, consistently high quality, and often similar to consumer products found in the first world. These technologies are provided by corporations that not only have the resources to develop and market such goods but also can do so most efficiently. Appropriate technologies, on the other hand, are produced by and for local people, often with technical assistance from non-governmental organizations, and are of a type and quality consistent with local needs and characteristics of the local workforce. Transitioning from the latter approach to the former, then, implies different kinds of social organization, different imaginings of the causes of poverty and the characteristics of users, and, finally, fundamentally different technologies.

While both Bottom of the Pyramid proponents and appropriate technologists speak explicitly of the kinds of technologies associated with their methods, similar transitions occurring in the environmental policy sphere are generally understood to be technologically agnostic. Indeed, the fact that market-based environmental policy tools do not select technological winners *a priori* is one of the main arguments for their perceived superiority (for a review of these arguments, see Kemp & Pontoglio, 2008). In this realm, the transition to market-based methods has been driven largely by the perception of its economic efficiency but also by the belief that markets are superior to traditional command-and-control environmental regulation policies in forcing technological change towards cleaner, greener options (see, for example, Jaffe & Newell, 2002).

The Empirical Context

Improved biomass cookstoves are a primary example of the kinds of technologies imagined by sustainable development: replacing traditional stoves and three-stone fires with improved cookstoves can address severe public health and local environmental problems in less developed countries as well as the global problem of climate change. Due to their ubiquity, biomass cookstove technologies play a large role in several health and environmental concerns; nearly fifty percent of the world's people use biomass for cooking and heating (Smith et al., 2000). Due to poor stove efficiencies and lack of proper ventilation, many users of traditional biomass stoves are exposed to products of incomplete combustion that contribute to poor indoor air quality and numerous respiratory illnesses (Smith, 1994; Bailis, Ezzati, & Kammen, 2005). In addition to indoor air pollution, these low efficiencies require users to expend more time and labor than necessary in collecting fuel and put additional pressure on forest and biomass resources, contributing to local deforestation (Smith, 1994; Galitsky, Gadgil, Jacobs, & Lee, 2006). Moreover when fuelwood is harvested unsustainably, it results in a release of carbon dioxide into the atmosphere not taken up again by forest regrowth the following year, thus contributing to global warming. Even when fuelwood is harvested sustainably, many of the products of incomplete combustion are powerful global warming gases; biomass stoves account for about 1% of global methane emissions and are strong contributors of emissions of carbon monoxide and non-methane organic compounds such as black carbon to the atmosphere (Smith, 1994; Edwards, Smith, Zhang, & Ma, 2004; Ramanathan & Carmichael, 2008.).

Research Questions

This dissertation uses improved biomass cookstoves to examine the proposition that market-based approaches are superior for development and dissemination of green technologies for the poor. It does so through attempting to answer the following questions: First, what are the technological characteristics favored by and resulting from market-based approaches? Second, what reconfiguration of social relations are implied or favored by these approaches? Finally, how are these technological and social changes dynamically interacting and mutually constituting each other?

Approach

This dissertation is comprised of five chapters, including the introduction. Chapters 2,3, and 4 are presented as papers for publication. Chapter five concludes and integrates the document. The following is an overview of the chapter topics:

Chapter 2 – "Freedom from Smoke, Freedom from Waste": the Coproduction of Improved Cookstoves and the Movement

The second chapter, a history of cookstoves, uses a Science and Technology Studies theoretical framework and qualitative methods to follow the trajectory of the material form of improved biomass cookstoves as well as cookstove movement from the 1960s to the present. Archival sources supplemented with interviews were used to analyze the ways that the technology and the movement changed from one driven by appropriate technology and health concerns, using locally produced stoves, to one in which commercialized approaches are more common, and cookstove companies sell mass-produced, identical stoves produced in China and India. The chapter shows that the current material form of cookstoves reflects underlying changes in values among the organizations developing them; in turn the cookstoves produce effects in the social realm as well, enabling certain forms of market organizations to enter this traditionally non-profit and government world and constructing different understandings of the relationship between these technologies and the global poor for whom they are created.

Chapter 3 - Cookstoves, Clean Water, and a Patent? The Role of Intellectual Property in Humanitarian Innovation

The third chapter takes one particular market-based tool, intellectual property, and analyses the effect of deploying it in the realm of green technologies for the poor. To do so, the chapter uses the contrasting cases of UV Waterworks and the Berkeley-Darfur Stove. The cases are able to highlight the role played by intellectual property because they form a kind of natural experiment: both were invented by the same person, handled by the same technology transfer office, and attempted to use patents and licenses to drive commercialization and deployment. The outcome, however, was very different in each case, allowing for at least a preliminary identification of the social and technical characteristics that determine the positive or negative effects of the use of intellectual property for technologies for the poor. Further, the chapter suggests that, with this move towards market-based approaches for development and dissemination of these technologies, the broad social categories of for-profit and non-profit are no longer analytically useful, and that the complex institutional ecology surrounding these technologies requires a closer look at the various elements comprising the overall structure, each of which may use different tools and strategies traditionally belonging to either the market or charity realms.

Chapter 4 – Market-based Environmental Policy Tools and Innovation in Green Technology for the Poor: The Case of Carbon Credits and Improved Biomass Cookstoves

The fourth chapter looks at one specific environmental policy market mechanism, the carbon market, and its role in stimulating technological change, invention, innovation, and dissemination (Schumpeter, 1942) in biomass cookstoves. Market-based environmental policies are supposed to be more effective in stimulating innovation in clean technologies, but often black box the innovation process itself, making it difficult to understand the effects of the policy or the mechanisms that might lead to such effects (Taylor, 2008). This chapter uses document analysis and interviews with cookstove designers, carbon developers, cookstove project implementers, and thought leaders in the cookstove field to take a close look at the process of innovation in improved cookstoves so as to identify the if and how carbon credits are affecting innovation and dissemination of this technology. It shows that carbon credits are thus far improving diffusion of current cookstoves but failing to stimulate innovation in cookstoves that would make them more beneficial in terms of both their health and environmental impacts. Findings from this chapter suggest that carbon credits will not have the desired effects in terms of forcing technological change in green technologies for the poor unless the policy is modified and supplemented by additional policy mechanisms. The chapter goes on to consider the question of whether or not carbon credits could be an effective policy for driving green technology for the poor or what kinds of alternative policy instruments might be more effective.

Chapter 5 - Conclusion

Chapter five reviews the findings of the three main chapters and presents conclusions for each chapter as well as the dissertation as a whole.

Chapter 2 – "Freedom from Smoke, Freedom from Waste": the coproduction of cookstoves and the movement

ABSTRACT

This chapter analyzes the coupled trajectories of the material design and broader social movement of improved cookstoves and technologies for the poor over the past thirty years. It traces the history of the cookstove movement in the 20th and 21st centuries to show that while the term "improved cookstove" is often used uncritically to encompass the entirety of the stoves that have been promoted to replace three stone fires, in fact, what it means to be an "improved cookstove" is a matter of social negotiation. The idea of what kinds of improvements these cookstoves represent, either technologically or in terms of social welfare, has been and continues to be very different amongst the many groups involved in developing and disseminating cookstoves. These contested and changing values are both reflected and reinforced by the form that stoves have taken over time. The cookstove technologies that have resulted from these social negotiations have, in turn, constructed particular forms of social organization and understandings of the role of technology in development.

1. Introduction

Throughout the whole of human history technological change and innovation have been constant. Humans have created artifacts to help them survive and live more comfortably, and these artifacts, in turn, have led to further developments, both social and technological. Our technological engagements at various points in history both reflect and produce what we imagine ourselves to be, as well as our values, goals, and commitments.

Perhaps no technologies through this length of time have been more symbolic of what it means to be human than those which create fire.. Of course, fire is not just symbolic; the ability to make fire enabled humankind to spread to cold and harsh environments around the world. Nor is it purely historic: for roughly two billion people today, biomass fires continue to be the main source of energy for heating, lighting, and, the focus of this paper, cooking.

Humans have been improving cookstove technologies for thousands of years, probably for as far back as they have been using fire for cooking food. From using different shapes and sizes of stones, to adding rudimentary wind shields, to lining buckets with rice husk ash, people around the world have been remarkably creative in adapting their cooking technologies to their needs. Yet, beginning sometime in the mid-20th century, we start to see something different: systematic attempts by governments and non-governmental organizations to bring improved cooking stoves to the poor in developing countries as part of the new movement towards directing aid and development dollars towards the poor in so-called third world countries. But what does it mean to "improve" a cookstove? What are the metrics by which we measure that improvement and judge one cookstove to be "better" than another? How are these values embedded in the design of the stoves, and what effects do those embedded values create in the world? In attempting to answer these questions, this chapter analyzes the coupled trajectories of the material design and broader social movement of improved cookstoves and technologies for the poor, over the past thirty years – how and why cookstoves and the movement have evolved to take their present form and what that tells us more generally about how our society imagines the role of technology and development.

In this chapter, I will trace the history of the cookstove technologies and the cookstove movement in the 20th and 21st century to show that while the term "improved cookstove" is often used broadly and uncritically to encompass the entirety of the stoves that have been promoted to replace three stone fires and traditional stoves, in fact, what it means to be an "improved cookstove" is a matter of social negotiation. The idea of what kinds of improvements these cookstoves represent, either technologically or in terms of social welfare, has been and continues to be very different amongst the many groups involved in developing and disseminating cookstoves. These contested and changing values are both reflected and reinforced by the form that stoves have taken over time. The cookstoves, in turn, have produced effects in the social realm as well, enabling certain forms of market organizations to enter this traditionally non-profit and government world and constructing different understandings of the relationship between these technologies and the global poor for whom they are created.

Most of the early cookstove programs were based upon the ideas of Appropriate Technology, which saw stoves not only as technologies to remove smoke from kitchens but also as tools for community capacity-building and empowerment. To achieve these ends, stoves were locally designed and constructed and made from freely available local materials such as mud and clay. However during a critical period in the 1980s, the cookstove movement coalesced around a different understanding of the role that cookstoves should play. Amidst fears of rampant environmental destruction and global energy crises, cookstoves came to be seen primarily as a tool for addressing deforestation. As a result, the defining characteristic of improvement for cookstoves became fuel efficiency, rather than the ability to empower a community or create local jobs. Although a minority of actors within the cookstove movement held alternative definitions of improvement, the attributes that they favored, as well as those valued by the users themselves, were discarded in favor of fuel-efficiency. Acceptance of the primacy of efficiency led to development and selection of stoves that were more highly engineered, made of non-free materials, and mass-produced. As this stove type became ascendant, it in turn enabled or required the development of international stove businesses that are increasingly seen as the future direction of cookstove production today. This shift from an appropriate technology conception of the role technology in development to one in which the poor are seen as consumers is connected to broader societal shifts along these lines and is embedded and reinforced in the material form of the cookstove itself.

The article first lays a theoretical and methodological foundation with a discussion of STS theories of technology and an explanation of the methods used. The presentation of the analysis of the evolution of the cookstove social movement and its technologies follows a historical path, beginning with traditional cookstoves, followed by descriptions of early cookstove projects from the 1950s and 1960s, second generation projects from the 1970s and 1980s, and the current generation for projects, primarily drawn from the 2000s.

2. Science and Technology Studies as a Framework for Analysis

Technological change is often portrayed as a uniformly forward motion, with new inventions or modifications representing improvement and advancement over the old, propelled by logic and destiny. In this telling, many popular accounts of technology actively work to hide the role that social factors have played in technological development so that the technological outcomes appear merely to be the inevitable result of logical improvements. These accounts create narratives of technological development that leave out the avenues not pursued or describe efforts in other directions but dismiss them as mere mistakes, correctly abandoned to focus on the better technology. Social factors are admitted only to be cast as the cause of scientific or technological failure. The assumption seems to be that if we can only hold the social factors at bay, science and technology will find the right solutions.

This teleological view of technological progress has been questioned on many fronts, perhaps most powerfully by scholars of science and technology studies who have turned the process of developing technologies itself into a productive site of study. By closely following the path of development of various technologies, science and technology studies (STS) unmask the influence of social factors throughout this process. STS holds that the social and the technological are always connected, always interacting, that there is no such thing as a “pure” science or a technology that has developed “as the sole result of its internal logic.” (Winner, 1986, p. 21) Instead outcomes are contingent, based on choices made along the path of development, one direction favored over another, one line of research pursued while another is ignored. These choices have consequences, though, as structures and institutions and technologies, once in place, acts to shape future evolution of both the social and the technological.

Two things here are important to note. First, the choices made are the result of numerous factors that arise from both material constraints and opportunities, as well as social factors. The decisions are not pre-ordained, and are not necessarily reflected in a “better” technological outcome in an objective sense. Indeed, “better” or “improved” is often itself a matter of social contention and deliberation (Bijker, 1995). Secondly, and equally important, is that the effect of social factors should not be taken to indicate that the results, the technologies themselves, are flawed. Unlike popular accounts of flawed science and technology that blames the social, STS accounts seek to include those cases that have been useful and successful as well, to show that the influence of the social is inevitable but not negative (Bloor, 1991). Instead the point is to show that other paths were possible, that outcomes could have been different. Recognizing that the technologies that we have now are not the technologies we *had to have* allows a more critical analysis of these technologies, so that we can ask if they do “work,” or, perhaps more importantly, for *whom* do they work? Doing so empowers those for whom the current technology is not working, those who may have preferred the alternate routes not taken; it shows them that the other possibilities exist, that they can create a different future.

The various schools of STS, then, attempt to tell alternative narratives of technological development that explicitly account for the role played by social factors in this development. To do so, each school employs distinct analytical concepts, many of which prove useful for understanding the history of improved cookstoves. In the following section, I provide an overview of a few of the main schools of technological theory in STS and pull out the concepts from each of them that will be used to frame the cookstove history discussion that follows.

2.1 Social Construction of Technology

One school of thought that provides many useful concepts for analyzing technological development is the Social Construction of Technology, exemplified by Weibe Bijker and his seminal work *Of Bicycles, Bakelite, and Bulbs* (1995). Bijker stated that his attempt with that work was to "study how technologies are shaped and acquire meaning in heterogeneity of social relations" (p. 6). In doing so, he was explicitly trying to counter the typical linear development models that "result in reading an implicit teleology into the material." As can be ascertained from the name given to this school of thought, SCOT essentially assigns full causality of the technological and societal outcome of technological development to the social. This pure constructivism has been criticized by some as a social determinism because it refuses to assign any agency to the material world that often gives shape to our daily lives (Jasanoff, 2005). To put it another way, SCOT notices the ways that we act upon technology, but not the ways that technology acts back. However, SCOT still provides many useful concepts that will be drawn upon for my discussion of the history of cookstoves:

2.1.1 *"Working," "Nonworking," and Technological Frames*

Bijker challenges the argument that we have the technologies that we have because they are the ones that "work." Whether or not a technology "works" is not an explanation for its success; instead it is a perception that needs to be explained. Why is a technology considered to "work" or not? What are the criteria by which we define this? Who gets to define what "works" or does not work?

The criteria by which "working" and "nonworking" are defined comprise an individual's technological frame. This technological frame includes an individual or group's goals for the technology, the problems they see in its operation, possible solutions, etc. It is both cognitive and cultural in that it structures the way each person sees and interacts with a technology.

2.1.2 *Interpretive Flexibility*

The idea that whether a technology "works" or not is as much a function of human judgment as a description of material realities, is closely connected to this second concept of interpretive flexibility. Bijker states that any single technology can actually be seen as multiple technologies, with different social groups seeing the technology in different ways. Different social groups have different criteria by which they judge technologies; they use them for different purposes.

So, for example, a cook in Africa has a set of tasks that she would like the stove to accomplish, a number of characteristics she would like it to have. These goals for the cookstove help determine her framework for evaluating technological utility; they make up what Bijker calls her "technological frame," which is likely quite different from that of a climate change scientist in California. Perhaps the cook cares primarily about speed of cooking – she may say that a stove that cooks too slowly does not work. The climate scientist cares most about emissions reductions – she may say that a stove that emits a lot of greenhouse gases does not work. A working stove for each of these same women might be the same stove, if it cooks quickly and has low emissions, but it might not, if it only accomplished one of these goals.

Cookstoves, and many other technologies for the poor, are often seen as "win-win" technologies (Simon et al., 2010) that are able to equally (or at least sufficiently) accomplish the goals of multiple constituencies, such as development and environmental organizations. In Bijker's terms, the assumption would be that in regards to this type of technology, all of these organizations would have the same frame. However, when the technology is looked at closely, in the case of cookstoves at least, this assumption does not necessarily hold, both in terms of design and diffusion. As will be shown below, while an improved cookstove can certainly accomplish a variety of goals to some extent, often the achievement of one goal, fuel efficiency, for example, results in a less satisfactory outcome for other goals, perhaps in this example local employment.

Defining the technological frames held by the various relevant social groups helps to explain the trajectory of development, why some designs win out and why others fail. Whose technological frame wins out is often a matter of power. So looking at technological development in this way allows us to see the role of power and politics in the process, as various groups struggle to have their technological frame become the dominant one that defines for society more broadly whether a particular technology "works" or not.

2.1.3 *Closure*

When the technological frame of one group wins out and one interpretation of a technology is accepted by all, closure has been reached. At the point of closure, interpretive flexibility has almost totally disappeared, and there is broad agreement on what form the technology should take.

Bijker describes multiple mechanisms that groups can use to achieve closure. One of the most relevant to the history of cookstoves is the definition or redefinition of the problem. The technological frame of a group or individual is driven in part by what problem they want the technology to solve. For the cook in the example above, it was speed of food preparation. For the scientist, it was climate change. One way that a group can achieve closure so that their vision for the technology comes to dominate is by defining the problem in such a way that their technology is the answer. Alternatively, if one group is unable to have their vision of the problem become accepted by the others, closure may not be achieved. To continue the example, if the cook never comes to believe that climate change is the problem that her stove is supposed to solve, she will not be willing to accept a stove that compromises her utility to achieve greater climate change mitigation.

Successfully controlling the definition of the problem is critically important because it then leads to searching for certain kinds of answers; it creates one path down which to head. Once that path is taken, it is easy to forget or pretend to forget that there were other paths available. The solution set is now bounded, and the way forward seems clear and defensible. Defining the problem is very powerful that way – once the problem has been broadly agreed upon, the solutions seem to flow naturally with a kind of internal logic and inertia, and the fact that the definition of the problem itself was a matter of contention is easily forgotten.

For this reason, Bijker suggests that looking for problems encountered along the historical path of development and the way that those problems were solved, or seen to be solved, is a very productive way to discover the various technological frames that were involved and to uncover the other options that were later abandoned.

2.2 Actor Network Theory

Another school of thought in STS that has many related concepts is that of Actor Network Theory, perhaps best exemplified by Bruno Latour and Michel Callon. Callon, in his work on scallops describes a similar trajectory to that of Bijker – from a situation in which many options exist to a kind of closure in which there appears to be only one answer (Callon, 1986). Callon, however, describes this trajectory through the lens of an actor or protagonist building a network of allies that includes other humans but also non-humans such as the technology itself.

Where SCOT follows a technology, focusing on points of problems and solutions, ANT suggests that the analyst "follow an actor" as he or she marshals a network to achieve the desired outcome. Callon describes this process as a "simultaneous production of knowledge and construction of a network of relationships in which social and natural entities mutually control who they are and what they want" (p. 69). His breakdown of the steps provides additional useful concepts that synthesize nicely with the SCOT approach above – problematization, interessment, and enrollment.

2.2.1 *Problematization*

Like Bijker, Callon recognizes the importance of the way that the problem is defined. In this network view taken by Callon, not only does problem definition determine or enable certain paths of action at the expense of others, it also elevates the role of certain social groups over others. Callon recognizes that the way in which a problem is defined determines which actors or social groups should be involved in solving the problem and what their roles should be. Further, this process, which Callon calls "problematization," is one which the actor uses to structure the social network in such a way that the actor him/herself becomes indispensible to solving the problem, an "obligatory passage point." In the history of cookstoves, for example, the problem that cookstoves are supposed to solve (whether it be poverty, deforestation, pneumonia, or climate change) not only defines a "working" stove, as suggested by SCOT, but also defines who should be involved in developing this stove (e.g. fieldworkers, engineers or users) and what their roles should be. Defining these identities and structuring this network is ongoing work that must be performed throughout the process from problem definition to closure: problematization encompasses this entire process and includes two different stages, interessment and enrollment, which are discussed below.

Methodologically, ANT, in this conception, follows one actor or group of actors as they attempt to perform "problematization" and structure the network so that their role is most important. While I do use some of these concepts and tools from ANT in the analysis, I do not fully embrace its method as, in this case, it risks assigning too much agency to any single group, when, in actuality, a variety of actors and groups have played important roles in cookstove development. Moreover, the ANT view of an actor-driven problematization process could be read to imply strategy and self-interest on the part of various actors, so I should note here that where I do say that certain groups are performing problematization (or interessment or enrollment, next section) I do not mean to say that they are motivated by self-interest. Rather, various social groups have different internal cultures and sets of beliefs around what constitutes valid knowledge and which values are hegemonic; in this account, these factors, not a grasping self-interest, should be seen as motivational.

2.2.2 *Interessment*

Interessment is one stage of problematization in which the actor "attempts to impose and stabilize the other actors it defines through its problematization" (Callon, 1986, p. 71). Through interessment, the actor tries to define the goals of the other groups that are involved such that they are allied with her own and in competition with those who would like to define them otherwise.

2.2.3 *Enrollment and Dissidence*

If interessment is successful, it achieves enrollment, a stage in which the various groups and individual accept the identities, roles, and goals assigned to them by the actor. Once enrolled, the other groups fall in line with the problem and solution as defined by the actor. This stage can be seen as analogous to SCOT's concept of closure in which one technological frame becomes dominant, and the others drop into the background, often to be forgotten.

Callon, however, does not assume that enrollment is stable – the network that has been mobilized and structured by the actor can be undone by the dissidence of any of the assembled allies. While some networks prove stable and long-lasting, others are found to be fragile and quickly dissolve. Dissidence occurs when some ally or group of allies was not effectively interessed and comes to challenge their identity, role, or goals as defined by the actor. Dissidence by one group of allies can set of a cascade, dissolving the entire network.

2.3 Social Worlds

As alluded to above, one criticism of ANT's approach is its reliance upon a single protagonist or set of protagonists. Many cases do not truly have a central character, and creating one through the analysis gives more weight to the viewpoints of some groups, often those who are already privileged, at the expense of others. In my analysis, while I do use many concepts from ANT, I try to temper the tendency to focus on a single protagonist.

A useful alternative methodology is put forward by a body of theory known as Social Worlds, exemplified by Adele Clark and Susan Leigh Star. Social worlds "assumes multiple collective actors – social worlds – in all kinds of negotiations and conflicts….The framework is relentlessly ecological, seeking to understand the nature of relations and action across the array of people and things in the arena…." (Clark & Star, 2008, p. 113). In contrast to ANT, social worlds theory takes particular care to remind the analyst not to privilege a single viewpoint but to look at the interaction from the perspectives of the different groups involved, each with their own discourse and activities.

In that way, social worlds can be seen as compatible with the SCOT approach of understanding the different technological frames that various social groups operate through with respect to the technology. Both approaches enable the analyst to better understand the technological outcome as a result of certain kinds of power, the hegemony of one perspective over another. Indeed, in some ways, I use the social worlds perspective as both starting and endpoints for the analysis – in defining an "improved stove" whose voice is heard? But it combines nicely with the questions raised in SCOT – does the technology "work" or *for whom* does it work?

In addition, social worlds contributes two key analytical concepts that are useful for the discussion of cookstove history that follows: *boundaries* and *implicated actors*.

2.3.1 *Social World Boundaries*

One of the activities that individuals within various social worlds perform is that of drawing and maintaining boundaries between their world and others, primarily through discursive means. Boundary work, as this is sometimes called (Gieryn, 1995) has been recognized perhaps most commonly in the scientific realm, in which claiming that something belongs to "science" rather than "art" or "instinct" can be a powerful form of legitimization. This can be seen, too, in engineering where lab-based work done by PhDs is distinguished from "tinkering" in one's garage.

2.3.2 *Implicated Actors*

The second concept from social worlds useful to the analysis here is that of *implicated actors.* These are individuals or groups who are "silenced or only discursively present – constructed by others for their own purposes" (Clarke & Star 2008, p. 119). These *implicated actors* are affected by or concerned with the issue at hand but not actively included in negotiations. When useful, other actors who are actively involved can claim to represent the interests of these groups. In that one set of actors is defining another, this concept is related to *interessment* from ANT, but even more so in social worlds, there is an attempt to understand what these *implicated actors* may have wanted and to give them the voice that they were denied.

I would also argue that many *implicated actors* are the ones that become dissidents, in the ANT framework, because although they may be temporarily enrolled as allies, their needs and desires are not truly taken into account, and thus their allegiance to the project is fragile.

2.4 Coproduction – Winner and Jasanoff

As a complement to the concepts and frameworks discussed above, SCOT, ANT, and Social Worlds, I add one final, yet crucial, body of theory from STS: coproduction as seen in the work of Sheila Jasanoff and Langdon Winner.

Where these other frameworks, especially SCOT, focus primarily on the way that the social acts upon the technological, coproduction adds another dimension. As those frameworks describe, technology is to a large extent the result of the various and competing values of different groups acting in its development. Winner and Jasanoff go a step further in then documenting the ways that those values are embedded in the material form of the technology, which itself then acts upon society, enabling or supporting certain forms of organization or social relations. As Winner writes, "As we 'make things work,' what kind of world are we making?" (1986, p. 17).

Because of the complex interrelationship between *nature*, as known and applied through science and technology, and *society*, including its trappings of politics and power, traditional disciplines and discourses fail to adequately describe the creation and effects of this interconnection. As Jasanoff (2005) writes, "Increasingly, the realities of human experience emerge as the joint achievements of scientific, technical and social enterprise: science and society, in a word, are *co-produced*, each underwriting the other's existence" (p. 17).

Coproduction seeks to more accurately portray the ways in which science and technology both influence and are influenced by society; in doing so, it reacts against both a technological determinism that sees technology as ordering society around its internal logic, and a social determinism or pure constructivism that refuses to assign any agency to the material world that often gives shape to our daily lives. According to Jasanoff (2005), there is a history of such coproductionist work in STS and other fields, although it has acquired the name only recently. She cites, for example, work in Actor-Network Theory (such as Latour, 1993) that has been foundational in understanding the dual construction of Nature and Society but also work from political theorists (such as Scott, 1998) that shows how such constructions are taken up and do work in the world. Langdon Winner is one of her prime examples of STS scholars who, though their work predates the idiom of coproduction, have not only linked the political and the technological but demonstrated empirically the ways in which each acts upon the other.

Winner, like Jasanoff, seeks a mode of analysis that not only recognizes that the material world matters, but also does not deny the role of human society in shaping and governing that same world. Winner describes social determinism, the view that "[w]hat matters is not technology itself, but the social or economic system in which it is embedded," as a reaction against a pervasive technological determinism which holds that "technology develops as the sole result of an internal logic and then, unmediated by any other influence, molds society to fit its patterns" (1986, p. 20-21). While understanding the desire by social determinists to locate agency in the social realm in order to end the practice of ignoring the very real social context in which technology must operate, Winner believes that this view goes too far in pretending away the similarly real effects that artifacts have on that same social context.

Winner tells us that a full understanding of the role of these technologies can only be achieved by incorporating into our analysis the social context all along the process of inventing and using a technology, both the prior arrangements and institutions in which the technology is embedded, as well as the rearrangements or reinscription of power through the use of that technology. In this view, technologies are not seen as neutral because they are not dropped, untouched, onto a blank canvas. They are molded and designed to fit into and accomplish their work in a social milieu already ordered by legal systems, complex relationships, cultural norms, and power dynamics.

We must pay attention, then, to the flexible characteristics of the technology itself and the ways in which the individuals or groups responsible for design and implementation choose and shape those characteristics based on their own backgrounds and values: their interests may shed light on aspects of the technological consequences that would not be revealed by an analysis that assumed that the only driver of technology is efficiency or improvement. As Winner says, "Technological change expresses a panoply of human motives ... even though it may require an occasional sacrifice of cost savings and some violation of the normal standard of trying to get more from less" (1986, p. 24). At the same time, we must also notice the ways in which certain material formations of the technology not only put in place durable structures that feed back onto future technological and social change but also frame the ways that we imagine the social world and its relationship with technology.

In the context of cookstoves, how does the definition of the technological problem stoves are supposed to solve lead to certain kinds of cookstoves? How do those particular types of cookstoves then produce the new and different social organizations necessary for their deployment? Moreover, how do certain kinds of cookstoves construct the ways that we imagine the global poor, the users of those technologies?

3. Methods

I trace this development of values, organizations, and technologies with the use of archival sources supplemented by interviews of key actors currently involved in the cookstove world. These sources, drawn from the academic literature, conference proceedings, and organizational reports and websites, are used as historical evidence of certain attitudes and beliefs held by those responsible for cookstove development and dissemination. They also provide documentation in the material changes in the cookstoves themselves over time, with descriptions and illustrations capturing different moments in cookstove development.

The history of cookstoves is long and varied; in no way is my treatment of it intended to be a comprehensive review of all cookstove projects over time. Instead, I describe traditional cookstoves, then focus on three different historical periods of improved cookstoves, periods defined by interviewees and various reports in the literature as different "phases" or "generations" (Smith, 1987; Dean Still personal interview, Nov. 2010). In the earliest phase, it is possible to cover nearly all major projects in order to construct the background from which the later programs emerged, and I do attempt to discuss most of the major projects in brief. However, as the number and diversity of cookstove projects grew from the late 1970s onward, it becomes less feasible and less useful analytically to attempt to document each program. Several periodic reviews provide much of that information, and I attempt not to duplicate their efforts (see Foley & Moss 1983; Manibog, 1984; Barnes, Openshaw, Smith, & Plas, 1993; Gifford, 2010).

Instead, I focus primarily on significant trends as well as three key cases, the details of which illuminate critical periods of change and choice in the development of improved cookstoves: the development of the Lorena cookstove by Aprovecho in Guatemala, the development of the tungku sae stove by Yayasan Dian Desa in Indonesia, and the creation of StoveTec, a for-profit stove production spin-off from Aprovecho . Close examination of these cases provides insight into the thoughts and motivations of those involved, allowing me to draw the connections between those social factors and the technological developments of the stoves. The three cases were chosen primarily for the fact that they are considered by those involved and in the literature to be landmarks in the movement, but also because they were representative of the thinking at the time as reflected in conference proceedings and various publications.

Finally, I use conference proceedings and academic and gray literature publications to provide the large context for analysis of the cases. This literature is particularly useful because it gives a behind-the-scenes view into the normative work being done by key players in the cookstove movement. These reports and discussions of the scientific and policy leaders of the movement document the changing motivations of the cookstove movement and how those changes are reflected in and reinforced by the material form of the cookstoves being designed and produced.

The sources drawn upon for that discussion fall into three main categories. The first is review articles documenting cookstove projects around the globe, including primarily Foley & Moss (1983), Manibog (1984), Gill (1987), and Barnes et al. (1993; Barnes, Openshaw, Smith, & Plas, 1994). The second is published writings from those involved in the cookstove movement, including Samuel Baldwin's 1987 book *Biomass Stoves,* and Kirk Smith's 1987 book *Biofuels, Air Pollution, and Health*. The third category is made up of the proceedings from three conferences in the early 1980s held on cookstoves.

The conference proceedings provide documentation the first two International Workshops on Stoves Dissemination, which represent the initial efforts to create a more coordinated international cookstove movement. The first meeting was organized by Stephen Joseph and was held in Wolfheze in the Netherlands in October-November of 1983. The meeting included representatives from some of the more successful programs along with other researchers and rural development specialists (Prasad, 1985; Joseph, 1990). The proceedings of that meeting were published in book form in 1985 and are heavily cited here. Out of this first meeting arose an international organization called the Foundation for Woodstove Dissemination, which later was responsible for organizing the second International Workshop on Stoves Dissemination held in Guatemala in 1987, titled "Stoves for the People." Proceedings from that meeting were published in 1989. In referring to works published in these proceedings, I call them the First Workshop and Second Workshop, respectively. Finally, the third set of proceedings comes from the International

Seminar on Solutions to the Fuelwood Crisis, sponsored by the Aprovecho Institute and held in Oregon in 1982.

These reviews, publications, and proceedings represent the voices of the leaders of the movement and provide insight into their thoughts and actions as they attempted to *problematize* cookstoves. They also reflect the beliefs that came to dominate the movement, setting in motion a social and technological development process that has produced cookstoves and a cookstove movement very different from that envisioned during the early days of improved cookstove projects.

4. Coproduction of Improved Cookstove Technologies and the Cookstove Movement from the 1950s to 2000

Improved cookstoves have come to be extremely popular development technologies for both governments and NGOs, although the cookstoves used in the various projects often look quite different. The term "improved cookstoves" has generally been used as a broad description of nearly any stove that is not a three-stone fire or a traditional cookstove. Two key questions that give rise to much of the following discussion center around the definition of the "improved" in improved cookstoves – In what way(s) are these cookstoves an improvement over others? And for whom are they improved? These questions are analogous to that of whether a technology "works" or not and are meant in the same spirit. Improvement is not a given; it does not explain why some forms of cookstoves have been chosen over others. Rather, the notion of "improvement" itself needs to be interrogated.

As Bowker and Star note, "One of the ways the past becomes indeterminate is through gradual shifts in what it means to 'really be' something – the essence of it" (Bowker & Star, 2000, p. 43). We see this process clearly in improved cookstoves as the idea of what an improved cookstove should be, what kinds of problems it was meant to solve, and what kind of form it should take, has shifted over the years, and even now is somewhat contested. This shift reflects many of the concepts explored in the previous section. In short, the goals of cookstove programs were redefined in the 1980s in a process of *problematization*. The way in which these goals were defined implied that only certain kinds of stoves would be good solutions. Other kinds of stoves, some very effective at solving other kinds of problems, were broadly belittled until they came to seem fully inferior, hardly "improved" at all and not worth pursuing. The stoves that fit within this narrowed technological frame also required specific forms of production, leading to the creation of new forms of social organizations such as cookstove factories. At the same time, elements within the movement continue to contest both the material form and the intentions attached to these stoves, rejecting these stoves' anointment as the right kind of improved stove as well as the direction in which they feel these stoves are leading the movement.

4.1. Traditional Cookstoves

The oldest and still most common cookstove technology is the three-stone fire. By arranging three stones around the burning biomass, cooks were able to balance pots, both round and flat-bottomed, above the fire and shield the flames from breezes.

The three-stone fire has often been the "straw man" in arguments espousing the need for improved cookstoves due to both its excessive smokiness and presumed inefficiencies. The cookstove literature is replete with accounts of the horrors of the three-stone fire. Yet, starting at least in the early 1980s (Foley & Moss 1983; Gill 1987) there began to be a recognition that, while it did produce a noxious smoke, the three-stone fire may not have been as inefficient as assumed, and that many of its attributes were valued by the users. This new understanding was precipitated in part by the surprising lack of interest shown by many three-stone fire users in replacing it.

Throughout much of the world, in addition to the three-stone fire, various designs called "traditional cookstoves" arose from the local population. These stoves are often considered in the same category as the three-stone or open fire and have also been targeted for replacement with improved cookstoves. Most of these traditional stoves are made of mud and other local materials. They can take many forms, but at the most basic level generally act to shield the fire from drafts. Foley & Moss (1983) describes these shielded fires as "a simple and natural evolutionary step from the open fire" (p. 91). It uses less fuel, is cleaner, and safer. It is found almost everywhere in the world in slightly different forms and materials. For example, Foley & Moss describe a variety of ceramic, one-pot traditional cookstoves in Asia, while in sub-Saharan Africa, where there was less interest or experience in ceramics, they found stove shields made of mud blocks and screens (Foley & Moss 1983; see also De Lepeleire, Prasad, Verhaart, & Visser, 1981).

Figure 1: Three-Stone Fire[1]

Figure 2: Traditional Stove in Nepal

Some of these traditional stoves are actually quite sophisticated from both fuel conservation and convenience standpoints. The Thai bucket stove, for example, consisted of an inner pottery lining surrounded by a metal, bucket-shaped exterior. The space between the pottery and the metal was filled with insulating ash from rice husks. Although the Thai bucket originated around 1920, it was used as a model for improved stoves late into the 20th century (Foley & Moss, 1983).

4.2 Early cookstove interventions of the 1950s and 1960s

Probably the earliest coordinated attempts at replacing these traditional stoves and three-stone fires occurred in the 1950s, initiating what can be thought of as the first phase of

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[1] Both pictures from Engineers Without Borders: http://www.ewb.org.au/announcements/748/10743, accessed May 25, 2011.

cookstove projects, which were driven primarily by concerns over the living conditions of the rural poor, particularly women, and continued through the 1960s. Because of the ebb and flow of popular and political interest in cookstove projects, it is common in cookstove circles to refer to the evolution of the movement in "waves," "phases," and "generations (see, for example, Barnes et al., 1993). I follow Smith's 1987 categorization of these different phases, which I found to be most compatible with evidence from my archival sources. Smith calls the early efforts of the 1950s and 1960s the "first generation" of improved stove programs, distinguished from later efforts in that they were developed "sporadically and indigenously" in a small number of developing countries and "were motivated principally by concerns about smoke exposures" (Smith, 1987, p. 259).

Because of the particular way that the cookstove was imagined, as a solution to smoke in the kitchen, the designs from this era all included chimneys, the most effective technology in ridding kitchens of harmful smoke. Moreover, because these generally were locally driven solutions without the backing of resource-rich donor organizations, the cookstoves made use of materials that were widely available locally and were free for the taking, such as clay and mud.

4.2.1 Magan Chulha 1940s

Some of the earliest work in improved cookstoves began in India in 1934 when the Magan Chulha was created "in order to improve the living conditions of the village women" (Muniandi, 1994). The Magan Chulha was a massive stove that took a full month to construct (Muniandi, 1994). It was built with clay mixed with straw or dung and included a chimney, a metal grate, a pit for ash collection, and an air vent beneath the grate. The stove was designed with local cooking styles in mind and had the ability to use multiple fuels including wood, charcoal, and dung (Foley & Moss, 1983). Elements of this stove, such as the clay mixture and chimney, would be found in many of the improved stoves of the 1970s, including the archetype of early improved stove efforts, the Lorena. As Foley & Moss noted, "In many respects, this stove was the direct precursor of the Lorena stove" (p. 103).

In the 1950s, the Gandhiniketan Ashram, an institution whose "main aim is to spread the living message of Gandhiji" took up the cause of improved stoves and began to modify the Magan Chula, producing a smaller version called the Kallupatti. (Muniandi, 1994). The Chairman of the Ashram in the 1980s, K. Muniandi, reported that the Kalupatti was "popular because it would burn dried leaves and twigs, reduce smoke, last for a generation and save up to 30% on fuel costs" (Muniandi, 1994).

4.2.2 Raju

Projects promoting improved mud chulas, as part of the broader rural development program inspired by Gandhi (Foley & Moss, 1983; Sarin, 1987), gained momentum in India in the 1950s and 1960s. While the projects had multiple development goals, reducing fuel use and smoke from cooking were the primary objectives (Smith, 1987; Foley & Moss, 1983). In his widely disseminated pamphlet "Smokeless Kitchens for the Millions," S.P.

Raju (1953), addressing his women readers, elevates these concerns to the level of human rights and freedoms:

"You are working for the emancipation of women. Do not forget the millions of your sisters in the bondage of criminally unhygienic kitchens. Do not rest until you have fought and won for every housewife in India her Five Freedoms of the Kitchen:

1. Freedom from Smoke,
2. Freedom from Soot,
3. Freedom from Heat,
4. Freedom from Waste,
5. Freedom from Fire Risk."

Raju is a key figure in these early programs, both because of his efforts at mass dissemination of cookstoves and because he is recognized as the first to apply "scientific and systematic approaches in traditional cookstove design," thereby initiating the first phase (or first generation) of improved cookstove development (Koopmans, 1997). He developed many cookstove designs, most made of mud and incorporating L-shaped ducts for improved efficiency and chimneys to reduce smoke (Foley & Moss, 1983). The stoves, known as HERL chulas, were emulated by many improved stove projects around the world in the 1960s and 1970s (Foley & Moss, 1983). The stoves did reduce smoke, but, although Raju claimed that they were fuel efficient, later studies suggested that the stoves saved little if any fuel (Geller, H., as cited in Baldwin, 1985).

In addition to Raju's designs, many other mud chulhas were invented during this time, though many were similar and lacked widespread distribution. A 1964 survey by the National Building Organization of India found over 55 designs for improved stoves in India (Foley & Moss, 1983).

4.2.3 Solar Cookers in India

Another, very different, form of improved cookstove introduced in India in the 1950s was the parabolic concentrator, a form of solar cooker.. These devices are designed to concentrate solar energy on a pot, often by simply reflecting it off of bended metal, cooking food purely through the free and clean energy of the sun. As described by the German Appropriate Technology Exchange (GATE) and Aprovecho (GATE, 1984) citing the accounts of Farrington (1975), these "mass produced aluminum parabolic collectors" were brought to India in the 1950s by American promoters as a solution to the problem of deforestation. Though there is little information about the program, and it appears not to have been successful, solar cookers, including not only the parabolic concentrator but other types as well, have been and continue to be introduced around the world, often with limited success.

Solar cookers are an excellent illustration of the concept of technological frames and the ways in which different social groups might define a "working" technology very differently. To environmentalists, solar cookers are an ideal technology with a strong base of support that continues to promote them all over the world (see, for example www.solarcookers.org). They see solar cookers as superior to improved biomass stoves because they are powered completely by clean energy. But to many users, the solar cooker does not "work" at all, much less represent an improvement over their current options. Solar cookers work well for cooking things like stews that simmer on a low heat all day, but they do not generally enable stir frying or other high heat methods of cooking, and cannot be used early in the morning or when it is cloudy or raining. Environmentalists and promoters of solar cookers have thus far been unable to enroll users in their conception of the problem and solution of cookstoves, and the cooking quality compromises that the device entails has meant that solar cookers have largely failed to catch on.

4.2.4 Singer Stoves in Indonesia

Improved cookstove design and investigation was also underway in Indonesia by the late 1950s, primarily through the efforts of Hans Singer of the Central Forestry Association of Switzerland, who was working as a consultant for the FAO and the Swiss government on a project to improve cooking technologies (Foley & Moss, 1983). Singer undertook both testing and design, and his report (1961) contains the first published data on cookstove thermal efficiency, later to be an important topic among cookstove researchers and promoters (Foley & Moss, 1983).

Singer conducted efficiency testing on traditional Indonesian cookstoves, and reported that the traditional woodstoves converted only 6-7% of the energy from the wood (GATE, 1984). He then set about designing his own series of more efficient "Singer Stoves." These stoves, consisting of three multi-pot models with chimneys, were similar to Raju's but made of bricks instead of clay. Singer claimed that lab testing had revealed these new stoves to be much more efficient than traditional stoves and began to promote the stove through cooking demonstrations and courses in cookstove construction (GATE, 1984; Foley & Moss, 1983).

As his contract was only for three months, Singer had to leave the country before his designs could really take hold, but he assumed that his efforts would be continued by volunteers. However, in what was to become a common trend in stove projects, the project was dropped once Singer left Indonesia so that, as Foley & Moss reported in 1983 "there is no record of them being adopted in Indonesia or elsewhere" (p. 105). The designs, however, with precise measurements and directions for construction, were published and remained in circulation in cookstove manuals published by organizations such as Volunteers in Technical Assistance (VITA, 1980).

Much in the same way as solar cookers, Singer's efforts appear to represent a technological frame that had little in common with that of the local people and was driven more by environmental concerns. It seems that he imagined the users would be as concerned with fuel efficiency as he was and would readily adopt his fuel-efficient design.

The events in Indonesia suggest that Singer (along with the early solar cooker proponents) was one of the first of many to conceive of stove users in the developing world as a group of people ignorant of their own best interest. Throughout the history of the stove movement, there is an underlying assumption that the reason that people are not adopting these "improved" stoves is because they just do not understand how much better they are. It is not that the users have made an informed decision to reject the stove based on their own goals for the technology and assessment of its utility but that they do not understand the implications of their decision in terms of either their own health or the financial pay back or they are unaware of the environmental repercussions.

One final trend seen in Singer's work was the linking of improved stoves to the massive deforestation across Indonesia (GATE, 1984). His work remained well-known and highly regarded by later cookstove promoters, one of whom described his efforts as "one of the first attempts to address the problem of deforestation at one of its sources" (Kaufman, 1983, p. 5).

4.2.5 Conclusion to Early Programs (First Wave)

Information on these early programs remains thin, but generally they do not appear to have achieved, or even perhaps to have attempted, mass penetration. Projects were motivated by multiple concerns including smoke, deforestation, and, more generally, rural development. Cookstoves tended to be high mass mud or mud mix stoves with chimneys and fixtures for multiple pots, designs congruent with an understanding of health and smoke emissions as the problem that improved cookstoves should address. Projects were mainly initiated by figures within developing countries, rather than outside NGOs, although with the Singer and solar cooker examples we see the first attempts to import stove "experts" to provide analysis of the problem and to suggest design solutions. Finally, the Singer example also represents, in the laboratory testing for cookstove comparison, the first attempts to apply conventional scientific techniques to the search for better cookstove technologies, which are clearly related to the *problematization* by Singer and others that identified deforestation as the problem that cookstoves were meant to address. In sum, although there was little impact from these early programs in terms of numbers of stoves built, they laid the foundation, in design, development, and dissemination, for the next wave of programs in the 1970s and early 1980s (Foley & Moss, 1983).

4.3 Programs of the 1970 – 1980s

Interest in cookstove projects appears to have held steady or even declined slightly in the 1960s and early 1970s. However, in the latter half of the 1970s, cookstove projects began to garner a great deal of interest internationally. Smith refers to the projects of the late 1970s and 1980s as the "second-generation" of improved stove efforts. They are distinct from the earlier wave of projects both in that they involve a new set of actors, international development NGOs, and in that the motivations for those actors were encompassed "the triple concerns of energy, appropriate technology, and deforestation" (Smith, 1987, p. 259). However, important distinctions also existed within this phase as the late 1970s and early 1980s saw a transition from a movement driven by the ideals of appropriate technology to one that was concerned primarily with energy and deforestation. This new *problematization* in the early 1980s resulted in a changed understanding of what an "improved" cookstove should be and led to a transformation of both the cookstoves themselves and the organizations that supply and create them, laying the foundation for the kinds of cookstoves technologies and organizations that are ascendent today.

4.3.1 Trends in the 1970s and 1980s

According to a global cookstove review by Gifford, drawing from Caceres et al. (1989), "Between 1977 and 1985, over 42,900,000 improved cook-stoves were distributed in developing countries at a minimum cost of US $40 million." This number is somewhat in dispute - other figures from the literature include "several hundred thousands of stoves" (Prasad, 1986, p. 1), "fewer than 100,000" (Manibog, 1984, p. 203), and "many thousands of households" (Baldwin, 1985). Despite the lack of agreement or specificity of the numbers, it is clear that the late 1970s through the 1980s and even the early 1990s was a time in which interest in such programs grew considerably. A 1994 report listed 137 programs begun in the 1980s or early 1990s (Barnes et al.). During that time, not only did the number of cookstoves disseminated grow at the global scale, the size of individual programs also increased, so that the cookstove situation went from one in which only a handful of programs had distributed upwards of 5000 stoves (Manibog, 1984) to one in which massive governmental programs by China and India had resulted in dissemination of 120 million and 8 million stoves, respectively (Barnes et al. 1994).

One theme of publications from the period, however, is the high rate of failure of many of these programs (Smith, 1987). For example, the editor's note to the 1985 Woodstove Dissemination Conference Proceedings read, "After more than a decade of intensive effort, it is clear there are still far more problems than solutions" (R. Clarke, p. 5). Similarly, Manibog reported in 1984 that of the stoves disseminated globally thus far, "10%-20% have fallen into disuse and another 20%-30% are used only intermittently" while only about ten percent of stove projects "survived over two years" (Manibog, 1984, p. 203). Later reviews tended to agree with those dire assessments. Gifford (2010) comments, "past programs have failed to achieve successful adoption rates," (p. 4) while Barnes et al. state, "The early programs assumed that people would adopt the improved stoves quickly and that an initial intervention would lead to a self-sustaining program….[but] many programs failed" (Barnes et al. 1994, p. 13).

The factors to which these authors and others assigned blame included, but are not limited to, overly high expectations, lack of appreciation for the benefits of the traditional stoves and open fires, not enough consideration of user needs and feedback (especially those of women), and inability to quantify and prove savings relative to traditional cooking technologies (Manibog, 1984). At a very general level, these various factors can be reduced to a serious underestimation of the difficulty of the enterprise and a failure to appreciate the diversity of technological frames regarding what an "improved" stove would look like. Many organizations assumed that these projects would be simple because in their estimation they were providing poor people with a clearly superior technology that the poor would be happy to adopt to improve their quality of life. The possibility that some of the improved stoves suffered from serious deficiencies or that local people would not immediately embrace them appears to have been disregarded, or if considered, not to have been taken too seriously (Gifford, 2010; Barnes et al., 1993). Despite these concerns, the number of programs and the breadth of their distribution continued to grow throughout the 1980s.

Because many of these projects are well-covered in other reviews (see, especially, Foley & Moss, 1983), I will not offer lengthy descriptions or attempt to touch on all of these programs. Instead, below I discuss two projects in detail: Aprovecho's development of the Lorena in Guatemala and Yayasan Dian Desa's work the tungku sae stove in Indonesia. These projects were chosen for discussion not only because they are "landmark" projects in the sense that they were two of the largest, most successful, and, in the case of the Lorena, most influential projects, but also because they illustrate the general trends of this generation of stoves and projects. The Lorena project, in particular, provides a detailed empirical example of the motivations, methods, and stove characteristics that comprised the appropriate technology approach to cookstove design and dissemination. That approach, which was common to many of the cookstove projects of the late 1970s, was to be largely abandoned in the 1980s in a major change of direction for both cookstoves and the social organization of the movement. The Yayasan Dian Desa project, beginning soon after Lorena, was based on the same ideals and technology, but illustrates the transition to a new *problematization* of cookstoves as well as the resulting coproduction of new kinds of technologies and social organizations within the movement.

4.3.2 The Lorena Stove and Appropriate Technology: Process over Product

The Lorena cookstove was developed in highland Guatemala in 1976 during reconstruction after the 1976 earthquake. The project was led by Evans and Wharton of Aprovecho in collaboration with Estacion Experimental Choquie, Quetzeltenango (Foley & Moss, 1983). According to an Aprovecho worker, the project began when a local woman "saw a drawing of a stove in a visitor's notebook," at which point she asked if such a thing could be built for her in order to take the smoke out of her kitchen (GATE, 1984). The initial prototype was based on the HERL Chulhas developed by Raju and others in India in the 1950s (Childers, 1980; Foley & Moss, 1983). These first prototypes were not successful, as they immediately began to crack upon drying. The instructions, based on the chulhas in India, were to build the stoves of pure clay, but the designers in Guatemala quickly realized that adding sand to the clay mixture would prevent the cracking (Childers, 1980; GATE, 1984). They eventually found that a mixture of mud and sand would solve the problem, (GATE, 1984) and this new mud/sand material inspired the name of the stove, "Lorena," a combination of the Spanish words for mud "lodo" and sand "arena" (Foley & Moss, 1983).

The Aprovecho fieldworkers next turned their attention to adapting the stove for local preferences and cooking practices. Although they had built the first prototype at the request of a local woman, they had not involved locals in the prototype development, relying instead on the opinions of expert outsiders, which resulted in some less-than-optimal design characteristics from the perspectives of the users. For example, the designers were told that because the local women cooked on the ground when using three-stone or traditional cookstoves, they should respect this custom and build their stove low to the ground as well. One fieldworker recalled:

> *"Demonstrations of these stoves were met with polite attention but without enthusiasm. Finally one woman scolded us: 'What kind of fools do you take us for? We know perfectly well how high a real cookstove is. Why are you building these*

> *insulting, floor level, undignified cookstoves?' Feeling rather foolish, we immediately began building stoves 75 - 90 cms (30-36 inches) high."* (GATE, 1984, Ch. 3, n.p.)

Fig. 3. Lorena Stove[2]

As opposed to trying to stabilize their own technological frame by convincing the locals that the stove was an improvement, the Aprovecho workers accepted the technological frame of the local people and tried to design a stove that would suit their needs. This adaptability to local needs, conditions, and materials was seen as a major benefit of the Lorena type stove (Childers, 1980). Soon more adaptations were made based on user feedback, the stoves appeared to gain in popularity, and the Aprovecho designers began to seek wider distribution. Although the design was intended to vary slightly from place to place, it was essentially a high mass, mud/sand stove with a chimney to remove smoke from the household.

In addition to smoke reduction, the designers claimed that the stove was also highly efficient, requiring 50-75% less fuel for cooking than the open fire (Foley & Moss, 1983). Moreover, it was thought that, because the stoves were relatively simple to construct, local craftspeople could be taught to build them in workshops lasting only a couple of days. They could then build them for their friends and neighbors, thereby generating local employment (Foley & Moss, 1983).

Initial attempts at broader distribution met with early success. Aprovecho fieldworkers, for example, described putting on a construction workshop attended by over 200 people (GATE, 1984). However, a follow-up visit to the same village six months later revealed that the no new stoves had been built, and the two stoves constructed during the workshop had been destroyed. By questioning the villagers about the stoves, the fieldworker found out that pebbles had dropped from the stoves into food, causing at least one man to break his tooth (GATE, 1984).

The fieldworker concluded that the mud found near this village was much more prone to crumbling than the mud around the experiment station, resulting in small rock pieces that could easily fall into a cooking pot (GATE, 1984). This result was embarrassing to the Aprovecho fieldworkers, who felt that the inadequacy of the building material could have been known early on, had they involved the local villagers in stove design. The lesson that

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[2] From http://sustainableinchicago.blogspot.com, accessed May 25, 2011

Aprovecho took from the experience was that users must be involved, not only in the initial development of the stove, but in each location in which they hoped to introduce the stove.

The involvement of local people in the development of cookstoves became a cornerstone of what was described as Aprovecho's "Lorena System," which itself was grounded in the broader movement of appropriate technology (Childers, 1980). An Aprovecho worker, describing their understanding of appropriate technology, stated:

> *Appropriate technology involves people taking charge of their own lives cooperatively, and in a community framework…– villagers learning from Aprovecho and Aprovecho learning from villagers (and villagers learning from each other) - are prime objectives….Appropriate technology is a means to the ends of self-management and improved existence, rather than an end in itself."* (Childers, 1980, p. 3-4)

In this appropriate technology view, the effect of the technology itself is important, but it is the process by which the technology is developed that produces the more lasting impact. The role of technology imagined here is much different than that of Singer or of what would follow. Because it is the development process that generates the benefits, rather than the technology itself, each technology must be specific to its location, developed by and for local people. In this technological frame, in which mutual learning and self-management are the goals for the technology, local design and construction, are more important characteristics of the stove than efficiency or even smoke reduction. To be "working' or "improved," the stoves must be co-designed and co-constructed with local people. The technology that this frame requires, then, is a stove built with local materials, freely or cheaply available, and according to designs that are not only locally appropriate but also simple enough to be built with local tools and methods.

Even as the Lorena program expanded to introduce the stove in many new communities, Aprovecho and their collaborators continued to stress the *process,* which was equally as important as the technological *product*:

> *The* process *[emphasis theirs] of introducing the Lorena system of stove-building, therefore, has involved a fundamentally non-authoritarian approach…based upon respect for traditional ways and for the intelligence and capacity of all people involved. Participation and mutual learning, of* both *community members* and *development workers, appears to be central to the expanded application of appropriate technologies in the Third World.* (Childers, 1980, p. 11)

These Lorena projects enjoyed quite a strong reputation among stove developers and were considered quite successful (Foley & Moss, 1983). The Lorena stove itself was described as "a major contribution to the art of stove design" (Hottenroth, 1982, p. 1) and was thought to be "highly energy-efficient" (Childers, 1980), in large part due to its high mass, which was seen by many practitioners as an important element of thermal efficiency (GATE, 1984). By 1983, about 6000 Lorenas had been built, by 1985, possibly as many as 18,000, making it one of the largest programs to date (Caceres as cited in Foley & Moss, 1983; Caceres as cited in Clarke, 1985).

The impact of the Lorena, however, was felt far beyond Guatemala. The material, design, and method of production for the Lorena was replicated, in modified form, in cookstove projects around the world for years to come. Modified Lorenas were attempted in Nepal, Upper Volta (Africa), Senegal, Jamaica, the Dominican Republic, Mexico, Honduras, Indonesia, and Ecuador (GATE, 1984; Foley & Moss, 1983; Childers, 1980). Although flattered by the imitation of the Lorena design, members of Aprovecho had doubts about its transferability, which in many ways contradicted Aprovecho's commitment to local input and the mutual learning process of cookstove development. This concern led them to shift their focus from one particular cookstove to developing and sharing broader design frameworks and principles of stove construction (Childers, 1980). Although this transition may have seemed natural at the time, it was to lead Aprovecho in a whole new direction that would eventually lead them away from a focus on process and in favor of product.

4.3.3 Evolution of Aprovecho

The shift to design principles by Aprovecho, while it did not stop others from copying the Lorena design, marked the beginning of an effort in which Aprovecho is still heavily involved to this day and which has had a profound influence on the cookstove world. By acting as cookstove consultants and developing design principles that could be transported to any community anywhere in the world, Aprovecho has extended its influence to hundreds, perhaps thousands, of individual stove programs. By their own estimate, over thirty years they have had a hand in design or production of roughly 2 million stoves (Aprovecho 2011a).

Still, in their initial efforts as stove consultants, such as their government-sponsored 1980 project in Senegal, Aprovecho modeled both the stove and the design/dissemination process on the Lorena. In the Senegal project, the resulting stove was very similar to the Lorena but given a local name "Ban-ak-Suuf" (Foley & Moss 1983). Despite the fact that the stoves themselves had a short life expectancy, the Ban ak Suuf stove project was still seen as valuable because of the "Lorena system" of development and design, illustrating the stability of the appropriate technology frame:

> *'The positive aspects of participation in a group activity such as stove building can have a tremendous impact on village women....Even if Ban ak Suuf stoves have somewhat of a short life expectancy, all the preliminary work, organization, and accomplishment that leads to the actual construction is an accomplishment worth noting in terms of community development." (Fattibene as cited in Foley & Moss 1983, p. 111)*

Aprovecho, however, was seeking to become less involved in leading a "Lorena system" process in each location, and to focus their efforts instead on the quality of the stoves themselves, particularly in respect to fuel efficiency. A turning point came in 1982, when Dr. Larry Winiarski, an engineer at Aprovecho, developed and published ten principles of wood burning stoves, based on his previous work with cooling towers. These principles, perhaps more accurately described as empirical rules of thumb, give general direction on how to make a stove more fuel efficient. For example, Principle Number Two states, "Place an insulated short chimney right above the fire to burn up the smoke and speed up the draft" (Winiarski, 1982).

Winiarski's principles have been used as the basis for the design of cookstoves that have reached millions of households around the world. Using his "rocket stove" design, which applies these principles, he and others at Aprovecho have traveled to communities around the world, helping local people adapt their traditional stoves to be more efficient. While the principles of these stoves are universal, the actual shape each stove takes in each new place can be unique to that location and created with input from the local people; in that way, even today, some aspects of the ethos of the "Lorena system" and appropriate technology still hold. To some extent then, Aprovecho's design principle approach can be seen as a bridge between the technological frames that came before and after, striking a balance between the appropriate technology goals of local empowerment and the efficiency focus that was to come. This balance is reflected in the material form of the stoves: the outside can be made of mud, co-designed with local people, and owner-built, while the inside, which largely determines efficiency, can be ceramic, designed to specification, and mass-produced by artisans or in factories.

Even as Aprovecho was initiating its transition away from full commitment to the "Lorena system," the reputation of the Lorena cookstove itself had begun to fade in some circles. Its performance came under fire by the academic community as early as 1983, even as it was still being praised and copied by development organizations. While practitioners were citing the high mass of the stove as the reason for its energy efficiency, the scientific community raised questions about the assumptions underpinning the widely stated theory that high mass stoves were necessarily efficient. This theory, though popular with practitioners, did not conform to thermal efficiency theories from the scientific literature, leading many to wonder about the claims of fifty percent fuel savings for the Lorena (Prasad, 1985; Scoble 1985).

For many of the Lorena proponents, however, efficiency, while beneficial, was beside the point. Modifications driven by users and judged by local people to be "improvements" were more desirable than extraneously applied standards of efficiency. Therefore, anecdotal claims of wood savings had been enough evidence of the Lorena's fuel efficiency, and little, if any, testing was done to measure or verify these claims. Indeed, for most stoves of the late 1970s and early 1980s, lack of testing or even standardized testing methods meant that efficiency claims were usually both anecdotal and provided by their promoters, making them highly suspect (Gill, 1987).

Later reviews have found that the claims of fuel savings by the Lorena (as well as many other stoves) largely overblown. For this reason, among others, the initial success of the Lorena was not to endure. In 1994, Barnes et al. reported, "The first 'energy-efficient' Lorena-type stoves introduced into Central America…did not save much fuel and were mostly abandoned, although a few were retained because of their convenience and smoke reduction" (p. 18). The stove was abandoned not just by users but also by the cookstove movement. As stove projects began to shift priorities in the 1980s from community empowerment to fuel efficiency, the Lorena stove and the "Lorena process" were no longer well-suited to accomplishing the goals of the movement. By the mid to late 1980s, when cookstoves were widely seen as a tool to fight problems of deforestation and fuel shortages, to many the Lorena would not even be considered an "improved" stove at all (see, for example, Gill, 1987). Production of the Lorena stove gradually decreased throughout the 1980s, although they continue to be produced in small numbers to this day.

However, although perceptions regarding both the benefits and the acceptance of the Lorena faded over time, in the early years of this second generation of cookstoves, the Lorena project was seen as proof of the concept that cookstoves, specifically very cheap or free owner-built stoves, created with input from local people and disseminated through NGO and government channels, could be a viable solution to multiple problems afflicting the developing world. It not only was understood to save fuel, but also reduce toxic smoke emissions, and, perhaps most importantly, through the process of its design and construction, to empower local people and build community capacity. Design blueprints and instructions for the Lorena stoves themselves were published by Aprovecho and the Intermediate Technology Development Group and found their way into the hands of NGO volunteers and personnel around the world, who used them as a starting point for dozens of projects that were being initiated in the late 1970s and early 1980s.

One of the more notable of these was the Yayasan Dian Desa program, which not only was one of the larger early efforts, but also encountered many of the obstacles that would be faced by other stove projects throughout the 1980s.

4.3.4 Yayasan Dian Desa – Indonesia[3]

If the Lorena case can be considered illustrative of the appropriate technology ideals guiding many early cookstove projects, the Yayasan Dian Desa case demonstrates the transition in both motivation and technology that was to follow. Yayasan Dian Desa (YDD), the Village Lamp Foundation, began its involvement with improved cookstoves in 1978 when they hosted a young American by the name of Don Flickinger as part of the Volunteers in Asia Program. YDD was a locally-run NGO that engaged in a variety of "self-help" projects in various villages, at times hosting international volunteers to help with these projects. Don Flickinger came without a defined project but within a few weeks hit upon the idea of introducing improved cookstoves to combat the "twin curse" of firewood scarcity and forest depletion, which he had read about in Aprovecho's book *Lorena Stoves,* published by Volunteers in Asia in 1978 (Sudjarwo, 1985).

Flickinger began trying to construct Lorena stoves, based on the directions and figures in these manuals. Although he at first had trouble with the construction materials, he continued to build stoves and to experiment with both design and materials. He promoted the stoves as highly energy-efficient, although their performance had yet to be proven in Indonesia: "We kept telling people that these stoves would use half the normal amount of fuel,…but really at that point in time we were just repeating what we had read or had been told" (Kaufman 1983, quoting Flickinger, p. 10).

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[3] Except where noted, the story of Yayasan Dian Desa comes from Kaufman 1983, From a Lorena to a Mountain of Fire, in which Kaufman, a staff member at YDD, recounts the history of their stove program as a case study, including quotes from many of the people involved from the beginning.

In 1978 YDD decided to do a stove demonstration project based on Flickinger's work. They created a stove team comprised of four local men, and together this team constructed hundreds of Lorena-like stoves throughout 1978 and 1979. The team not only used the Lorena stove design as a model, they also incorporated many elements of the "Lorena process," involving local people in modifying the stove to suit local conditions and creating many versions to suit the needs of different households (see Fig 4).

Figure 4: YDD Cookstove Modification

Modification was seen as desirable - the stove team considered the Lorena stove to be "in no way a fixed design, but rather a concept which could and should be modified to meet local standards and conditions" (p. 15). In soliciting feedback from users on potential modifications the stove team quickly learned that while fuel efficiency was the impetus for YDD's program, it was not nearly as important to users as other aspects such as speed, size, appearance, and durability, so they began to alter the design to better meet these needs. Some of the modifications requested by users likely affected the efficiency of the stoves, but that was not a concern voiced by the stove team, and efficiency testing was not conducted. Instead, based on this interaction with stove users, the project began to expand its goals beyond prevention of deforestation to things like decreasing cooking and fuel foraging time, reducing smoke to enhance health, upgrading the kitchen environment, and expanding the role of women in village development efforts (p. 27).

Thus, much like the Lorena case, in the early days of the YDD project, the fieldworkers did not try to stabilize their initial technological frame but attempted to take on the technological frame of the users. In doing so, they incorporated many goals other than fuel efficiency and produced a variety of stove designs, each meant to meet some goal that the users had defined and involving those users as co-designers.

However, this approach and the resulting technologies were soon to change. Due to the success of the pilot project, YDD was encouraged by the government to scale up the stove work and expand to many other villages. As the project grew, it was impossible to keep tabs on all of the stove builders, and quality began to suffer. Kaufman describes the new mindset of the program as "asal jadi," meaning "as long as you can count it, it's good" (p.

18). Foley & Moss's review in 1983 offers additional evidence of the poor quality: he notes that one of the most popular models developed by YDD, the Katesan stove, was distributed to over 5000 homes, but just three months later inspections showed most to be unused or broken (Foley & Moss, 1983). During this phase, members of YDD and the stove team began to realize that neither the kinds of stoves they were making, custom-built in home out of available materials, nor the process they were using, training groups of local people to make stoves for friends and neighbors, were well-suited to rapid scale-up.

Compounding these issues, around the same time in late 1979, YDD began to conduct efficiency tests to measure the fuel savings that it had been promoting for the past year. The findings showed that "a large portion of the new stoves were no more efficient than the traditional stoves they replaced; and in some cases were even less efficient" (p. 20). These findings in conjunction with their difficulty in scaling up, caused YDD to begin to question its approach. A speech given by YDD's Director Sudjarwo around this time demonstrates the shift in thinking, which echoes a similar transition in the broader stove movement. In it, he compared cookstoves to birth control, asking the audience to imagine the effect on family planning efforts if each recipient had to make their own birth control device.

> *"As ridiculous as this sounds, this is exactly the approach we (and many other stove promoters) have taken, in our search for a solution to deforestation. By embarking on fuel efficient stove programs which require local villagers to 'build their own,' we have resigned ourselves to years and years of work, which by all indications will result in but a small improvement in the problem. Imagine 30 million wood burning cooks in Indonesia all studying combustion theory and stove construction as a pre-requisite to acquiring a fuel efficient stove! How many training programs, how many field workers, how many years will it take?"* (p. 30)

This change in approach appears to have represented, among other things, a recommitment to the designation of deforestation as the single most important problem that cookstoves were supposed to solve. While the stove team had been content to let efficiency slide while responding to user feedback and alternative goals, Sudjarwo believed that stoves were a "solution to deforestation," and thus had to be highly efficient and of high quality. In criticizing their approach, he speaks of "years and years of work" as if design and building of the stoves is a burden necessary to be undertaken in the cause of fighting deforestation. Such a view contrasts strongly with earlier appropriate technology "Lorena-system" conceptions of the stove design and building process as a key tool for mutual learning and empowerment.

Once deforestation was understood to be the problem, both the designs and methods previously employed by YDD were no longer acceptable, leading to new kinds of stoves and new forms of social organization within YDD. For stove production, YDD decided to move away from the user-built approach to one in which some components of the stove, chiefly the liner, could be mass-produced. Because the liners are the part of the stove most critical to fuel efficiency, it was hoped that producing them in more centralized facilities with greater quality control would ensure that the stoves would perform well regardless of the construction of the other components. Much like Aprovecho's approach in the 1980s, this strategy was in part a compromise between the old and new ways of doing things in that the outside components could still be constructed and designed locally.

The new approach to production required a new stove design, one that incorporated ceramic liners to enable partial mass-production: the *tungku sae* stove. With this new stove and production method, the pace of production increased as desired. Sudjarwo noted, "One trained potter can produce 100 stoves per month, more than most mud-stove builders could produce in a lifetime" (1985, p. 163). The quality, however, was still not consistent, so in 1982, YDD created a small five-person factory, followed in 1983 by a larger one. By 1985, these factories were producing 5,000 stoves per month, and feedback from users was positive as they found the stoves to be fast cooking and easy to use (Sujarwo, 1985).

YDD was happy with the results of the change in approach. Sudjarwo stated, "In the early years Dian Desa's approach was to try to develop site specific stoves in each area. This approach is slow and biased towards the use of local materials and local resources – mud and village labour…this bias has limited the efficiency of the production system" (1985, p. 166). Thus, in some sense, the YDD case picks up where Lorena left off, exemplifying the shift in both the technology and the social organization of the movement that was required once fuel efficiency became the salient characteristic defining "improved" stoves.

4.4 Cookstoves are the Answer – What is the Problem? Social Construction of the Fuel-Efficient Improved Cookstove

These early years of the 1980s were a key moment in cookstove history, setting the path down that movement was to follow for the next thirty years and laying the groundwork for both the cookstove technologies and the social organizations that we see today. Setting all this in motion was a stabilization of a single technological frame that saw prevention of deforesation as the primary goal of improved cookstove technologies. In that frame, "improvement" was defined as fuel efficiency, and "improved" stoves were understood to be highly engineered, of consistent quality, and rapidly produced. Stove characteristics favored by other conceptions of improvement, such as community empowerment or user convenience, came to be devalued by leaders of the cookstove movement.

The cookstove programs of the 1950s and 1960s, as seen above, had many motives but were primarily directed at the issue of smoke inhalation. This was a time that saw Raju's "Smokeless Kitchens for the Masses" pamphlet and the development a "smokeless ovens." Although deforestation and efficiency were beginning to be concerns, the more prevalent view among cookstove promoters of the time was that improved cookstoves should reduce or eliminate smoke from the kitchen (Smith, 1987).

By the late 1970s the goals of cookstove programs even more diverse: fuelwood scarcity (termed "the other energy crisis" by Eckholm, 1975), deforestation, smoke, and community development were all motivations. This period of time, from the 1960s to the late 1970s demonstrates a considerable amount of interpretive flexibility. What an improved stove should do, what it should look like, the materials with which it should be made, who should construct it – these were all relatively open questions at the time. So a stove like the Lorena, for example, was initially developed for smoke reduction but was soon found to have other important benefits, not only efficiency but also mutual learning, and local capacity building in accordance with the appropriate technology ethos.

Aprovecho understood and defined the Lorena stove within the context of the appropriate technology movement, which saw technology as ”a means to the ends of self-management and improved existence, rather than an end in itself” (Childers, 1980, p. 3-4). Similarly, many of the early programs that tried to copy the Lorena model, while they may have promoted the stove as a tool for combating deforestation among other things, were more interested in the Lorena process of local stove development than in fuel efficiency. This can be seen in the early days of YDD’s projects, for example, where local communities and users were encouraged to make modifications to the stove design, with no real concern about how these changes may affect the efficiency of the stove (Kaufman, 1983). In part due to this willingness to sacrifice efficiency for convenience of use, many of these early stoves were later shown to have very little, if any, fuel saving advantages over the three-stone fire.

However, by the time that stove projects were beginning to grow rapidly in the early 1980s, the technological frame was beginning to stabilize as concerns over deforestation and energy, especially during the time of the oil crises, became ascendant. Perhaps the most influential publication on this topic was Erik Eckholm’s 1975 Worldwatch Institute publication *The Other Energy Crisis: Firewood,* which effectively bound together these two concerns. Eckholm argued that past deforestation had created a fuel shortage in developing countries and that the collection of fuelwood was leading to further deforestation. This argument became the accepted wisdom at many international institutions including the FAO, which warned that half of the world’s poor lived in areas of acute fuelwood scarcity (Gill, 1987; FAO, 1981).

Fears of mass deforestation began to be increasingly cited as the *raison d’etre* for many cookstove programs in these years. Instigators of these projects argued that deforestation was a very immediate threat, that fuel for cooking was one of the main drivers of this phenomenon, and that if left unchecked, mass starvation would result. Aprovecho, for example, held a conference in 1982 entitled “Solutions to the Fuelwood Crisis” the proceedings of which contain passages such as this:

> *“Inefficient use of wood in open fire cooking is using up the supply of wood faster than the forests can replenish it….The waste is so great that in less than twenty years the supply will be less than the demand and 250 million people will face famine because there will be no wood to cook their food unless corrective steps are taken on an urgency basis.”* (Hottenroth, 1982)

These fears were apparent at the project level as well. In the introduction to YDD’s publication on their cookstove program, their founder, Sudjarwo is quoted as saying that the primary reason for the disappearance of rain forest “piece by piece,” “has been the world’s two billion wood burning cooks” (Kaufman, 1983, p. i).

However, this rhetoric in which deforestation and fuel shortages were described as disasters in the making was not entirely hopeless. While warning of imminent crisis resulting from fuelwood scavenging, the authors simultaneously posited a solution:

efficient cookstoves. As one attendee of the Aprovecho conference remarked, “It is rapidly becoming apparent that the sole hope of warding off a truly catastrophic situation is a massive reduction in the consumption of fuelwood for cooking” (Hottenroth, 1982, p. 2).

This process of *problematization,* in which the root problem that cookstoves should address was defined as deforestation, was to set the technological path that cookstoves would follow over the next twenty years. Once key actors within the movement identified deforestation and fuel shortages as the principle problem, they narrowed the frame of of what an improved cookstove should be – highly and consistently fuel efficient and capable of being scaled up quickly. This improved cookstove was not the same as the improved mud cookstoves developed previously; the Lorena stove was not going to solve deforestation. Manibog argued in his 1984 review that though interest in mud stoves was based on “the possibility of using cheap and locally available materials, which was fully consistent with the self-reliance objective of the ‘appropriate technology’ approach,…in view of the fuelwood crisis, this category may be a questionable choice” (p. 218*).*

The prioritization of fuel-efficiency above all other concerns would necessitate many changes to the old stove models. First of all, different materials would be needed. Scientific testing in laboratories was showing that the high mass of the Lorena-type stoves did not create the kinds of efficiencies initially assumed. Instead, metal and ceramic stoves had been shown to be more efficient and durable than the mud stoves.

It was recognized at the time that changing to materials which could not be freely collected locally by owners, was a challenge to the previous ideology of the movement. Prasad noted at the First Wood Stove Dissemination Conference, that despite the fact that metal was “distinctly superior,” "the possibility of a metal stove for the rural poor has been more or less ignored in the literature. The main reasons are obvious: metal conflicts with the general philosophy of appropriate technology which stresses the need for local resources and skills" (Prasad, 1985, p. 68). However, given the dire problems posed by deforestation and fuel shortages, it was argued that these changes were necessary. As Masse argued at the same conference, "It is tempting to agree with the general aim of using local materials to build improved stoves. But as a technical constraint, the use of local materials may be dangerous and limiting” (Masse 1985, p. 22).

Second of all, in order to be efficient, these stoves demanded precision engineering. Even tiny changes of a few millimeters in the dimensions of critical components could nullify any planned-for gains in efficiency. One of the points of agreement that Manibog found in his 1984 review was the “sensitivity of net fuel performance to precise stove design specifications…” (p. 210). Barnes et al., meanwhile, noted ten years later in their 1994 review that “small variations in the specified dimensions of the stove's interior ceramic or metal parts can cause critical decrements in the stove's efficiency” (p. 19). The precision and quality necessary for efficiency would not only have implications for the stoves themselves, but also for the manner in which they would have to be produced, as discussed below.

Thirdly, in order to respond to the crises of deforestation and fuel shortage, the stove would need to be one that could be built quickly so that it could be brought to scale in time to fend off the looming disaster. Masse summed up the sentiment well in his writings at the First Conference, "The improved stove will contribute to a global solution only if it is disseminated on a large scale…The fuelwood crisis is a fight against time" (1985, p. 22).

Already the scale and speed these cookstove leaders were envisioning was orders of magnitude beyond what could likely be achieved by Lorena-type projects in which teams traveled from village to village, building perhaps a few thousand per year. In her editor's note for the proceeding for the First Conference, Clarke wrote, "Some 100 million improved stoves need to be introduced before the end of the century if effective action is to be taken to improve the fuel supply situation of the 2,000 million people who depend for energy primarily on fuelwood or charcoal" (1985, p. 5). To achieve such a goal would take not just a whole new kind of stove but a totally different approach. As Manibog wrote, "At the rate of two to three monolithic stoves built by a mason and a helper per day, there is no way that sufficiently large numbers can be disseminated rapidly enough to make any measurable fuelwood savings" (1984, p. 219).

For all of these reasons, the materials, the precision, and the scale, this new technological construction of the improved coosktove would also require the coproduction of new forms of social organizations to produce them. Much in the way that YDD decided that rapid production of efficient stoves was not feasible with their train-the-trainer approach, more generally the perceived need for a stove that would solve "the fuelwood crisis" called into question the model of owner-built stoves that had been common in the late 1970s. That process of production was based in part on the belief, common to appropriate technology, that part of the purpose of a stove was to empower local communities through cookstove design and construction. But once the goal of cookstoves was narrowed to addressing deforestation, this method of production, incompatible with both rapid scale-up and consistent quality, was seen as wrong-headed.

4.5 Efficient Cookstoves Re-Configure the Social: Stove Production

The identified crises and their terrifying immediacy, then, not only prescribed a particular form of improved stove, they also suggested a means of production: centralized production or manufacturing. The necessary efficiency required extreme precision, likely only possible in some kind of centralized workshop of factory, and the scale of the problem was so enormous (also, often, stove lifetimes so short) that to make any kind of real impact, stoves would have to be disseminated in huge numbers and quickly. Both of these arguments suggest the need for a move away from owner-built, or even many kinds of artisan-built, methods that had been popular with the Lorena and the early days of the YDD project but were seen as slow and lacking in quality. Moreover, once the appropriate technology focus on the *process* of design and production had been discarded in favor of efficiency, stoves could begin to be seen in the same light as other consumer products, enrolling them in the logic of the market and which would lead eventually to the most cost efficient form of production – mass-manufacturing.

Given the immediacy of the deforestation problem and the kinds of stoves that battling deforestation would require, approaches such as the “Lorena system” were seen as far too time-consuming and difficult to bring to scale. Manibog (1984) describes the Lorena-type process, which he says was used by “[n]early all improved cookstove programs” of the late 1970s, as taking approximately five years, three for stove design and two for demonstration. To those who believed that cookstoves were the primary tool to fight deforestation, this was not a process that could move fast enough to prevent the impending crises. When pushed to move faster and scale more quickly, the custom-built approach had problems maintaining consistent quality, as happened in the case of YDD.

This inability to scale quickly was not previously understood to be a problem because some of the most positive outcomes from the earlier projects were seen to result directly from that lengthy, iterative, and participatory process. But in the new *problematization* the proven difficulties with rapid scale-up meant that the approach was seen as flawed and that it should be abandoned in favor of centralized production.

Moreover, the “Lorena system” was ill-suited to the kinds of precision engineering and consistent quality that the new technological frame demanded. The instructions for building the mud stoves such as the Lorena were generally passed between organizations and fieldworkers through pamphlets involving hand drawings with general guidelines and low-tech methods for measurement and construction. Owners or volunteers were then taught to build the stoves, often in relatively brief workshops lasting just a few days (Sudjarwo, 1985). This process, while acceptable when the goal was community development, could not produce or maintain the precision and consistency required for fuel-efficiency. Even if the original was highly efficient, the performance of each copy would be suspect because of a lack of uniformity.

Describing these manuals and methods of production at the First Workshop, Prasad argued, "Every stove made in this way will be unique, with a unique performance. … The procedures discussed above encourage design irresponsibility" (Prasad, 1985, p. 68). Baldwin put forward similar arguments stating that cookstoves must be "widely, rapidly and accurately replicated….Many of the more successful projects have used artisans or even factories…. Centralized production can provide quality control, reduced cost and a high production rate (1987, p. 284).”

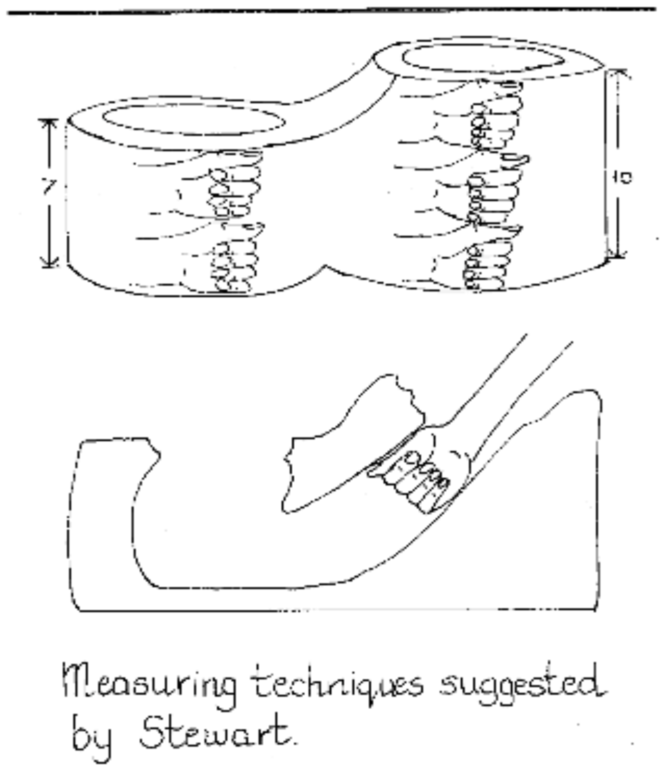

Fig. 5 ITDG/VITA Cookstove Handbook 1984

This process of *interessment* by engineers and the leaders of the cookstove movement persuaded the stove community that not only was efficiency the defining characteristic of the improved cookstove, but that only certain kinds of stoves (highly engineered) made of certain kinds of materials (metal and ceramic) would be capable of performing at a high level of fuel efficiency. That kind of improved stove would then require certain methods of production(centralized) in order to deliver that efficiency with unfailing consistency in each stove. As Baldwin wrote,

> *"The necessary precision of a few millimeters…has some very important consequences. Such high precision in stove and pot dimensions requires centralized artisanal or industrial mass production based on standardized templates and molds. Owner-built or site-built stoves can rarely be made so precisel.y"* (1987, p. 49)

This technological frame, defined by the goal of preventing deforestation through fuel-efficient cookstoves, achieved a high level of stabilization in the 1980s as it became the dominant vision for the kinds of cookstoves and the types of production methods that were pursued moving forward. That stabilization was accomplished through a number of mechanisms, described below.

4.6 Stabilizing the Frame

4.6.1 *Redesignating Good and Bad Stoves*

One of the primary ways in which this technological frame was stabilized and achieved closure was by drawing strict boundaries between the new highly engineered stoves and the stoves of the past and by disparaging the old stove and old methods. Because it was believed that the stoves of the 1970s, primarily user-built mud stoves, “could never be very efficient” (Foley & Moss 1983), and, as described above, they were incompatible with this new technological frame for a variety of reasons, they were seen as “not working” by leaders of the stove movement.. Yet many of those older stoves had been designed to suit purposes other than fuel efficiency and were fully willing to compromise fuel efficiency in order to attain other goals. But by recasting these earlier versions as simply less-improved (or not improved), rather than as tools for different ends, stove movement leaders were able to create a narrative of linear stove progress in which the current highly-engineered stoves were in all ways superior to the old.

Gill, for instance, wrote of the early stoves, ”It is important to note, however, that whilst these were referred to as 'improved' stoves, in most cases their designers did not give any figures on the expected reduction in fuel consumption” (1987, p. 136). Baldwin seemed to concur, writing, "Under the banner of 'appropriate technology,' new designs were quickly labeled improved stoves,” which seems to imply that perhaps they did not deserve such labels (1987, p. 280).

Drawing this clear separation between new efficient “second generation” stoves and the mud stoves of the past, which had failed to achieve mass penetration, also served to distinguish the new approach from the old. Doing so legitimized more recent efforts towards centralized production and standardization and provided an argument for why the new model would be more successful. It was claimed that the failed programs of the past used low-quality stoves, hardly better than a three stone fire (Manibog 1984), and that the quality of those stoves, especially regarding fuel efficiency, was reason to question the value of the whole appropriate technology approach, whose ethos they seemed to embody..

A key argument deployed to prove the superiority of both the “second generation” stoves and the new methods of design and production was the involvement of scientists and engineers, not fieldworkers. The new fuel-efficient stoves would result from the use of modern methods by trained professionals. De Lepeleire stated at the First Conference that because the problems faced had been so dire, many “poorly-defined stove models” had been promoted by fieldworkers and other “non-technical people.” He went on to say, “This shocks engineers who claim that knowledge and facts should be the basis for any programme. They believe that wood-stove design needs an engineering approach (1985, p. 76). Or, as described by Verhaart, developing a “perfect woodfiring cookstove,” the likes of which were not yet available, would take “a great deal of high quality engineering effort” (1982, p. 1).

According to this view, the work that the appropriate technology groups had done eliciting feedback and improving the design through many iterations, as seen in both Guatemala and Indonesia, was not real scientific research of the kind that could lead to true improvement., Not only was the research not done by scientists, it also did not conform to scientific norms. Valid scientific research, as described by Popper (1959), is generally understood by scientists as requiring formulation of falsifiable theories which can be tested. Norms of science, following Merton (1942) among others, further prescribe publishing of results in peer-reviewed journals and reproduction of results by others under independent conditions. In engineering, specifically, results should be able to be understood based on current scientific understanding of the constituent phenomena. Because the fieldworkers had not followed these scientific norms in developing their version of improved stoves, those stoves were doubted by the scientists and engineers who were increasingly becoming the leaders of the stove movement.

As Masse wrote at the First Conference, "For a long time…improved woodstoves in developing countries did not attract the attention of scientists in the industrialiazed countries and thus improved stoves were mostly developed without research" (1985, p. 1). This situation was changing, though: with the interest of scientists piqued, the argument went, it would now be possible to develop stoves that were truly improved, meaning, highly efficient. Baldwin's 1987 book *The Design of Wood Burning Cookstoves* was an excellent example of this kind of thinking. In his introduction, he wrote, "The primary intent of this book is to resolve some of the technical problems of conserving fuelwood supply. This is done by using the principles of modern engineering heat transfer to redesign traditional energy technologies" (1987, p. ix).

Thus, through this process of *interessment* and boundary drawing, the new stoves in the 1980s were cast as strict improvements over the old, obscuring the different motives that had driven design in the earlier stoves and creating a narrative of linear progress.

4.6.2 *Different Problems, Same Solution*

Another way in which the technological frame was stabilized was through a kind of "big tent" process where the problems that could be addressed through fuel efficient-cookstoves were expanded to include things like fuel shortages, health, and poverty. This process was driven by the increasing recognition that fuel collection was not a primary cause of deforestation. However, instead of destabilizing the frame and calling into question the solution of fuel-efficient cookstoves, the cookstove movement retained the solution and reconfigured the problem.

Even at the First International Workshop on Stoves Dissemination in 1983, some participants were admitting that the link between fuelwood collection and deforestation was tenuous at best, although local fuel shortages were still a problem. In her editor's note to the Proceedings, Clarke notes that one of the articles "makes the point that deforestation is not caused by stoves….." (1985, p. 9) The same year, Foley & Moss's review pointed out that while "[s]tove programmes are widely assumed to have an important role in reducing the rate of deforestation" actually population growth and agriculture were much bigger drivers of deforestation. (Foley & Moss 1983, p. 13).

However, despite evidence to the contrary, many in the movement continued to espouse the belief that cookstoves and deforestation were intimately linked. From the same workshop proceedings as above, Prasad argued that millions of fuel-efficient stoves were needed because "without widespread replication, it is unlikely that improved stoves would be able to contribute significantly to…alleviating the problems of deforestation" (Prasad 1985, p. 1). In addition, some key international institutions, such as the FAO continued to link cookstoves to deforestation, reporting in 1985 that "fuelwood supplies have been rapidly depleted ,and the cutting of fuelwood has in turn been a major cause of excessive deforestation" (FAO, 1985).

Yet for those that did accept that cookstoves were neither responsible for, nor appropriate solutions to, deforestation, fuel-efficient cookstoves were still seen as necessary for addressing other issues, such as local fuel shortages, which had always been closely linked with deforestation. The first line of the action plan for the 1990s from the Second Workshop, reads, "Firewood has become a matter of serious world concern owing to dwindling forest and ligneous resources resulting from wasteful and inefficient methods of cooking…" (Caceres, p. ix).

Leaders in the stove movement also identified efficiency as the answer for other issues that cookstove programs had tried to address in the past. For example, highly efficient cookstoves could reduce smoke emissions and produce health benefits. In his 1987 book *Biofuels, Air Pollution, and Health*, Kirk Smith described increasing fuel efficiency is one approach to reducing exposure to cookstove pollutants. "All else being equal, the use of less fuel per meal will mean less emissions" (Smith 1987, p. 260).

It was also argued that highly-efficient stoves could address the kinds of social issues that had driven some of the earlier appropriate technology projects such as economic development and gender relations. Proponents of efficiency argued that the appropriate technology co-design and local production approach was not really necessary to achieve these ends. Highly-efficient stoves could accomplish many of the same things despite being centrally produced. For example, Gill wrote that fuel efficient stoves were argued to "reduce the time spent in cooking and collecting fuel. Rural women could usefully spend the time saved in income-generating activities…." (1987, p. 136). Similarly, writing about the First Conference, one participant stated that there was broad agreement that fuel-efficient stoves could "improve domestic environment, encourage people's participation in development, reduce drudgery, give women time for other productive activities, and frequently promote their status in society" (ITDG, 1984).

Thus, even when the original *problematization* of deforestation was called into question, the solution of efficient cookstoves was not. Instead, the range of problems that fuel efficient cookstoves could solve was expanded, thereby stabilizing the technological frame in which fuel-efficiency was the metric by which improvement would be measured.

4.6.3 *Efficiency Testing*

Further steps towards stabilizing efficiency as the definitional characteristic of improvement involved efforts to make efficiency testing both standardized and universal. Promoters of efficiency argued that if organizations wanted to know if they were distributing improved stoves, stoves that "worked," they needed to know how efficient they were. To measure how much more efficient these stoves were than the open fire was to measure improvement. Stoves could then be selected for projects based on their relative efficiency.

Calls for a standardized method of measuring efficiency were increasingly common by the early 1980s. Joseph, the organizer of the First Conference, wrote in 1980, that "the task of choosing a suitable stove would be made much easier if a standard test were used by all stove designers" (Joseph & Shanahan, 1980, p. 10). Although some stove efficiency testing was already being conducted, ideas about how to go about this testing were varied. Thus, in 1982, Volunteers In Technical Assistance (VITA) sponsored a workshop attended by the major stove research groups to create a set of international standard tests (Smith, 1987). These standard tests, the Water Boiling Test, the Controlled Cooking Test, and the Kitchen Performance Test, have since been revised slightly but continue to this day to form the basis of stove comparison worldwide. They are, for example, the methods employed to calculate carbon savings under approved United Nations methodologies. This is despite the fact that literature since the 1980s suggests that certain of these tests, particularly the Water Boiling Test, are not good predictors of field performance and should only be used for limited purposes (Still, Ogle, & Bailis 2003). Problems with efficiency measurements are discussed more fully below.

4.6.4 *Evidence of Closure and Stabilization*

The constancy of the concern with, above all, efficiency in cookstoves, suggests that the *problematization* was generally a success and that the technological frame was stabilized. Allies were *enrolled* from many various organizations, and efficiency became the currency of choice in the stove world. Efficiency testing and reporting is common, with numerous peer-reviewed articles in the academic literature as well as hundreds of organizational reports in the gray literature. When reading about any cookstove, the first attribute to be described will likely be its efficiency or fuel savings over an open fire. At this point it is virtually assumed that any improved cookstove is at least attempting to be more efficient than the open fire.

At least in the leadership of the cookstove community, as represented in their writings from various conferences and published reviews, the efficiency frame was effectively stabilized early in the 1980s. At Aprovecho's conference Solutions to the Firewood Crisis in 1982, Verhaart wrote of efficiency as "the great catchword in debates on the relative merits of cookstoves" (p. 2). In his 1984 review, Manibog wrote that cookstove projects were conducted "with the primary if not sole objective of increasing energy efficiency" (p. 200).

Not only had the primacy of efficiency stabilized, but so had the stove characteristics and production approaches derived from it. Listing the main conclusions of the First Conference, Clarke wrote that "the case for professionally-made and commercially-marketed stoves may be greater than the case for low-cost, owner-built models for which there is no quality control and no assured life time. This is a reversal of stove thinking over the past decade...." (1985, p. 8).

Evidence that this reversal of thought was changing the material form of cookstoves and the way that they were produced can be seen, for example in Baldwin, "Professional stove makers are now producing portable metal or ceramic stoves in conjunction with projects in Botswana, Burkina Faso (formerly Upper Volta), Indonesia, Kenya, Mali, Nepal, Niger, Sri Lanka, and other countries" (1985, p. 284). In 1993, Barnes et al. wrote that "most owner-built stove programs in the world, including the two largest in China and India, are moving toward centralized, artisan production for the interior parts of the stove, usually made of ceramic or metal, where dimensions are most critical" (1993, p. 128).

Thus, in a span of about a decade, the dominant technological frame changed from one that accepted a multiplicity of goals for stoves and was dedicated to a process of user-driven, local design with local materials at low or no cost, to one in which improved stoves were defined by efficiency and built to precise specification at centralized facilities.

4.7. Dissidence

Although this *problematization* was generally successful, there has been, and continues to be, *dissidence* within the cookstove world. One form of this *dissidence* has been from within the movement and concerns both whether or not efficiency is a useful concept in terms of fuel savings as well as whether it truly meets the variety of goals that motivate cookstove programs. The other has come from users themselves, whose technological frame was often substantially different from that of cookstove promoters and often subsumed by concerns about efficiency.

4.7.1 Dissidence within the movement

Although the *problematization* described above is still dominant within the cookstove movement, some dissidents within the movement were never fully in support of the use of efficiency as a definition for improvement.

One set of these concerns over efficiency arise from problems of measuring efficiency. As efficiency became the primary sought-after characteristic stoves, measuring and proving high efficiency became an obligatory passage point for stove dissemination. Yet some have felt that efficiency as a metric is quite problematic, especially when it is measured using the Water Boiling Test (WBT), the most commonly used efficiency test. The idea for testing cookstove efficiency by boiling water was derived from methods for measuring performance in industrial boilers (Joseph & Shanahan, 1980). In the WBT, water is brought to a boil twice, once on a cold stove ("cold start") and once on a stove that has already warmed up ("hot start"), and simmered for fifteen minutes. These three phases of the WBT are meant to be representative of the main tasks that users perform with their stoves, boiling and simmering. Although the WBT measures multiple aspects of stove performance, it is most often used to generate efficiency numbers..

The most significant problem with using with WBT-measured efficiency as an obligatory passage point is that it has been shown to have very little relation to fuel saving performance in the field, which is what drove interest in efficiency to begin with. This lack of congruence between measured efficiency and fuel use in the field was recognized early on. At the First Conference, for example Masse wrote that many stoves claimed, based on their efficiency, that they would cut fuel use in half; however, "[n]umerous such models exist, yet there has never been a case where wood consumption has actually declined by 50 percent" (1985, p. 22). Despite ongoing criticism, the efficiency frame has been highly stable and continues to be widely used and reported. As Dean Still wrote in 2003, "The decades old books and articles explained that the PHU [efficiency] test did not accurately predict success at cooking, even though the use of the test today continues to be almost universal" (Still, Ogle, & Bailis, 2003, p. 1).

These debates destabilize the generalized concept of efficiency as a solution, but they do not challenge the dominant technological frame of an improved stove as one that uses less fuel and must therefore be highly engineered, made of metal or ceramic, and produced at some centralized facility.

That frame, though, has been challenged by other *dissidents* within the cookstove world. Some, for example, continue to reject the notion that efficiency is the salient characteristic of an improved stove. They believe that the community development resulting from local design and construction is more important than efficiency. The *Instituto de Desenvolvimento Sustentavel e Energias Renovaveis*, for instance, says in their profile on the Partnership for Clean Indoor Air website (a clearinghouse for stove projects worldwide), "Our approach is based on locally constructed stoves and its parts. We do not believe in large scale mass production from central manufacturers" (IDER, 2011).

Even while the First and Second Conferences were proclaiming centrally produced, precisely constructed, commercialized stoves to be the direction of the future, some implementing organizations were not persuaded. GTZ, the German society for technical cooperation, wrote in its Fuel Saving Cookstoves manual in 1984,

> *The need to produce comes from the industry itself. This type of system works badly for rural people in poor countries. Because the product is manufactured elsewhere, it sucks scarce capital out of rural areas, making the people increasingly dependent on cities and other richer countries. Stoves, because they are technically simple and often use local materials, belong to another system. This means that the people themselves can exert pressure for technical help, adding their ideas to those of outsiders to produce not a product but a technique. Through refinement by the people instead of for them, the technique spreads and adjusts to all of the local variations in cooking habits, fuels, climate and family*

> *structure. This allows people to be part of developing their own technologies, and ensures that technical solutions respond to their needs.* (GATE, 1984, n.p.)

Finally, there have been and continue to be some within the stove community that accept the need for precision engineering and mass-manufacturing but still question the primacy of efficiency. This group defines reduction of hazardous smoke emissions as the goal of cookstove programs, and a stove that is efficient but does not reduce health-damaging pollutants does not "work." In the *problematization* process, these allies were brought on board through an alignment of their goals with efficiency as increasing fuel efficiency necessarily results in decreased emissions. Proponents of fuel-efficiency argued that even with only minor attention to emissions, improvements in fuel efficiency were almost certain to yield emissions and health benefits.

However, while these goals are generally compatible, it is not true to say that improvements in efficiency necessarily yield improvements in emissions. Emissions are a measurement of the mass of fuel used multiplied by the emissions per mass of fuel (emission factor). If one stove uses less fuel than another but combusts each gram of fuel less cleanly, that stove could have either higher or lower emissions than the other.[4] (Smith, 1987). Moreover, recent research has suggested that the health effects from reducing emissions are not linear – that most of the benefit is received only after emissions have dropped significantly, perhaps by as much as 80 or 90% (Smith, personal interview Dec., 2010). Virtually no biomass stove can meet that kind of emission criteria without use of some kind of fan, which increases the cost considerably.

Given these contradictions, there have been some efforts to push back on the idea that efficiency should be the main indicator of stove improvement and instead to "explicitly recognize the possibilities and benefits of reduced smoke exposure as well as fuel use" (Smith, 1987, p. 259).

4.7.2 Dissidence from the Implicated Actors – What do users want

The most significant form of *dissidence* in terms of the effects on stove programs as a whole has come from stove users, those at whom these programs are directed, but who have very often been *implicated actors* without a seat at the table when important decisions regarding the direction of stove programs have been made. Perhaps because their views have been largely ignored, users have often responded by rejecting the improved stoves in favor of their traditional stoves or three-stone fires, thus leading to the widespread failures of cookstove programs over the years (Gifford, 2010).

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[4] Kirk Smith covers this topic extensively in his 1987 book and has many examples that of modifications that improve overall efficiency but also increase emissions per mass of fuel (the "emission factor" or EF). For example, lowering the rate at which fuel is burned increases heat transfer efficiency, but lowers combustion efficiency, increasing the EF (p 274-276).

While the need to listen to the user and incorporate their desires is nearly universally recognized in the stove literature, within the efficiency frame, the their desires can only be accommodated within the parameters determined by efficiency. Generally it was assumed that this would not be problematic because, in many cases, it was thought that efficiency was desired by users; by using less fuel they would save themselves time and/or money.. Or, in some cases, when cooks did not indicate that fuel saving was important, designers would try to meet their stated needs to the extent possible while still optimizing designs for efficiency. That is, a cook's desire for less smoke could be met, at least to some extent, by a fuel-efficient stove. Or stove height, for example, could be adapted to user specification with no effect on efficiency.

However, at least some observers recognized that there were cases, perhaps more common than admitted, in which design for efficiency and for user needs was incompatible. In Barnes et al.'s 1994 review, they noted,

> *"Offsetting some of their benefits, improved stoves are sometimes more temperamental than traditional stoves. A common reason for this problem is that stove designers, in their desire to reduce heat loss, provide too small a hole for adding fuel, requiring the cook to spend much time in cutting the wood into small bits that fit in the hole (Openshaw 1982). In addition, some design changes intended to increase heat transfer efficiency by decreasing air flow can actually increase smoke emissions. Conversely, efforts to reduce smoke exposure by introducing chimneys can reduce efficiency.* (p. 10)

In these cases, designers generally chose to optimize efficiency, which they felt was the most important attribute, even if the users themselves did not recognize it as such. Rarely was this sentiment stated so explicitly as by Masse at the First Conference when he remarked that improving fuel efficiency "is difficult enough without including other requirements. Cooks, though, were often "more concerned with advantages such as smoke removal, or a decrease in the danger of accidental burns, or social prestige than with reduced wood consumption" and thus could not always be trusted to "respect the critical dimensions" (1985, p. 22).

When efficiency was chosen at the expense of other user-friendly characteristics, cooks could and did express their *dissidence* by rejecting improved cookstoves, even those given to them for free. Indeed to users, these cookstoves may not have seemed improved in any important sense but might actually appear to be worse than the open fire. Given the qualities that mattered to the cooks, which in many cases did not include fuel efficiency, many of these improved stoves did not "work."

There were a number of ways that improved stoves might not represent an improvement over three-stone fires, and with so many failed efficient cookstove projects, at least some observers started to realize that the traditional fire might have some advantages over these efficient improved stoves. Foley & Moss, for example, recognized that traditional stoves are not "optimized around a single design parameter" but instead "represent an effective compromise between the often conflicting requirements of utility, economy, convenience, and general compatibility with the domestic environment (1983, p. 48).

Manibog came to similar conclusions in his review, noting that three-stone fires were multifunctional, providing " lighting, heating, drying, a communal gathering point, repelling insects, and others." Other benefits included zero building and maintenance costs as well as ease of operation. He concluded that users reject improved cookstoves "when one or more of these needs are not met by the ICS but are valued more than the promised fuel and time saving…." (1984, p. 213).

It becomes clear, therefore, that the users, who many would have considered to be the most important ally in this *problematization,* were never fully enrolled, perhaps in part because they were never given much of a voice. Although in some places fuel shortages did occur and fuel efficiency was important to the local population, in many areas they were more interested in attributes like speed of cooking or smoke removal. These users showed their *dissidence* through rejection of the improved cookstoves, resulting in the failure of dozens of efficient cookstove projects.

5. Coproduction of Cookstoves and the Movement, 2000-2010

Despite these nodes of resistance, the *problematization* process of the early 1980s was quite successful, and the technological frame defining improved stoves as fuel efficient has remained stable over more than twenty years. Actors and events in the early 1980s coproduced both a new technology, the efficient improved cookstove, as well as the new forms of social organizations to design, test, and produce them. This reconfiguration of the social arrangements around cookstoves in the 1980s had implications for the technological and social organizations in the 2000. Shifting the goals from those of appropriate technology, base on local design and empowerment, to that of producing highly efficient stoves at a global scale, enabled cookstoves to be enrolled in the same market logic that governs other consumer products. This process has culminated in the 2000s with the creation of cookstove companies mass-producing hundreds of thousands of standardized efficient stoves in factories in India and China for distribution to the poor around the world.

5.1 Reformations: Programs and Trends of the 1990s and 2000s

By the mid-1990s, the wave of popularity for cookstove projects had waned. The enormous national programs in India and China were drawing to a close, and the problems encountered by the Indian program, in particular, were causing many to question whether cookstove programs were justified (Kishore and Ramana, 2002). However, cookstove momentum began to build again in the 2000s, with cookstoves receiving renewed interest in part due to their potential role in climate change mitigation. Although the movement remains fairly heterogeneous this wave of projects in the 2000s has largely maintained the frame of the 1980s and continued the trend towards mass-production of fuel-efficient cookstoves.

A 2010 review by Mary Louise Gifford described the current cookstove landscape, and her work forms the basis of much of this section.[5] Gifford surveyed 101 cookstove programs that are either ongoing or ended sometime after 1994, the year of the last comprehensive cookstove review, which was a technical paper for the World Bank by Barnes et al. Her review shows growth in both the size and geographical extent of cookstove programs in the 2000: at least 95 new cookstove programs have begun since the late 1990s at a cost of more than $50 million.

One trend that can be seen in these projects is an increase in scale. While the India and China programs were orders of magnitude larger than any others, Gifford lists at least eight projects that have distributed over 100,000 stoves (Gifford, 2010). This trend towards larger scale projects has been enabled by and is reflected in the kinds of stoves and methods of production used, with a gradual move away from owner-built mud stoves to factory-built stoves of metal and ceramic. By the time of Barnes et al.'s writing in 1994, cookstove production had begun to shift to regional manufacturing centers, which still allowed some capacity-building and training of local people but also ensured a consistently high level of quality and could reach a larger scale. In the 2000s, some programs have taken this shift a step further, establishing manufacturing centers in China and India to ship fully manufactured stoves to project locations in Africa, Latin America, and elsewhere in Asia. Most current stove programs (88%, according to Gifford, 2010) sell the stoves to consumers, either at full or subsidized prices, and many are exploring alternative funding sources such as micro-credit and carbon finance.

This commercialized, mass-manufacturing approach, although it is in many ways simply an extension of the trends of the 1980s, stands in sharp contrast to some of the early programs, such as the Lorena, which were grounded in the values of appropriate technology, emphasizing user involvement in stove design and production and focusing on the system of stove development more than the stove itself. The new approach is exemplified by two organizations, Envirofit and StoveTec, the largest international producers of mass-manufactured stoves. StoveTec, in particular, provides an excellent illustration of these changes in approach in that it has grown out of Aprovecho, the organization responsible for the Lorena. A discussion of the genesis and growth of StoveTec, based primarily on interviews (Nov., 2010) with its founder and first CEO, follows.

5.1.1 StoveTec

StoveTec is a for-profit (or, as they say, "not-just-for-profit,") stove corporation that is wholly owned by the Aprovecho Research Center, which I shall here call "Aprovecho." The company was started in 2007 with the purpose of creating a stove business that could provide Aprovecho with a sustainable flow of funding, freeing it, to some extent, from

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[5] As the Gifford review is recent and comprehensive, I refer readers interested in the scope of programs to that report and instead limit this discussion to general trends and significant changes that have occurred in cookstove projects over the last fifteen years.

reliance on grants and foundations. StoveTec sells, improved rocket stoves developed at Aprovecho to individuals, governments, and NGOs. Through a licensing agreement with Aprivecho, royalties generated from these sales, as well as payment for services, flow back to Aprovecho. This arrangement is mean to provide a significant portion of the funding for Aprovecho's R&D work, which includes the StoveTec stoves as well as stoves designed by other organizations.

Although StoveTec officially opened its doors in 2007, Still conceived of it some years earlier. At that time, and to some extent still today, a large part of Aprovecho's main work consisted of visiting factories and stove projects throughout the developing world to advise them on ways to make more fuel-efficient stoves. Through these projects, typically funded by government organizations or foundations, Aprovecho has dispensed advice to dozens of factories and organizations over the years, and their influence has been felt in hundreds of thousands of households around the world.

Yet, although Aprovecho's work with these factories usually improved efficiency in the stoves the factory was producing, Still felt that the efficiencies could have been higher if factories would be willing to switch over to production of Aprovecho-designed rocket stoves. However, the ceramic rocket stoves were not always feasible alternatives for the factories and NGOs that he was advising. This room for improvement motivated Still to explore other options for stove production and eventually led him to found StoveTec, which he started as a way to "have the best quality stoves out there." This commitment to high efficiency stoves and a centralized production process fits well in the technological frame of the 1980s but stands in sharp contrast to the Lorena approach that Aprovecho was originally known for.

At the same time, according to Still, Aprovecho was getting pressure from one of their biggest funders, the Shell Foundation, to find a way to be self-sufficient. At the same time, according to Still, Aprovecho was getting pressure from one of their biggest funders, the Shell Foundation, to find a way to be self-sufficient. "[W]hen we worked for Shell Foundation, they kept on pushing us and pushing us…you know, NGOs should be self-supporting. So we said, OK, we'll do it."

Fig 6: StoveTec Stove from www.stovetec.net

This message appealed to Still and others at Aprovecho, who were, to some extent, feeling hamstrung by the need to serve the desires of donors rather than choosing their own projects and methods of operation. Still described the thinking as, "Let's be in charge of our own destiny, let's do our own projects. Let's create a stove in China. Let's do it again and again and again…, and let's not be dependent on the whim of a funder!"

A commercial approach, then, would allow Aprovecho the freedom to do the kind of research and projects that they wanted to do and to make the kinds of stoves that they thought were needed. It would provide an alternative way in which to get cheap, high-quality stoves out en masse. Still's imagining of an improved stove was one that would require a mass-manufacture process, and to make it would require the creation of a for-profit company.

With the seeds for this new approach planted, Still was open to such opportunities that might present themselves, and he found what he was looking for in China. There he found a manufacturer that could make a fuel-efficient stove at low enough cost that it could be viable commercially: "And the idea was that we'd have our $5 rocket stove for sale…[T]hat was the idea, that it'd be cheap enough that you could then sell it commercially."

"Commercially," here, does not mean directly to consumers; StoveTec does not do stove distribution themselves. Instead, the stoves are sold at a profit to NGOs, governments, or commercial retailers, "people, " as Still says, "who will buy the damn thing….You don't care if they go to refugees in Darfur or if they go in market shelves in Mexico."

StoveTec is now a self-sustaining business that hired a CEO, Ben West, in 2009. According to the Aprovecho website, "Over 70,000 stoves have been sold in the past year, with a production capacity of 500,000 stoves per year. Stoves are purchased by the container load, ready for distribution" (Aprovecho, 2011b). The StoveTec approach has garnered much attention and positive press, including the 2009 Ashden International Energy Champion Award which was jointly shared by Aprovecho and the Shangzhou Stove Manufacturer.

As a case, StoveTec clearly illustrates how the goal of a high-quality, fuel-efficient stove that grew out of the *problematization* of cookstoves in the 1980s, coproduced social solutions for production resulting in a for-profit cookstove company: StoveTec.

5.2 The Sociotechnical Legacy of Efficiency: Users as Consumers

To a large extent, the course of cookstoves in the 2000s was set when efficiency became the agreed-upon definition of improvement in cookstoves. While the motivations for cookstoves has changed over the years, the efficiency solution, the same technological frame put in place over twenty years ago, has remained remarkably stable. This frame pushed aside the Lorenas of the 1970s in favor of efficient, engineered, mass produced stoves in the 1980s and created a certain kind of industrial logic that is embedded in cookstoves today. The acceptance of the goal of efficiency over such process-driven aims as mutual learning was a necessary first step in creating the transition to centralized and standardized production. Once the transition from process to product had occurred, cookstove production became subject to the same market logic that governs production of other consumer goods. That logic, combined with the particular kind of cookstoves needed for efficiency, has not only driven the move towards mass-manufacturing and cookstove factories that is evident today but has also changed the way that we think about the role that technology should play in development. Whereas technologies for the poor were once imagined as ways to create opportunities for local production, they are now seen as opportunities for improved consumption. The user, once imagined as a co-designer and constructor is re-imagined as a consumer.

The technological frame from the 1980s of "improved" stoves as "fuel-efficient" stoves remains remarkably stable, despite nodes of *dissidence*. When people speak of improved cookstoves, it can be understood that they mean fuel-efficient cookstoves. Nearly any large, visible organization that is involved in cookstoves makes reference to efficiency. Tests developed in the early 1980s to measure efficiency are now built into a number of baselines and standards, including the methodologies for calculating carbon savings under the UNFCCC Clean Development Mechanism. The ability of any cookstove project to enter this multi-billion dollar market is determined almost exclusively by efficiency as measured in a WBT. Moreover, to the extent that cookstove designers are beginning to modify their designs in order to take advantage of carbon financing, the tests for which they are designing measure efficiency

While the kinds of stove production and stoves technologies that are dominant today may in retrospect appear to be the result of a linear progression of improvement over traditional stoves, in reality, they reflect choices made to value efficiency above qualities such as local production, zero cost, or user involvement in design. The change in the way that the coosktove movement thought of the purpose of stoves – as a product to combat deforestation rather than a tool for empowerment - has left a material and social legacy. Stoves produced today continue in the same mold, with a form designed to optimize efficiency; production of that form of stoves required the creation and maintenance of the kinds of cookstove factories and companies that are coming to dominate the cookstove movement today.

Perhaps this process can be seen most clearly by imagining a counterfactual in which the Lorena system and its like had continued to be the dominant form of cookstove technologies and production. Mud stoves, built in-home with the involvement of the user, would have entailed a number of constraints on the social structure of the organizations promoting them. There could be, for example, no international production of such stoves, no large-scale manufacturing. There could also be very little in the way of private enterprise, and certainly one would never see a multi-national corporation living off the profits of mud cookstoves – the scale would simply never be large enough, and the labor resources too great.

Instead, what we see today is a landscape in which, for example, Aprovecho has spun off a for-profit company making stoves in China; Envirofit manufactures 100,000 stoves per year in India; and the "latest focus is on large scale factories" (Gifford, 2010). Such centralized, international production incorporating large-scale private enterprise is a far cry from the appropriate technology vision espoused in the days of the Lorena, and is a result, at least in part, of the type of stove envisioned in the 1980s. This modern-day cookstove movement, then, has been co-produced with the current material form of the cookstoves technologies themselves, "each underwriting each other's existence."

One result of creating the particular social arrangements that make up contemprorary cookstove companies like StoveTec and Envirofit, is that today's efficiency-driven cookstoves also embody something new: a reimagination of the role of technology in development that constructs the user as consumer.

The modern commercialized cookstove movement with its mass-produced efficient stoves is more likely to understand stoves as a commodity, rather than as part of a process of empowerment and mutual learning. As mass-produced cookstoves have led cookstove organizations to a more commercialized model requiring sales of cookstoves to support their work, their focus has changed from one of in-depth engagement with the communities that they seek to serve to a relationship defined by commercial transactions. As an example of this change, a CEO of a cookstove company described their mission thusly, "It's our mission to deliver the best available stove possible in the largest quantity." His job is not to solve problems of health or poverty but to sell stoves, which will presumably solve those problems through their use.

Moreover, because their designs are fixed, these mass-produced stoves preclude the imagining of the user as co-designer. There is no way for users to meaningfully participate in modification of the design once manufacture has begun. This means that within a target community, users are not approached as potential sources of knowledge and production, as they were in construction of the Lorena stoves, but instead are asked to participate only in focus groups designed to ascertain whether or not they will purchase various stoves. They are targeted with social marketing messages that encourage them to buy the stoves using common tools of consumer messaging and advertising, which may or may not include raising awareness of the ways stove might improve health or reduce fuel.

This construction of user as consumer has both its positive and negative aspects. On the one hand, the relationships, learning, and attention to the ways in which development of a stove technology might address other social problems is largely lost. On the other hand, in some ways, consumers have greater power than users have traditionally been granted in cookstove and other technology development programs. Their technological frame must be considered because they are newly understood to have the ability to make choices about whether or not a technology works for them. While there is limited opportunity for them to modify these mass-produced, commercial stoves, they do have the power to reject them, and repeated rejection could doom a for-profit cookstove company to failure.

Moreover, in their construction as consumers, these users are seen as more analogous to people in developed countries, capable of making rational decisions regarding whether or not to adopt a technology. In an interview, one cookstove developer commented,

> *The reason many stove projects have failed over the years is that a development agency comes in, they do an analysis, they pick a product that they think is going to be 'best for that audience,' usually because it has the highest efficiency or the highest health benefits, and what they don't do effectively is understand truly the consumer perspective, meaning no matter how much or little money you have human nature is pretty similar. Somebody who is making a dollar a day has many of the same kinds of beliefs and aspirations and desires as we do.* (Neil Bellefeuille, personal interview, Dec. 2010)

Thus, these mass-produced cookstoves as consumer products are designed to meet consumer needs and desires, in much the same way as all other types of consumer products. In this way, the construct of user as consumer then feeds back on cookstove design, as each reinforces the other, whether for good or ill.

However, in some ways, the user as consumer is not a completely authentic construction. Although designers must pay more attention to users in order to keep their businesses afloat, when it comes to choosing stoves, users are often left with the same choice they have always had: accept the single improved stove they have been offered or retain the three-stone fire. The fact that a user's decision to accept or reject the stove has monetary consequences for designers and distributors does give the user more power, but on an individual basis, that power has limited effect. Rarely are there multiple cookstove companies competing for consumers, especially in rural areas inhabited by the very poor. This situation may be changing, too, though, as stove companies are attempting to develop a range of products, and stove project managers are more interested than ever in offering their users, now consumers, a range of options to choose from. While right now the user as consumer is more imaginary than real, this imaginary may be driving real changes as projects adapt their methods to more effectively treat users as consumers.

These changes in cookstove design and social organization echo and reinforce broader societal conceptions of the role that technology should play, particularly in sustainable development. Technologies are seen now less as tools to be used in a process of empowerment than as technical solutions to environmental and sometimes social problems. Perceived successes and failures of technologies in meeting these goals either reinforce or destabilize these imaginaries. The widely reported abandonment of cookstoves by users in the India National Program, for example, contributed to the idea that the appropriate technology approach to development should be rethought; likewise, the success of cell phones and other IT in the developing world has bolstered support for the consumer model of development for technologies for the poor and the kinds of mass-manufactured technologies that that construction entails.

In sum, the current model of mass-produced, standardized, cookstoves is the result of an imagined technical solution, taken to the extreme, to the problem of deforestation. Defining the goal for cookstoves as reducing deforestation led to a focus on fuel-efficiency, which required cookstoves to become standardized, efficient, and rapidly producible. The focus on combating deforestation simultaneously led to a prioritization of the technological product over the development process, which allowed cookstoves to be enrolled in the same market logic as other products. The new cookstoves, standardized and efficient consumer products, caused a reconstruction of the social development sphere in which commercial approaches and international for-profit cookstove companies are now seen as acceptable, even preferable, tools of development. This transition echoes broader trends in our understanding of the role of technology for the poor, as the global poor are re-imagined as consumers of technological products, not producers to be involved in technology design and production.

6. Conclusion

The trajectory of cookstoves is not simply one of linear progress. It reflects choices on the part of designers, particularly in terms of which aspect of stoves defines improvement. Stove projects originally targeted the reduction of smoke, user convenience, and local capacity development. But during a critical period of 1980s, the cookstove movement began to characterize the problem primarily as one of energy and deforestation, whose logical solution was large scale deployment of fuel-efficient cookstoves. To be highly efficient, of consistent quality, and able to scale quickly, it was determined that these improved stoves must be precisely engineered and centrally produced.

This particular construction of the problem and its solution set the technological frame that eventually gave rise to the cookstoves that are ascendant today: metal and ceramic stoves mass-manufactured in India and China, sold by the container load to NGOs in the developing world, who then distribute them to consumers.

These mass-produced stoves, in turn, have enabled the coproduction of a cookstove movement in part comprised of for-profit and market-oriented non-profit companies who focus solely on cookstove design and engineering and distribute stoves globally. This commercialization process has resulted in a re-imagining of the user as consumer, further reshaping the technological design of future cookstoves and reconfiguring social relations within the cookstove movement. Both the stoves and the organizations that have emerged through this process of coproduction are likely to play a critical role moving forward, particularly in efforts to use improved cookstoves to mitigate climate change using carbon markets.

Although the focus on efficiency and scale has to some extent obscured or devalued the other routes that cookstove development could have taken, it has not achieved full dominance. On the one hand, it has failed to enroll some groups within the cookstove movement. Certain actors and organizations still see the benefits of cookstoves as derived more from the process of local production than the product itself, while others see smoke reduction as a more important goal. These groups doubt that their primary goals for cookstoves will be met by the dominant focus on efficiency. On the other hand, the users themselves have often not been fully *enrolled* in the efficiency program. For them, the definition of an improved cookstove may be its ability to cook faster or smoke less. While cookstove designers and engineers know that they must appeal to the users' desires in order to ensure that the stove is actually used, they have often been willing to accommodate these desires only within the parameters set by increased efficiency. However, the new construction of user as consumer may change this dynamic by imbuing users with a new power as they control the profits that are the lifeblood of any cookstove company.

The path that cookstoves have taken to this point has not been one of linear improvement, nor has it been inevitable. It has resulted, rather, from particular characterizations of problems and solutions. Recognizing this interplay between the social and the technological allows for more agency and more nuanced understanding in selecting the paths that may be taken in the future. Although the efficiency frame has remained stable over the last two decades, we may now have reached a particularly opportune time for reflection. As the cookstove movement stands poised again at a moment of huge growth, we should take a moment to re-examine the problems that we want cookstoves to solve and the kinds of cookstoves and organizations those solutions will help create.

Given the changing goals for cookstove programs, is efficiency still the definition of improvement? In allocating dollars for measurement and monitoring, should efficiency be the sole metric? Finally, if we accept that for many users, efficiency does not necessarily entail improvement, how do we resolve contradictions in fuel savings and user preference? This article does not seek to answer these questions but rather to suggest that they are ones that need to be asked, that we do not blindly follow the path we have been set on by our history but open ourselves to new opportunities moving forward.

Chapter 3: Cookstoves, Clean Water, and a Patent? The Role of Intellectual Property in Innovation for the Poor

ABSTRACT

This paper examines the effect of deploying intellectual property in the realm of green technologies for the poor. The contrasting cases of UV Waterworks and the Berkeley-Darfur Stove highlight the differential roles played by intellectual property in this context and offer preliminary identification of some of the social and technical characteristics that must be considered in assessing to what extent intellectual property may support or impede technological innovation for the poor. Further, the cases suggest that the move towards market-based approaches for development and dissemination of technology for the poor has rendered the broad social categories of for-profit and non-profit less analytically useful. The complex institutional ecology surrounding these technologies requires a closer look at the various elements comprising the overall structure, each of which may use different tools and strategies traditionally belonging to either the market or charity realms.

1. Introduction

Although the causes of endemic poverty are various and complex, low-cost technologies can play a vital role in improving the lives of billions of people (Cash et al., 2003). There is growing interest in designing and disseminating technologies for the poor, perhaps with the articulation of the Millennium Development Goals as well as the increasing awareness that traditional development methods have fallen short (Easterly, 2003). In part because private investment is inadequate to address human need for these technologies, foundations and governments sometimes support early research and development in places like non-profit organizations, universities, and national labs. However, good results are rare: mobilizing technologies for the poor ends is a complex proposition involving many obstacles all along the supply chain from invention to distribution to adoption. After initial development and even prototyping, most of these technologies never make it into the hands of their intended beneficiaries. This is as much true of medicines as it is for what have been called “mundane” technologies (Kammen & Dove, 1997) or what we call “technology for the poor”: hardware projects such as water purifiers, solar lights, irrigation pumps, and improved cookstoves that are designed specifically for use by the poor in developing countries and have the potential to enhance health, generate income, and conserve local environments.[1]

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[1] We define “the poor” here as those of the lowest socioeconomic classes living within developing countries, keeping in mind that the poor are not one entity and that part of what is at stake is an understanding of differentiated poor.

Partly in response to perceived development failures of the past, new approaches are being sought. Many of these new approaches to development, including public-private partnerships as well as "Bottom of the Pyramid" and other related approaches (Prahalad & Hammond, 2002), involve a hybrid mixture of organizational and funding structures from both the for-profit and non-profit world. In Prahalad's Bottom of the Pyramid view, the market for the poor, while individually quite small, is collectively very large, which should enable businesses, even those with no overtly social mission, to adapt their products for markets in developing countries and be extremely profitable. At the same time, growth in socially responsible investment (SRI) and so-called "patient capital" has meant that even with very low return on investment, those seeking to develop and distribute technologies for the poor may be able to obtain investment capital instead of traditional donor funding.

These market-based approaches are seen by some to have multiple advantages over the traditional system of philanthropic and charitable support. Not only do they require greater efficiency in organizational operations, they also allow for technological distribution systems that are self-sustaining over the long-term rather than dependant upon annual grants and the ever-fluctuating attention of donors. As such, many humanitarian engineering initiatives, even those funded by the non-profit sector, are experimenting with market-based approaches as a means of generating the financing needed to develop and implement new technological systems (Thomas & Amadei, 2009; Prahalad & Hart, 2002).

Moreover, some of these organizations are finding advantages to eschewing non-profit status in exchange for investor funding. Although not traditional, this structure may make sense for many humanitarian engineering organizations, especially those interested in distributing technologies on a large scale. For example, one attractive model has been one in which the humanitarian engineering organization is incorporated as a non-profit but attains full cost-recovery for its projects by selling its technology, either to other NGOs that distribute it or directly to consumers. This model has some advantages over a more traditional non-profit approach in that the organization can become largely free control by donors or foundations and has some market signal to provide feedback on its product. However, in order to scale up, the organization will need additional capital to build new factories and distribution infrastructure. In the non-profit cost-recovery model, the organization would still need to get that capital from donors or foundations because it was not allowed to generate profit on the sales of its technology initially. Cost-recovery will allow them to keep the operation running but not to expand. For this reason, some of these organizations may find it worthwhile to pursue a private model in which investors can provide the capital to enable rapid scale-up and expansion as well as fund additional research and development to create new products.

The variety of hybrid approaches which combine aspects of the for-profit and non-profit world allow for the incorporation of tools from both of these spheres. However, many of the actors and organizations experimenting with these new forms are unfamiliar with these tools, and their effects, when transferred from their traditional contexts, can be unexpected. One of the most important of these tools is intellectual property. Although it can be useful in generating the financing needed to develop and implement new technological systems, many organizations transitioning to market-based approaches are struggling to define the role it should play, whether and how to invoke intellectual property protection in their products for the poor. This chapter examines the effect of deploying intellectual property in the realm of sustainable technologies for the poor by examining the contrasting cases of UV Waterworks and the Berkeley-Darfur Stove.

Although policymakers and activists have recognized humanitarian engineering as a key tool of sustainable development, the role of intellectual property in promoting the research, development, and dissemination of humanitarian engineering is not well understood. In general, research in this area falls into four camps (Graff, personal communication, Dec. 2010). The first, following Kapczynski (2009), attempts to ensure that IP does not block reasonable spillovers or transfers of appropriate technologies to humanitarian applications. The second, following the PIPRA humanitarian use licensing argument, seeks to use IP to engage in market differentiation between higher income commercial market applications and humanitarian applications. The third, again from PIPRA, is to incentivize development of technologies arising from developing country (typically public) R&D for local, regional, or global commercial applications. The fourth, is the use of IP to incentivize development of technologies arising from developed country R&D for developing markets or humanitarian use in the global South. This fourth angle is the one least explored in the literature. As such, it represents andimportant gap as the use of intellectual property strategy is becoming more important at foundations, universities and firms that are funding humanitarian R&D. It is also the angle from which this paper approaches the general topic of IP for humanitarian technological development in the hope of generating some evidence of the effects of using IP in this context.

In theory, intellectual property (IP) can promote innovation by assigning exclusive property rights to inventors and authors, enabling the collection of revenue to cover costs and make profit, thereby incentivizing more private investment in inventive activity. With IP protection, the inventor can be free from competition in the short-term, and during that time, they are able to charge higher prices for their product to recoup their investment before competition from other companies drives down prices to the marginal cost. The rationale for intellectual property seems to be weaker for most humanitarian innovation: the potential payoffs of commercialization are small, undermining the appeal of investment and therefore IP. Consumers of the end product generally do not have the money to produce a profit for the IP holder or even, at times, to allow them to break even. This lack of “market pull” seems to nullify the proposed benefits of IP – in the near absence of profit from a product, there is little use in expending resources to protect that product from competition. The value of IP protection is proportional to the value of the market for the product being protected.

Since individual patents appear relatively useless as an inducement mechanism for work on problems facing the poor in developing countries and have been seen to block access in some important cases, patenting is often viewed as unnecessary, perhaps even harmful to the interests of the poor. A leading option would appear to be the release of innovations into a commons or the public domain, and seek public finance, yet patenting is occurring in the domain of mundane technology.

The two case studies discussed below, *UV Waterworks*, a water purification technology, and *Improved Cookstoves for Ethiopia*, high-efficiency cookstove, shed important light on the role and potential of intellectual property in innovation for the poor. These two cases reveal how patents within a new kind of humanitarian innovation space perform important kinds of work in the R&D process -- from structuring networks of private and public actors, to preserving inventor control for follow-on work. At the same time, intellectual property can erect technical barriers that are difficult to overcome. Together, these case studies suggest the importance of understanding the effects of incorporating market-based tools such as IP in efforts to remediate global inequalities.

2. Case Studies

The cases involve technologies aimed at improving basic living conditions through purification of drinking water and preventing hazardous emissions from cookstoves, respectively. Water sanitation and indoor air quality (which is strongly affected by emissions from household cooking) are critical components of human health and well-being. Because twenty percent of the global poor lack access to clean drinking water (Bartram, Lewis, Lenton, & Wright, 2005), mass adoption of water purification technologies has the potential to save millions of lives. Without intervention, unsafe drinking water and poor sanitation will lead to the deaths of as many as 135 million people by 2020 (Gleick, 2002). Cookstoves also play a central role in the health of the poor, especially women and children. Two billion people worldwide use biomass for cooking, largely on inefficient traditional three-stone fires that require an excess of firewood and produce large amounts health-damaging pollutants. (Smith, 1994; Smith et al., 2010**)** These stoves are strongly associated with number of negative health effects including pneumonia, tuberculosis, and low birthweight (Fullerton, Bruce, & Gordon, 2008).

UV Waterworks and the Improved Cookstoves share a number of key characteristics. Like many of the artifacts categorized as humanitarian, they came out of an academic laboratory. Home to significant resources in science and technology (both human and material), and driven by public missions, universities and national laboratories are particularly well-suited for innovation for the poor (Cash et al. 2003; Kammen & Dove 1997). Universities, in particular, have long histories of involvement with engineering technologies for the poor.[2] In this case, both technologies came out of work done at the University of California Berkeley and the Lawrence Berkeley National Laboratory (LBL), which have a close partnership. In fact, the two technologies discussed below also share an inventor: Ashok Gadgil, a Senior Scientist at LBL and professor at U.C. Berkeley. In addition, they were patented by the same Technology Transfer Office (TTO) at LBL.

Despite sharing common characteristics, the innovation paths and outcome for each technology were quite different. Because intellectual property concerns were central to these different outcomes, and because they both emerged from the same institutional

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[2] See, for example, various projects from any of the numerous university programs targeted at developing technologies for the poor including Engineers Without Borders (www.ewb-usa.org), UC Berkeley Blum Center (http://blumcenter.berkeley.edu/), University of Colorado Mortenson Center in Engineering for Developing Communities (http://ceae.colorado.edu/mc-edc/), and MIT D-Lab (http://d-lab.mit.edu/).

milieu, the contrasts of the cases furnish insight into the role of intellectual property in enabling and obstructing humanitarian R&D.

2.1 Case Study 1: UV Waterworks

2.1.1 *Invention and Patent*

UV Waterworks is a community-scale water purification technology distributed by the private, for-profit company WaterHealth International and invented by Dr. Gadgil. Gadgil's work to create a water disinfection technology arose out of the outbreak of a strain of vaccine-resistant cholera in India in 1993. Born and raised in India but working at LBL on U.S. indoor air pollution issues at the time, Gadgil had long been interested in water purification but, because it was not a part of LBL's research agenda, had restricted his actual work on the problem to sending suggestions to Indian colleagues in the hopes that they would follow up. However, when the cholera outbreak hit India in 1993 and tens of thousands of people died per month of this preventable disease, Gadgil decided to work on a way to disinfect water that was effective, affordable, and scalable. He spent some time thinking about and researching potential solutions to the problem, and eventually concluded that UV disinfection offered a potential method for getting clean drinking water to the roughly 600 million Indians who currently did not have access. Dr. Gadgil had no grant to work on this project but in the summer of 1993 was able to get a colleague to fund a graduate student to work on the UV water disinfection project over the summer in exchange for advising the student's Masters thesis work during the academic year. The student began by working out the economics of UV water purification under ideal conditions, and Dr. Gadgil quickly became convinced that, given the size of the market and the low cost of the UV disinfection process, there was no doubt that they could create a cost-effective solution to the water purification problem using a UV technology.

By 1995, after a series of field tests and modifications, Dr. Gadgil had developed a prototype of the UV water-disinfection system. This system, designed for community level use, uses a 60-watt ultraviolet bulb to disinfect contaminated groundwater. The UV Waterworks system delivers 120 mJ/cm^2 of ultraviolet radiation to the water surface, which disrupts the DNA of microorganisms in the water, deactivating 99.9999% of contaminating pathogenic bacteria and microbes. By delivering a UV dose to the water that is three times higher than that required to disinfect the water per US Environmental Protection Agency (USEPA) standards, the system ensures a very large margin of safety in the disinfection process. Gravity moves the water through the system, and, in the case of some kind of malfunction or loss of electricity to power the ultraviolet light, a valve shuts automatically, preventing further water from entering the device. One unit can provide safe drinking water for approximately 2000 people (LBL, 2010a). Although the use of UV light to disinfect water was well-known and, not in itself a new invention, Gadgil's design was innovative in that it used a gravity feed that eliminated the need for a pressurized water delivery system and consistent electricity inputs, both of which made it more applicable to developing country contexts in which such things are often difficult to guarantee (LBL, 2010b). Also, the lamp-in-air design and careful attention to hydrodynamics ensured no fouling of the lamp and a uniformly reliable dose of UV energy to the water (Fig 1).

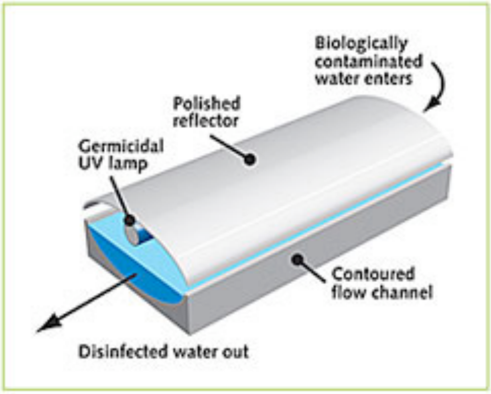

Figure 1. UV Waterworks Technology[3]

As required by his employment agreement, Dr. Gadgil disclosed the prototype to the technology transfer office at LBL so that they could decide how to proceed with the IP. Gadgil's original intent had been to post the design publicly on the internet so that anyone could build a UV Waterworks system. However, personnel at the Technology Transfer Office at LBL dissuaded him. Their argument, which Dr. Gadgil found persuasive, was that individuals would not have the interest or capability to build a UV Waterworks system on their own; it needed to be developed and manufactured by a company. They argued that it was unlikely that a company would invest resources into distribution systems and the other infrastructure unless they were guaranteed some kind of "lead time" to recoup the initial investment before competitors entered the market.

Looking back, Gadgil thinks the logic of patenting was sound. The rural poor of a developing country constituted the potential market for this technology, making it unlikely that larger and more established companies would have interest in developing the project. Interest in the technology would probably come from smaller, nimble companies willing to take a risk in an unpredictable climate. These companies, in particular, would need the security of IP protection to ensure that once they had done the necessary work of developing the technology and solving the dilemma of dissemination, they would not be immediately undercut by a large company. Gadgil had done the rough calculations to show that there was potential for the technology to become profitable and agreed that large-scale dissemination would be more likely if the technology were developed by a for-profit organization.

In 1996, the LBL office of technology transfer filed the patent for protection in the US and several other countries internationally, excluding India under a deal with the joint inventor of the technology. They then put the technology up for licensing with a caveat stating that the technology must be disseminated in a developing country chosen from a list compiled by the TTO, although if the licensee complied with that requirement, they could also enter the US market. A number of small companies showed interest, each wanting an exclusive license. LBL chose to grant the exclusive license to the Elwin Ewald Group, a group of

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[3] Figure from Waterhealth International, Retrieved May 30, 2011 from http://www.waterhealth.com/water-solutions/technology.php

"socially-conscious" investors that had been searching for a technology upon which to build a company to serve the poor. The Elwin Ewald Group then formed the for-profit company WaterHealth International and began the process of developing and disseminating UV Waterworks in India.

2.1.2 *Investors*

Elwin Ewald, the founder of the Elwin Ewald Group, had spent many years working in developing countries. With no interest in profit, Ewald sought to serve the needs of the world's poorest through the development of a technology. When he found the UV Waterworks technology at the LBL, he believed it offered a unique opportunity to benefit the poor and decided to procure it from the TTO at LBL. In searching for a technology, Elwin Ewald had initially preferred to pursue a non-profit route to development and distribution. But he did not believe that he had enough money to start an effective non-profit and instead decided to create a for-profit company, which would allow him to bring in investors. In the initial round of financing, Ewald was able to attract about $500,000 in investments from socially responsible investors (half coming from his own family) who were interested in helping the poor. While these investors wanted to make back the money that they were investing and make a small profit, roughly 4%, they were not motivated by a desire for a large return on investment.

Having secure IP rights to the technology was instrumental in allowing Ewald to finance the project. In fact, the power and necessity of IP protection for the "socially conscious" investors became clear when a number of them threatened lawsuits if a licensing dispute in the early days had not been resolved. Ewald had understood that they had exclusive worldwide rights to the technology. In fact, LBL had previously given a joint inventor rights to license the technology in India in exchange for LBL's undivided right to license it in the rest of the world. When this situation came to light, Ewald's investors threatened to withdraw funding unless Ewald could consolidate the rights to the technology. Ultimately, the Elwin Ewald Group, now WaterHealth International, was able to purchase the India-specific rights after the Indian venture went bankrupt and has gone through several additional successful rounds of financing attracting the socially-responsible arms of multiple corporations.

2.1.3 *Commercialization and Dissemination*

The process of developing the UV Waterworks technology for the market was not a smooth one. When Ewald purchased the license for UV Waterworks in 1996, the technology was still at the prototype stage. Moreover, there was no business model for how to distribute devices, and WaterHealth International (WaterHealth) had to spend much more time and resources than they had anticipated in experimenting with versions of the technology and different business models, each of which depended on the other.

In the beginning, WaterHealth intended to use an approach that Gadgil describes as the "lightbulb factory." Under that business model, the role of WaterHealth would be to simply produce and sell community-sized UV Waterworks units that consumers would take to their communities and plug in to receive clean water in the same way that they might buy a lightbulb, take it home, screw it in, and get bright light. WaterHealth soon realized, however, that this model is effective only because the utility and all the other components of the electricity system are in place and of high quality: you can't use a lightbulb if there is no socket and no power and no switch and no grid. In the case of UV Waterworks, the analogous system was lacking, which meant that the lightbulb factory approach turned out to be unsuccessful, nearly driving the company into bankruptcy.

The problems with this approach involved both profit and quality. Regarding profit, those installing the storage tanks and water pumps – so-called system integrators -- were charging high rates for their services so that much of the money that consumers were paying for the purification units was actually going to these system integrators, not to WaterHealth; the system integration turned out to have much higher profit margins than the sale of the UV Waterworks units. Furthermore, some of these system integrators were taking shortcuts to save costs such as using poor quality pumps and low-grade plastic for the storage tanks, and these shortcuts were giving the Waterhealth system a bad reputation, even thought they were the fault of the system integrators, not the units themselves.

Through this early experience, WaterHealth learned that if they wanted to be a successful company, they needed to do the system integration themselves so as to retain more of the profits from their product and to ensure the kind of quality that would grow the market for UV Waterworks. During the process, the company came close to failure and was forced to file for bankruptcy protection before it discovered and refined its current successful technological and business model: fully integrated, community-scale water treatment plants. In this model, WaterHealth constructs "WaterHealth Centers" which are each intended to provide enough clean drinking water per day to serve either 2,000 or 6,000 people, depending on the type and size of the unit. The UV Waterworks units and all of the system integration (which includes plumbing as well as machinery and controls for pumps, tanks, motors, leveling, and the attractive civil structure to house it all) are included in the Center, and ongoing staffing, water quality testing, and maintenance is performed by WaterHealth employees. WaterHealth also uses an innovative financing model in which communities that desire a WaterHealth Center must provide a down payment, but the rest of the cost is then financed, primarily through either local banks or the International Finance Corporation, which provided $15 million in financing to WaterHealth in 2009, so that Centers can be paid for by the community over time (WaterHealth, 2009). Once the WaterHealth Center is fully paid off, it becomes an income-generating asset for the community. The company also partners with a local NGO to provide education around clean water to its consumers.[4]

WaterHealth is now a very successful operation with about 400 WaterHealth Centers, the majority of which are in India. Their service capacity now exceeds two million people per year, and they were estimated to have earned $10-25 million in revenue in 2009 (Zoominfo, 2009). They have also expanded geographically and have installations in Philippines, Sri Lanka, and Ghana.

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[4] Description of WaterHealth's approach and facilities as well as more information on their activities can be found at: www.waterhealth.com

2.2 Case Study 2: Cookstoves for Ethiopia

2.2.1 Invention and Patent

In 2004, an officer from the United States Agency for International Development (USAID) requested that Dr. Gadgil visit Darfur to investigate the possibility of developing an improved cookstove for Darfur refugees in order to decrease the refugee women's exposure to the risk of rape. Because the refugee women regularly had to leave the safety of the camps to find wood for their cooking fires, USAID thought that a more efficient cookstove using less wood could improve women's safety by lowering the number of fuel collection trips needed. Gadgil visited Darfur in 2005 and surveyed improved cookstoves available in the camps to see if one of them would suffice. Following a variety of field tests, he concluded that none of the stoves was sufficient but that one of them, the metal wood-burning "Tara" stove from India offered the best starting point from which to develop a more culturally-acceptable and fuel-efficient cookstove designed especially for the people of Darfur.

Over the next several years, Gadgil worked on improving the technology, now known as the Berkeley-Darfur Stove, with the assistance of engineers at LBL, Engineers Without Borders San Francisco Professional Chapter, and many different students from the University of California Berkeley. In all, he estimates that around 150 people were involved in the project in some way and that costs, not accounting for time donated, have reached around $300,000, which have been received from the Blum Foundation and Lawrence Berkeley Lab, among others. The stove, now in its fourteenth version, uses less fuel and burns more cleanly than the three-stone fires or mud cookstoves traditionally used in the region and has been adapted to the cooking styles and pots specific to the Darfur region. In 2009, in response to NGO interest in distributing the stove in Ethiopia, the Berkeley-Darfur Stove was also modified for use in Ethiopia; this new model of the stove is known as theBerkeley-Darfur Stove – Ethiopian version (BDS-E) and is more fully described below.

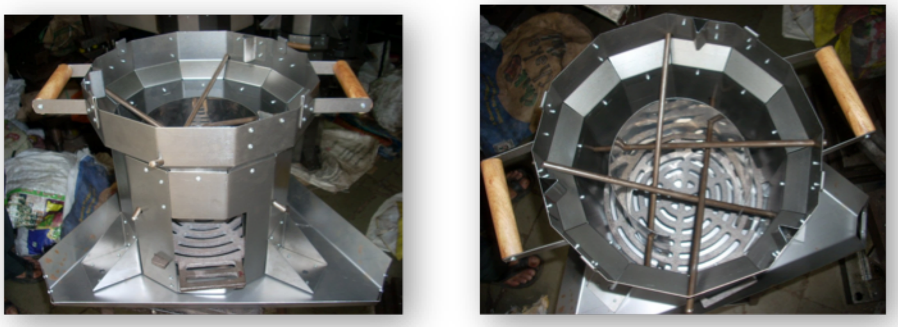

Figure 2: The Ethiopian version of the Berkeley-Darfur Stove

Initially the TTO of LBL decided not to patent the Berkeley-Darfur Stove, primarily because, given the weaker legal systems in Sudan, the patent would likely not be enforceable and, thus, not confer any benefit. However, Dr. Gadgil believed that because the stove could eventually be widely used in Africa, with potential application to as many as 70 million people, it was worthwhile to protect the invention and try to draw the interest of a company in a similar way to what was done with UV Waterworks. He also hoped that the stove, if commercially successful, might generate a small stream of revenue for the UC Berkeley and LBL as well as his ongoing work on humanitarian engineering projects. A third rationale for a cookstove patent was to retain some power to prevent the distribution of knock-offs of inferior quality: because design modifications of even a centimeter could make the stove much less efficient or a safety risk, quality control was perceived to be essential. Poor manufacturing or knock-offs could decrease the good name of the design around the world. Patents were seen as one way to increase the amount of control the inventor might have in assuring the bona fides of manufacturers.

Improved cookstoves had not traditionally been profitable enough to draw the interest of private investors, but many in the stove community believed that the advent of the carbon market was about to change that. While NGOs, governments, and academics had long been interested in improved cookstoves for their promise of better health for women and children and reduced local deforestation, the carbon market added a profit-motive to these so-called social and environmental "co-benefits" (see, e.g., Haines et al., 2009)**.** Because improved cookstoves can generate cost-effective carbon emission reductions through reduced fuel use, private investors were beginning to show interest in the stoves as an opportunity to make profits in the carbon market. Given this changing outlook for cookstoves as a commercial venture, the TTO decided that it would be worth filing a patent in order to interest carbon companies that might require IP protection as a condition of investment in developing the stove. In 2007, LBL applied for and was granted a design patent, weaker than a utility patent, which covers the "look and feel," of the Berkeley-Darfur Stove.[5] Since then, there have been a number of people and organizations seeking free licenses or free access to the stove's technical specifications. These have been denied, spurring some criticism among some advocacy groups.

2.2.2 *Development Partnership*

Dr. Gadgil hoped that the licensing would proceed much as it had for UV Waterworks and that companies would come forward to commercialize the stoves. However, though the stove had gotten positive attention in the media and in academic circles, no companies approached LBL to purchase a license. There began to be interest, though, from NGOs with activities in Africa.

In the fall of 2008, Dr. Gadgil was approached by World Vision International (WVI), the world's largest NGO, which describes itself as a "Christian relief, development and advocacy organization dedicated to working with children, families and communities to overcome poverty and injustice" (WVI, 2011). WVI had heard of the Berkeley-Darfur Stove and was interested in using it in a project in Ethiopia to be partially funded by carbon credits generated through use of the stove. WVI had an international investor who would supply the up-front money in exchange for a portion of the carbon credits, which could then be

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[5] In general, a "utility patent" protects the way an article is used and works (35 U.S.C. 101), while a "design patent" protects the way an article looks (35 U.S.C. 171) (US Patent and Trademark Office, 2011).

sold at a profit on the European market. World Vision's intention was to distribute 100,000 cookstoves, which would be large enough to generate the kind of profit necessary to interest a private investor. In preliminary estimates, a Berkeley-Darfur Stove – Ethiopian version would cost about $30, last five years, and generate ten metric tons of carbon offsets worth more than $150, thus enabling a carbon-credit financed self-sustaining cookstove dissemination program.

In the first stage of the project, WVI was seeking multiple stove models to test in Ethiopia for efficiency and user preference in order to determine which models they would ultimately distribute. Initially, WVI wanted to simply purchase the stoves from LBL. But as a research laboratory, LBL never sells products, relying on partners to take the technology from the invention stage through commercialization. WVI did not typically engage in product development, but Dr. Gadgil proposed that together he and WVI could apply for a technology commercialization grant that had been put out by the Department of Energy. This grant could pay for testing and modification, as well as technical support by Gadgil and his students for the commercialization process. World Vision agreed to partner with LBL to develop the stove for Ethiopia because they were very interested in certain aspects of the stove, such as its potential for local manufacture in Ethiopia. In addition to their technical support and "show how", Gadgil and LBL also promised assistance with the supply chain they had set up as part of the Darfur stove project. The grant application was successful, and in March 2009, Dr. Gadgil received $138,000, to be matched by World Vision (now World Vision Australia, not World Vision International) to pursue the modification, commercialization, and distribution of the Berkeley-Darfur Stove in Ethiopia using carbon credit financing.

2.2.3 *Commercialization and Dissemination*

To obtain the project funding, each side had to sign a cooperative research and development agreement (CRADA), a boilerplate contract required for any such partnership with a national lab. CRADAs typically run several pages and include some items that are negotiable, such as the royalty terms of the license, and some that are not, such as liability.

One piece of the CRADA between LBL and WVA, as is typical, was a licensing agreement, in this case specifying that WVA would agree to a non-exclusive license of the Berkeley-Darfur Stove. The terms of the licensing agreement demonstrate a desire on both sides to see the stoves get disseminated as widely as possible. For example, although the TTO did not give WVA the license for free, they set the up-front payment very low so as to be affordable, even for an NGO. Why not give the licenses away for free? The LBL TTO required some form of up-front payment because they want the organizations purchasing licenses to demonstrate sufficient resources for developing the technology. Further, LBL does not want to create a slippery slope in which other organizations would demand free licenses for technologies whose charitable purpose was more questionable. However, because they do not want the up-front cost to be a barrier to technology licensing, they can use their discretion to significantly lower the amount required, as they did in this case. Additionally, they decided to try a novel approach whereby the Lab would receive a fraction of the carbon credits instead of traditional royalties, again making the license more affordable to WV and delaying royalty payments until such time as the project was successfully selling carbon credits. From their side, World Vision indicated that they did not want an exclusive license as they wanted other NGOs in the region to be able to use the stove if they so desired.

During the grant application process, control of the project on the World Vision side was transferred to the Australian office, World Vision Australia, which had already successfully undertaken a carbon forestry project in Ethiopia. However, while World Vision International had indicated willingness to license the technology, WV Australia was more reluctant. A main sticking point of which was the license. While WV Australia was willing to pay the up-front sum and the carbon credit royalties, the organization was unwilling to indemnify LBL and UC Berkeley against all liability: they felt the organization simply could not take on this kind of risk. For TTO at LBL, use of the clause indemnifying the Lab in case of harm was a non-negotiable piece of all its licenses, a position that is echoed in nearly all universities and national laboratories.[6] Because of this indemnification issue, LBL and WVA were unable to come to agreement over the license, so it was eventually removed from the CRADA.

In August 2009, five months after the grant was initially awarded, the CRADA, now without the licensing agreement, was signed and funds released for the project. Currently, World Vision Australia has plans to produce and disseminate up to 1000 of the stoves this year, even without a license from LBL. LBL has signed a "nonassert" covenant saying that they will not seek to enforce their patent against WV. In doing so, they have enabled the project to move forward, but they have lost out on any future carbon royalties, which may turn out to be significant. Nonassert covenants (or "nonasserts") are usually signed statements giving explicit permission to third parties to practice a patent they would otherwise infringe.[7] In this case, both WVA and UCB/LBL believe that the absence of a formal license offers them some liability protection. However, because there is no official agreement on the use of the stoves, liability, should someone decide to sue for damages from the stove, is unclear.

3. Discussion

Sociologists and economists of innovation have moved from a linear model of technological development to an ecological one, and from a notion of technology as a bounded material objects to heterogeneous networks of institutions, things, and actors (see, e.g., Latour, 1992; Bijker, 1995). In theory, intellectual property can help configure and shape those networks (Strathern, 1996) by making legal fences to keep certain actors out, and opening restricted byways to selective collaborators. In general, IP has been theorized in a context in which markets have the power to pull private capital into the research and development

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[6] Universities and national labs require indemnity so as not to threaten their broader educational and research missions with liability lawsuits resulting from their licenses, which form a relatively minor part of their operations. As entities with very "deep pockets," they may be attractive targets for such lawsuits and as such are very vigorous in protecting themselves from liability.

[7] To execute a nonassert, a patent holder usually makes a public or private declaration that they will not legally enforce the patent with respect to certain uses and users. "Legally, nonasserts are patent-infringement settlement agreements that are designed and drafted with the purpose of preemptively resolving future infringement disputes" (Krattiger 2007).

process, snapping an innovation network into place: both IP and a robust consumer market are important. Where consumer signal is weak, however, the rationale for IP seems to be diminished. This position appears to imply that if one wishes to innovate for the poor, intellectual property should be put into a commons so that actors interested in developing, distributing or selling discoveries are not excluded from doing so, thus bringing down prices.

Yet some organizations in humanitarian technology development for the poor are seeking IP protection, and bringing this market-based tool into a traditionally non-profit realm has generated unexpected outcomes. Based on the cases of UV Waterworks and Cookstoves for Ethiopia, we identified multiple issues that should be considered when attempting to determine the effect of IP in this context. Perhaps the most important is that of organizational structure. As described in this paper, the institutional ecology of innovation for the poor is complex, often consisting of multiple partners at various stages. Yet our cases suggest that the role of IP can be best understood by categorizing these complex arrangements into two stylized types based on funding models of the commercialization and distribution partners.

The first type, *Investor-Financed Commercialization/Distribution,* is rather more straightforward, while the second type, *Donor Funded Commercialization/Distribution*, calls for further considerations.

3.1 Type 1: Investor-Financed Commercialization/Distribution

If the development and distribution process requires private capital at any point, then securing IP protection may be useful. In the case of UV Waterworks, Lawrence Berkeley National Lab took out a patent to help induce investment. As it turned out, the patent was necessary: socially responsible investors involved in the early stages of WaterHealth demanded that the technology be patented so that if the necessarily large up-front investments eventually paid off, they would be able to, at the minimum, recoup their investment, even at the relatively modest levels that WaterHealth initially required. After all, the Elwin Ewald group had to not only move the technology from prototype to product, but also develop the enabling infrastructure and distribution systems.

As it turned out, it also took several years and a significant amount of trial and error, including bankruptcy, to find a business model that would be profitable and sustainable. These difficulties suggest that, at least when investor funding is involved, IP may actually be *more* useful for technologies for the poor than in standard product development. To some extent, the issues faced in developing technologies for the poor are analogous to those in developing medicines – both face a public goods problem in that large amounts of up-front investment are required, and later market entrants can act as free riders, appearing upon the scene once the hard work has been done and cutting into the profits of the original developer. IP is supposed to mitigate just such a problem by providing protection from competition for long enough to allow the initial developer to recoup these high initial costs (Sampat, 2010; Graham & Sichelman, 2008). Without such protection, no one company has the incentive to commit the resources to the up-front investment; each would prefer instead to let another company make that investment and move in when that work has been done.

In medicines, this problem results from the astronomical costs of the drug approval process. The first company to bring a drug to market must pay for extensive clinical trials costing millions of dollars. In technologies for the poor, costs are likely an order of magnitude lower, but they are certainly higher than those of traditional product development because of the need to establish the periphery infrastructure, build local capacity, and overcome the various obstacles of working in an undeveloped market. These costs, while not on the order of millions of dollars, are significant for the kinds of organizations involved, typically NGOs or small start-ups, and are very high relative to the potential revenues. Even more importantly, initial entrants into markets for the poor face a high degree of risk, especially on the distribution side – they must find the right business model and then prove that it is viable. As Gadgil describes this process, "It is not sending another product down the road. There is no road!" Getting financing to operate in such risky environments can be incredibly difficult, especially for the first mover. However, once these pieces are put in place by the initial developer and the model is proven, later entrants benefit from this hard work and face much lower costs of entry. Therefore, IP protection may be necessary to incentivize the initial entry.

Some may question the value of IP in these cases in the developing world in which profits may be low and enforcement is likely to be difficult and costly, if not impossible. Yet the attitude of the investors in the UV Waterworks case bears out findings from the developed world that show that intellectual property protection is important to investors even when there are no revenues to protect *i.e.* patents with no intrinsic value to the company still had extrinsic or 'optical' value to investors (Graham & Sichelman, 2008, p. 1078). Even though it was highly unlikely that LBL would sue patent infringers in India, unless they were large multinational companies, the investors felt secure in their investment only when they had the patent and exclusive license in place. Furthermore, the liability hold-up discussed in the cookstove case is less likely to occur where there are for-profit licensees, as commercial entities are more accustomed, given the right price, to shouldering liability. If the liability risk is not extraordinary, it is less likely to be a barrier to investment.

3.2 Type 2: Donor Funded Commercialization/Distribution

The contrasting case occurs when the commercializing or distribution partner does not rely on investors for financing but uses grants and donations for their operations. In this case, there is no need to pull in for-profit investors who might require the legal power to sue unauthorized makers, users and sellers of the technology. The organizations distributing the technologies, generally non-profit development organizations, have already built substantial links to their donors, so that the attractive force of IP is not necessary for moving through the R&D network. Yet, the case is not so clear cut that one can simply conclude that IP should be avoided in these situations. When the implementing partner is not investor-funded, simply eliminating IP does not resolve the fundamental difficulties of development of technologies for the poor. Instead, we have identified two distinct issues that deserve consideration when attempting to predict the effect of IP in a donor-funded context: risk of liability and control of technology.

3.2.1 *Donor Funded: Risk of Liability*

In these types of cases, in which private investment is not needed, the act of negotiating the IP and assigning liability can threaten the partnerships needed to successfully develop and deploy these technologies for the poor. The formal and legal linkage that IP establishes between the inventor and the implementer brings unacceptable risk to these organizations; through these links that liability can be assigned to either party. The non-assert letter used in the cookstove case was a pragmatic way to work around this perceived liability by attempting to weaken that link so that liability cannot be traced back to either WorldVision or LBL. However, the actual legal outcome, should a lawsuit arise from harm caused by the cookstove, is far from clear given the foreign jurisdictional issues.

The Cookstoves for Ethiopia case illustrates, then, how in these types of cases IP can in fact impede technological development and deployment. The mechanism, though, was distinct from those typically discussed in the literature. In this case, it was not price or access by the poor that was at issue, but rather attribution of risk and liability on the part of the patent-holder and the implementing partner. To some extent, this was a clash of cultures problem. The culture of a non-profit organization like WorldVision Australia was unaccustomed to dealing with technology transfer and product development. The TTO is a unique kind of commercial agency working within the non-profit academy, primarily licensing technology to industry, not NGOs. LBL/UC Berkeley and WorldVision are both organizations with broad social missions and significant assets that they are unwilling to put at risk through the technology transfer process. The partnership between a National Lab/University and a non-profit organization was new territory for both parties, so assigning and accepting risk was the subject of drawn-out negotiations. Whereas for UV WaterHealth, product liability was just one of many risks known and accepted by the investors as a part of doing business, WV Australia refused to accept this kind of mundane liability. Ironically, the stalemate was resolved in a way that potentially left both parties open to the very legal and monetary threat they were attempting to avoid.

Yet, forgoing the patent and license, while it avoids the precarious negotiations that almost destroyed the Ethiopian Cookstove Project, does not eliminate the risk and liability that would continue to be issues for any non-profit oriented organization interested in picking up a technology such as this. Given that there will likely be instances in which a humanitarian technology organization decides that IP protection is worthwhile, one important avenue for future research would be to investigate ways in which to defuse the risk and liability issues that plagued the negotiations in this case and are sure to obstruct similar collaborative projects. One recent proposal has been to create some kind of insuring organization that will accept liability in cases like the Ethiopian cookstoves when both the inventor and the implementer are not-for-profit and risk averse. The organization could be funded by dues from participating organizations or could apply for grants from other charitable foundations.

In lieu of such an organization, the threat that IP can pose to the complex institutional linkages of the donor funded context of development and deployment of technology for the poor is an important effect of IP that must be taken into account. It implies that IP in these situations can do more harm then good. On the other hand, the effect of IP in donor funded situations is not likely to be uniformly negative. Our cases suggest that IP may serve a beneficial purpose, at least from some perspectives, in allowing inventing organizations to maintain control over their technologies through additional stages of the innovation process.

3.2.2 *Donor-Funded: IP as a Method of Control over Technology*

The two cases above illustrate the way in which actors motivated by humanitarian goals have staked out intellectual property rights as a means of better fostering and controlling innovation networks where there are weak market signals but great human need. They look to IP in order to establish a commanding position in the assembly chain of technological network, what sociologists of science and technology have called an "obligatory passage point" (Callon, 1986). The cases discussed above suggest that even where humanitarian motives are dominant, inventors within academic research laboratories look to retain this control for a variety of reasons.

The most important of these appears to be a desire to maintain a connection with their technology in order to control quality. Both Gadgil and the LBL TTO expressed concern that putting the designs for the Ethiopia cookstove into the commons would likely result in poor quality knock-offs. This quality issue was less important for the UV Waterworks design, as its construction required a level of knowledge and experience in engineering beyond that of the common person. Indeed, the fact that the design could not be built by the average individual was one key reason why LBL chose to patent – they thought that wide-scale dissemination would depend on finding a business to produce the technology. But for something like the BDS-E, a relatively simple technology, many actors and organizations possessed the knowledge and tools necessary to produce it.

Development NGOs are not experienced in setting up manufacturing and supply chains – many still need the advice and technical assistance that can be provided by someone like Gadgil. Technologies like the cookstove, while deceptively simple in appearance, require precise design, engineering, and manufacturing if they are to perform well. They are also relatively specific to certain kinds of cuisine, cultures, fuels, and cooking implements. By patenting the stove, Gadgil and the TTO at LBL hoped to prevent it from being produced by a fly-by-night organization that would produce low quality stoves or distribute them in inappropriate locales where they would not only fail to achieve the promised results but potentially spoil the market for improved cookstoves more generally and, perhaps, damage the reputation of the university and the national lab.

Gadgil's actions with the Darfur Stoves Project speak to his desire to ensure that the quality of the stoves that he has designed. He remains in close communication with the single manufacturer regarding materials and design modifications. In addition, he has traveled to the workshop to observe conditions of both the equipment and the workers. Were the designs published on the web, for example, this kind of attention would be impossible.

3.3 Organizational Structure Considerations

The distinctions discussed above are important because both of these types of cases exist in the space of technologies for the poor, and in bringing market-based solutions into this realm traditionally dominated by NGOs and governments, caution must be used in broadly applying the tools developed for a world of private actors. Although traditional development work has been done through NGOs and governments, there do appear to be some technologies and some populations well-suited to an investor-funded business model. As a first pass characterization, the UV Waterworks case suggests that when operation and maintenance costs of equipment are likely to be large and long-term, an investor-funded model may be more effective. Additionally, those technologies that need a large infusion of up-front capital for development of the technology itself or the supporting infrastructure may find that capital more readily available from private investors rather than traditional donors.

Of course, in either case, in order to attract investment, in addition to IP, the technology and business model must be such that a sustainable business appears possible. For profit investors must envision how revenue will exceed costs in the not-too-distant future, either because the costs to produce the technology are so low as to be affordable, even to the very poor, or some kind of innovative consumer finance options are available. Many businesses large and small are beginning to explore how they may enter into and profit from such a market (Prahalad & Hart, 2002). However, despite the enthusiasm around those kind of enterprises, an investor-funded model will not work in all situations, with all technologies. As the Ethiopian Cookstove case suggests, when there is little long-term, ongoing maintenance required, a sustainable business may not be necessary. Perhaps more importantly, when the technology remains too expensive for consumers, there is no profit to be made, so an investor-funded model is out of the question, and distribution must be through other sources, such as the NGO or government sectors.[8]

One final consideration is that the context in which these technologies and actors are embedded is dynamic. A technology that is unprofitable today may not be so in the near future. This is another reason why Gadgil wanted to pursue a patent on the stove, to pave the way for an investor-funded model in the future should the stove eventually become a profitable technology, either through carbon credits or some other mechanism. Putting the patent into place early on would, he hoped, protect the stove, at least against large industrial competition, so that if opportunities for expansion presented themselves in the future, he would be able to pursue funding from private investors should he so choose.

4. Conclusion

Intellectual property is often justified on the grounds that it generates private investment into inventive activity by offering profitable monopolies on new technologies. What should the role of IP be where profit is not the aim, and where initial funding is often supplied by the charitable sector or the state? As part of a general trend towards using market-based approaches to development, intellectual property is increasingly being pursued within humanitarian-motivated engineering, but IP mechanisms and logics cannot simply be lifted from the for-profit context and expected to play the same role. Given the complexity and relative newness of using IP as a tool in humanitarian engineering, a case-driven approach

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[8] Although, even in these cases, there may be opportunities to market to NGOs and government agencies who would be able to buy the technology at the price necessary to create a sustainable business.

was chosen in order to advance understanding of how IP mechanisms can and do operate. At present, relatively few in-depth case studies exist in the literature.[9]

Drawn from a single laboratory at University of California at Berkeley, and Lawrence Berkeley National Laboratory, the UV Waterworks and Ethiopian Cookstove case studies demonstrate how technological trajectories are embedded within a network of social, organizational and economic relationships. Intellectual property helps to structure these relationships, both linking and blocking actors, organizations, and resources in ways that can both inhibit and facilitate different outcomes. Analysis of these cases helps unpack a variety of considerations that must be dealt with in determining when and how to use IP protection in technology development for the poor. While IP can offer the inventor a measure of control over the technology and help first movers overcome some of the special barriers to entry in these emerging markets, it can also generate friction over risk and liability claims. The varying effects of IP in these cases suggest that the impact of IP is highly contextual - it can operate very differently depending on the characteristics of both the technology and the organizations at either end of the transaction.

Despite their obvious differences, both of these cases underscore the fluidity of the categories of non-profit and for-profit in the domain innovation known as "humanitarian." As market-based approaches become more accepted in the development world and new hybrid organizations and networks arise in this realm, it has become less analytically useful to assign them, as a whole, to a particular category. In order to actually understand how they work, how they will act, and what effect they are likely to have, it has become necessary to understand them as a sum of their parts, some developed and taken from the world of profit, some from the world of charity. IP is one of the pieces, transported from the for-profit world into the world of social justice, traditionally dominated by governments and non-profits. In this new arena, the tool acts differently but under the right circumstances can be harnessed to support development and deployment of technologies for the poor.

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[9] Although, see PIPRA IP Handbook for some excellent examples.

Chapter 4 – Market-based Environmental Policy Tools and Innovation in Green Technology for the Poor: The Case of Carbon Credits and Improved Biomass Cookstoves

ABSTRACT

This paper looks at the question of whether the Clean Development Mechanism, as well as other voluntary carbon markets, is likely to induce the needed further innovation in cookstoves. Using interviews with cookstove designers and carbon developers, I show that carbon markets are not yet inducing further technological innovation in the cookstoves themselves. Instead, they are acting effectively as a selection mechanism that is narrowing the scope of cookstoves achieving widespread dissemination, which may be a first step in guiding and incentivizing further innovation. However, I also show that carbon markets are not yet effective at driving innovation in cookstoves that would lead to some of the most desired sustainable development effects, especially improvements in health. At a more general level, the case of cookstoves suggests that market-pull policies will operate differently for different kinds of technologies and that the effects of such policies may be different than predicted. This is especially important in the field of sustainable development in which various co-benefits from technological innovations are often assumed but not often measured.

1. Introduction

If we are to meet the basic needs of millions of people while still averting catastrophic climate change, a rapid increase in technological innovation is needed. While technology is not "the answer," it can and should play a role in drastically reducing greenhouse gas emissions and improving the lives of the world's poorest and is certainly needed if both goals are to be accomplished. For that reason, in recent years, interest has heightened in creating and improving those technologies that occupy what Casillas & Kammen (2010) call the "energy-poverty-climate nexus," in which rural poverty alleviation, increased energy access, and climate change mitigation can be mutually addressed by a single technological intervention. Such technologies may include biogas digesters for electricity, water purification technologies, or, the focus of this article, improved biomass cookstoves. This paper uses interviews with cookstove designers and carbon developers to assess whether the CDM, as well as other voluntary carbon markets, is likely to induce needed further innovation in cookstoves.

Environmental policies have been recognized to have a strong effect on the rate and direction of technological change, whether or not such effects are the stated intent of such policies (see, for example Jaffe & Newell, 2002; Vollebergh, 2007). Many recent studies of environmental policies regard their innovation effects as a valuable measure of their worth and an important aspect of the benefits to be gained by such policies if correctly designed (Porter & van der Linde, 1995; Kemp & Pontoglio, 2008). However, the vast majority of these studies tend to be focused on innovation by and for the developed world, neglecting the important issue of climate friendly technological innovation for the developing world. This lack of critical attention is problematic for two reasons. On the one hand, while results from studies of environmental policies and innovation can be cross-applied in some instances, we know that innovation for the poor is fundamentally different than innovation for the markets of developed countries or even for the higher socioeconomic classes in the developing world.(see, for example, Boettiger & Alvarez, n.d.; Thomas & Amadei 2010). For that reason, care must be taken in applying learnings from the first world directly to what may appear to be similar situations in developing countries.

On the other hand, while "clean" or "green" technological innovation in and for developed countries is certainly needed, technologies designed specifically to meet the needs of people in developing countries are equally, if not more, critical for climate change mitigation. If the two billion people currently using biomass as their primary source of energy climb the same "energy ladder" using the same technologies as the currently developed countries, greenhouse gas emissions will increase to catastrophic levels (Goldemberg, 2000). Although it is likely that some of this need can be met through direct technology transfer, sending technologies developed for the United States and Europe to Africa and Latin America, for many end-uses technologies specifically designed for the poor will be needed.

Recognizing this need for technological change directed at the global poor and for a better understanding of the ways that environmental policies may induce such change, this article analyzes the innovation effects of one major climate change policy on one technology that sits at the poverty-energy-climate nexus. Specifically, this article seeks to answer the following question: to what extent and in what ways are carbon markets driving technological change in cookstoves? It is argued here that attention to the innovation process in this representative technology can provide empirical evidence of the role of environmental policies on the innovation actors operating in the space of technology for the poor, thereby suggesting ways in which the policy could be improved to achieve greater innovation effects across the spectrum of technologies for the global poor.

The paper proceeds as follows: it first provides background on the relevant carbon markets for the developing world: the Clean Development Mechanism (CDM) its voluntary market equivalent, the Gold Standard. It then reviews the literature around using market-based environmental policies to induce innovation in "clean" technologies as well as pertinent literature in Science and Technology Studies and Technological Innovation Systems that open up the black box of the innovation process for further analysis. With this historical and analytical framework in place, this paper present the results from interviews and a discussion of the findings as they relate to using market-based environmental policies to stimulate technological innovation in sustainable development technology for the poor.

2. Background

2.1 Carbon Markets

2.1.1 Development of CDM

The Kyoto Protocol requires that developed countries, "Annex I," not exceed agreed-upon emissions of greenhouse gases during the first commitment period (2008-2012). In order to make compliance easier and more cost effective, the Protocol includes three so-called "flexibility mechanisms": carbon credit trading among Annex I countries (Article 17), joint emission-reduction projects with other Annex I countries and those with economies in transition (Joint Implementation, Article 6), and emissions-reduction projects in non-Annex I countries (Clean Development Mechanism, Article 12).

The CDM was a last-minute compromise, sometimes called the "Kyoto Surprise," (Streck & Lin, 2008; Lecocq & Ambrosi, 2007) inserted into the Kyoto Protocol in the last stages of negotiations in 1997. As such, it was meant to appease the developed, or "Annex 1" countries, who were interested in creating lower-cost options for meeting their emissions reduction commitments, and developing or "non-Annex 1" countries who were seeking channels for development assistance. To do so, the CDM in Article, 12.2 of the Kyoto Protocol, allows Annex I countries to meet part of their obligation through projects in non-Annex I countries, which should be a cheaper option than in-country mitigation, but it also requires that these projects contribute to sustainable development in the host country, satisfying the non-Annex I countries that they would benefit from these projects.

Specifically, Article 12.2 states that "the purpose of the clean development mechanism is to assist countries not included in Annex 1 in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3."

At the time of signing the Kyoto Protocol, in 1997, the actual details of how the CDM would work was left until later and was not formalized until the Marrakesh Accords in 2001. One particular controversial detail was the determination of whether a project contributed to "sustainable development" as required in Article 12.2. At Marrakesh, this disagreement was resolved by a proposal from the developing countries to have the decision of what constituted sustainable development rest with each country individually, not generally defined by the Articles the Protocol. Thus it was agreed that authority over the sustainable development consideration of each project should reside with a Designated National Authority in each country, usually located in the ministry of the environment, who would have the power to accept or reject any project based on whether or not it met the country's sustainable development goals. Many critics of the CDM and its contributions to sustainable development point to this lack of a broad standard of sustainable development as a key reason why the development gains of the CDM have been modest (Olsen, 2007; Wara, 2008).

2.1.2 How Carbon Credits Work

Each project in the CDM generates credits through emissions reductions of any of the six so-called "greenhouse gases" covered under the Kyoto Protocol: CO2, CH4, N2O, HFCs, PFCs, and SF6, which are then converted into their "carbon dioxide equivalent," or CO2e. These reductions are determined by first calculating a baseline, essentially a counterfactual of what would have happened had the project not been in place. Every baseline is calculated according to methodologies approved by the CDM Methodology Board.

The baseline calculations are necessary because the CDM host countries, the developing countries in which the products are taking place, do not have emissions caps. For industries covered by caps, companies can emit up to the capped number of credits that they have received, so baseline production does not matter except for possibly determining the number of credits to be allotted. But the credits generated through CDM projects (called Certified Emissions Reductions) are extra credits that can be purchased by developed countries with caps and used to offset an increase in domestic emissions in the developed country.[1] Every CDM project must prove that it would not have occurred in absence of the carbon project in order to receive approval; this critical attribute is called "additionality."

Once the baseline emissions have been calculated, the technology is introduced and the new emissions levels are calculated. The carbon credits earned are the difference between the annual emissions with and without the project and are registered and traded as metric tons of carbon dioxide equivalent. The project emissions are also calculated using approved methodologies, and default values, from the Intergovernmental Panel on Climate Change, can be used for many of the variables.

The baseline and project emissions, once calculated, are put into a Project Design Document (PDD) that details the proposed project, its expected emissions, and its measuring and monitoring plans. The PDD is then validated by an independent organization, a so-called Designated Operational Entity that has been approved by the CDM Board, who then submits it to the CDM for approval. Once the PDD has been approved, a project is considered "registered" and can then begin generating carbon credits. After one year of producing credits, the project is audited again by a DOE to ensures that the project is following the monitoring plan laid out in the PDD and that the expected emissions have occurred. If that is satisfactory, the credits are issued. Those credits can then be used by one of the organizations involved in the project or sold, either directly or on an exchange such as the European Union Emissions Trading Scheme platform. Annual monitoring reports are required for the length of the project.

2.1.3 Current Status

The CDM, tasked with the dual goals of cost-effective climate change mitigation and sustainable development, has been alternately lauded and criticized on both points. While supporters tout the amount of emissions reductions generated by the CDM, 450 million metric tons of carbon dioxide equivalent annually as of 2011 (Clean Development Mechanism [CDM], 2011) critics question both whether these numbers represent actual reductions and emissions and whether those reductions could have come at lower cost (Wara, 2008). On the sustainable development side, CDM supporters might point to the number of projects in developing countries, 2,438 as of October 2010, while detractors note the unequal geographical distribution of projects, with 63% of projects in India and

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[1] Because these credits are extra, that is, generated outside of the capped system of the developed countries, it is critical that they be real reductions, not just payment for something that people were already doing or going to do in absence of the project; if the reductions are not additional to a business-as-usual scenario, then the extra credits that they are inserting into the capped system are not real, meaning that the increases in emissions that they are supposed to be offsetting are not actually offset, and actual emissions are rising, thereby negating the effect of the emissions caps.

China and only 1.96% in Africa, (CDM, 2010) and question the existence of real sustainable development benefits (Olsen, 2007). Among the reasons given for continued support of the CDM (and associated non-compliance carbon markets, discussed below) is its ability to "initiate major shifts in attitudes and technologies in the developing world that can set the stage…for transitions to low carbon futures" (Liverman, 2010, p 133).

2.1.4 Voluntary Markets

In addition to the regulated carbon trading markets of the CDM and the Kyoto Protocol more generally, there exists an entire spectrum of voluntary carbon trading organizations and certification schemes. These organizations are not bound by the same regulations as the official carbon trading markets and run the gamut from highly-funded, well-organized, rigorously monitored systems to fly-by-night, internet-based, unverified scams.

This article refers only to the regulated carbon trading market of the CDM and to the most highly regarded, popular, and sought after voluntary equivalent, the Gold Standard. All of the major cookstove designers and carbon developers interviewed for this study focus exclusively on these two types of carbon credits.

2.1.5 The Gold Standard

The Gold Standard Foundation is a Swiss organization that certifies carbon credits, both as an additional "gold star" for the best CDM projects, GS-CER, and for high quality non-CDM projects, GS-VER. The Gold Standard Rules and Procedures were launched in 2003, initially only for CDM projects, with the idea that the agreed-upon rules for the CDM were not strong enough to guarantee real emissions reductions and sustainable development. The Gold Standard seeks to improve the quality of carbon projects, both in terms of the rigor of measuring and monitoring emissions and, especially, the sustainable development aspects of the project (Gold Standard, 2011a).

Carbon projects can obtain Gold Standard Certification in much the same process as is used to go through the CDM certification process, but the rules are slightly different, and the governing board is the Gold Standard Secretariat. Gold Standard credits are believed to fetch a higher price than other voluntary certification schemes.

2.2 Why Cookstoves

Cookstoves have increasingly been promoted in the context of climate change particularly because of their ability to deliver both climate and development benefits (Sagar & Kartha, 2007; Smith & Haigler, 2008). This mutually beneficial climate and development effect, sometimes known as "co-benefits" (Smith & Haigler, 2008) is advantageous for both those coming from the climate change world, for whom the development benefits of cookstoves fit the sustainable development mandate of the CDM, and those coming from the health and development side, for whom the climate mitigation potential of cookstoves has opened up a whole new sector of funding opportunities.

While not the only technology to have such co-benefits, (household lighting and water purification also fit well in this articulation) it is clear that improved cookstoves are an important technology for both climate change mitigation and development, especially health. Approximately 2 billion people cook with biomass, many millions of those with three-stone fires and inefficient cookstoves that contribute to enormous health burdens on the women and children who populate the kitchens of the third world (World Health Organization [WHO], 2006). Emissions from these cooking fires are a factor in chronic obstructive pulmonary disorder, heart disease, and lower respiratory infections in children (Torres-Duque, Maldonado, Perez-Padilla, Ezzati, & Viegi, 2008; Wilkinson et al., 2009). Regarding climate effects, biomass cookstoves have been shown to contribute greenhouse gas emissions to the atmosphere, primarily through emissions of CO2 but also methane (Smith et al., 2000). Replacing these three-stone and open fires with cookstoves is seen as a cost-effective mitigation strategy for climate change, with an average cost of $5.60 per metric ton of CO2e, well below that of most other interventions(Smith & Haigler, 2008). Moreover, recent studies suggest that replacement of three-stone fires and traditional cookstoves with improved cookstoves could be an effective mitigation tool for black carbon, reductions of which could have immediate climate impacts and could buy time needed to put longer term strategies into place (Bond et al., 2004; Ramanathan & Carmichael 2008). However, because most improved cookstoves deliver relatively small emissions benefits, on the order of 1-3 metric tons CO2e annually (Harvey, 2009), these stoves must be deployed at great scale in order to have a significant climate effect.

If cookstoves are going to achieve the scale necessary to have the desired impacts in both climate and development, they will need to improve over past efforts at cookstove dissemination, which have failed at achieving mass diffusion (Garrett, Hopke, & Behn, 2009). One aspect of this improvement, although certainly not the only one, is the technical device itself, which must be efficient, have low emissions, as well as be affordable and attractive to users, a combination that has proved largely elusive over the last thirty years of cookstove projects. In fact, there has not been a substantial amount of innovation in cookstoves related to emissions and efficiency in the last few decades. Possibly the most popular improved biomass cookstove design is the so-called "rocket stove," (Gifford, 2010) the basic design of which was developed in 1982 by Dr. Larry Winiarski of Aprovecho, a non-profit technology research center in Oregon. An average rocket stove has an efficiency of around 30% (Larry Winiarski, ETHOS conference presentation, Jan. 2011); in contrast, a three-stone fire or traditional stove has an efficiency somewhere around 10-20% (Baldwin, 1987; Foley & Moss, 1983).

Thermal efficiency of cookstoves has two different components: combustion efficiency, which measures how much of the fuel gets converted to usable heat energy, and heat transfer efficiency, which measures how much of the heat energy is transferred to the cooking pot. Much of the fuel savings from these rocket stoves and most of the other current generation of improved biomass cookstoves has been achieved through improved heat transfer efficiency (Kirk Smith, personal interview, Dec. 2010), while little has been done to improve combustion, which has important consequences for the emissions improvements that can be achieved by these kinds of stoves. Some emissions improvements can result from an increase in thermal efficiency, whether it be from heat transfer or combustion, simply because less fuel is going in, so less smoke should be coming out. However, if most of the improvement is coming through heat transfer efficiency, emissions reductions may be much lower than if the efficiency improvement was primarily the result of improved combustion.

Take, for example, a comparison of the rocket stove with the Philips fan stove, a more technologically complex and expensive stove that employs an electric fan to create turbulence and inject oxygen into the fuel chamber, which improves combustion efficiency.[2] Based on tests conducted at Aprovecho, the fuel use of the two cookstoves to boil water was similar, with the rocket stove actually using less wood than the Philips. In terms of health-related emissions, however, the emissions of the Philips stove were an order of magnitude (i.e. ten times) lower than those of the rocket (MacCarty et al., 2007). In that study, even the rocket lowered emissions by about half, which in itself is significant. However, health experts are now beginning to demonstrate that the dose-response curve for toxic emissions of wood smoke is not linear and that most of the benefits come at the end, meaning that a rocket-type stove might not have as much of a health impact as it might at first appear and that these stoves with very low emissions will be needed to get the strong health effects that people are looking for from improved biomass stoves (Kirk Smith, personal interview, Nov. 2010)

This type of next generation, very low-emission stove, such as the Philips may also be much more effective in fighting climate change. In recent years, evidence increasingly points to the strong and immediate climate effect that improved cookstoves could have by reducing black carbon, the tarry soot emitted from biomass combustion (Bond, 2010). It has been generally assumed that all improved cookstoves reduce black carbon simply by reducing fuel use; however, the same 2007 study from Aprovecho shows that the black carbon emissions from the rocket stove were nearly identical, while those from the fan stove were almost two orders of magnitude (i.e. 100 times) less. Therefore, from both a climate and health perspective, while current generation cookstoves certainly have some benefit, there is good reason to push for technological change towards super-clean next-generation biomass cookstoves.

2.3 Cookstoves and the carbon market

Improved biomass cookstoves are eligible for carbon credits in the CDM under the AMSIIG small-scale methodology, "Energy efficiency measures in thermal applications of non-renewable biomass." However, as of March 2011, only one project had been issued credits and three had been registered (CDM Pipeline, 2011). The high transaction costs of the monitoring and the CDM project registration cycle as well as certain aspects of the methodology have acted as barriers to many cookstove programs interested in participation in the carbon market (personal communication, CDM Practitioners Workshop, Oct. 2009). The cookstove community has suggested multiple changes to the CDM methodologies that could increase participation, primarily the ability to use default instead of calculated values in the methodology, but the CDM Methodology Panel has yet to fully embrace that approach due to concerns that it would lessen the rigor of the

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[2] I will call stoves such as the Philips "next-generation" stoves because, while they exist in small numbers in slightly more developed countries such as India, they are not nearly as widely disseminated or available as the current generation stoves, such as the rocket.

calculations, potentially leading to the issuing of carbon credits that had not produced real emissions reductions. One move that the CDM has made that has enabled more cookstove projects is to establish what is called a Program of Activities in which numerous projects can be grouped together and thus lessen the transaction costs per stove or per project. As of June 2011, eleven cookstove projects had been validated under the Program of Activities, although none had yet been registered or received credits (CDM 2011b). The Gold Standard has had somewhat more success with cookstove projects. Although only two cookstove projects have been issued credits under the Gold Standard, as of May, 2011, seven have been registered, and twenty-three more have begun the process (Gold Standard, 2011b).

Yet despite this rather limited success in obtaining carbon credits, cookstove project implementers remain very enthusiastic about the potential for carbon credits. In her 2010 global survey of cookstove programs, Gifford found that 25% of projects had received or were planning to receive carbon credits for their projects (Gifford, 2010). It is clear, therefore, that the creation of carbon credits has enjoyed a high participation rate from cookstove projects. This analysis seeks to clarify the effects of such participation on stimulating technological change in improved cookstoves.

3. Literature and Methods

3.1 Technological Change and Environmental Policy

Much of the literature on environmental policy and technological change (see, for example, Jaffe & Newell 2002), points to Schumpeter 1942 as the originator for theories of technological change. Schumpeter (1942) defined three stages of technological change, invention, innovation, and diffusion. Invention represents the early concept and creation stage in which prototypes may be developed. Innovation is the commercialization stage, in which technologies are developed and adapted for the market. Diffusion is the ultimate stage in which these technologies are widely adopted. Although the implied linearity of this description has been largely discredited by sociologists and economists of innovation (see, for example, Fagerberg & Verspagen, 2009; Latour, 1987; Kline & Rosenberg, 1986), the categories defined by Schumpeter continue to be analytically useful. In the last fifty years, studies of innovation have proliferated; the subset of that literature which is most relevant to the objects of inquiry of this paper is that which attempts to understand the effect of environmental policy on technological change.

According to Kemp and Pontoglio (2008) most of the work on technological change and environmental policy comes from four different literatures: "(a) theoretical models of incentives for eco-innovation, (b) econometric studies about the effects of environmental policy instruments on technical change and (c) case studies of the effects of environmental policy instruments on innovation, and (d) surveys of firms seeking to distinguish the influence of different environmental policy instruments, amongst various other factors, on eco-innovation" (p. 2). Of these, they argue that case studies are both the most limited and the most urgently needed, as they point to empirical inconsistencies with the theoretically derived work and suggest additional issues that have escaped notice in the other literatures.

Many of the studies from all of these streams of literature have attempted to distinguish between the effects of market-based environmental policies (such as tradeable permits) versus command-and-control regulations (such as requirements to use "Best Available Control Technology") in terms of their success in stimulating technological change (Milliman & Prince, 1989; Jaffe & Newell, 2002; Vollebergh, 2007). Generally, these studies hypothesize that market-based policies are not only more efficient than a command-and-control regulatory approach (as shown, in the case of tradeable permits by Coase, 1960) but have enhanced innovation effects that may offset the costs of compliance (Porter & van der Linde, 1995) or more generally lead to technological innovation, a good worthy of societal pursuit for a variety of reasons (Fagerberg & Verspagen 2009).

Among the reasons to expect that market-based policy instruments would be more effective in stimulating innovation are 1) while command-and-control can be technologically forcing, requiring all firms, regardless of ability and resources to meet the same standard is inefficient and costly, and 2) the government knows less about the feasibility of various technological improvements and, thus, has difficulty in setting standards that are more stringent than currently available technology but still achievable. Market-based instruments, in contrast, reward firms for becoming as clean as possible, thereby leveraging private capital and expertise to generate more innovation more efficiently (Jaffe & Newell, 2002).

Results from studies on market-based policy approaches and innovation, however, have varied and do not show clear superiority of market-based instruments on innovation. While some have found market mechanisms to be more effective (Milliman & Prince, 1989; Jaffe & Newell, 2002;) others have found either that command and control or a combination of the two can be equally effective (Frondel, Harbach, & Rennings, 2007) or that the distinction between these two broad categories obscures more important characteristics of policy design (Vollebergh, 2007).

Moreover, in addition to the lack of a clear innovation-based mandate for market instruments, results from these studies further suggest that a closer empirical look at the innovation process is lacking and very much needed. The innovation effects of environmental policies are often conceived of at a very abstract or theoretical level in which the actual process of innovation and possible variations in that process among different kinds of technologies and social organizations is not considered (Kemp & Pontoglio 2008; Taylor 2008). Yet various fields related to the study of technological innovation have shown that the process of technological change is not a simple input-output model but a complex and contingent process in which the results are often not predetermined nor predictable.

Science and Technology Studies, for example, has shown that social relations are important determinants of technological outcomes (Bijker, 1997; Kloppenburg, 2004), that technology and social organization both interact and co-produce one another (Jasanoff, 2005; Winner, 1986), and that innovation can be understood as a network of human and non-human actors acting upon one another (Latour, 1993; Williams-Jones & Graham, 2003). In a slightly different vein, Technological Innovation System research, and its closely linked predecessor evolutionary economics, focuses on the dynamic and interactive nature of innovation, particularly the role of actors and institutions, arguing that successful innovation, resulting in mass diffusion, is determined by multiple factors, both technological and social. Echoing Jasanoff's theories of co-production, evolutionary economics sees the social and technological worlds as exerting "strong mutual influences" (Fagerberg & Verspagen, 2002), and technological innovation systems scholars point out that past actions by actors result in institutional structures that affect future technological development; this technological development, in turn, affects these structures, altering the social milieu in which future technological innovation takes place (Jacobssen & Bergek, 2004). This process of technological and institutional change can be described in evolutionary terms of "variation" and "selection," in which a variety of technological options exist and are continually created ("variation") and selected for through markets as well as other selection environments (Suurs, 2009). Importantly, these selection environments are not driven simply by prices but, because actors are considered to not be fully rational, by existing structures, including routines and organizational rules of thumb (Suurs, 2009). STS scholars such as Winner add to this schematic a consideration of the role of power in the constitution and retention of these structures and the ways in which they shape technological trajectories to reinforce current power structures.

Without explicitly alluding to these literatures, even more traditional policy and economics scholars have found that, in contrast to many theoretical models of innovation, that the innovation outcomes from environmental policies are highly contextual, dependent upon both the details of the policies and technologies themselves (Taylor, Rubin, & Hounshell, 2005; Mickwitz, Hyvättinen, & Kivimaa 2008; Frondel et al., 2007), as well as pre-existing social organization and the actors involved (Taylor, 2008). As Kemp and Pontoglio (2008) state, "[E]ffects of environmental policy instruments in the real world are governed by the complexity of the innovation process and political considerations of using instruments…The specifics of policy and the situation in which they are applied are all-important for the outcomes" (p. 2)

Taken together, these literatures suggest that policies that assume that simply creating a market will inevitably lead to more and better technologies, are not likely to be successful if they do not take into account the wider context into which the policy and technology will be embedded. In particular, stimulating the invention, innovation, and dissemination of high performing and widely distributed technologies requires an understanding of the pre-existing innovation organizations and structures. Debates about whether and how to use market-based environmental policies to induce technological development to combat climate change and catalyze sustainable development could benefit from a closer look at how innovation in these technologies occurs in order to ensure that the policies are successful.

3.2 Methods

Following these literatures, this study provides a close analysis of the process of technological change in a single climate-poverty-energy technology, improved biomass cookstoves, and the effect of carbon credits on that process. As described, the innovation and STS literature suggest that a case study approach may be necessary for understanding how these policies are affecting the innovation decisions made by people along the supply chain. A case study approach, though harder to generalize, is needed to provide empirical evidence of the relationship between market-based policies and technological change (Kemp & Pontoglio, 2008) as well as nuanced understanding of the innovation process is needed to guide policy makers (Taylor, 2008). Studies of environmental policy and green technology have been particular stymied by the "difficulty of measuring the extent or intensity of inducement," and have resorted to unsatisfactory proxies in order to do so (Jaffe & Newell, 2002). As an alternative solution, this study uses qualitative methods to see, from the actor's point of view, the effect that these policies have had on their innovation decisions for this particular technology.

In order to understand the motivations and perspectives of actors along the chain of invention, innovation, and diffusion, interviews were undertaken with (1) cookstove designers and developers, (2) carbon developers who have been involved in cookstove projects, (3) thought leaders in the cookstove movement (as identified by other interviewees), and (4) actors who have led cookstove projects that have obtained or attempted to obtain carbon funding. In accordance with traditional case study methods, the interview subjects were not randomly selected but were chosen to represent certain key constituencies that together make up the cookstove and carbon innovation system. These interviews were supplemented with participant observation at conferences and workshops, archival research on cookstoves over time, and document analysis from the CDM and Gold Standard websites.

In sum, due to the recognized need to develop technologies for the poor that will both mitigate climate change and allow for improvement in living standards, it is important to understand whether or to what extent carbon credits will affect invention, innovation, and dissemination in these technologies and, if so, what that effect is likely to be. A meaningful answer to that question requires a nuanced and qualitative examination of the innovation process of these technologies, which was obtained primarily through interviews and participant observation, the results of which are presented in the next section.

4.0 Results

The results of the study are presented according to Schumpeter's (1942) conception of technological change as invention, innovation, and diffusion. However, the effects on invention and innovation could not be distinguished from one another, as most work in cookstove design begins with some pre-existing model or materials re-worked to achieve some desired improvement. Therefore, I consider effects on invention and innovation together, using the term "innovation" primarily, but separately from those on diffusion.

4.1 Invention and Innovation

> *People were motivated by reducing wood use long before they were motivated by carbon. So carbon has provided the ability to finance projects, but it really hasn't driven the design, because that was already being driven by people desiring to spend less money on wood or spend less time gathering the wood.* (Bryan Wilson, personal interview, Nov. 2010)

Interviews with cookstove designers revealed that by and large, consideration of the carbon market is not currently influencing their cookstove designs, at least in terms of efficiency and emissions. This result is not unexpected in that original motivation for many cookstove programs in the 1970s and 1980s that led to current designs was combating deforestation. Thus, most of the current cookstoves have been designed with fuel efficiency as a primary consideration.

This lack of an invention effect from carbon credits appears to both a result of the specific design of the policy in terms of both stringency and the methodology with which the carbon credits are calculated. This finding is entirely consistent with results from the literature which suggest that stringency is one of the most important policy characteristics in terms of driving technological change (Taylor et al., 2005; Frondel et al., 2007). Stringency here refers to the fact that prior invention and innovation was sufficient to meet the standards, in this case financial sustainability, imposed upon the technology. As discussed above, current models of improved stoves, such as the widely available rocket design, are about 30% efficient, which is enough to make the projects financially attractive to investors. According to their PDDs, three of the five CDM registered small-scale household biomass cookstove projects use rocket-type stoves with estimated efficiencies of 25-30%.[3]

These stoves, which are an improvement over traditional stoves but are not among the most efficient available today, are attractive for carbon finance for two reasons. The first is that they are low-cost, meaning both that they do not need to generate a lot of carbon credits in order to pay their costs and begin generating a profit, and that they are less risky than high priced stoves that demand a larger up-front investment that has so far been difficult for cookstove projects to find. Moreover, although they are not extremely efficient themselves, the baseline default figure set by the CDM, the efficiency for the open fire, is extremely low at 10%. Therefore, even an improved stove that has only 20 or 30% efficiency can earn carbon credits because it is significantly better than the baseline.

> *The stoves that are getting carbon credits are basically charcoal stoves… [T]hose are stoves that are already in the market or are market-based and they don't reduce fuel use to the optimal degree, and they don't reduce emissions…[but] they're better than the really horrible baseline.* (Anonymous #1, personal communication, Nov. 2010)

While it is true that many traditional stoves do have "horrible baselines," the use of a 10% default efficiency should give pause to those concerned with the accuracy and legitimacy of these credits. Although 10% is widely cited in the literature, apparently many of those citations can be linked back to anecdotal evidence from just a few sources (as cleverly demonstrated by Gill, 1987), and this figure has been under suspicion for quite some time. As Barnes et al. (1993) noted, "It is now recognized that traditional stoves used in fuel-scarce areas often have efficiencies substantially above 10 percent, instead of the 5 to 10 percent efficiencies assumed in the early days" (p.

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[3] Project Design Documents available at http://cdm.unfccc.int, Retrieved May 4, 2011.

124). In fact, three-stone fires and traditional cookstoves have been shown to have efficiencies above 15 or even 20% (Baldwin, 1987; Foley & Moss, 1983).

Another aspect of carbon credit policy design that has limited a drive towards cookstove invention is also related to this question of the testing methodologies, although it has less to do with stringency, i.e. how much carbon is saved, and more to do with the way in which that carbon effect is measured. As alluded to in the above quotes, carbon credit allocation is based upon fuel efficiency of the new device as compared to the fuel efficiency of the old device, rather than an emissions measurement. The rationale behind these methods is that most of the climate effect from cookstoves results, not from the combustion process itself, but from the cutting down of trees, specifically, trees that will not be replaced with other trees, known in climate policy as "non-renewable biomass." Based on this model of the cookstove-climate relationship, the crucial measurement is not the emissions, the vast majority of which are CO2, but the amount of fuel used, and more carbon credits can be generated only by using less fuel. Interestingly, this corresponds exactly to the design criteria used historically by cookstove producers, and for this reason, they feel that they have already done as much as they can in this regard, given the constraints of producing for a very poor population. As one interview subject noted, expressing comfort with the amount of progress already made towards fuel efficiency, "[W]ith the technology where we're at right now, we've been able to reduce carbon and wood use and therefore carbon and emissions" (Bryan Wilson, Nov. 2010).

Nearly all respondents did note, however, that the situation would be different if emissions were measured, specifically if black carbon were to become one of the carbon-credit earning gases. An inclusion of black carbon would have two related but separate effects on cookstove invention. On the one hand, because traditional cookstoves and open fires emit large amounts of black carbon, improved cookstoves can have large emissions reductions, providing greater numbers of credits. On the other, in contrast to fuel efficiency, black carbon creates a new "design problem" (Bryan Wilson, Envirofit, personal interview, Nov. 2010) because emissions have not traditionally been something that cookstove designers were specifically designing for. As one respondent said,

> "*There's two types of efficiency – there's fuel efficiency and then there's emissions efficiency. Carbon credits are calculated off of fuel efficiency, and I think that fuel efficiency is pretty good – I don't see how it could be dramatically better. But emissions efficiency could be dramatically better. Unfortunately those stoves will cost 50-100% more than they cost right now."* (Anonymous #2, personal interview, Nov. 2010)

While there has been ongoing work on stoves with dramatically better emissions, such as fan stoves and top lit updraft stoves, this work has been motivated by the desire to improve health, both for altruistic reasons and to appeal to funding from the humanitarian NGOs and government agencies that have traditionally funded cookstoves. Stove designers generally felt that a market did not yet exist for those kinds of stoves, which tend to be much more expensive, but if such a market did develop, if black carbon could earn credits, for example, they would have already done much of the initial design work. Current carbon credit mechanisms were not seen as a viable option for creating the necessary market for these stoves.

However, although carbon credits are not yet changing cookstoves in terms of efficiency or emissions, they are indeed having an effect on cookstove durability. Durability, or lifetimes, has not traditionally been a part of the cookstove testing regime in any systematic way, but designers report that carbon financing is driving them to test and improve the lifetimes of their stoves. There is no lifetime standard or official requirement for carbon, but because carbon projects can last multiple years, the longer the initial improved stoves are in the field and still performing well, the more money to be earned on that first investment. Over the life of the project, any stoves that are found to lose their efficiency or break or be abandoned, must be repaired or replaced.

When asked about the effect of carbon credits on stove lifetimes, Dean Still, head of Aprovecho responded:

> *"When you factor carbon credits in there, they want us to make stoves that last 5 years….Most stoves now in use last 6 months! So it's a big, big jump to go from 6 months to 5 years. It's pushing for longer and longer lifetimes in stoves. And that's more important than saving fuel, really. I mean, both are important, but longevity for a carbon credit project is really important. So we've just changed our stove to go from a 2 year life expectancy to a 5 year life expectancy*. (Personal interview, Nov 2010)

This effect of carbon credits on lifetimes points to the potential that a correctly designed policy might have on cookstove innovation. Designers are taking into account the desires of the carbon developers and have responded rapidly by increasing the durability of their stoves. However, it also implies that they are not getting similar signals regarding emissions or large increases in emissions, both of which are characteristics that should be desirable from both a carbon and development perspective.

4.2 Diffusion

Unlike invention and innovation, the diffusion stage of technological change is undergoing a significant change resulting from carbon credits. Understanding that, as discussed above, technological change is not linear, it is possible that these shifts in diffusion strategies and technological selection will eventually drive concomitant shifts in invention and innovation, a possibility further explored in the discussion section.

4.2.1 Carbon as enabling factor for diffusion

The most noticeable and remarked-upon effect of carbon credits has been in the scale of cookstove diffusion. While high transaction costs and some difficulties related to the timing of funding in the project cycle of the CDM and Gold Standard have kept carbon-funded cookstove projects from expanding as quickly as was hoped, nevertheless carbon has created an infusion of private capital into the cookstove world that has allowed multiple large-scale projects. One word that came up over and over again when discussing carbon and cookstoves was "enabling," meaning that carbon is providing the resources needed to do more projects, larger projects, and projects in places that had been previously rejected as being too poor to be able to support a cookstove program.

For example, according to their Project Design Documents two CDM projects in Africa (Nigeria and Lesotho) use the Save80 cookstove, which is highly efficient but extremely expensive (around $100 each) and had not previously been used in projects in Africa. So although carbon policies are not stringent enough to require these highly efficient stoves, as discussed above, they can enable the diffusion of these stoves at higher numbers and in places with poorer populations than was possibly previously.

It is interesting to note that, from the cookstove designer and implementer points of view, this "scale of diffusion" effect was the primary one that they had anticipated from carbon. Many saw carbon from the beginning, and still do, as simply a means with which to distribute more stoves, as another funding source for the underfunded work they had been doing for years.

4.2.2 Technology Selection

Another diffusion effect of carbon credits that was less anticipated but no less important is the way that carbon credits are shaping cookstove selection at the project administration level. In carbon projects, cookstove selection is changing both in terms of the methods of selection and the characteristics that projects are selecting for.

All carbon developers and most project implementers involved in carbon interviewed for the study reported that they would perform both focus groups and efficiency testing in order to select cookstoves for the project. Although some projects reported that they had done some of this before carbon, they stated that carbon was making this kind of testing much more pervasive in cookstove projects. As one carbon developer said,

> *"The majority of stove projects, many of them quite small in scale and the majority of which use locally manufactured stoves, will say, 'Yeah it's so and so more efficient than the open fire,' but actually very few people went ahead and tested that. Really surprising to me as I've been getting into this area how few people have actually projected their stoves through WBT [Water Boiling Test], CCT [Cooking Control Test], KPT [Kitchen Performance Test], things like that, so it forces you to be straight up with that."* (Daniel Farchy, C-Quest Capital, personal interview, Dec. 2010)

A project implementer, Andrew Binns from World Vision (personal interview, Jan 2011) said that previously, in non-carbon projects, they would likely have trusted the manufacturer reports on stove efficiency rather than go through the cost and effort of repeating the tests in the field themselves. But for carbon, his feeling was that field testing was absolutely necessary because of the need to know how the stoves would perform when trying to line up investors and plan the project because most of the cost is up-front while the payment from the credits comes later. He also noted that because many carbon projects are large, there is much more at stake, which has meant for them that have to be very certain and confident in their stoves. He feels that for carbon, you need to do more focus groups and more testing because you need to be sure that people will keep using them and that they will continue to perform in the long-term to pay for the project.

Although this testing is expensive, indeed one of the largest costs of doing a carbon project is the testing, most thought it was a good thing. As stove designer argued, this testing is "great for the field" because "for the first time people will know what their stove does" (Anonymous 2, personal interview, Nov. 2010). These comments echo similar arguments made in the innovation literature around information barriers and learning effects, essentially that inadequate information is one source of market failure (Jaffe & Newell, 2002) and that when a firm increases its own knowledge through R&D it is better able to later utilize outside knowledge for innovation (Cohen & Levinthal, 1989). In this case, the argument would be that when a stove designer knows the efficiency and performance of their own stove, they are better able to gauge where it stands in the field of cookstoves and thus, make better decisions regarding how or whether to improve their product.

One additional important point that was raised regarding testing was a concern with the testing methods and, therefore, the confidence that should be placed in the results. Specifically, a number of respondents were uncomfortable with the fact that the CDM allows projects to use laboratory results to predict the fuel savings from their cookstoves even though it is well-known, and has been for some time, that laboratory results are not predictive of actual performance in most cases. (Baldwin, 1987; Still et al. 2003) Moreover, all currently registered CDM cookstove projects used some version of the Water Boiling Test (WBT) to calculate efficiency values for the PDD despite the fact that, from the 1980s to today, the literature states quite clearly that the WBT should not be used to predict field performance (Still et al. 2003), likely because the WBT is much cheaper than other tests, especially the field-based kitchen performance test (KPT). One interviewee who is an expert in stove testing remarked that use of laboratory results and the WBT is a huge step backwards from best practice and does "almost exactly what you shouldn't do when we are very aware that there is not a lot of correlation between lab and field testing" (Dana Charron, Berkeley Air Monitoring, personal interview, Jan. 2011).

This issue is concerning for a number of reasons. The first is that, when used as a way to select stoves for use, these faulty tests might lead projects towards choosing the less optimal stove, thereby reducing the amount of carbon saved in a project. Another is that, on the innovation end and related to the comment above regarding informational barriers, these tests may be producing bad information and creating incentives towards innovating for stoves that perform well on that test although they might not do well in the field. Finally, when cookstove projects use the WBT for monitoring purposes, as all of the CDM registered projects do, the actual amount of carbon saved by these projects will be largely unknown, which is very concerning from a carbon standpoint given that these CDM credits are being used to offset real emissions in the developed world. While it is possible that the WBT underestimates fuel savings (as found by Johnson et al., 2009), little work has been done on the subject, and, thus, there is the very real possibility that some of the credits measured using these methods are fictitious.

In terms of the characteristics that these projects are testing for, carbon credits has created a kind of "obligatory passage point" for cookstoves (Callon, 1986) by creating a common definition of what projects should look for in an improved biomass stove. Specifically, to get chosen for a cookstove project, a cookstove should ideally be (1) more efficient than the traditional stove (2) liked enough by the local population that long-term use is likely (3) long-lasting, ideally at least five years (4) able be produced in large numbers (5) consistent and (6) low-cost relative to its carbon benefits.

As one carbon developer said, “More than anything else what matters is how much fuel it’s going to save and how long it’s going to last,” (Matt Evans, Impact Carbon, personal interview, Oct. 2010) while another said, “I think it forces a standardization-- vigorousness in terms of the actual stove efficiency.” Or as one designer put it, carbon developers are looking for “efficiency, durability, and cost. It’s all about what kinds of carbon, how will the finances work for the project. It’s definitely about being financially sustainable, but for many organizations it’s about making money” (Anonymous #2, personal interview, Nov. 2010).

Although many of these characteristics have been seen as desirable for some time, they were often not tested or were sometimes less important than other characteristics such as being made of a locally available material or able to provide employment to local artisans. In fact, most carbon developers and project implementers thought that carbon was pushing projects away from these local, artisanal stoves that arose out of the appropriate technology movement and are still somewhat common among stove projects today. One carbon developer said,

> *I think carbon finance has really pushed ... people away from the small artisan approach, for better or for worse. That’s not completely true. There certainly are some parties that are working somewhat with local artisans, but for carbon finance projects, you really can’t do, or I’m not aware of any examples, and it seems extremely hard to do projects at a really large scale, a project that would work with small stove builders.* (Matt Evans, personal interview, Nov. 2010)

While the shift towards mass-produced stoves preceded carbon, as discussed in my chapter on the history of cookstoves, carbon seems likely to stabilize that shift as cookstove projects increasingly turn to carbon funding, and mass-produced stoves are much more compatible with carbon funding due to their ability to scale rapidly and their consistency. This selection effect is similar to that found in Taylor et al. (2005) regarding SO2 in the United States in which she found that environmental policies, in her case regulations, could act like a filter, guiding innovation and diffusion down particular technological paths. For cookstoves, the fact that the high costs of testing and monitoring favor larger cookstove projects likely means that the mass-manufacture approach will become even more common for cookstove projects.

4.2.3. Use/Interface

Another diffusion effect of cookstoves can be seen in the adoption of more professional practices and a more business-like approach by NGOs responsible for disseminating cookstoves. Taylor (2008) calls actors like these NGOs “interface actors” and argues that these actors, who control the flow of information between “inventors/manufacturers” and end users is of critical importance to the success or failure of a policy in terms of driving environmental change. In her paper on the solar industry in California, she showed that the way that policies to encourage solar hot water heater diffusion were designed allowed for the interface actors, in her case the installers, to game the system and install bad technologies, thereby limiting innovation and poisoning the market for such technologies for years to come. She suggests that policies need to consider ways to strengthen the interface and guard against gamesmanship by the interface actors.

An opposite effect is seen here, however, likely because the policy, unlike the policies in Taylor's case, are specifically designed to reward *use*, not simply dissemination (analogous to installation). Rather than acting as a weak link in the innovation chain, the interface actors in cookstoves have been pushed by carbon policies to improve their practices, possibly better enabling future innovation. The perception from many of the interviewees as well as the published cookstove reviews (Barnes et al., 1994; Gifford, 2010) has been that little long-term field monitoring of performance or use had taken place prior to carbon, that cookstove projects had traditionally been, as one interviewee said, "chasing the numbers," focusing more on giving out a lot of stoves than on putting resources into following up on them over the long-term. Both the CDM and Gold Standard, in contrast, require annual monitoring of stove use and performance for the life of the project, usually seven or ten years. As one carbon developer noted,

> *There's been a real lack of decent follow-up in most stove projects. The presumption being, we get them out there, note down the number of stoves that are being sold, disseminated, given away or whatever, and automatically translate that to an improvement in the situation. And that really doesn't fly with carbon. You simply can't do that. You'll never get any carbon credits. So I think it promotes something that stove projects really should be doing anyway; it necessitates, not even promotes.* (Daniel Farchy, personal interview, Dec. 2010)

Cookstove project implementers seem to agree. While one interviewee argued that they have always monitored cookstoves that they had distributed, that was only for the length of the project, usually two years. Another said,

> *A really credible Gold Standard project forces you to be very aware of a bunch of things: every stove that is abandoned is very expensive; every stove that is mismanaged is very expensive. The good side about this is that it does force you to be much better at all aspects of the project. When we first built our [first batch of stoves], we built them, we came back, and we did a little bit of training, and we said, 'All right. They know how to run this stove. I mean, I can run it. They should know how to run it. We've told them how to run it.' They have no clue how to run it! And so now we go back, and we go back, and we go back, and we go back.* (Richard Lawrence, Proyecto Mirador, personal interview, Dec. 2010)

This kind of long term monitoring is crucial for innovation because it generates the kind of data needed for improvement. That data can be used in two ways. First, it allows stove designers to know where they stand, in a similar way to the initial testing described above. Second, and perhaps more importantly, it allows interface actors, those NGOs selecting cookstoves for projects, to be better informed in making those selections, which should ultimately guide the market and spur innovation. Because durability and long-term performance are so important to the financial success of a carbon cookstove project, NGOs are trying to select for these features, but without long-term monitoring they would not know which stoves had these characteristics and should thus be chosen. This information has hitherto been lacking. As one carbon developer who has been working on a project for a few years described it,

> *So it's always funny when you meet with a manufacturer … they'll always tell you, "My design is 50% efficient, and it's going to last for five years," and usually that's a little inflated – when you do actual monitoring on the stove, you find that the technology is just fine but usually not as good as they reported*. (Caitlyn Toombs, Impact Carbon, personal interview, Sept. 2010)

Related to this adoption of long-term monitoring methods has been a general professionalization of the practices of these NGOs, often helped along by the carbon developers that they are working with. These NGOs now keep information on who is buying or receiving stoves, when they are doing so, where they live, and how they can be contacted for follow-ups. Often, the on-the-ground NGOs doing the dissemination are lacking the capacity to do this well, so the carbon developers send project managers to the field to build capacity in these areas specific to monitoring but also more generally related to business. Because these carbon developers need the projects to run for the full lifecycle in order to get the expected returns, they need the entire supply chain to be able to meet demand and to be functional for the next seven or ten years.

If the stove supplier is international, such as StoveTec or Envirofit, this aspect of the project is unnecessary (which may ultimately lead to a preference for such suppliers when possible), but if the factory is local, there is often a fair amount of hand holding, at least initially, in which the developers, usually MBA graduates or with experience in business, help the factories think through expansion, budgeting, and investment. This again is in welcome contrast to many prior cookstove efforts in which local artisans would be trained initially, but little thought was given to how financially sustainable a stove building business might be for those artisans, often resulting in eventual project failure; indeed, such business training and long-term concern for the profitability of these local factories has been a suggested (but mostly ignored) "best practice" in the cookstove literature at least since the 1990s (Barnes et al., 1993).

Slightly less tangible, but clearly pervasive was what many of the respondents described an almost cultural shift in the way that cookstove projects are done with carbon, in contrast to traditional ways of operating. As one respondent said,

> *Carbon financing … creates a revenue stream that is completely different than a donor-driven model. It changes the dynamic of financing from one of, 'I am a donor, and I'm doing God's work, so here's some money. Godspeed and tell me what you do in two years.' And, 'Oh, you did good!' or, 'oh you didn't do anything, well OK. Done,' to 'If you give me carbon reductions, I'll give you money. And you have to monitor for [the reductions].* (Anonymous #3, personal interview, Nov. 2011)

The change can be described as a shift from one in which an organization assesses community needs and tries various methods and programs to meet those needs to a more specialized consumer approach in which the goal is to get the most cookstoves out as possible. I believe this shift can be ascribed to two interrelated factors. The first is that carbon has created a growing number of actors, primarily the carbon developers, whose sole focus in a project is cookstoves because their entire revenue stream for that project, relies on successful dissemination and continued use of these cookstoves. Whereas before, cookstove projects were usually managed by NGOs and government agencies that balanced time and resources of that project with a variety of other health or environmental concerns, there are now many more people and resources dedicated solely to making cookstove programs succeed. The second is that many of these people come from a more business-oriented background than those traditionally involved with cookstove projects. Carbon developers are tend to have MBAs or other business experience, and they bring that orientation to the work that they do with cookstoves.

Both of these factors have led to more of a consumer product mindset in carbon cookstove projects that pays close attention to business management and quality on the supply side but also to creating demand much in the same way that it is done for other consumer products. Impact Carbon, for example, launched a social marketing website and toolbox created specifically in response to their work with carbon cookstove projects and their perception that cookstove projects should be doing a better job of creating demand for these products using marketing techniques. Traditionally, the approach has been, and continues to be, to assume that people would buy cookstoves if they could be made to understand the benefits, such as health. Failure to understand or value these benefits has been assumed to be the cause of the demise of many cookstove projects, so the approach has been to do things like utilize health educators to spread the message or put up signs in the health clinic (Anonymous #3, personal interview, Nov. 2010). Carbon instead imagines the user of a cookstove as a consumer who should be treated much like consumers in the developed world. This viewpoint was captured particularly well by one carbon developer,

> *The reason many stove projects have failed over the years is that a development agency comes in, they do an analysis, they pick a product that they think is going to be "best for that audience," usually because it has the highest efficiency or the highest health benefits, and what they don't do effectively is understand, truly, the consumer perspective, meaning no matter how much or little money you have human nature is pretty similar. Somebody who is making a dollar a day has many of the same kinds of beliefs and aspirations and desires as we do making one hundred times that much, but what they don't have is the options, so when you come in and you bring me, as a rural Kenyan, a stove, and you say, 'Hey we're going to give this to you. This is going to solve this problem,' and you haven't...properly analyzed the fact that well I may not like the way that stove looks or I might not like how quickly it cooks....So we want to offer a line of products.* (Neil Bellefeuille, The Paradigm Project, personal communication, Dec. 2010)

While many of the interviewees expressed generally positive views of these trends in the interface actors, some also expressed concern about what is being lost with this changing of approach. Some respondents mentioned a loss of the "community aspect" that used to be a key component of cookstove programs, meaning both that people running a more traditional stove project would have a deeper understand the community they were serving, as well as that those projects gave local people more of a say in designing the stove to suit their specific needs. Another concern centered around the possibility that the profit drive inherent to carbon cookstove projects, at least on the part of the investors, would mean that the very poorest would be left out because they would never be able to buy stoves without a substantial subsidy. In general, though, respondents were happy with the diffusion effects of carbon on cookstoves and felt that carbon was bringing about some changes in the diffusion stage that should have happened long ago.

In sum, the results from the interviews and observations suggest that carbon credits are not yet leading to changes in cookstove design related to emissions and efficiency, the characteristics most of concern for both development and environmental reasons. The switch to more durable materials in response to carbon suggests that carbon could drive innovation, but current policy design does not support that outcome. Instead, most of the effect has been on the diffusion end, where carbon has brought in private capital, which has succeeded in increasing the number and size of projects. Carbon has also shaped the selection of cookstoves, leading to a narrowing of the scope of cookstove designs that are considered for projects. Carbon is causing projects to do more efficiency testing, more monitoring, and has led to an improvement in business practices in the interface actors as well as more consumer product mindset. Thus, while carbon markets not yet creating cookstove innovation in the aspects that are of concern, it is likely leading to a dropping out of the worst cookstoves, in terms of efficiency, and enabling distribution of some of the more expensive, more efficient cookstoves.

5.0 Discussion

The results above raise a number of issues regarding technological change in cookstoves as well as the efficacy of carbon credits in driving it. Currently, carbon markets appears to have been much more successful at enabling diffusion of current models of cookstoves, rather than driving innovation towards new and better models. However, this result could be in part a consequence of the relative newness of this market. Recognizing that technological change is not a linear process, perhaps the diffusion effect is merely preceding an innovation effect. Although cookstove designers are not currently designing differently due to carbon, in terms of efficiency and emissions might the diffusion effects such as selection, testing, and learning drive future innovation changes? If so, what kinds of cookstoves could we expect to result from that pressure? And finally, even if can be seen to drive innovation, is it the right tool to do so, both for cookstoves and more broadly for other green technologies for the poor?

5.1 Will Innovation Follow From Diffusion?

Both the literature and the results of this study can provide support for either an affirmative or negative response to this question. A key theoretical piece of support for the affirmative position is the role of learning and information in innovation. It may be possible that much of the current barrier to innovation into next-generation cookstoves is owed to informational gaps and limited opportunities for learning.

This might be true in a couple of ways. First, as discussed in the section on "selection," and suggested by the work of Cohen and Levinthal (1989) it may be that many designers are not themselves aware of the performance characteristics of their stoves and of where they stand relative to the field, and that once more testing is done and they have a better understanding of their stoves and how they compare to the field, they will be better able and more motivated to improve them. Moreover, as more NGOs and governments are aware of the performance as various stoves, there may be social or pressure not to select the dirtier ones, even if they can be financially sustainable using carbon financing. A version of this view was expressed by Kirk Smith (personal interview, Nov. 2010), a respected public health expert and champion of cookstoves for health improvement: "So what looked good 10 years ago, even five years ago, certainly 20 years ago no longer looks good. And it gets into an ethical issue. Do you promote something when you know there is something much better?"

There is also some evidence of such a shift in the fact that organizations that currently produce rocket stoves, such as Envirofit and StoveTec, are now working on fan stoves, although they are not yet ready for commercialization. This work has apparently been driven by concerns about health, which motivate many in the stove community, not carbon, and recognition that cleaner stoves are both needed and feasible. From Kirk's perspective, "They see the writing on the wall."

The other related reason to think that innovation will be driven by the diffusion effects of carbon on cookstoves is a potential learning effect resulting from the increasing number and scale of cookstove projects. The literature suggests that innovation often requires "learning by doing," (Goulder & Matthai, 2000) and it may be that there had not been enough opportunities for this kind of learning in the past due to the small size and distributed nature of cookstove projects. Further, the lack of learning opportunities was likely compounded by the information barriers discussed above: without good performance data, it would have been hard to know what was successful and to learn from past experience. This view was expressed by a stove designer who commented:

> *The stoves available today …made by the main stove developers, if not good enough, they are very good. What we need today for the stove market, is we need to do pilots. And when I say pilots I mean, even 100,000 stoves…. So we need to put stoves in the field. As a stove developer we learn more about what works, what doesn't work. And distributors need to learn same thing, the financing side, so we just need to get more and more practice, iterations…. We need to get these stoves in the market and start practicing and developing the market little by little.* (Mouhsine Serrar, Prakti Stoves, personal communication, Sept. 2010)

However, both the literature and empirical evidence seem to suggest that this innovation will not occur unless the policy is changed or other standards are put in place to require or encourage higher efficiency and lower emissions. In particular, one common thread of the environmental policy and innovation literature is that stringency is the most important characteristic in terms of driving innovation (see, for example, Nill & Tiessen, 2005; Frondel et al., 2007). If there are suitable technologies available, there will be a shift towards selection of those options, but little innovation (Ashford, Ayers, & Stone, 1985). Such is clearly the case with cookstoves where many currently available models are financially sustainable given current carbon prices. As one carbon developer said, "If the stove is really, really cheap, even if it makes a marginal improvement in efficiency, you could still do it" (Anonymous #4, personal interview, Dec. 2010). Looking at the currently registered CDM projects confirms this statement. While there are a couple of very efficient stoves being used, there are also multiple projects using stoves of 25-30% efficiency, right around the average of most current improved biomass cookstoves.

In fact, under the current carbon financing model, there is some pressure towards using cheaper stoves with moderate efficiency gains rather than expensive stoves with larger efficiency gains. Because cookstove projects remain a fairly risky investment, and most financing is needed up-front when risk is greatest, having low up-front costs (by, for example, using cheap stoves) can help these projects secure financing. When asked about more expensive but cleaner stoves, one carbon developer replied that carbon-financed cookstoves are still considered risky, and the future price of carbon is another source of risk, "so that's a lot to ask for somebody to invest in. If they're purely investing in it for social reasons and not to make a return, but if someone's looking to make a return on their investment, then it's very difficult to finance" (Daniel Farchy, personal interview, Dec. 2010). High priced stoves are also difficult to justify for NGOs that are trying to self-finance the project as they often do not have the kind of capital necessary to pay for thousands of $80 or $100 stoves.

Thus, the way that the selection function in cookstove diffusion is working right now, there is, to some extent, an obligatory passage point in that project managers are testing to see how the stoves perform in terms of efficiency, durability, and usability. So stoves that are extremely inefficient or unusable or only last six months will likely gradually become less numerous, but the passage point is wide enough that many current cookstoves can pass right through in addition to the very clean stoves. The shift towards more durable stoves shows that carbon-driven cookstove selection can result in innovation, but the evidence suggests that under the current policy design, it is unlikely to do so in terms of emissions or efficiency.

5.2 What kinds of stoves are being selected for

Given that this selection function does appear to be one of the stronger effects of carbon financing on cookstoves, we need to ask what kinds of stoves is carbon selecting for. Is it leading to the kinds of stoves that are desirable from a climate and development standpoint?

Here, the answer is empirically derived in one sense but open to interpretation in another. In terms of efficiency and emissions, climate change and health, the cookstoves being selected for are almost certainly better than traditional and three-stone fires. They may reduce fuel use by 30% or more, and the reduction in fuel alone means that less smoke is emitted, and, thus fewer hazardous pollutants and fewer greenhouse gases. However, these stoves are not optimal from either a health or climate standpoint, and if these are the stoves being selected for under carbon, and it is not clear that further innovation will be driven by carbon, then we may not be getting the kind of climate and health benefits that have driven the support of carbon cookstove programs. Moreover, it does seem possible that if carbon actually to some extent favors these stoves, because they are cheap, it might lead to *less* innovation and diffusion of cleaner stoves.

On the climate side, stoves are selected based on efficiency, using methodologies that are suspect for a number or reasons, as described above, and emissions are not measured as part of the CDM. The bar for financial viability is low, as mentioned, so even stoves without large efficiency gains can be supported by carbon. One specific concern, and perhaps opportunity, regarding climate change and the ways that it is measured for the CDM is related to black carbon, which is increasingly being promoted as the main climate benefit of cookstoves because the effect is strong and immediate (Bond, 2010). Yet efficiency, the measurement that generates carbon, is largely unrelated to black carbon emission, as explained above. A cookstove that reduces fuel use by even 50% may not change emissions of black carbon because black carbon reductions require changes in combustion efficiency, not just heat transfer efficiency. The rocket stove, for example, which is being used in two of the five currently registered CDM cookstove projects, has equivalent black carbon emissions to the three-stone fire (MacCarty et al., 2007). Given that the selection criteria for carbon credit projects includes only efficiency and not emissions of black carbon and that the two are not necessarily related, there is reason to think that cookstoves receiving carbon credits have as strong of black carbon emissions as other stoves. Moreover, if black carbon reductions are not being selected for because there is not monetary benefit to having lower black carbon emissions, then carbon credits are unlikely to lead to further innovation and diffusion in cookstoves with lower black carbon emissions.

A similar problem exists in health: the emissions that cause health problems are not necessarily strongly reduced by improvements in efficiency, and stoves that produce those health benefits in addition to efficiency are likely to be more cost more while not being any more attractive from a carbon-finance standpoint. As argued by Kirk Smith,

> *We now know that there are stoves out there that get a factor of ten or twenty lower emissions per meal. They're not any more energy efficient than the [rocket stoves] that are getting a factor of two or three reduction in emissions. They don't get hardly any more energy efficiency, so in one sense there's no extra incentive, and they're certainly a lot more expensive.* (Personal communication, Nov. 2010)

So, again, the stoves being selected for under carbon are not the ones with the strong health benefits. In fact, given that many of the health benefits accrue only under very clean conditions, the health effects from the kinds of cookstoves selected for through carbon might be less than commonly assumed.

These problems were fairly well recognized by many of respondents. They believe, by and large, that current stoves leave much to be desired, that much better, cleaner stoves are possible, and they are the direction that the field should be moving in. As one respondent argued,

> *If, in the end what's really going to get you the health and climate and other benefits we're after is these really advanced stoves then we owe it to the field, to our work to figure out how to get really high quality affordable solutions, either clean fuels or clean stoves or clean stoves with processed fuels, or some version of all of that into the marketplace of the developing world at a price that people can afford and that people will pay for.* (Anonymous #3, personal interview, Jan. 2011)

However, most still felt that, although cookstoves now do not have the climate and carbon benefits that could be achieved by next generation stoves, carbon markets were doing a good thing by getting the current stoves out into the field because they are better in terms of both health and efficiency than traditional stoves and three-stone fires. One carbon developer said,

> *We have looked at stoves … as low as 30% efficiency with the mindset being something is better than nothing, and if the alternative at this point is nothing, then if we can make 30% financially viable, then we should do it until we can find a better solution.* (Neil Bellefeuille, personal interview, Dec. 2010)

Or, as multiple respondents put it, "We should not make the perfect the enemy of the good."

In the meantime, recognizing that the black carbon and health benefits are not likely to come just from carbon, many suggested changes that could be made either to the policy or in supporting policies and other mechanisms that would ensure that those aspects are considered in selection. For example, one commonly suggested improvement to the current policy was to add in black carbon, as well as other gases that have both health and climate effects, as a covered gas under the CDM, which would encourage innovation in stoves with low black carbon emissions, which is more closely linked to emissions of health impairing gases than is efficiency. As one described it,

> *Currently, given the protocols in CDM, and the voluntary carbon market, the two major avenues, well they don't pay you for anything but CO2, and CO2 is not a health hazard. So you can have a perfectly good stove program that reduces CO2 and does nothing for health. In fact, I daresay that's mostly what happens…! if you can throw in some other things, black carbon and methane and other CO and volatile organics into that mix, then they would have an advantage and get credit for those on the carbon side, and those are all on the health side [too].* (Kirk Smith, personal interview, Nov. 2011)

One option of other supporting policies was the creation of indoor air pollution standards by the World Health Organization that would bar any cookstoves with emissions above that limit from being distributed. Another, more market-based approach, was to have a certification agency that would measure emissions and certify stoves at different levels, so that NGOs would know which stoves were the cleanest and could advertise the fact that they were picking clean stoves over dirtier ones. Finally, also on the public side, was the idea that if there were some kind of public fund to replace investor financing at the front end, then that fund could require that any project receiving those funds, which would presumably have better terms than those from private investors, would have to use approved stoves or stoves that could be proven to have certain health and/or climate benefits.

In general, the lesson here seems to be that assumptions of a climate and development "win-win" are not entirely justified. Even though cookstoves, both current and next generation, have the ability to mitigate climate change and improve health, changes made to achieve carbon credits, as defined and measured by current CDM policy, do not necessarily lead to strong health benefits. If carbon, measured through efficiency, is the only aspect supported monetarily, and we are depending on the market to choose technologies, then the resulting technologies can be expected to exhibit greater efficiency but not necessarily reduced emissions of health-damaging pollutants.

5.3 Is carbon the right tool?

The results of this study suggest that carbon markets, arising from climate change policies, are enabling diffusion of current improved cookstoves but not, at least as currently designed, inducing innovation or diffusion of next generation stoves, in large part because the current generation of cookstoves are profitable carbon investments. Yet, for both climate and health purposes, the next generation of cleaner cookstoves is highly preferable; the current generation of cookstoves is not adequate, especially in terms of health. This raises the following question: if our goals are climate mitigation and sustainable development, is carbon trading an effective tool to get us there, either for cookstoves specifically or green technology for the poor more generally?

In many ways, cookstoves are not a natural fit with carbon trading. Their emissions reductions are low per stove and highly variable, leading to very high transaction costs. Recognizing the difficulty imposed by those costs, many have suggested that they need to be lowered in order to make carbon cookstove project more financially viable. This could be done by, for example, accepting more default values in the methodologies or certifying stove designs for certain emissions levels, each of which would lower the testing and monitoring costs, which often make up the largest cost for cookstove projects. However, doing so, given the high variability in fuel use between households and the traditionally uneven performance of many cookstoves in the field, would raise questions of environmental rigor (as well as threaten some of the main benefits of lower emissions mentioned in this chapter). The purchasers of these credits are governments and firms that are going to emit the full amount of greenhouse gases that these credits allow; if the credits are not earned through real reductions, there is risk that actual overall emissions will rise.

But for many people involved in carbon cookstove projects, the real value of these projects is not carbon at all but health. Carbon is seen as a means to an end, a way to enable distribution of these cookstoves in order to achieve their real benefits, which are seen to be health. When asked the main benefit of an improved cookstove, nearly every single respondent replied that health was the largest or most important benefit. As one cookstove designer said,

> *The carbon issue, we get caught up in that. It's enabling, but the benefit is really improving the lives of people using these stoves. I wouldn't discount the impact that we could have on climate change. If we could do this at scale, because of the black carbon, you might be able to buy a decade or so…. But I suspect really the benefit is health*. (Bryan Wilson, personal interview, Nov. 2010)

But evidence thus far suggests that current carbon policy is not pushing towards innovation and dissemination of the kinds of super-clean next generation cookstoves that really have these strong health benefits; in fact, it may be pushing selection towards cheaper stoves that are moderately energy efficient, creating fewer opportunities for dissemination of next generation stoves to the global poor.

As one designer said,

> *That's the thing about carbon credits is you can then put in all of the protect health, reduce climate change stuff in your stove although … that's not really rewarded by carbon credits which is just based on reduced fuel use.* (Dean Still, personal interview Nov. 2010)

And another:

> *There's a lot of discussion now about whether current emissions reduction levels are adequate....Kirk Smith would say, well no it's not 80%. We need 99, 99.9%. And we can probably do that, but there is no additional savings in carbon….* (Bryan Wilson, personal interview, Nov. 2010)

There is, thus, a real weight to the concern that carbon is not going to lead us towards the kinds of cookstoves needed for both health and climate. Perhaps, in contrast to the perfect as the enemy of the good, we should be worried about the good as the enemy of the perfect.

Finally, one last point to consider is the issue of who is really benefitting form the use of carbon trading as a tool. Many respondents expressed disappointment with the way in which the carbon largess is being distributed, with far too much going into the pockets of the investors who provide the up-front funding and far too little going to the development organizations, communities, and users themselves. While there is excitement that carbon has allowed these kinds of projects access to private capital, there is a general feeling that although this capital does enable projects to get off the ground, only a small fraction of the money being leveraged by carbon is going to the poor; instead most of it is merely being re-circulated among the already rich. With little experience in financial markets and few resources of their own, many NGOs have found themselves on the short end of deals with the carbon investors.

> *This is why a lot of people have gravitated towards [experienced carbon investors]. You have all these little projects, and [the investor] sweeps in and says, 'We know what we're doing. We'll do it for you,' and what they'll do is they'll go out and they'll*

> *get a great carbon price, and they'll fund the project with $2 or $3, but they're getting $10 or $12 per credit….* (Richard Lawrence, personal communication, Dec. 2010)

To be fair, for many NGOs, getting even a few dollars of a project paid for by carbon emission reduction is beneficial. One respondent argued,

> *World Vision would be tickled to death if they could get half of the expense of the stove covered by carbon credits over the long term….[T]hey're just tickled pink to not to have to donate the full cost of the stove. They can donate half the cost of the stove and get the rest through carbon credits, or the rest back.. And that's where the business model of [carbon investors] works because they don't have to get as much back to the project…. And I'm sure for [the NGO]s, you tell their stakeholders that their money went twice as far b/c they utilized carbon credits, it's got to make their stakeholders just drool. Their money goes twice as far!* (Anonymous #2, personal interview, Nov. 2010)

Moreover, as some carbon developers argued, taking risks on things like the carbon market is not appropriate for development NGOs in any case. It is totally appropriate to have a for-profit investor shoulder the risk by paying the up-front costs and keeping most of the carbon credits that are generated. This point is certainly valid; however just because within the context of a carbon market, it is desirable to have investors take the risk, that does not mean that the carbon market mechanism is the right way to approach innovation and dissemination of these technologies. Likewise, the fact that we could fix the various problems of the current carbon policy by, for example, including black carbon, setting health standards, certifying stoves, or providing public upfront financing, does not mean that carbon is the right tool. It proves that it could be a *better* tool, but it does not justify choosing that tool over other potential alternatives that might provide better health and climate benefits and make more efficient use of private money than the carbon market.

For example, one could imagine a policy tool that would take a percentage of the trading revenue of more common, centralized, industrial type CDM project and put that money into a fund for projects like cookstoves that are known to have some climate and development benefits. To access this fund, projects would have to monitor use for the life of the project and would have to use cookstoves that had been certified according to their health and climate benefits as proven through field testing; using stoves with higher certifications would earn more money from the fund. The fund could adopt many of the practices suggested to make the CDM more cookstove friendly, such as default values and cookstove certification, because these projects would not be creating credits that would be used to allow emissions elsewhere. Moreover, the fund could require publishing of testing and monitoring results on its website, thereby solving some of the learning and informational barriers to innovation, and it could put some of the money into cookstove research, providing funds necessary to explore future invention and innovation.

This fund is just one example, certainly with its own drawbacks. Yet it demonstrates that an alternative policy to the carbon market may achieve many of the current benefits of the carbon market, such as leveraging private capital and increased testing and monitoring, in addition to more effectively stimulating innovation and dissemination of green technologies for the poor.

6. Conclusion

This paper has shown that carbon markets and carbon credit trading are succeeding in diffusing current generation of cookstoves but are not likely to lead to innovation and diffusion of next generation stoves that have substantially greater benefits in terms of both health and climate. To some extent, this failure to induce further innovation in cookstoves is a result of the particular ways in which the CDM was designed and could be mitigated by policy modification conjunction with deployment of other policy tools to require or encourage the needed improvements. However, the results also suggest that the carbon market may not be the most effective tool for further technological change in cookstoves and that, more generally, carbon markets might not be a good fit with these kinds of technologies for the poor, which are often highly decentralized and desired more for their development benefits than for their climate change mitigation potential. Alternative policies might be more effective in stimulating the needed technological change in green technologies for the poor and should be considered. Such policies could be similar to traditional tools of stimulating R&D, such as government funding of research or, alternatively could resemble something like the proposed X Prize for cookstoves.

More research is needed to determine how generalizable this result is to other technologies for the poor and to identify characteristics, both of the technologies themselves as well as the actors and organizations that comprise their innovation chain, that might determine compatibility with carbon markets as a driver of technological change. Additionally, there is a need to further explore alternatives to carbon markets that build on the ways that they are successful but exhibit fewer of their deficiencies.

Chapter 5: Conclusion

This dissertation examined the proposition that market-based approaches are superior for development and dissemination of green technologies for the poor using improved cookstoves as representative technology.

It began by asking the following three questions: First, what are the technological characteristics favored by and resulting from market-based approaches? Second, what reconfiguration of social relations are implied or favored by these approaches? Finally, how are these technological and social changes dynamically interacting and mutually constituting each other?

In attempting to answer these questions, the dissertation took a theoretically-framed but empirically driven look at the technological and social evolution of improved biomass cookstoves from the 1960s to the present day; analyzed comparative case studies of technologies that employed a particular innovation tool taken from the for-profit realm, intellectual property; and interviewed various cookstove and carbon actors about the effects that carbon credits, a market-based environmental policy tool, on cookstove design and dissemination.

Each chapter produced its own results and conclusions based on the particular question it was meant to answer, but viewing the results holistically, they also address the three questions motivating the dissertation. However, perhaps the clearest conclusion to be drawn from the chapters is that the technological and social aspects of green technologies for the poor are tightly intertwined, that they are, in fact co-produced and mutually constituted. Thus, because it is unwieldy and conceptually problematic to discuss the technological and social impacts separately when they are so tightly linked, the conclusions will be discussed in a context more suited towards the third question: *how are these technological and social changes (towards a market-based approach) dynamically interacting and mutually constituting each other?*

Market-based approaches and the social arrangements that they entail are clearly more compatible with certain kinds of technological characteristics than others and can lead to a dominance of those types of technologies. At the same time, the particular ways that various technological problems are imagined define the traits required by technological solutions. When those traits are more compatible with certain kinds of organizations and can lead to a dominance of those kinds of organizations.

The cookstove history chapter (chapter 2) showed that particular conceptions and articulations of the problem that cookstoves were meant to solve led to a definition of technological "improvement" that included fuel efficiency, consistency of performance, and ability to scale quickly. 'Improvements' in design were not dictated by technical issues alone, but were selected according to particular problem frames and processes of social negotiation. This particular type of cookstove, though was much more compatible with mass-production than traditional artisanal production, calling into creation social organizations that could mass-produce cookstoves, which then encouraged a commercial approach, at least at the production level, in order to recover those costs. So the move to a market-approach was in part driven by and in part the cause of a particular kind of technology, demonstrating clearly the mutual co-production of the social and technological.

The findings of the intellectual property chapter (chapter 3) demonstrate that certain technological characteristics, such as high, long-term operating and maintenance costs, for example, or production costs above the willingness to pay, imply certain kinds of social arrangements for their development and distribution. However, these social arrangements are not uniform at every stage technological change – often distinct actors are involved invention, innovation, and diffusion, and each may use a different type of funding. Tools that were developed by and for the private sector can be useful, but care must be taken to ensure compatibility with the organizations involved at the level at which the tool is targeted: these different types of organizations at each different level on the innovation and diffusion chain have different orientations and incentives that must be understood before applying market-based tools such as intellectual property. The particular configuration of these innovation networks, especially whether or at what stages it includes investors versus donors, both determines and is determined by the kinds of technologies that will be produced. Technologies that have high, long-term operating costs, may function better if the dissemination organization is investor-funded, and once an organization is investor-funded, it is only compatible with technologies that can generate the necessary return on investment.

Finally, the results from the carbon credit chapter (chapter 4) show that the carbon market is selecting for certain kinds of technologies, which are very similar to those discussed in the history chapter: efficient, capable of consistent performance , and able to scale rapidly. The organizations most able to supply those kinds of stoves are stove production companies, which is likely to lead towards more centralized production and commercial approaches. At the same time, these consumer-product type stoves with their fixed design re-construct the stove users as consumers and shape the ways that stove organizations are interacting with the user population.

Thus the three chapters show a compatibility between the market-based approach and technologies that are standardized and can be rapidly produced. Belief in the necessity of those kinds of technologies can produce market-oriented organizations, and belief in the superiority of market organizations can produce those types of technologies. Once in place, each reinforces the other.

These findings are consistent with the theories of coproduction put forward by theorists in Science and Technology Studies (STS), notably Sheila Jasanoff (2005) and, though not explicitly called such, by Langdon Winner (1986). While popular accounts of technology often portray technological change as a series of objective improvements untouched by social or political considerations, STS theorists seek to unmask the role that social factors play in technological development. Of particular interest in this dissertation has been the importance of the definition and articulation of the problems that technologies are meant to solve, including who is involved in (or left out of) those decisions. Co-production extends that analysis to then understand the ways that the resulting technological outcomes then act back upon the social and political, reinforcing or destabilizing the social structures in which they are embedded.

This understanding of the interdependence of society and technology, which can be seen clearly in the case of improved cookstoves, has implications for the ways that we think about how to approach catalyzation of sustainable technologies for the poor. If each technological solution implies a concomitant social re-organization, and particular social orientations imply the development of compatible technologies, then both must be considered in policy design and implementation; each has consequences for the other.

Regarding market-based approaches in particular, this dissertation concludes with two lessons learned from the results.

The first lesson is that, in developing and deploying sustainable technologies for the global poor, leveraging the private market and using tools that have arisen in that sector can have unexpected and unintended effects for both the technology and the social arrangement. It should not be assumed, as it sometimes is, that the only impact will be to create access to the world of private capital. Market-based policy tools should be used only with an informed understanding, to the extent possible, of other potential consequences of using such tools in terms of technological and social commitments that they are likely to entail. This dissertation has suggested what some of those might be, but further and more generalizeable research is needed for better prediction and understanding.

For example, the findings from Chapter 2 demonstrate that using commercial approaches to improved cookstove dissemination result in a re-imagining of user as consumer. This reconstruction has some positive aspects, such as a stronger consideration of user preference in design, but also circumscribes the role of the poor as technology designers and limits the engagement of cookstove organizations in the communities that they seek to serve. Chapter 3 illustrates the cultural dissonance that can arise when importing market-based tools into traditionally non-market spheres and the obstacles to technology development that may result. In the case of the Ethiopia cookstoves, the NGO responsible for disseminating the cookstove exhibited discomfort with participation in the licensing process. In particular, they balked at the liability clauses contained within the license. Contract negotiations delayed the project for several months, forcing a temporary work-around to the problem and nearly derailing the project. Chapter 4 show that attempts to use carbon financing for cookstove projects are narrowing the scope of the kinds of cookstoves that are being deployed. The particular way that the policy was crafted, using lab-based efficiency as a basis for carbon savings, prioritizes efficiency over other stove characteristics, such as health or even, potentially, climate change mitigation potential. Moreover, the high transaction costs of measurement and monitoring require cookstoves that have consistent performance and can scale rapidly, leading projects to select mass-manufactured stoves over those that are locally developed and produced.

When comparing potential policies that are meant to stimulate technological change, these complexities must be taken into consideration. That is to say, for instance, if a market-based policy is highly likely to lead to technological solutions that are standardized and mass-produced, is it still the right policy? It may be, but to know for sure, we first need to ask ourselves what kinds of technological and social outcomes are desirable. Only then can we determine if a market-based policy is likely to get us there.

A second is that, in green technologies for the poor, the ecology of the various actors and organizations involved all along the innovation and diffusion chain is highly complex and diverse. Such complexity of organizational structure, though daunting to assemble, actually offers a number of opportunities for incorporation of market-based tools. Moreover, these tools may usefully contribute to solving certain persistent problems in technology for the poor. Drawing from the cases in this study, for example, it is clear that private investment can significantly increase the resources available for technology development and dissemination, perhaps bridging the gap between the lab and the field or allowing for more rapid expansion. Or, for instance, a commercial approach to dissemination can ensure an on-the-ground provider with more consistency, quality, and long-term sustainability.

However, to understand and predict the performance of market-based tools, the complex structures along the technology innovation and diffusion chain must be broken down to their component parts. Tools that can be effectively deployed at one level or for one technology may be inappropriate for another. For example, as shown in the IP chapter, rapid scale-up and commercialization of a certain technology may be more compatible with an investor-funded organization; yet, the dissemination end might be better handled by a donor-funded organization willing to offer the technology at a subsidized cost to the very poorest. Furthermore, it should not be assumed that just because, for example, dissemination by a donor-funded organization is preferable in a certain case, either (1) that the same will be true in all cases, *or* (2) that the other stages should also be handled by donor-funded organizations. Support for market-based approaches at some levels and for some technologies should not be generalized to support market-based approaches for all technologies or for all levels or stages of technological change.

Recognizing the ways in which the social and technological aspects of sustainable technologies for the poor are tightly intertwined, developing and deploying these technologies requires that we have a clearer understanding of both aspects at all levels of technological innovation and diffusion. Different combinations of market and non-market approaches are likely to work for each stage of innovation and diffusion and for each distinct kind of technology. A combined approach, thoughtfully incorporating aspects of market-based and other approaches and targeting them at different stages, is necessary if we are to solve the difficult problem of how to develop and diffuse promising technologies. Yet realizing the potential of these mixed approaches will be difficult and will require coming to terms with multiple social and technological complexities and commitments.

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