challenge paper

WATER & SANITATION

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Sanitation and Water Challenge Paper*

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Abstract: This Challenge Paper focuses on sanitation, as the world has met the water Millennium Development Goal, but will likely miss the sanitation target. It considers what it would cost to improve service for both the unserved population in developing countries, those one billion or so who must defecate in the open, and what it would cost to improve the quality of service for those people in urban areas who are nominally "served" but struggle to realize the gains from sanitation because of the challenges of emptying and safely disposing of latrine/septic tank contents. Dramatically cutting open defecation rates in rural areas has been shown to be feasible with a reasonable public investment. At a scale of tens of millions of people, it has a positive, though modest, pay-off as measured by benefit cost analysis. Rural water interventions, which we consider briefly (as water was covered extensively in the previous Copenhagen Consensus round), have similar modest pay-offs. In the case of urban sanitation, the theoretical benefits of basic onsite sanitation will not be achieved unless specific innovations are put in place. Investments in technological and institutional innovations to reduce the cost and increase the effectiveness of sanitation services to empty and treat human waste collected in latrines and septic tanks would have a very large pay-off. We believe the innovation required is achievable and that there is credible evidence that the fraction of roll-out costs to achieve adoption that would need to be borne by the public sector is sufficiently small as to make such an investment feasible and attractive. Finally, there is also a need for radical innovation to "reinvent the toilet". Such radical innovation is indeed high risk, but if successful would lead to very attractive benefit cost ratios.

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1 The Challenge

The world has met the Millennium Development Goal (MDG) on water five years early, according to the most recent Joint Monitoring Program update, released in March 2012, but will miss its goal on basic sanitation by almost 1 billion people (WHO and UNICEF, 2012). An astonishing one-third of the world population, 2.5 billion people, does not have access to basic sanitation and over one billion people defecate out in the open. In light of the evidence that the world community is making progress in the water sector, and because sanitation is typically the neglected half of the water and sanitation challenge, including in the previous Copenhagen Consensus challenge paper on water and sanitation (Whittington et al., 2008) this paper redresses that imbalance and focuses primarily on sanitation and the question of whether and how it would be cost-effective to dramatically change levels of investment to solve this problem.

The benefits of sanitation as a public health solution seem self-evident. Quotations like this one from a recent Lancet (2008) editorial are easy to find: *"It is already well known that improved sanitation could prevent 1·5 million deaths from diarrheal illnesses a year, enhances dignity, privacy, and safety, especially for women and girls, benefits the economy—every dollar spent on sanitation generates economic benefits worth around nine more—and is better for the environment*." In the United States, large public sector investments to provide clean water and sewerage were jointly responsible for most of the rapid decline in the child mortality rate in the early 20th century (Cutler and Miller 2005), and more recently for substantial health improvements on Native American Indian reservations (Watson 2006).

And yet, the continued burden of unsafe and inadequate sanitation is easy to identify. Inadequate sanitation caused a cholera outbreak in Haiti in late 2010 that has now made half a million people sick and cost some 7,000 lives (McNeil, 2012). Smaller cholera outbreaks are still commonplace during the rainy season in Bangladesh or the low-lying parts of many Africa cities (Zuckerman et al., 2007). Diarrheal diseases are still a leading cause of death for children under five, second only to respiratory infections (Black et al. 2010). The burden extends beyond health. The Water and Sanitation Program (WSP) of the World Bank in 2007 launched a series of national studies to assess the economic impact of poor sanitation. In the Economics of Sanitation Initiative (ESI), a series of reports dating from 2008 to late 2010, WSP concludes that the economic impact of poor sanitation can be as high as 7% of GDP for some Asian countries (Bangladesh: 6.3%; Cambodia: 7.2%; India: 6.4%; Lao PDR 5.6%) while it is still on the order of 1-2% of GDP for African countries (Benin: 1.5%; Burkina Faso: 2%; DRC: 1.6%; Ghana 1.6%; Kenya 0.9%) and some other Asian countries (Indonesia: 2.3%; Philippines: 1.5%; Vietnam: 1.3%) (Hutton et al. 2008, 2009, Barkat 2010, Tyagi, 2010, WSP 2011).

Why has the sanitation challenge proved so elusive for many countries? The simplest answer is the cost of current technologies. For about two hundred years the water closet – the flush toilet with its smell-limiting water seal that brought the "outhouse" indoors – and the associated sewer networks have been the technology of choice for all who can afford it. The 2008 Copenhagen Consensus sanitation and water paper (Whittington et al., 2008) estimated that the cost of such conventional "modern" water and sanitation systems is on the order of $50-100 per household per month – which puts them squarely out of reach for those living on $1-2 per day.

Faced with such costs and the potential to decouple water and sanitation services, many governments and households have prioritized water over sanitation. Take the cases of China and India, for example: Of the 1.8 billion people who gained access to improved drinking water sources between 1990 and 2008, 47% lived in China and India alone. Of the 1.3 billion people who gained access to basic sanitation in the same period 38% lived in China and India. But while in 2008 88% and 89% of the population in India and China, respectively, had access to improved water services, only 55% and 31% had access to basic sanitation (WHO and UNICEF, 2010).

Why does sanitation lag so far behind water? There is a strong *a priori* case to suspect significant disease externalities and intra-family distributional inequities that would lead to inefficiently low private investment. Standard public finance arguments would thus support public contributions to sanitation. There is also suggestive evidence that improving sanitation presents a coordination failure and that behavioral biases prevent optimal take-up, which also bolsters the case for subsidies (Ban, Koola & Zwane 2011). Similar arguments have been used to support subsidies for water quality, vaccines, bednets, and primary education in developing countries (Ahuja, Kremer & Zwane 2011, Holla & Kremer, 2008).

In addition to these market failures in the sector, the continued focus on water-borne technology compounds the challenges of extending sanitation service to all. Whittington et al. argued in 2008 that the cost of flush toilets and sewers limits their reach to the top one or two income quintiles. Conventional waste water treatment plants are not only expensive to construct, but costly to operate because of their high energy requirements. As a consequence, in a typical country in Sub-Saharan Africa, sewers serve only a small core of large cities.

The sanitation that serves those households not in the sewered core is not networked; it is on-site sanitation, i.e., latrines or septic tanks, an investment for which the owner of the house bears primary responsibility. In high density, low-income urban areas, where one or more families share a single room, finding space for a latrine is problematic and constructing a new latrine when an existing one fills is usually out of the question. Under those conditions latrines have to be emptied and the fecal sludge has to be transported to a place where it can be dumped safely if health benefits of sanitation are to be realized.

In practice, the urban sanitation service chain often breaks down at the emptying stage to such an extent that the context is one of functional open defecation. This point, that the reality of urban sanitation is a broken service chain that makes health benefits illusive, is central to our argument in this paper that innovation, not just investment in current technology, is needed if potential health benefits are to be realized.

Some pits and septic truck are emptied with a vacuum pump truck, which is the standard developed country solution for emptying septic tanks. Vacuum trucks are expensive and not well suited to empty latrines in high-density low-income urban areas where lanes are small and narrow. An estimated 200 million latrines and septic tanks are emptied manually, by a worker descending in the pit with a bucket and spade. When this approach is taken, pit contents are generally subsequently dumped or buried in the immediate environment. This reintroduces to the environment pathogens previously contained in the pit or tank. Health costs are also imposed on emptiers. Even when pump trucks are used, in many cities the fecal sludge is not safely disposed. It is dumped in fields or on beaches. The final result is again that the health benefits of sanitation, which assume that fecal matter does not enter the environment, are not realized. [3]

This Challenge Paper takes on the question of what it would cost to improve service for both the unserved population in developing countries, those one billion or so who must defecate in the open, and what it would cost to improve the quality of service for those people in urban areas who are nominally "served" but struggle to realize the gains from sanitation because of the challenges of emptying and safely disposing of latrine/septic tank contents. We argue that dramatically cutting open defecation rates in rural areas has been shown to be feasible with a reasonable public investment at a scale of tens of millions of people and that it has a positive, though modest, pay-off as measured by benefit-cost analysis. Our argument on this question is qualitatively similar to that made by Whittington et al. in 2008. In the case of urban sanitation, which Whittington et al. did not consider, we argue that the theoretical benefits of basic onsite sanitation will not be achieved unless specific innovations are put in place. Investments in technological and institutional innovations to reduce the cost and increase the effectiveness of sanitation services to empty and treat human waste collected in latrines and septic tanks would have a very large pay-off. We believe the innovation required is achievable, as it requires integration and product development rather than blue sky research and discovery. There is credible evidence that the fraction of roll-out costs to achieve adoption that would need to be borne by the public sector is sufficiently small as to make such an investment feasible and attractive. Finally, we argue that there is also a need for radical innovation to "reinvent the toilet". Such radical innovation is indeed high risk, but if successful would lead to very attractive benefit cost ratios.

Our approach to making the cost-benefit estimates for sanitation that is the primary focus of this paper is to build upon the exemplary recent work done by the Water and Sanitation Program of the World Bank as part of its Economics of Sanitation Initiative (ESI). We do not re-visit in detail the ESI calculations and dispute particular parameters; thus we take on the Copenhagen Consensus "challenge" in a way that differs from the tack taken by Whittington et al. in 2008. There is no need for further detailed calculations when we can build on the ESI work. Rather, we accept throughout this document the ESI estimates of various levels of total annualized costs of basic sanitation and the associated benefits as appropriate starting points. However, we make arguments that lead us to conclude that the ESI estimates are theoretical maximums and not ratios that could be realized in the world with existing technologies and approaches to service delivery. Under current conditions we argue that the solutions evaluated by ESI suffer from poor adoption as well as poor operation and maintenance, which implies that the health and related water quality assumed by ESI could not be realized.

[3] An overview of the situation in five cities is provided by Norman and Parkinson (2011).

Indeed, the lack of progress in sanitation relative to water is what economists would call a "revealed preference" argument for this case. If the lost GDP estimated by ESI, and referenced above, were real, then this would be powerful evidence of "dollar bills left on the sidewalk." We do not believe that there are such unrealized gains simply available for the picking. Rather, key investments are needed to create services that people actually want to use, in the case of latrines in rural areas, and that actually result in health benefits, in the case of current non-networked urban sanitation. Adjusting for the implications of these investments for the benefit and cost estimates generated by ESI allows us to implement a straightforward illustrative calculation that we believe creates a powerful rationale for investment in the three sanitation interventions we propose in this paper. The Bill & Melinda Gates Foundation, following the analysis as presented in this paper, is investing on the order of one half a billion dollars in these three interventions in the period 2009-2015.

For completeness, we also consider a rural water supply intervention that could serve some large fraction of the 770 million people currently lacking access to safe drinking water (WHO and UNICEF, 2012). This is in fact the rural water intervention consisting of boreholes equipped with hand pumps, as analyzed by Whittington et al. (2008) for the last round of Copenhagen Consensus debate, contextualized by our interpretation of the data supporting alternative management models for this sort of infrastructure. We accept the conclusion of Whittington et al. that this intervention would have a modest, positive benefit cost ratio, but argue that it is likely to be lower than the 3.4 that is their preferred estimate, because the life of rural water infrastructure is often curtailed in practice.

The remainder of this document is organized as follows: Section 2 summarizes the conventional sanitation solutions that exist to potentially meet the sanitation challenges and provides the specification of a series of innovations that could increase the effectiveness of, or replace, existing solutions. Section 3 summarizes briefly the methodology used by the ESI and the results of that exercise. Section 4 builds on the previous information and presents our estimates of the benefit-cost ratio associated with tackling the sanitation challenge. In Section 5, we consider the rural water intervention. Section 6 concludes.

2 Sanitation solutions

2.1 Basic "improved" sanitation

Basic sanitation is the simplest form of sanitation, usually just a latrine that meets the minimum requirements to contain pathogens (such as a latrine cover to keep out flies), but often not pleasant to use. In low density rural areas, households are expected to have enough space to construct a basic latrine on their plot, at an adequate distance away from their living space and from their water source, and to rebuild a new latrine if the old one fills up. ESI analysis of basic latrines in rural areas in the Philippines and Vietnam shows economic returns as high as benefit-cost ratios of 5-8, with annualized costs per household as low as $20.

Smell and flies are key barriers to satisfaction with basic sanitation. There are many latrine designs that attempt to reduce smell and prevent flies from spreading disease through forms of ventilation and systems of double vaults or pits, allowing the waste in one pit to decompose while the other fills up.

Generally speaking, the cheapest and affordable forms of these that cost $30-$100 to construct tend to be quite unpleasant to use, and the more sophisticated double vault pour-flush latrines or septic tanks are quite expensive to construct ($500-$2,000) and need to be emptied periodically. People have a strong preference for at least a pour-flush latrine, a latrine with a smell-reducing water seal, where users flush urine and excrement with a small amount of water also used for personal hygiene.(Anal cleansing with water rather than paper is the norm in all of Asia and much of Africa.)

Ecological sanitation emphasizes the recycling potential of human waste, i.e., considering urine and feces as a resource than can be made safe to re-use, as an alternative to the emptying and disposal of pit contents or simply leaving full pits undisturbed. In principle, this could increase the benefits associated with rural sanitation. Urine contains significant amounts of nutrients that can be re-used as fertilizer (Esrey, 1998, Water and Sanitation Program, 2009). Feces has a high energy content that can potentially be recovered for use as fuel. Composting toilets use microbes to decompose human waste and generate compost, but simple models are not that easy to manage and do not effectively remove pathogens; sophisticated ones are not cheap. Biogas toilets also use microbes to decompose waste but capture the methane generated in the process for use as, for example, cooking gas. Some pathogens are particularly difficult to get rid of through these processes. It takes at least six months of composting to remove the large majority of helminth eggs, for example. Some pathogens survive for years in composting type toilets.

2.2 Sewered systems

The conventional solution, the gold standard, and for many governments still the only acceptable long-term solution to the sanitation challenge, is the flush toilet. A toilet is a water closet that is linked to a sewer network that transports human waste diluted in a large volume of clean water to a wastewater treatment plant where it takes considerable energy to remove the waste from that water. Using large volumes of water treated to drinking water quality to flush excrement down expensive pipes in order to spend more money to try to clean that water up again is not necessarily a smart idea anywhere. The ESI estimates the annualized cost per household for sewer networks with wastewater treatment alone for China, Indonesia, the Philippines and Vietnam to be $100-200. As mentioned before, the Copenhagen Consensus Challenge Paper authored by Whittington et al. (2008) estimated that the cost of conventional "modern" water <u>and</u> sanitation systems is on the order of $50-$100 per household per month.

Though we will not pursue this question further in this paper, we do note here that there is a potential middle ground between traditional sewerage and the non-networked solutions we discuss. Simplified or low-cost sewer systems, using shallow small-diameter pipes at low gradients at community level, are used in some areas, particularly in Brazil, and may be combined with small-scale decentralized wastewater treatment systems or constructed wetlands (Mara, 2008, Mara and Alabaster 2008). Particularly in areas with multi-level apartment blocks these systems may have an advantage over latrines but they have not been widely adopted. A challenge for a future paper might be to estimate carefully the potential market for this approach, barriers to adoption, and potential net benefits.

2.3 Fecal Sludge Management

In urban areas where latrine and septic tanks have to be emptied, and the fecal sludge has to be disposed off safely, its management is a challenge associated with on-site or non-sewered sanitation. In locations where there is a relatively active market for mechanized latrine emptying with vacuum trucks fecal sludge that is dumped safely is generally kept in large drying beds and left to decompose for at least six months (Klingel et al., 2002, Krekeler, 2008).[4] It is common practice, however, for the sludge trucks to dump their hazardous content directly into agricultural fields, rivers, or on beaches. Certainly, new solutions for fecal sludge management, whether it is technology or business and regulatory models that end such unsafe disposal, are required if hundreds of millions of people are going to be served by non-networked solutions and realize the gains of safe sanitation.

2.4 Innovative sanitation solutions

This paper proposes three novel sanitation solutions for consideration in the Copenhagen Consensus process as potentially worthy of large scale investment. The three novel sanitation solutions are:

1. Community Led Total Sanitation (CLTS++): various forms of an approach that emphasizes behavior change, particularly the community's responsibility to share in the creation of open defecation free communities, particularly in rural areas;
2. Sanitation as a Business: new approaches to on-site sanitation that combine technical innovation to empty latrines and process waste with innovative business or service models to create sustainable sanitation services, particularly in low-income urban areas; and
3. The Reinvented Toilet: efforts to stimulate technical innovation, particularly harnessing advances in physics, chemistry, and engineering, to create a radically reinvented toilet that recycles human waste into reusable products at the household scale.

Below, we describe these three solutions in some detail, before proceeding with their benefit-cost analysis. A separate section at the end of this paper includes information on a rural water intervention.

Community Led Total Sanitation (CLTS++)

Community Led Total Sanitation (CLTS) was developed by Kamal Kar, working with the Bangladeshi NGO, VERC and WaterAid, some ten years ago and has since spread very rapidly, both in its original form and through variations developed by a range of implementing organizations, usually under their own brand names, that collectively we will refer to as CLTS++.

Kar and Milward (2011) describe CLTS as follows:

> *"CLTS is an innovative approach for empowering communities to completely eliminate open defecation (OD). It focuses on igniting a change in collective sanitation behaviour, which is achieved through a process of collective local action stimulated by facilitators from within or outside the community. The process involves the whole community and emphasises the collective benefit from stopping OD, rather than focusing on individual behaviour or on constructing*

[4] Subject to the addition of appropriate amounts of water, sludge can also be introduced to the wastewater treatment system. This is generally how the waste from septic tanks owned by affluent households would be dealt with.

toilets. People decide together how they will create a clean and hygienic environment that benefits everyone. Certain features have been fundamental to the evolution of CLTS as an approach to sanitation issues. CLTS involves no individual household hardware subsidy and does not prescribe latrine models. Social solidarity, help and cooperation among the households in the community are a common and vital element in CLTS. Other important characteristics are: the spontaneous emergence of natural leaders (NLs) as a community proceeds towards open-defecation-free (ODF) status; local innovation in low-cost toilet models using locally available materials; and community-innovated systems of reward, penalty, spread and scaling up."

CLTS has been very successful in rapidly displacing the previous approach to sanitation of development organizations such as UNICEF, WaterAid, or Plan International (which mostly focused on latrine construction, often through hardware subsidies) and having spread from its original base in Bangladesh to over 40 countries by Kar's estimate (Kar and Milward, 2011), with at least five African countries adopting CLTS as the major approach to be used in their national sanitation strategies. UNICEF brands its approach as CATS (Community Approaches to Total Sanitation). The World Bank's Water and Sanitation Program (WSP) calls it TSSM (Total Sanitation and Sanitation Marketing) when combined with some additional supply side activities, but the core elements of CLTS are more or less common across these "branded" approaches.

The original CLTS approach as championed by Kar focuses purely on facilitating collective action to generate behavior change, assuming that community members have the wherewithal to construct simple latrines if they want to. The CLTS-variations used by large implementers such as UNICEF or the government of Indonesia tend to combine the behavior change elements to stimulate demand with efforts to improve the supply side as well. On the supply side that usually involves at least training local masons to become sanitation entrepreneurs, offering to construct latrines, and in other cases the development of a network of sanitation shops. We refer to CLTS++ as the intervention we are considering to indicate the collective of CLTS and its variations and derivatives implemented by a range of agencies and actors.

Impressively, CLTS++ programs have reached at least tens of millions of users and are expanding rapidly. Although not all communities in these programs become Open Defecation Free (ODF), assessments show that for some CLTS programs some 25-40% of communities do attain ODF status (Otieno et al., 2011) while other programs achieve 30-80% ODF communities within 3-6 months which is a much higher success rate than previous sanitation programs (focusing on simple subsidies in the form of hardware handouts as a means of achieving rapid coverage). CLTS++ is not without its challenges either, particularly:

- because the latrines constructed through CLTS tend to be of the simplest, sometimes rudimentary, form, user satisfaction tends to be quite low and there is a significant risk of re-lapse to open defecation;
- because proper latrine construction does require quite a significant investment by the household, the poorest households in the community are the hardest to reach, particularly without any subsidy (which some CLTS++ programs do in fact employ). This makes achieving open defecation free communities a challenge, even when significant construction may be observed, unless targeted subsidies are included in the program;

- rigorous health impact data of improved sanitation through CLTS++ are still elusive[5] – at least in part because of a lack of an evaluation culture with the implementing organizations, but also likely a result of the limited achievement of ODF status in practice; and
- the cost of CLTS++ delivery programs varies from $3-25 per person, which means that while $3 likely yields an attractive BC ratio and is possibly low enough to enable large scale roll-out, $25 probably is not.

The CLTS++ intervention proposed for Copenhagen Consensus consideration is a large-scale program, reaching at least hundreds of thousands of people at a one-off delivery cost of $5 per person affected, i.e. a person gaining access to ODF community status, and resulting in the benefits associated with rural sanitation as estimated by the ESI.

Targeted subsidies for the poor can be accommodated at the delivery cost of $5 per person, which we believe is important for achieving sustained ODF status and realizing associated health gains. When subsidies can be accommodated, the hardware costs can be relatively higher, raising also the total cost of the intervention. Concerns about sustainability with CLTS when implemented as a strictly behavior change intervention motivate this element of the proposal.

Given the rapid adoption of CLTS++ at a scale of tens of millions of people over the last ten years, and the relatively high rate of success this has in achieving open defecation free communities, we would consider this to be a comparatively low-risk intervention. Many development organizations and a first cohort of developing country governments have adopted CLTS++ as best practice for rural sanitation. The Gates Foundation, for example, has committed about $100M in grant funding to support CLTS++ programs that aim to achieve open defecation free communities for an additional 20-30 million people over the coming 3-5 years.

Why are we still proposing CLTS++ as an intervention for the Copenhagen Consensus project, if it is being implemented and adopted quickly and successfully, you might ask. The primary reason is that while this is a proven solution with an attractive, though modest, BC ratio, as we will show hereafter, the observed levels of investment are inadequate to achieve acceptable coverage, as shown by the latest assessment of progress on safe drinking water and sanitation services just released by WHO and UNICEF in early March 2012. Development agencies (over-)emphasize safe water projects and under-invest in sanitation. In addition, the lion's share of sanitation investments is still focused on sewer networks and wastewater treatment plants that are largely irrelevant for the low income part of the population. The sanitation policy of many developing country governments is still exclusively focused on sanitation through sewer systems. Both lending agencies and developing country governments tend to focus investment programs on "hardware", or infrastructure, at the expense of soft measures such as

[5] A single recent exception is a randomized-controlled trial of a community-lead total sanitation campaign in 40 villages in Orissa, India. Dickinson et al. (2009) find that the campaign increased child mid-upper arm circumference (MUAC) z-scores by roughly 0.25 standard deviations. The study did not have sufficient power to detect effects on diarrheal disease in children.

behavior change or demand creation programs. In short, we are proposing this first intervention primarily as a call to increase investment levels in this relatively new, but tested, solution.

Sanitation as a Business

As previously described, a critical bottleneck for the existing over two billion latrines and septic tanks in developing countries, affecting particularly the urban poor, is that there are no affordable and sustainable services to effectively and efficiently empty them and process the fecal sludge safely and economically.

While governments tend to consider the supply of drinking water or the construction of sewer networks a public responsibility, servicing latrines and septic tanks, e.g., by having a municipal service similar to garbage collection, is not common. There are exceptions; effective government-run emptying services were organized nation-wide in Malaysia before the sewer network was constructed. The city of Addis Ababa, capital of Ethiopia, runs a fleet of over 60 vacuum trucks that empty latrines and septic tanks at a subsidized rate of $10. More common is a situation like that in Dakar, Senegal, where the government has a few vacuum trucks, but the majority of the service is provided by a fleet of over 100 trucks operated by private businesses, in addition to many individual entrepreneurs who supply manual emptying services. Households that contract with a private emptier using a vacuum truck pay $50-100 for the service. Many of these are owner-operator single truck businesses that are only profitable by combining latrine emptying with other seasonal use of their trucks.

Based on a study we undertook in 2011 of the emptying business in 30 cities in ten countries in Africa and Asia (Bill & Melinda Gates Foundation, 2011) we estimate that some 200 million latrines are emptied manually, by workers descending into the pit with a bucket and shovel. The city of Durban, South Africa, is the only place we know that runs a municipal service to empty some 35,000 ventilated improved pit (VIP) latrines manually (but with workers properly protected) at the city's expense.

Urban sanitation is also provided at communal and public toilet "blocks." A well-known organization to provide sanitation services through this model is Sulabh International in India. Sulabh's founder Bindeshwar Pathak developed a two-pit pour-flush latrine to avoid manual emptying (or scavenging as it is called in India – which is traditionally the work of the lowest caste, now formally illegal but not rooted out) in 1970. Sulabh, the story of which is ably told by George (2008) operates 6000 communal toilet blocks that serve an estimated 10 million users on a pay-per-use basis, providing caretaker employment to former scavengers. There are other international NGOs and some (social) enterprises that provide mobile or community toilets on a (semi-)commercial basis, but other than Sulabh none of these operate at scale.

The sanitation as a business Intervention proposed for the Copenhagen Consensus is a sanitation service provided by a sanitation entrepreneur at a cost of no more than $10 per household per year and that consists of emptying the latrine or septic tank, transporting the fecal sludge to a treatment plant, and treating it to acceptable levels prior to reuse and/or dispersal into the environment. The investment proposed will take the following innovations from early stage development to demonstrated scale:

- effective communal toilets: on a pay-per-use basis where high density prevents household or shared toilets – similar to the Sulabh model;
- scheduled desludging: (re-)organization of the latrine emptying market by municipal governments to enable households to pay an emptying fee as part of their water bill (same as the sewer charge often levied now, even to households not connected to a sewer system) and contracting out regular desludging to municipal services or the private sector;
- privately managed fecal sludge plants: outsourcing management of fecal sludge treatment plants to the private sector to reduce illegal dumping and manage the treatment plants as a business, maximizing revenue from recycled products such as compost;
- innovation in latrine emptying technology: dedicated mechanized emptying technology that empties latrines effectively and affordably under developing world urban slum conditions; and
- Innovation in fecal sludge treatment technology: small scale neighborhood fecal sludge processing plants that generate biogas, biochar, biodiesel, fertilizer and/or compost while safely removing all pathogens in small footprint plants.

While most of these elements have been, or are being, developed and tested individually in a variety of locations, with support from the Bill & Melinda Gates Foundation they are put together and tested at scale in Dakar, Senegal, at the scale of one million people over the next five years. Further development and testing for some 10 million people is proposed for consideration here.

The Reinvented Toilet

Using biological processes to decompose human and animal waste into manure or night soil has been common practice for thousands of years. This is in essence the technology used for composting toilets. "Modern" networked sanitation systems based on sewers have been around for several hundred years. Real investment in innovation over the last several decades has focused almost exclusively on improvement of waste water treatment – removing nutrients to prevent surface water pollution such as algae blooms in lakes, and recovery of energy from sewage sludge most recently. The innovations developed for processing or recycling other waste streams, such as gasification, have not yet been applied to human waste.

Early in 2011 the Bill & Melinda Gates Foundation challenged over 20 top universities around the globe to use modern science and engineering to come up with a radically different form of processing and recycling human waste that does not depend on sewers networks and large volumes of water for transportation (Nash, 2012). The challenge was to develop a system that is: off the grid, affordable for the poorest members in society (less than $0.05/day), and an aspirational product – something everyone will want to use and that over time replaces the flush toilet as the new gold standard. The foundation has awarded eight "Reinvent the Toilet Challenge" grants and funded another 57 small grants in 2011 that all aim to innovate all or part of the non-sewered value chain – from pyrolysis, gasification, hydrothermal carbonation, smoldering and thermo-mechanical treatment processes to microbial fuel cells to nano-technology based coatings that would make toilet bowls super-hydrophobic and/or self-disinfecting.

The "reinvented toilet" must overcome at least three principal challenges:

- At its heart it must use one or more processes to dry and heat human waste to safely remove pathogens and recover energy and nutrients in a manner that enables the process to be self-sufficient (carefully managing the energy balance).
- It must miniaturize and automate these processes in a household scale unit that is robust, safe, fool-proof and affordable.
- It must have a user-interface that people love to use and that supports a wide range of cultures and customs from sitters to squatters and washers to wipers.

All complete reinvented toilets are currently at the laboratory / proof-of-concept to prototype stage and therefore investments in the development of this solution are high risk. The foundation expects to review the first series of prototypes and proof-of-concept results for parts and processes in August 2012. Presuming a reinvented toilet can be successfully developed, and can become an aspirational product – the smartphone of sanitation – the issues of high cost, slow adoption and limited benefits that variously plague the current generation of sanitation technologies will be overcome.

The reinvented toilet proposed for the Copenhagen Consensus as the third sanitation intervention is a household-scale unit that costs less than $0.05 per person per day and that completely and safely recycles the human waste stream into reusable products or harmless emissions into the atmosphere; an aspirational product that becomes the new gold standard for sanitation.

Rural water services

As a fourth intervention we propose for consideration a standard rural water supply scheme consisting of borehole wells equipped with handpumps, as described by Whittington et al. (2008).

It would also be possible to combine CLTS++ with a water and handwashing or hygiene program to realize the gains of an integrated intervention. However, a paucity of convincing data on the benefits of combined interventions inhibits us from considering seriously an integrated intervention. The WASHBenefits project, ongoing research by the Bill & Melinda Gates Foundation grantee University of California, Berkeley, with fieldwork in Bangladesh and Kenya, seeks to address this gap in the epidemiology literature.

3 Overview of WSP Economics of Sanitation Initiative Cost Benefit Analysis

WSP's ESI is the most comprehensive effort to date to assess fully the burden associated with inadequate sanitation using secondary data. For 11 African countries and nine Asian countries[6], the studies published from 2008-2011 consider health, water, tourism, and other welfare impacts of sanitation. In a follow-up phase published in August 2011 ESI has estimated the economic returns to sanitation interventions in Cambodia, China, Indonesia, LAO PDR, Philippines, and Vietnam. They summarize data on costs of infrastructure from actual investments observed in country.

[6] Africa: Benin, Burkina Faso, DRC, Ghana, Kenya, Madagascar, Mozambique, Niger, Nigeria, Rwanda, Tanzania. Asia: Bangladesh, Cambodia, China, India, Indonesia, Lao PDR, Pakistan, Philippines, Vietnam. With more studies underway in Latin America and the Caribbean.

Benefits
The methodology adopted by ESI's studies of the economic impacts of sanitation, such as in India (Anupam, 2010) included disaggregating the economic impacts of inadequate sanitation into the following categories:

1. Health-related impacts: Premature deaths, costs of treating diseases; productive time lost due to people falling ill, and time lost by caregivers who look after them.
2. Domestic water-related impacts: Household treatment of water; use of bottled water; a portion of costs of obtaining piped water; and time costs of fetching cleaner water from a distance.
3. Access time impacts: Cost of additional time spent for accessing shared toilets or open defecation sites; absence of children (mainly girls) from school and women from their workplaces.
4. Tourism impacts: Potential loss of tourism revenues and economic impacts of gastrointestinal illnesses among foreign tourists.

Table 1 below summarizes the breakdown of benefits between health, water quality, "other welfare" (e.g., time savings and amenity benefits), and tourism, as reported by ESI for several countries. For most countries, the health and water benefits are the greatest fraction of total benefits, between some 70 and 90 percent.

Table 1: ESI estimates of economic impacts of poor sanitation

Country and Impacts	**Economic Losses**	
	US$ million	**%**
Cambodia	**448.0**	**100.0%**
Health	187.1	41.8%
Water	149.0	33.3%
Other welfare	38.2	8.5%
Tourism	73.7	16.5%
Indonesia	**6,344.0**	**100.0%**
Health	3,350.0	52.8%
Water	1,512.0	23.8%
Environment	96.0	1.5%
Other welfare	1,220.0	19.2%
Tourism	166.0	2.6%
Philippines	**1,412.1**	**100.0%**
Health	1,011.1	71.6%
Water	323.3	22.9%
Other Welfare	37.6	2.7%
Tourism	40.1	2.8%
Vietnam	**780.1**	**100.0%**
Health	262.4	33.6%
Water	287.3	36.8%
Environment	118.9	15.2%

Other Welfare	42.9	5.5%
Tourism	68.6	8.8%
TOTAL	**8,984.2**	**100.0%**

According to Anupam (2010), national data on incidence or actual numbers for the indicators in the above sub-categories (for example, diarrheal diseases, deaths, and so on) were compiled from secondary data sources (National Family Health Survey 2005-06, WHO Demographic and Health Surveys, National Sample Surveys, Census of India). Based on the review of scientific literature, attribution factors were used to estimate the populations impacted by inadequate sanitation and, finally, the economic valuation was carried out using costs/prices based on other secondary studies. ESI states that conservative assumptions have been used in economic valuation (e.g. a discount rate of 8% and a benefit stream capped at 20 years) and the analysis has been done for 2006 for want of comprehensive data for later years.

Health impacts are the most important drivers of costs attributed to inadequate sanitation, and thus uncertainty in this data is an important limitation for the work. This is distinct from the usual controversy associated with monetization of health benefits. For that element of the calculation, ESI take a conservative tack, using the human capital approach to monetize the costs of pre-mature death. The health gains are a reduction of 36% for fecal-oral diseases for basic sanitation and 56% for advanced systems. These are based on meta-analyses of sanitation interventions, referenced in the reports. A key issue for assessing whether the ESI numbers can be relied upon then for *ex ante* investment planning is the extent to which the interventions in these evaluations compare with the actual reality cities and the extent to which these analyses accurately capture the causal impacts of sanitation on health.

The Bill & Melinda Gates Foundation is supporting additional research on the benefits of sanitation that could be used to refine cost-benefit analyses three-five years from now. In particular, we are making significant investments in randomized controlled trials in three sites (Kenya, Zimbabwe, and Bangladesh) to assess the “environmental enteropathy” hypothesis.

Recently, nutritionists have hypothesized that reducing a child’s fecal bacteria exposure during the first years of life through improved sanitation (and/or handwashing or water treatment) may improve gut function (the ability of the gastro-intestinal tract to absorb nutrients) and subsequent growth (Humphrey 2009). The prenatal period and the first two years of life are a critical window for intervention in growth and development: infection and poor nutrition during this window can negatively impact an individual’s long-term cognitive development and lifetime physiologic trajectory. Yet, a systematic review of the impacts of complementary feeding and supplementation interventions reports that even the most successful of these interventions cannot eliminate the mean growth deficit for African and Southeast Asian populations. The hypothesis is that nutritional supplementation appears to be necessary but not sufficient to eliminate growth shortfalls because chronic infection and colonization of the gut by fecal bacteria, spread via poor WS&H conditions, impedes nutrient absorption and creates low-level immune system stimulation, a condition called environmental enteropathy.

If the environmental enteropathy hypothesis were to be correct, this would significantly alter our understanding of the health benefits associated with sanitation, and increase the estimated cost-effectiveness of these interventions. The change would likely be very large, because of the life-time gains associated with better nutrition in early childhood. Center for Diarrheal Disease Research, Bangladesh) that is the first empirical evidence consistent with the environmental enteropathy hypothesis (Personal communication, Dr. Stephen Luby, August 2011). UC Berkeley and ICDDR,B show that there are meaningful differences between Bangladeshi children in terms of enteropathy symptoms and stunting depending on their water, sanitation, and hygiene conditions in the home, even after controlling for sex, age, and socio-economic status. This is suggestive evidence that sanitation may be much more cost-effective as a public health intervention than previously supposed.

Consequences of the environmental enteropathy hypothesis may have implications beyond the sanitation and water sector, including the following:

- Reduced gut function may reduce the effectiveness of oral vaccines (e.g., for polio or rotavirus).
- Because reduced gut function reduces nutritional absorptive capacity – an effective nutrition strategy may then require joint action from agriculture, health and sanitation/water perspectives.

The inclusion of the costs associated with environmental enteropathy could affect the benefit-cost ratios calculated in the ESI, in the sense that it would significantly increase the benefits associated with sanitation measures.

Costs

ESI has estimated investment and annualized costs – including investment, operation and maintenance - per household for a range of sanitation interventions in three rural and three urban sites in six South-East Asian countries. The lowest total cost interventions are dry or wet pit latrines in rural or urban areas and shared or community toilets in urban areas with annualized cost per household ranging from US$20-50. The highest total cost interventions are sewerage systems with treatment at an annualized cost per household of US$100-200. With the cost of septic tanks ranging from low, approaching that of latrines (in some countries, without treatment) to high, approaching that of sewerage (in some countries, with treatment).

Table 2 below summarizes the cost estimates in the ESI for Indonesia as illustrative data. We will use these cost numbers for Indonesia as starting points for our analysis in this paper. Note that we argue that the simple pit latrines do not provide sufficient aesthetic benefits to ensure sustained use and that rural sanitation interventions must provide “wet pit” service, with targeted subsidies for the poor. Based on our experience at the Gates Foundation, programming costs on the order of $5 per person can sustain such interventions.

Table 2: ESI estimates of average investment cost by household for various sanitation technologies, Indonesia

Country	Dry pit	Wet pit	Septic tank	Sewerage with treatment
Indonesia- rural	27	32	82	
Indonesia- urban		37	70	317

Benefit Cost Ratios

ESI concludes that basic sanitation, dry or wet latrines and shared or community toilets, have the highest economic return per dollar invested, or benefit cost ratio, of at least 3 in Cambodia and urban sites in Indonesia and as high as 5-8 for rural and urban sites in the Philippines and Yunnan Province of China as well as rural sites in Indonesia. Sewers and septic tanks also have a positive, but lower BCR of around 2.

In our view, the key reasons these ESI BCR estimates are theoretical maxima rather than realistic estimates in practice[7], particularly for the lower cost basic sanitation interventions, are:

- Low adoption rates: even though all interventions as described have been available for many years; even if donor agencies or governments heavily subsidize the construction of latrines, or provide hardware free of charge, sustained use and effective operation and maintenance has time and again been lacking (Jenkins and Sugden 2006). CLTS that results in very low quality initial investments is also vulnerable to low adoption over the longer run, as the amenity value of the most basic forms of sanitation is so low.
- Reintroduction of fecal matter into the environment: when even a small share of all latrines is emptied manually and their content is dumped nearby in the environment, as we estimate to be the practice for some 200 million latrines in urban areas, then the assumed health gains from the meta analyses cited by ESI will not be realized.

Thus, our approach is to propose means by which these barriers to realizing the ESI benefits can be overcome, illustrate the cost of overcoming those barriers, and revise the relevant BCR calculations. When we argue that health benefits cannot be realized without innovation, as we do in the case of urban sanitation, we ascribe all health and water quality benefits estimated by ESI to the innovation investment. While this might be an over-estimate, if there are indeed some health benefits associated with the broken service chain we described earlier that are different from true open defecation, the excess burden of fecal-oral diseases associated with living in urban areas as opposed to rural one has been well documented using data such as helminth loads in children (e.g., Penrose et al. 2010, Garenne 2010, WHO, 2010), and as such this seems a reasonable approximation to make.

[7] Another technical issue is that the ESI model uses a discount rate of 8%, rather than the Copenhagen Concensus preferred rate of 3-5%. At a lower discount rate, BCR ratios would be modestly higher than those discussed here.

4 Benefit Cost Analysis of Our Proposed Three Sanitation Interventions

For our analysis of the economic returns to the three sanitation interventions we propose we use the cost and benefit estimates developed by ESI as the basis, but we propose additional innovations to realize, and improve on, the benefits as calculated by ESI as explained hereafter.

CLTS++

For sanitation in rural areas we propose CLTS++. The primary impact of CLTS++ as an intervention is that governments or another (development) agency implement a program that creates demand for latrines at the community level, combined with a form of social pressure to motivate late adopters , in order to achieve Open Defecation Free (ODF) communities. In terms of our economic analysis it is a one-off additional cost of about $5/person, or $25/household, or an annualized cost of about $6 per household for an assumed wet pit latrine life of 10 years and a discount rate of 8% – added to the latrine construction, operation and maintenance as estimated by ESI for wet pits – to be able to realize the benefits estimated by ESI.

That increases the ESI estimated annualized cost of the wet pit latrine from $32 to $38 per household, and with the same benefits as estimated by ESI, that reduces the BCR from a range of 5-8 to a range of 4-7. We do not believe that lower cost dry pit latrines provide sufficient amenity benefits as to be a sustainable intervention.

The attraction of CLTS++ for investors is that it has shown, in a relatively short period of time since its first development in 2000, to spread and raise adoption, while not to 100% then at least to much more respectable rates than anything that came before. As documented by Kar and Milward, this intervention that was developed in Asia has rapidly spread across Asia, and has become introduced in some 40 African countries and adopted as the national approach by at least 5. It has become the approach of choice of the key implementing international organizations such as UNICEF, WaterAid, Plan and WorldVision in a more or less modified form. Based on assessments of the experience with CLTS in Bangladesh over about ten years (Hanchett et al. 2011) and our experience with a range of implementing organizations, as contained in about ten current contracts (grant agreements negotiated in 2010-2012) we estimate that the Bill & Melinda Gates Foundation investment of US$100M will increase the number of people living in Open Defecation Free communities by about 23 million (an estimated adoption rate of about 50%).

Extrapolating that experience implies that of the total population in rural areas that does not have access to improved (basic) sanitation of 1.2 billion, about 50%, or 600 million people could be reached by an investment of US$3 billion, at a Benefit Cost Ratio of 4-7. Note that these numbers are modestly higher than those reported by Whittington et al. in 2008. Our assessment is that this is due to the updated information available from ESI on actual latrine costs and non-health benefits.

As stated earlier, given that this intervention has been tried and tested at a scale of tens of millions of people in Asia and Africa, we consider this a low-risk, proven intervention.

Sanitation as a Business

For urban areas we assume that latrines can be constructed with costs as assessed by ESI, and that these are either private, shared, or community toilets. We will use the ESI cost estimate for the annualized total cost (investment, operation and maintenance) for a wet pit latrine in an urban area of US$37, with a BCR of 3.2 (We use the ESI BCR figures for Indonesia in these calculations). In reality, as we have argued above, such latrines are often emptied by hand, thus, these costs understate what would be necessary expenditure for full health benefits to be achieved. Currently the annual cost of mechanical emptying with a vacuum truck is US$35-91 (Bill & Melinda Gates Foundation, 2011), which reduces the BCR to about 1 if we redo this calculation assuming an annualized total cost of $37 + $60.

Of course, even if a latrine is emptied by truck, the fecal sludge is often dumped illegally, or discharged at a waste water treatment plant where treatment incurs additional costs. The primary intervention we see as a necessary addition to realize the benefits estimated by ESI is an affordable and effective way to collect and treat the waste – in essence the equivalent of the sewer and treatment plant for a non-networked system. This is the package of institutional and technological innovations described in section 2 above that we collectively refer to as "Sanitation as a Business".

Our assumptions for this intervention are that it is feasible to invest in innovation to achieve the following:

- The current costs of mechanical emptying (with existing technology) are on the order of $35-$91 per household in the ten countries studied in Africa and Asia (BMGF, 2011). Based on the design of the project we are funding to put in place, for a million people in a low-income part of Dakar, Senegal, a scheduled desludging service, funded on a subscription basis, and outsourced to the private sector through an auction, we estimate that these costs can be brought down to $20 as a result of a more efficient market and more efficient desludging operations.
- We then assume that the cost of mechanical emptying can be brought down further to $10 through improved emptying technology that is currently in the design stage (an ongoing project with prototypes expected to be field tested in 2013). This new emptying technology, replacing the vacuum truck, would also be able to reach 100% of low income urban neighborhoods, including those with streets to narrow for regular trucks. Based on the experience in Addis Ababa, where a government subsidized mechanical emptying rate of $10 fully displaced manual emptying, we assume that at this rate we can achieve full mechanical emptying coverage in low income urban areas.
- We finally assume that neighborhood scale fecal sludge treatment units can be developed that are cost neutral, i.e. where the value of the materials recovered from the sludge is at least equal to the cost of processing. We think this can be achieved based on improvements to technology that is currently used to process fecal sludge in Durban (a thermo-mechanical process; the LaDePa sludge pelletizer), or forms of pyrolizers that are currently used to process wood chips and animal waste.

This Sanitation as a Business intervention is clearly more high risk than the CLTS++ intervention, as several of its elements still have to be developed (such as the improved emptying technology), and the full package of elements still has to be demonstrated to be effective at scale. On the other hand, based on a study that we have commissioned,(BMGF 2011) we think that the investment risks associated with this intervention are limited and reasonable because of the evidence that elements of the package have been tried and tested as follows:

- Scheduled latrine desludging, funded through a subscription service, is rare but has been rolled out effectively at national scale in Malaysia .
- We have invested in a project to transform the latrine emptying market in Dakar, Senegal, for a million people and understand what it costs to implement this innovation.
- Subsidized mechanical latrine emptying at a $10 price point has been shown to effectively displace manual emptying in Addis Ababa, the capital of Ethiopia, a low-income city.
- Cost-neutral fecal sludge processing units at neighborhood scale do not yet exist, but a working “prototype” of such a fecal sludge processor (that does not yet recover its full cost) exists in Durban, the LaDePa Pelletizer, and won an IWA Global Project Innovation Award (IWA, 2011) . Pyrolizer units that produce biochar from woodchips and animal waste are available in the market (e.g. from Re:Char) but not yet for human waste. We have invested in several projects to develop such fecal sludge processor units and have a fair understanding of the cost of this innovation.
- The most risky element of this package is the latrine emptying technology, which does not yet exist. We have, however, invested in several projects to develop this technology and consider it a project development integration challenge, rather than research or lab stage. These projects have Critical Design Reviews in April this year and are on track to field test prototypes in 2013.

We estimate the total investment cost to develop the latrine emptying and waste processing technology into commercial products and to develop and test the institutional innovations at a scale of a million people at US$100-120M; an investment that is part of the sanitation strategy of the foundation. In addition, to help develop and catalyze a market for Sanitation as a Business at scale, we assume it will be necessary to subsidize introduction of these urban sanitation services at US$10 per household for the first 10 million latrines, or households. If we assume a subsidy level of 25% borne by the public budget (with the remainder covered by households) of the sanitation service cost for ten million households for ten years (the life of the latrine) then the NPV of this investment at 5% is US$200 million.

We assume that this investment in both the innovation itself (US$120M) and market development (US$200M) would result in adoption of these sanitation services for 20%, or 40 million, of the urban latrines that are currently emptied manually. Assuming that 80% of ESI estimated benefits would be realized as a result of the sanitation as a business innovation, as this is about the fraction of benefits associated with health and water quality (see table 1), we then calculate a BCR of 46 for this Sanitation as a Business intervention of US$320M, improving sanitation service for 200M people in low income urban areas. Table 3 below lays out the detail of this calculation.

Table 3: Calculation of BCR for Sanitation as a business

	Parameter	Value	Notes
(1)	ESI estimate of cost of wet pit latrine	$37/year/hh	
(2)	ESI BCR	3.2	
(3)	Cost of unsafe disposal as currently practiced	$60/year/hh	Source: BMGF 2011
(4)	Cost of safe disposal that could displace manual emptying	$10/year/hh	Source: BMGF 2011; this price in Addis Ababa has ended manual emptying there
(5)	NPV of displacing cost	$77	Ten year life span; interest rate of 5%
(6)	Illustrative investment in innovation to achieve manual emptying displacement	$120 million	BMGF allocated budget (2010-15)
(7)	Cost to demonstrate technology for 10 million people	$772 million	
(8)	Fraction of cost to be borne by donors/government	25%	Based on BMGF grants in this sector made in 2011
(9)	Present value of costs to public budget	$120 million	Ten year life span; interest rate of 5%
(10)	Pits moved to safe service with technology that displaces manual emptying	40 million	20% adoption rate
(11)	Associated people served	200 million	At hh size of 5
(12)	Annualized marginal net benefits health and water quality	$1.9 billion	80% of total benefits – see table 2
(13)	Present value of marginal net benefits	$14.7 billion	Ten year life span; interest rate of 5%
(14)	Associated BCR- PV marginal net benefits/PV of cost to public budget (line 9)	47	

The highest risk element of the package is the technological innovation related to latrine emptying (as it does not yet exist). We assess the technical risk related to cost-neutral processing of the waste as "medium" given the extensive experience with biogas installations in China and the current use of a city-scale waste processor (the LaDePa pelletizer) in Durban. Therefore, the maximum impact of this risk on the BCR occurs if this targeted technology improvement fails to bring the annualized latrine emptying and processing cost down from $20 per household to $10 per household. In this case, assuming the investments are made but the cost reduction is limited to $20, we calculate a reduction in BCR from 47 to 23.

Given that this intervention is an investment in innovation, albeit an investment in product and institutional development rather than research, and that we have evidence of the feasibility for some of the key elements of the innovation package, we consider this a medium-risk intervention.

Reinvented Toilet

Even though we can reach large numbers of people with the two interventions described above, they would not reach everyone[8] and would still provide a service with pit latrines that people rate considerably below the unaffordable but gold-standard flush toilet. The Reinvented Toilet we have described in section 2 would, by definition if successful, provide affordable new-gold-standard service. The risk for this intervention is whether it is possible to develop such a Reinvented Toilet that meets the specifications we outlined above. As this is essentially an investment in research, i.e. in upstream innovation, it is clearly high risk. If it proves possible to develop such a new aspirational product that provides excellent service at an affordable price, then we can assume that it would enjoy rapid and widespread adoption. For these reasons we have referred to the Reinvented Toilet as the cellphone of sanitation.

The specification for the developers of the Reinvented Toilet is that it cannot cost more than $0.05 per person per day, or $90 per household per year. Using the same benefits for a wet latrine in an urban setting as estimated by ESI of $115 (a lower boundary given the much better service a Reinvented Toilet would provide), the annual net benefits per Reinvented Toilet would be $25.

We estimate the investment cost of the innovation program (research through product development) to bring one or more models of the Reinvented Toilet to market at $50M. This investment is part of the BMGF sanitation strategy. We assume that to gain traction in the market the Reinvented Toilet would have to be marketed (or the market would need to be developed through subsidies, or through partnerships with manufacturers to bring costs down, or via advance market commitments similar to those used to develop the market for vaccines). While clearly we cannot provide a careful estimate of the marketing or market development costs required at this stage, we use an order of magnitude of 25% of the cost of the Reinvented Toilet for one million households / toilets for three years, which is an estimated $75M. This brings the total required investment in the Reinvented Toilet to $125M.

If we assume that this investment would lead to 100% coverage for all latrines currently emptied manually, and allocate the net benefits this generates to this $125M investment, then this would have a BCR of 40, for an investment of $125M, serving one billion people. In addition, if successful, the Reinvented Toilet would serve many more people of the other 3.5 billion people who currently don't have access to a flush toilet, and indeed, over time would replace the flush toilet itself.

Of course, given that this intervention is an investment in an upstream innovation, a product that is currently under development in the laboratory at the proof-of-concept to prototype stage, we consider this a high-risk intervention.

5 Rural Water Services

In this section we consider a rural water intervention. In rural settings, the technologies for bringing safe drinking water to people are well known, similar to the situation in sanitation. The challenges are ones

[8] We have assumed 50% coverage with basic sanitation services for the currently unserved in rural areas and 20% coverage with safe sanitation services in low income urban areas currently emptied manually.

of sustainability, largely. A rural water intervention like that described here would target the 770 million people in Africa and Asia that currently do not have access to safe water.

To contextualize and value an integrated water intervention, we continue to take the approach used through this paper and build on excellent work done by others. We are fortunate that in the 2008 Copenhagen Consensus, Whittington et al. (2008) did extensive simulation work to estimate the net benefits of improved rural water service. We reproduce in summary form here that evidence and place this work in context as we did as Perspective Paper authors in 2008.

Whittington et al. found that there were modest positive net benefits associated with rural water service from new borehole wells, with benefits that would be greatest in places where the burden of diarrhea is relatively high and existing water facilities are sparse. Of course, as they point out, such settings may also be those where capital costs are highest, which increases costs as well. The estimated BCR using a base case set of assumptions about an illustrative investment is 3.4. This is close to our estimate of the BCR for the rural sanitation intervention we consider. Below, we sketch out how Whittington et al. arrived at the BCR estimate.

To estimate the economic costs of the installation of a borehole and a public hand pump, Whittington et al. use a capital cost estimate of US$6,500 (range US$5,000–$8,000). Program overhead that includes capacity-building and "software" costs for a large national rural water supply program is estimated at US$3,500 (range US$2,000–$5,000), for a project total of US$10,000. The capital costs are annualized assuming a capital recovery factor of 0.093 (interest rate of 4.5% and assuming a life of the infrastructure of 15 years) which implies annual capital costs of $930. Recurrent expenditures of about $100 per year are also assumed. Using an approach that we critiqued in 2008, and which we say more about below, Whittington et al. estimated the labor costs of maintenance at $500 per year, assuming that these costs are implicitly incurred by a well-functioning village water committee in a demand-driven, participatory model. We will come back to this question, but for now accept the estimate for a total annual cost of US$1530, or about US$128 per month.

The total monthly costs must be divided among the users of a borehole, which of course varies widely in practice. In a reasonable assumption, Whittington et al. take as a base case a well used by 60 households. Assuming a family size of five people, the monthly cost per household comes to about US$2.13.

The economic benefits of the borehole and public hand pump described by Whittington et al. come from the value of time savings and the monetary value of health benefits. There are other, smaller benefits from "lifestyle and aesthetic" benefits that are not directly related to health, in theory, but in practice these are very small. The value of time savings depends critically on the wage rate and the assumed opportunity cost of time.

To illustrate the magnitude of the benefits associated with time savings, Whittington et al. begin from an assumption that a new borehole might afford the typical family with two cubic meters of water per month. The monthly time savings for collection of two cubic meters of water would be about 70 hours.

For purposes of illustration, benefit calculations are made assuming that the local wage for unskilled labor in this rural community is $1.25 per day (US$0.16 per hour) and that the value of the time savings from the new water system is 30% of this market wage. The value of aesthetic benefits is also assumed to be linked to the wage rate, and is estimated as 25% of the value of the time savings described above. To avoid double counting benefits that are actually related to health, these are further downward corrected, by 25%.

To calculate the monetary value of health benefits, the authors assume that the intervention reduces the case fatality rate of diarrhea by 30% to 25/10,000. Assuming a base case of the value of a statistical life of $30,000, the resulting value of the risk reduction due to the water supply intervention would then be US$33 per year, or about US$2.7 per household per month. In addition to the mortality benefits, individuals would also receive the economic benefits of not suffering from nonfatal episodes of diarrhea. To estimate these benefits, the authors assume the cost of illness for a case of diarrhea is US$6 (range US$2–$10). The US$8.10 cost savings per year from the implementation of the water supply intervention would come to about US$0.68 per month.

Table 4 below summarizes the data used to calculate the net benefits of the rural water intervention and the steps taken to arrive at a preferred estimate of 3.4 for a BCR. As with the work done by WSP for sanitation, the care and thought put into this exercise is exemplary.

Table 4: Base Case Results Borehole and Public Hand Pump Intervention evaluated by Whittington et al. (2008) [a]

	Before hand pump + borehole intervention	After hand pump + borehole intervention	Change in physical units	Change in monetary units by discount rate		
Benefits				3%	4.5%	6%
Time spent collecting initial quantity of water (hrs per hh-month) [Value of time savings]	100	30	70	$3.28	$3.28	$3.28
Water use (L per hh-month) [Value of aesthetic and lifestyle benefits from increased water use]	2,000	3,750	1,750	$0.54	$0.54	$0.54
Number of nonfatal cases of diarrhea (per hh-month) [Value of reduction in morbidity]	0.38	0.26	(0.11)	$0.68	$0.68	$0.68
Risk of death from all diarrhea (per 1000 hh-month) [Value of reduction in mortality]	0.30	0.21	(0.09)	$2.70	$2.70	$2.70
Total benefits				$7.19	$7.19	$7.19

Costs						
Expenditures by all parties for new water system (per hh-month)				($2.00)	($2.13)	($2.26)
Benefit–Cost Ratio				3.6	3.4	3.2
Net Benefits				$5.20	$5.07	$4.93

[a] For the results reported in this table, all parameters were set at their *base case* values as described in the text describing the approach used by Whittington et al.

In 2008, we raised concerns about this set of calculations that are similar to those that we have raised about the WSP estimates for sanitation, which have to do with the challenges of bringing estimated BCRs to the reality of the facts on the ground (Rijsberman and Zwane, 2008). In the case of this rural water intervention, our concerns largely center around sustainability. Whittington et al. argued that challenges of sustainability and maintenance have been "largely overcome" by the use of participatory demand-driven village water committees for oversight and maintenance. We argued that the data did not in fact support that claim and thus, the benefits estimates here may be largely overstated. Efforts to assess the functionality of installed handpumps at a large scale as undertaken by WaterAid in Tanzania, Uganda and Malawi (water point mapping) show that a large share of the handpumps installed less than five years are no longer providing service. We continue to believe that this is the case, and in fact, since 2008, the policy dialogue seems to have moved away from voluntary committee based management models, increasing the role for district governments as service providers. This likely implies higher labor costs for O&M than $500 per year, but also increases the probability that the stream of benefits assumed by Whittington et al. could be achieved.

Our Perspective Paper in 2008 (Rijsberman and Zwane, 2008) also raised the concern that the health benefits of the water intervention may be understated because of a lack of consideration of infectious disease externalities. We also discussed the potential for benefits to be increased by adding source-level community chlorine dispensers, which would have low costs, but the additional benefits associated with protective effect of chlorine to maintain water quality during transportation and storage. Innovations for Poverty Action estimates that about 150-200 million people would be well served by chlorine dispensers, based on an analysis of populations in areas where the diarrheal disease burden is high and there is reasonable chlorine acceptability (mostly eastern and southern Africa). The number of lives that could be saved each year is up to 30,000 using this conservative estimate of total coverage. The cost per person per year is estimated to be less than $0.5 per person with access per year, and the cost per DALY saved is $25-$35 (Ahuja et al., 2011).

To understand how much it would cost to implement this rural water intervention, we begin with the most recent estimate of the number of unserved. The total number of people left without access to safe water in rural areas, according to the new JMP2012 is 770 million. Given that wells and handpumps are a proven method that would work wherever there is access to groundwater, we assume that the maximum number of people that could be reached through the intervention is 90% of those currently not served, or 700 million people. According to Whittington et al. the annualized cost of service per well to serve these people is $1530 per well (which serves 300 people). Thus, providing 15 years of service to all the unserved would cost ($58.9 billion = $1530 x 15 x770,000,000/300) or some $4 billion per year, a net present value of a bit over $40 billion (at the same interest rate of 4.5% as used above).

To estimate the (external) investment required to achieve the maximum level of coverage (assumed at 90%, or 700 million people), the practice is that external donors or the government subsidize most or all of the initial investment cost. In some cases the beneficiaries are asked to contribute part of the initial investment cost, in cash or kind through donated labor , to increase their sense of ownership and increase the likelihood that there is adequate maintenance – which is a key challenge as we argued above. That means the external investment ranges, in practice between 80% of the capital costs (estimated as $6,500 per well plus pump, serving 300 people) and 100% of the capital plus program costs (estimated at $10,000 per well plus pump serving 300 people), or a total investment covering 700 million people ranging between $12-23 billion.

6. Conclusions

We have based the calculations in this paper largely on the extensive cost and benefit data published recently by the very significant Economics of Sanitation Initiative (ESI) of the Water and Sanitation Program of the World Bank, resulting from its research undertaken over 2007-2011 on the impacts of sanitation and the economic returns to sanitation interventions in over 20 Asian and African countries. The data this program has generated fill a real gap in knowledge concerning the costs and benefits of basic onsite non-networked sanitation as well as modern networked sewerage and treatment systems. We have generally accepted the cost data for wet and dry latrines in urban and rural areas as realistic and the best available. We have also accepted the benefit estimates of sanitation as the best available.

ESI concludes that basic sanitation, wet and dry latrines, have the highest Benefit Cost Ratios of all sanitation interventions, in a range of 5 to 8. We do not agree that current technology does indeed generate these benefits, both because the adoption rates for dry latrines are low in rural areas and the lack of effective and affordable latrine emptying and fecal sludge treatment services means that particularly in low income urban areas, the benefits estimated by ESI are not realized.

We propose three sanitation interventions that can potentially help realize the benefits estimated by ESI and have analyzed their Benefit Cost Ratios as follows:

1. CLTS++, a behavior change program to create demand for sanitation in rural areas: an investment of US$3 billion could serve 600 million people, 50% of the rural population currently without basic service, with a BCR of 4-7 at a discount rate of 8%. This is a low-risk investment already demonstrated to be effective at a scale of tens of millions of people. Targeted subsidies for the poor will likely be a critical element of a successful program, so that Open Defecation Free status can be achieved and health gains realized.
2. Sanitation as a Business, latrine emptying and fecal sludge processing services at an annual cost of US$10 per household: an investment of US$320 million ($120 million in technology and institutional innovation, and a further $200M in market development) could serve 200 million low-income urban people, 20% of the latrines currently emptied manually, with a BCR of 23-47.

This is a medium risk investment in a product and development innovation package, key elements of which have already been demonstrated to be feasible.

3. Reinvented Toilet, an off-the-grid toilet that processes and recycles human waste at household scale and provides an excellent user experience affordably: an investment of US$125M ($50M in technology innovation and product development, and a further $75M in market development) could serve a billion low income urban people, 100% of the latrines currently emptied manually (and potentially many more people) with a BCR of 40. This is a high-risk investment in research, product development and market development for a product currently at the proof-of-concept / prototype stage.

The fourth intervention we propose is based on the analysis presented in the Copenhagen Consensus paper of Whittington et al (2008), it is a rural water intervention which consists of boreholes equipped with handpumps. An investment of $12-23 billion could potentially reach some 700 million people with water services, with a BCR of around 3.4. This is a low-risk investment in proven solutions that are primarily in need of increased levels of resources to roll them out to unserved populations. These results are summarized below in table 5.

Table 5: Summary of BCR analysis

Intervention	Investment (US$ M)	BCR	People served (M)	Risk
CLTS++	3,000	4-7	600	low
Sanitation as a Business	320	23-47	200	medium
Reinvented Toilet	125	40	1000	high
Rural Water	12,000-23,000	3.4	700	low

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