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# Affordable, Portable Water Cistern

Teresa Zhang, Jason Chen & Ryan Williams
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## *1.0 Summary*

Two hundred million rural farmers in China desperate need affordable and flexible water storage. In response, our team is developing a water cistern combining the strengths of many existing water storage solutions. Our design consists of an extremely large water bladder supported and protected by a hemispherical pit and a simple, folding metal frame. Using specially developed two-ply plastic rather than concrete will reduce the cost of the cistern to half that of comparable cisterns; and placing it mostly underground will discourage the water from freezing in the dry winter months. With the assistance of our community partners, we will design, build, implement, and test a working model in Northwest China this summer. Our goal is to enable China's poorest with safe drinking water and a means of rising out of poverty.

## *2.0 Background*

Water scarcity is an increasingly urgent problem worldwide. According to the World Health Organization, 1.2 billion people are currently without access to safe drinking water[1]. In rural China alone, seasonal water shortage is an economic and health barrier for 200 million people[2]. China ranks fourth in the world in terms of total water resources, but is second lowest in terms of per capita water resource availability[3].

The Northern half of China is especially dry, as it is home to 44% of the population and 66% of China's cropland but only 20% of China's water supply.[4] Of the water available, 80% is used to irrigate crops compared to 15% in US[5]. Furthermore, half the water used for irrigation is lost en transit to evaporation, etc[6]. As demand for water grows in all sectors, agriculture almost always looses out to industry and residences. A thousand tons of water produces one ton of wheat, which has a market value of $200, whereas the same amount of water used in industry yields an estimated $14,000 of output[7]. The agricultural communities of China's Northwest constitute our immediate target audience as they receive only one-tenth the per capita water used worldwide.[8]

Appropriate Technology Firms, such as International Development Enterprises (IDE), have developed a great deal of technology for water management in China, including rainwater collectors, treadle pumps, bio-sand filtration systems, and even drip irrigation mechanisms. However, the largest bottleneck for poor farmers is the availability of affordable and versatile water storage.

The Chinese government, in conjunction with a number of international humanitarian organizations, responded to China's dire need for water in the 1990's by providing over a hundred million families with water cisterns[9]. They recognized the development of water storage as a responsible approach to scarcity. Using stored water, as opposed to water from wells or municipal water supplies, helps avoid consuming more water than is sustainably available.

## *2.1 Prior Art*

Today's mostly commonly used cisterns are no different in design than those that have been used in China's Loess Plateau for hundreds of years[10]. Though the concrete cisterns can hold up to 18 cubic meters of water, they are difficult to construct, expensive and cannot be moved. At around $200 US, or $10 US/1m^3 water storage, they are out of the price range of rural farmers who earn less than one dollar each day. Because they are impossible to move and cannot follow weather patterns, 20% are currently not in use[11].

**Figure 2: Concrete cistern**

IDE has recently developed and implemented plastic water bladders, each capable of containing 0.6 cubic meters of water. World Health Organization environmental health advisor, Han Heijnen, has applauded this design because the sealed bladder prevents mosquitoes from entering the water supply[12]. These water bladders have greatly improved water control by rural people, allowing them to save more water and use water more efficiently. However, the capacity of these bags is not sufficient for farmers and the water bag cannot prevent water from freezing in the winter[13].

**Figure 1: Brick cistern**

IDE of Bangladesh has built off of IDE China's water bladder. They designed an above ground cistern composed of a sheet metal cylinder containing a plastic water bladder. While this cistern is a great improvement on Bangladesh's traditional cisterns in terms of cost and ease of maintenance, it still does not meet the functional and price requirements of the Chinese poor.

The US fosters a number of water storage options. The GrainPro Company of Concord, MA has developed, manufactured and discontinued a line of heavy-duty polypropylene bladders for storing water, gasoline, liquid fertilizers,

**Figure 3: Bangladeshi cistern**

**Figure 4: GrainPro bladder**

and other fluids.  The portable bladders range from 1.25 to 6.5 cubic meters but cost at least $60/m^3.[14]

The Sustainable Village Social Enterprise has designed underground cisterns holding up to 4.6 cubic meters but at over $200/m^3 they are too expensive for most of the world, let alone the poor[15].

gure 5: Sustainable Village
iderground cistern

**Table 1: Available water storage options**

| Storage Method | Type | Capacity m^3 | Unit Price $ | Volumetric Price $/m^3 | Drawback |
|---|---|---|---|---|---|
| Bladder | Portable | 0.60 | $3 | $5 | Too small Freezes |
| Bangladeshi | Aboveground | 3.00 | $30 | $10 | Too small Expensive |
| Sustainable Village | Underground | 4.62 | $960 | $208 | Expensive |
| GrainPro 6.50 | Portable | 6.50 | $385 | $59 | Expensive, Freezes |
| Traditional Cistern | Aboveground | 18.84 | $200 | $10 | Expensive |
| MIT IDEAS Cistern | Partly underground | 20.00 | $106 | $5 | |

Though there have been improvements in recent years, there is still great demand in China for a better cistern design to reduce the cost and increase the mobility of water storage options. To improve on currently existing water storage methods, a new design must compete with traditional cisterns in terms of capacity, durability, safety and easy of use.  In the North, it is especially important that the cistern is able to prevent stored water from freezing in the winter months.  However, in order to be implemented on a large scale, alternatives cannot rely on foreign aid.  New cisterns must be affordable to the average Chinese farmer.

## *3.0 Design Innovation*

Stored water is contained by a very large two-ply water bladder, held upright by folding metal crossbeams, though it will sit mostly underground, supported by the soil below.  Indirect immersion of the water into the ground will prevent it from freezing during cold, dry months.  The plastic sheeting will be hermetically sealed, and a hard cover will protect the cistern.

Though the design is inherently scaleable, we have decided to develop a cistern capable of holding twenty cubic meters of water and measuring four meters in diameter. Over a dry winter, this amount of stored water would mean economic prosperity for a farming family in need of irrigation.

These cisterns are meant to work in conjunction with rainwater collection systems, often as simple as residential roofs, commonly found in Northern China. Simple, extruded plastic pipes will constitute an inlet from the reservoirs to the water bladder. Likewise, inexpensive manual water pumps will be used to extract water from the cistern. The pipe fittings on the bladder are designed to work with a wide range of inlet and outlet ducts.

The two-ply bladder material is composed of a food grade impermeable layer and a durable woven layer. The inner bag is composed of two fused circular pieces of plastic sheeting. They are strategically folded along their joint edge to form a spherical shape and reinforced lips, which are used to connect the bag to the frame. The woven outer layer protects the inner layer punctures and failure due to UV light. There is excess sheeting material in the vertical direction so that only the weight of the plastic, not the weight of the water, is applied to the frame.

The frame design is cost effective and simple. The design is based on the trusses of folding display booths and warren bridges. Because the beams form a closed loop, the frame takes advantage of the material's tensile strength. The frame/bladder interaction is carefully designed to minimize strain and to maximize stability. Because of the expense of aluminum and stainless steel and the limited life of wood, we propose to use steel beams that treated for corrosion resistance or coated with plastic. We found plastic to be too week to use as beams, however it can be used in conjunction with a solid wall design.

**Figure 7: Bladder and reinforced lip detail**

Simple metal pins will be used as connectors. The pins are required to align the beams along its axis but the beams are laid out such that the forces on the beams press them together. The pins will be modular, replaceable and recyclable. In the event of failure, a scrap piece of metal, plastic, or even string may suffice as a temporary replacement.

A hard top will be developed as an optional component. Farmers will have the option of building their own hard coverings for the cistern to save on costs. Likewise, a small manual pump will be offered optionally. Both ApproTec and IDE are developing low cost manual pumps that we may purchase for this use. The pumps can be used both to retrieve water from large cisterns like this one and to irrigate crops.

### *3.1 Implementation Innovation*

While the implementation of the cisterns in the prototype and pilot phases will be carefully guided and closely monitored, we believe that the cistern is simple and intuitive enough to be used without outside help. We would like to document the set up process thoroughly and clearly in pictorial form so that even illiterate farmers can do so without confusion. The comprehensive user guide will also illustrate simple repairs using commonly found materials.

The cistern will be sold in agricultural supply stores as a kit, each one containing the folded frame, folded bladder and woven layer, tubing, connector pins, and of course the user guide. The hard top and the water pump will be sold as optional accessories for those who already have pumps or feel comfortable constructing a home made hard top.

Once rural farmers get a hold of cistern kit and learn how to assemble it, it will still require a significant amount of manual labor to dig a large enough pit. While this initially seems problematic, IDE has confirmed our belief in this aspect of the design. A great deal of appropriate technologies go to waste simply because end users find them too foreign. However, if the end users are physically invested into setting up the technology, they will be much more devoted to making use of it.

Most importantly, the cost of the cistern is dramatically reduced by its reliance on end user labor. This helps to keep the cistern affordable for a wider audience. Though this implementation scheme seems to require higher activation energy to initiate in comparison to more expensive options, it's cost savings and use benefits will be significant.

### *3.2 Justification*

Our design draws upon the advantages of many existing water storage solutions to meet the functional requirements of Chinese rural farmers at a price they can afford.

The primary advantage of this cistern is its affordability, which is a direct result of its minimalist design. The walls of the pit, the cistern's frame and the plastic sheeting, work together to act like the walls of above ground cisterns. Our conservative use of materials lends well to the cost effectiveness and the simplicity of the cistern.

This design takes advantage of the structure and the thermal resistance of the ground by storing the water mostly underground. Unlike completely underground cisterns, this decision eliminates the need for expensive hard shells required to withstand the weight of soil. Additionally, it is easier to access the water at this height.

Another main benefit of this design is its flexibility. Though we have decided to develop a twenty cubic meter cistern, the size of the design is flexible from five to upwards of fifty cubic meters. In this capacity, our design is far superior to the other options outlined in Table 1.

Moving the cistern, though labor intensive, is necessary at times. We have addressed this need by making the cistern components extremely portable. Both the bladder and the frame are foldable, with no parts weighing more than ten pounds or measuring more than six feet. The volume of the folded cistern is less than one-twentieth of the cistern in use.

Furthermore, the interactions of the components were carefully engineered to minimize stress and extend the life of the components. The parts themselves are designed to be uncomplicated for easy repair, and modular for easy replacement. In addition, the pictorial user guide will suggest simple repairs with inexpensive and commonly found parts. This attribute is important as it affects the reliability and the safety of the cistern.

In addition, the inner bag is completely sealed and protected. We realize that the costs of the cistern could be much reduced by eliminating the frame altogether but we found that such a setup fails in durability and ultimately safety. By raising the top of the bladder above ground level, we reduce the likelihood of water contamination from drifting soil, misplaced tools, curious animals or even children. Though we worked to reduce costs whenever possible, we found it unethical to do so at the expense of safety.

## *4.0 Implementation*

The goals for our project fall within the sequential phases outlined below.

| | | |
|---|---|---|
| Preliminary | Primary information gathering | **v** |
| | Design conception | **v** |
| | Alpha prototype | **v** |
| | Lab tests | |
| Phase 1 | Secondary information gathering in China | Summer 2003 |
| | Redesign and rebuild working prototype | |
| | Field tests and community education | |
| | Community feedback and monitoring | |

| | | |
|---|---|---|
| Phase 2 | Redesign for pilot | Fall 2003 - Fall 2004 |
| | Small scale manufacturing | |
| | Community feedback and monitoring | |
| Phase 3 | Search for investors and other supporters | Fall 2004 - Fall 2005 |
| | Production, marketing and sales throughout N China | |
| | Technology transfer and adaptation to other regions | |

### *4.1 Work to Date*

Over the last semester, our team has work hard on this project and made significant progress. We have learned about the severity and the pace of water shortage issues in China and worldwide. We have also researched the climate for developing appropriate technology in China by studying the culture, political infrastructure, economic mechanisms and product development capabilities.

We have designed and built an alpha prototype, from which we learned a great deal. We carefully weighed and documented possible design options. We considered modifications in the overall structure and use model including optional parts and eliminating the frame altogether. The plastic sheeting seal, the connection between the bladder and the frame and the structure of the frame in particular have undergone many design iterations based on new information and materials research. The initial design has been refined and modified repeatedly, and a second prototype is in the making.

Having just received samples from China, we are beginning to perform laboratory tests on the properties of the two-ply plastic at freezing temperatures. We are also very interested in studying the mean time to failure (MTTF), mean time to repair (MTTR) and simple ways of repairing the cistern in the field.

### *4.2 The Next Step*

IDE of China has invited us to discuss this project with their engineers in Beijing and has offered to guide us in visiting Northwest China pending funding approval. We hope to take advantage of this opportunity over this summer to get community feedback on the cistern. Though the design has been improved, we feel that it is important for us to remain open minded to the needs of our target audience. In the next step, community input is essential to redefining the functional requirements for the project.

We also plan to seriously consider the feasibility of this project on a large scale by researching the political, industrial, and economic layout to which developers of new technology must heed. This summer would also be a great opportunity to foster relationships with humanitarian organizations as well as for profit investors who may be interested in the development of such a product.

Pivotally, we would like to redesign the cistern and build a working prototype using the resources available in China to demonstrate the product performance and manufacturability. Human use and safety tests will be performed on this cistern, and finally it will be used as tool to communicate our ideas to potential end users and government agencies such as the Ministry of Agriculture.

## *4.3 Long Term Scope*

If communities are receptive to our cistern idea, we hope that our plan of actions will successfully bring the product to market within three years, with sales of 500 hundred cisterns in the first year and upwards of 100,000 in ten years. We think this is a realistic goal considering our relationships in China and the connections we have made in the appropriate technology community.

Following the lead of ApproTec's water pumps and Media Lab Student Saul Griffith's low cost eyewear, we would like to see this design developed into a for-profit business. Though this seems contrary to the humanitarian ideals of the project, time has proven that unless a project is self sufficient, it stands no chance of continuous, large-scale impact.

The demonstrated need for a water storage method offering the benefits of our design extend far beyond China. Other countries currently suffering or predicted to suffer from water shortage according to the United Nations include Bangladesh, India, Kenya, Peru, Nigeria, Singapore, Syria, South Africa, Cyprus, Barbados, Haiti, South Africa, Egypt, Qatar, Jordan, Ethiopia and Algeria[16]. We hope to expand the sales of our cistern to these countries in severe need of reliable freshwater storage.

## *4.4 Challenges*

Because cost is so critical to the success of this technology, financial constraints are our primary concern. The sale price of the cistern must be low enough to appeal to rural farmers but high enough to sustain the business. However, we believe in the merits of improved water storage and are confident that this product will give its users an economic edge well able to cover the initial costs of the cistern.

We are extremely serious about the safety and reliability of this design. We understand the ethical consequences of dealing with the management of a basic life necessity and this responsibility has not been taken lightly. We are reassured that safety will be a major concern in the development because we will be relying on it for our own uses during our fieldwork stages.

Another concern is social inertia, which may work in our favor or not. Rural areas have missed the globalization most of us have experienced. The involvement of foreign designers may not be the most welcomed. However, no one can deny the terrible need for the class of solutions we seek to create. We hope that our background will work for our advantage as we have the best of intentions and come with an open mind to community concerns.

Communication and education is always a problem with people who are leading a subsistence lifestyle. Again, we hope to meet this challenge by learning as much as possible about the ways of life we come across so that we can be sensitive to others concerns.

### *4.5 Support Network*

Establishing a strong support network has been a top priority for us. Because of the potential impact of this project, and hopefully the strength of our design, the responses to our project have been extremely encouraging. Our network of collaborators, advocates and potential investors grows consistently. We are especially fortunate to have found friends in the experienced and influential supporters described here.

**Dr. Xiaopeng Luo** was the first to reveal the problem of water scarcity in China to us. He has since remained instrumental in our design development. He is an economist with expertise in Chinese economy and agricultural economics. As the co-founder and director of International Development Enterprise's China Office, Dr. Luo has worked on a number of water management solutions for rural China including rainwater collection reservoirs and low cost drip irrigation systems. He will be crucial in the implementation of this cistern, and offer us connections in China

**Dr. Debu Sen** is an economist focusing on educational planning and entrepreneurship development. He is engaged in community services through non-profit organizations in India. His interest in drinking water issues originates from his concern for his fellow Indian population. Mr. Sen offers his guidance in implementation and technology transfer.

**Mr. Philippe Villers** is a graduate of MIT's department of Mechanical Engineering. He is also the president and founder of GrainPro, a local company specialized in mobile airtight grain storage. Mr. Viller's company has developed plastic sheeting zippers that are able to form an extremely reliable hermetic seal, which eliminates the necessity for chemical preservatives. We hope to implement this technology in order to improve the convenience and safety of our product. Mr. Villers offers his expertise in product development, particularly in airtight storage technology.

## *5.0 Community Impact*

This project has huge potential to improve the lives of the poorest people in China and other countries suffering from water shortage.

Health and quality of life stand to make the most immediate improvements. Clean water is a necessity for the human metabolism and for basic hygiene. Contaminated water serves to spread contagious diseases. Unsafe drinking water is responsible for 80% of diseases in developing countries[17]. The most common water borne infectious and parasitic diseases include hepatitis A, diarrheal diseases, typhoid, roundworm, guinea worm, leptospirosis, and schistosomiasis. Every year, diarrheal diseases alone cause 3 million deaths and 900 million episodes of illness[18]. Our cistern design stands to dramatically improve the lives of millions of Northern Chinese farmers.

There is a high correlation between rural poverty and water shortage in China. However, the cisterns built in the 1990's have proven the value of storing water through the dry season. One cubic meter of water is valued at approximately $0.10 US in the summer but $1.00 US in the dry winter[19]. This phenomenon alone would pay back the initial cost of the cistern in a few seasons. Furthermore, farmers stand to advance economically following improvements in agricultural yield. China's Ministry of Agriculture found an average of $35 billion US dollars in losses every year due to drought in the 1990's[20].

Beyond the indirect social benefits that come with increased wealth, the availably of water can bring more direct benefits. Very often, women and children are responsible for maintaining a family's water supplies[21]. They may spend up to six hours fetching water from increasingly parched pumps or murky rivers everyday[22]. This task often leaves children and women without the time or energy to pursue education. In turn, "education is one of the bastions of sustainable development. It is one of the most valuable means of achieving gender equality and the empowerment of women" says Ambassador Linda Tarr-Whelan, United States Representative to the United Nations Commission on the Status of Women[23]. Making the task of obtaining water easier is not a matter of mere convenience but one of global concern.

Another long-term benefit is sustainability. The international community is becoming more and more aware of the ecological benefits of harvesting rainwater for human consumption. Using water from a cistern is akin to purchasing items with cash whereas using water from wells and municipal supplies is similar to purchasing on credit. Promoting sustainable use in this way is important, as China has witnessed substantial drops in water tables approaching five feet annually[24]. Unlike many innovations, these cisterns stand to benefit millions of people in the short term without sacrificing the long term.

### *6.0 Conclusion*

By halving the cost of conventional water storage methods, we hope to enable poor farmers of China's dry North with the water storage capabilities they desperately need. We feel that our cistern a good investment for lasting improvements in human health, economy, equality and environment.

## *7.0 Biographies*

**Teresa Zhang** is a senior in Mechanical Engineering. Her focus at MIT is in the study of industrial ecology and sustainable design. She is committed to applying her strengths in engineering to benefit society; she has worked on projects for the developing world including a distributed wastewater treatment system and a portable vaccine cooler. She was born in Shan Dong Province at the mouth of the Yellow River. Despite its strategic location Shan Dong is now one of China's driest provinces as a result of decades of over-logging and unsustainable agriculture practices.

**Jason Chen** is a Fellow and MBA candidate in the Leaders for Manufacturing program at MIT. His expertise is in the commercialization of new products, and he was the winner of the 1994 MIT Entrepreneurs Contest and the 1996 Stanford Entrepreneurs Contest. Jason has a bachelors from MIT and a masters from Stanford, both in materials science and engineering. His previous work includes general management at a non-profit organization, engineering management at a biomedical device startup, and supply chain management at Cisco Systems. He plans to do business in Asia, particularly in an area that benefits society.

**Ryan Williams** is a Computer Science senior at MIT. Though many of Mr. Williams's interests lie in software, he is also skilled in building mechanical devices, and has a minor in Psychology. As an avid follower of current events, he has become increasingly concerned with humanity's failure to sustainably utilize its resources. This is his first project of this nature, and he is contributing to the design and prototyping of the cistern.

*8.0 Budget*

Developing our cistern will happen in three phases as outlined in Section 4 of our IDEAS final proposal. The total cost of three-month Phase I is split between R&D ($4,400), living expenses ($2,000), and marketing ($400). While the apparatus is quite simple, the high R&D costs reflect tooling for injection molding that can be used to mass manufacture parts in later phases. Initial marketing in the form of discussions with relevant Chinese officials is required to gain regulatory approval. Expenses in Phase II and Phase III include marketing, implementation, and manufacturing. A detailed budget is outlined below.

| | | | **Phase I<br>Working Prototype<br>5 units** | **Phase II<br>Pilot<br>50 units** | **Phase III<br>Area rollout<br>300 units** |
|---|---|---|---|---|---|
| Timeline | | | Summer 2003 | 2004 | 2005 |
| **Expenditures** | | | | | |
| R&D | | | | | |
| | Frame struts | | $1,900 | | |
| | Plastic bladder | | $1,000 | | |
| | Connectors | | $800 | | |
| | Top | | $600 | | |
| | Pump | | $100 | | |
| Living expenses, etc. | | | $2,000 | $5,000 | $40,000 |
| Marketing and market research | | | $400 | $5,000 | $40,000 |
| Manufacturing | | | | | |
| | Materials | | | | |
| | | Frame struts | | $ 150 | $ 900 |
| | | Plastic bladder | | $ 150 | $ 900 |
| | | Connectors | | $ 200 | $ 1,200 |
| | | Top | | $ 100 | $ 600 |
| | | Pump | | $ 200 | $ 1,200 |
| | Labor | Assembly | | $ 200 | $ 1,200 |
| | Shipping | | | $ 150 | $ 900 |
| **Total** | | | $6,800 | $11,150 | $86,900 |

Any prize money from IDEAS will be used towards R&D and marketing in Phase I during the summer of 2003. These funds will result in a working model, which will be used to motivate China's Ministry of Agriculture to support the manufacture and rollout of the project on economic and social merit. No additional outside funds will be needed after Phase II.

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