PILE FOUNDATIONS OF BRIDGES AND BUILDINGS

ENERGY ACCESS | LPG CYLINDER PRIZE WINNING SOLUTION (4/7)

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ABOUT IDEAS TO IMPACT

Ideas to Impact is an action-research programme designing, implementing and testing innovation prizes, to induce innovative solutions to development challenges in Climate Change Adaptation, Energy Access and WASH. A five year, £10.9m programme, funded by the Department for International Development (Dfid) that supports research and development in climate change, energy and WASH through a variety of innovation prizes. The prizes are designed to stimulate and incentivise development of technologies for low income consumers that will improve poor people’s access to affordable clean energy, safe drinking water and resilience to climate change.

ABOUT THE ENERGY ACCESS: LPG CYLINDER PRIZE

As part of the Ideas to Impact the Energy Access: LPG Cylinder Prize launched on July 7, 2015, focused on inducing innovations for recycling liquid petroleum gas (LPG) cylinders across sub-Saharan Africa. Applications were received from more than 180 solvers, from over 40 countries, proposing solutions to address the problem of how to maximise the value of large numbers of aging and unsafe LPG cylinders that might need to be retired in the event of market reforms. No readily available solution which could be implemented at scale was identified. However, seven winners were selected, who offered solutions which in the view of the judges had potential to address the challenge subject to further research and development.

Here we share one of these winning solutions.

ACKNOWLEDGEMENTS

The Energy Access prize is led by Simon Collings at Energy 4 Impact, and collaboratively designed with Jonathan Slater from The Blue Globe.

Ideas to Impact is managed by IMC Worldwide Ltd. With special thanks to the independent panel of judges who judged the winning solution, and to George Abouseif Emile Ibrahim, gabouseif@alum.mit.edu for submitting the winning solution.
USING OLD, SCRAPPED 14.5kg LPG BOTTLES FOR
PILE FOUNDATIONS OF BRIDGES AND BUILDINGS
AND OTHER APPLICATIONS IN SS AFRICA.

PART.A- APPLICATIONS.

I- Concept:

Pile foundations use piles — long members of wood, steel, or concrete that can be driven into the ground — as substructures to support structures built on top of them. These foundations are often used in marine construction for bridges, piers, docks, oil rigs, and wind farms as well as other large construction projects. They are also commonly used where poor soils will not support other foundation designs, and for supporting loads that would be too heavy for other types of traditional construction. They are a necessary element in many foundations today. See attachment: "Steel Piles."

Often, pile foundations are driven into place by a pile driver, a piece of heavy equipment that raises a weight to a certain height and drops it forcefully onto the top of the pile. The weight forces the pile into the ground. This is repeated until the desired depth is reached. Steel is particularly easy to drive into the ground in this manner because of its strength, resilience, and shock resistance.

Once all of the members are put into place for a pile foundation, a pile cap is then usually placed over them. This usually takes the form of a large thickness of concrete, into which the tops of the piles are embedded. The cap acts to transfer the weight of the construction above it to the members below, which generally support the structure by absorbing its load, and transfers this to the deep subsurface upon which they rest, as well as the soil surrounding the pile. This point shall be revisited upon describe the proposed pile made out of old, scrapped LPG bottles.
II- Why Old, Scrapped 14.5kg LPG Bottles Make Good Piles?

LPG bottles are Cylindrical in shape, about 30cm in diameter, and are usually made of special alloyed steel. They are robustly designed to a test pressure of 34 bars and a working pressure of 18 bars. It is 2.5-2.8mm thick alloyed steel, or other strong materials. They are, in essence, structurally extremely strong units which can be properly connected together to construct a robust, and strong steel pile.

Even old scrapped cylinders which are structurally defective, including some with serious dents, sizeable bulges and gouges on the cylinder, large corrosion pits, lines and general corrosion, leaks, and fire damage and scorching should not prevent it from becoming perfect steel piles. Such defects shall never compromise the pile’s intended function as one whole, large, structural, load-bearing construction unit.

Perhaps, the most important attribute of these scrapped bottles is its almost perfect and robust cylindrical sections which do not work under high inside pressure at all, but must bear both high external soil pressure, and also high longitudinal (axial) stresses during its driving process into the soil. In addition, its strong alloyed steel gives it extra strength, hardness, and corrosion resistance. Liquid petroleum gas is a solvent, and solvents can easily corrode plain steel.

Steel Piles Experiencing Soil’s External Compressive forces. Steel Piles Experiencing Axial Compressive Forces by Driver.
Examining a typical, old, scrapped 14.5kg LPG steel cylinder, one recognizes the following positive attributes:

1- For a standard 14.5kg LPG steel cylinder, the height/diameter ratio is \( \approx 53\text{cm}/30\text{cm} \approx 2 \), a value \(<10\) where buckling begins to occur under axial compressive force. Cylinder’s total length of 53cm is quite reasonable for the pile’s buildup application. It constitutes 70% of the total inventory.

2- The median circumferential weld line shown by the orange arrow in the above picture reinforces the cylindrical structure immensely. It is like a collar which keeps both halves strongly connected together even under large axial, compressive forces. It is an attribute absent in ordinary manufactures market steel piles.

3- All dents, gouges, and structural defects happen usually away from the two extreme ends of the bottle (top and bottom caps), which are the structurally strongest points. THE SHROUD-BUNG, AND BASE-RING ARE USUALLY INTACT.

4- The top and bottom caps are NOT sawed off the bottle in the present solution, and bottles shall be used intact with their shroud bungs and base rings. There is no need to repair the cylindrical shape if it is defective with any shape or size of dents/gouges. The cylinders are used as is.
Hence, scrapped 14.5kg LPG steel bottles provide a lucrative resource of valuable robust, cylindrical sections to form strong, alloyed steel piles once it is removed from the LPG market, as it still carries considerable values in terms of shape, length, diameter, construction, strong material, and robustness.

Overpass of a street over a highway shows a steel composite framework bridge on pile foundation. Steel pipe pile foundations can be used for bridge construction, to Support Building Foundation, for Piers, and many other applications.

III- Economic Value:

The most important component of old LPG steel bottles is its value of high quality of material used, and its cost. If brand new steel sheets are 500$/ton, or 0.5$/kg, the price of steel scrap resulting from these defective cylinders may be 0.1$/kg or even less in such developing countries. The reason is simple and relates to the fact that steel scrap can go nowhere but be exported by SSA countries to steel-making countries since the former do not have their own very expensive steel mills. The latter, being the only available buyer, pay very little after deducting sea-freight costs. In effect, scrap sells for nil.

For a medium size cylinder, 14.5kg capacity of LPG for example, the tare weight is 17.5kg of steel is shown in the table below. Hence, an old, defective, scrapped cylinder would only bring about 1.75$, or even less, if sold as scrap. Such a price is far less than the price of new cylinders,
or even cylindrical parts. See attachment: "Steel Price History" for full price details of steels.

Hence, the real value of any re-useable, old, structurally defective LPG steel cylinder is the initial production machining cost involved to construct it with enough thickness, and strong alloyed steel, and with its unique, universal cylindrical shape. This is logical if one recalls that these cylinders store extremely explosive fuels and, therefore, must be extremely well designed and manufactured using high quality steel. Selling it as scrap would instantly write-off all the above intrinsic benefits or values. This fact is the backbone concept of the current proposed solution.

IV- Constructing Steel Piles From 14.5kg LPG Bottles;

**Individual cylindrical sections of typical Imported steel piles.**

**THE CONCEPT BEHIND THE SOLUTION: STACKED LPG BOTTLES.**

The procedure for constructing steel piles out of scrapped 14.5 LPG bottles is:

1- Top/bottom caps are NOT REMOVED or flame-cut or sawed off including the shroud bung and the base ring. **THE ENTIRE BOTTLE IS USED.**
2- Bottles are welded to one another at their shroud bungs, and base rings, as shown below. Shroud bungs shall be welded together forming recesses, and base rings shall be welded together forming flat, continuous surfaces.

USED SECTION CONSISTS OF THE ENTIRE BOTTLE.

FINAL PILE OF LPG BOTTLES.
3- This scheme shall utilize the entire length of the old 14.5kg LPG bottles thus maximizing the pile’s length, shall not need any repair work, and shall result in a stronger steel pile. Only electric arc welding is needed and that is standard machine shop work. NO WORK WHATSOEVER IS NEEDED IN THIS APPLICATION BESIDES BASIC WELDING TO FORM PILE SECTIONS OF THE REQUIRED LENGTHS. DIAMETERS ARE 32mm WHICH BELONG TO THE 14.5kg BOTTLES. INDIVIDUAL BOTTLE LENGTHS ARE 53cm. The resultant steel pile is expected to be much stronger than these made of traditional steel pipes.
V- The 6kg Old LPG Steel/Aluminum Bottles (25% of Inventory.)

The 6kg LPG bottles are of dimensions 28cm height, and diameter of 30cms. This translates to an approximate capacity of ≈ 20 Liters or less.

Concrete and Food Mixer.

Every farmer, builder, or contractor frequently needs to do some repairs in his own buildings or roads. Instead of using a shovel and barrow, this hand-operated concrete mixer can be used if available at home. It is built of old 6kg LPG bottles which are terminally scrapped, regardless of any structural defects or minor leaks. In other situations, the same mixer can be used as a food mixer to mix jams, fruits, and juices at home where food is made in SSA.

FOOD MIXER.

6kgs, old LPG bottles may also be used to construct steel piles despite its short length. However, it is expected to demonstrate more compressive force-bearing abilities than that of the 14.5kg bottles, mainly because the building block (bottle) is smaller and more structurally robust.
They may also be used for **knapsack sprayers** for crops and plantations. They may be used as **cooking pots** instead of cast iron ones. Such applications have been described thoroughly in another separate solution for the same challenge.

**COOKING POT MADE OF 6kg LPG SCRAPPED BOTTLE.**

**VI- 14.5kg Old LPG Aluminum or Other Material Bottles:**

Naturally, such bottles do not acquire the high strength of steel. Hence, these specific bottles may be used for many other applications such as knapsack sprayers, turbine and windmill blades, or uses described in detail in another solution for this same challenge.

**VII- Large 48kg, Old Scrapped LPG Bottles: Acoustic Scarecrows.**

Instead of these ineffective scarecrows in the African fields, high amplitude, far reaching, low frequency noise can be generated by **Rijke tubes** made of cylinders of 48kg old LPG bottles which transforms heat energy into sound.
Children firing a small Rijke tube using an LPG flame.

PART.B- IMPLEMENTATION.

I- No Old LPG Cylinders are rejected in this solution:

THIS SOLUTION IS, THEREFORE, FOR SCRAPPED BOTTLES OF ANY SIZE, MATERIAL, SHAPE, AND WHICH HAVE BEEN DEEMED BY LOCAL AUTHORITIES NON-REFURBISHABLE, AND NON-RECERTIFIABLE ON THE BASIS OF ECONOMICAL/TECHNICAL OR SAFETY CONCERNS.

Hence, the supply (inventory) of scrapped, uncertifiable old bottles is a random array (assortment) of different bottle sizes, materials, and shapes with different or multiple defects including: serious dents, bulges, gouges, fire damaged, corrosion pits, lines and general corrosion, scorching, and leakage. In brief, it can be anything across the spectrum. Refurbishable bottles are not the subject of this solution since it is both a subjective and/or objective matter which depends on the judgement of the examiner alone.

II- Leakage Classification of Scrapped Bottles:

NO LEAK-PROOF REQUIREMENT IS NEEDED IN THIS SOLUTION EXCEPT FOR ALUMINUM BOTTLES WHICH MAY BE USED AS SPRAYERS.
III- Preparation.

ALL SCRAPPED CYLINDERS SHALL BE COMPLETELY FLUSH-CLEANED WITH COMPRESSED AIR IN THE OPEN AND AWAY FROM FLAMES. MOREOVER, IT SHALL THEN BE WASHED WITH WATER AND DETERGENT TO RENDER IT SAFE FOR USE ESPECIALLY WITH CROPS. THIS WILL ALSO MAKE IT SAFE ENOUGH FOR ARC WELDING APPLICATION.

PART.C- CHALLENGE REQUIREMENTS.

I- Irreversibility of New Non-LPG Cylinders or Parts Thereof:

In all the above mentioned applications, major machining operations have been made on each and every old LPG bottle which makes its reuse practically impossible. Perforating, cutting, removal of top and/or bottom caps, slotting and/or welding into other mechanical components is the main theme. Not one old bottle was used as it used to be while storing LPG. Once steel piles are made from welded bottles, it seems impossible to charge a 20m pile with LPG. Concrete and food mixtures are drastically changed LPG bottles. Hence, this specific requirement is naturally satisfied in all applications suggested in this solution.

II- Value Added:

It is also obvious that in all the mentioned applications, considerable value has been added to the worthless scrapped bottle of 1-2$ value to transform it into a useful machine, or a functional worthy component in construction work.

In terms of the construction society as a whole and its well being, very cheap steel piles have been fabricated out of 14.5kgs LPG bottles with minimum cost. The use of steel piles has increased significantly in residential and non-residential construction, especially where there are difficult ground conditions and structures are subjected to heavy concentrated loads. Moreover, hand-operated mixers were fabricated from 6kg LPG old bottles.
In terms of jobs for individuals, a new tier has been created or expanded:

Blacksmiths’ shops for preparing steel piles, and agricultural or construction tools are needed.

III- Solution’s Economical Effectiveness: Capacity.

With the ongoing development and construction in SSA countries, bridges, buildings, piers and general construction is booming. In country A, 70% of its 1.5million scrapped bottles are 14.5kg LPG bottles and add up to about one million bottles in all. With a total height/bottle of 52cm, a total pile production is approximately 500,000meters. With an average pile length of 25m, the total production is approximately 20,000 piles of 25m length. Bridges and large construction sites consume hundreds of piles each.

A PILE FIELD CONTAINING HUNDREDS OF STEEL PILES.

Hence, the total production in country A would suffice for about 200 construction sites for a population of 30millions.

In terms of finance, one million scrapped 14.5kg LPG bottle would net if sold as scrap about,

Net worth of scrapped 14.5kg LPG bottles= 1million bottle x 17kg tare weight x 0.1$/kg scrap=1.7million US$. 

The import price of fabricated steel piles is 1000$/ton FOB (or about 1200$/ton C&F, 1.2$/kg, which is 12 folds the local market price of steel scrap), as given by the following link:  www.alibaba.com/Steel-Piles

Hence, the equivalent market price of the locally fabricated steel piles= 12 x 1.7≈ 20 million US$. This is the sum of money needed to import new piles. If local traders import it, a gross profit margin of 100% is imposed which makes the local selling price 40 million US$.

Accounting for the entire SSA countries with a gross population of 300 million (10 folds the population of country A), the total market selling price of locally fabricated steel piles utilizing scrapped 14.5kg LPG bottles=10 x 40 =400 million US$. This is the amount of money needed to purchase equivalent steel piles made abroad.

Compared to the minimal local market scrap price of 17million US$ for the entire SSA countries (1.7million US$ x 10), 400 million US$ is a lot of value added to the worthless LPG scrapped bottles. The only cost involved is plain welding. In addition, one should also account for the remaining 30% of the total inventory which, by simple proportionality, would make the total sum≈600 million US$ as compared to a total local scrap price of ≈25 million US$ (1.0/0.7  x 17million US$) if all the total inventory (including all sizes) is sold as steel scrap for 0.1$/kg.

Steel piles are very simple products whose main constituent is plain alloyed steel. Nonetheless, their utmost importance in heavy-construction projects, and their very simple, local manufacturing procedure makes it a very attractive and suitable choice for the technical standards of the SSA labor force. There are no intricate processes, or sophisticated workshops or machinery, just plain arc-welding machines.

**IV- Environmental Impact:**

All applications suggested in the solution are environmentally more sustainable than the current scrapping solution. All old and rejected bottles are recycled with minimum modifications or operations. No process in this modification plan shall result in pollution or increase in non-biodegradable materials.
**V- Inventory:**

The solution gives an answer to **all the parts of the inventory**, regardless of the specific size, shape, material, or condition of the cylinder once it is scrapped. For each scrapped old cylinder, there is good use. Moreover, the solution can absorb the initial lump sum of 1.5 million scrapped bottles in the first year, followed by 150,000 scrapped bottles in the consecutive years.

**VI- Local Resources:**

All the above applications in the solution rely on technical and human resources that are already available in SSA and use African countries’ equipment and labor force. Nothing is imported, and no sophisticated machinery or technology is needed.

**VII- Geographical Context:**

From the outset, it was clearly stated that the solution was inspired from the social, economic and cultural contexts of sub-Saharan African countries in all its human and material aspects. Moreover, it was adapted to the agricultural sector which is the largest across all these 59 states.
1- LPG bottles are unique, valuable engineered structures that are used for a very critical purpose, mainly the storage of highly explosive liquids under considerably high pressures. Hence, such containers do possess the attributes of both high structural and material strengths and, therefore, cost a considerable sum of money. These attributes are the real residual values in old LPG bottles.

2- Structural strength is manifested in both the cylindrical form, and its manufacturing processes. Material strength is manifested in its expensive alloyed steel, and also the wall thickness of 2.5mm or more.

3- Using one or all of the above attributes in any chosen application would definitely ensure the preservation of their embedded values even for old, scrapped cylinders. Use is made of whole bottles in this solution and to serve the construction business for bridges, buildings, or piers. The latter is the main exploding sector in SSA countries and, therefore, any extra investment in it should give the highest returns. Many sectors of the labor force are engaged in this field which is closely related to the area’s infrastructure and, therefore, the betterment of the entire African population.

4- Moreover, traditional and simple but effective applications were chosen to make the process viable as it only needs the least training, production tools, and techniques. Cost of transformation of old, scrapped LPG bottles to any application mentioned above is minimal in money as well as in effort and time.

5- The final and major objective is to produce more value for old, scrapped LPG bottles with little expenditures. Secondary objectives are also reached. A lower import budget, a larger construction labor force, and more newly created jobs.

6- In terms of saved funds, it is estimated that such exercise should result in savings of about 600 million US$. This lucrative amount can be used to acquire modern machinery that could not be made out of scrapped bottles.
PART.E- SUPPLEMENTARY INFORMATION.

a. **Motivation:**
The solver lives in North Africa and is already familiar with gas bottles, its misuse, and its accidents. In addition, he is aware of the old traditional agricultural tools in the entire continent, being the major economical field.

b. **Background:**
The solver is an individual mechanical engineer who acquired his PhD from a prestigious engineering school in the U.S. Later, he returned home and worked in agricultural industry. In addition, the solver is a member of Innocentive’s challenges’ solvers group. This is how he heard about the Challenge.

Hence, it seems natural for an African citizen, with mechanical engineering background, and a contributor to Innocentive’s challenges to take-on such a challenge in order to help find solutions for his home continent. If circumstances allow, the solver is willing to work further in this opportunity and describe his expertise if the client is indeed interested.