RECYCLED LPG VESSELS USED AS SUBSTITUTES OF STEEL REBARS IN REINFORCED CONCRETE

ENERGY ACCESS | LPG CYLINDER PRIZE WINNING SOLUTION (2/7)

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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.
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The Challenge:

This paper proposes a solution to InnoCentive’s issued Challenge #9933755:

“Ideas to Impact: Recycling Liquid Petroleum Gas Cylinders Across Sub-Saharan Africa”

Goal of the Challenge: “In order to foster the development of its LPG market, Country A is undertaking measures to improve LPG uptake, including the introduction of the above mentioned Marketer-Controlled Cylinder model. Consequently, one of the issues Country A has to deal with is to remove/refurbish the old cylinders from the market, because they are potentially dangerous.

The solution proposed:

ABSTRACT

We propose to repurpose the old LPG cylinders as partial substitutes of the steel bars used in the fabrication of steel reinforcements of reinforced concrete. For that use, the LPG will be first modified by removing (cutting) the top and bottom of the cylinder, converting it into a short tube which can be filled with concrete, and soldered to other tubes and steel rods to form a strong concrete-reinforcing structure to be used in structural applications such as building construction.
DETAILED DESCRIPTION:

We propose to repurpose the old LPG cylinders as partial substitutes of the steel bars used in the fabrication of steel reinforced concrete structures.

To better understand how the LPG cylinders fit into the proposed use, we will first describe reinforced concrete and the role of steel as reinforcement.

Reinforced concrete

Reinforced concrete (RC) is a composite material in which concrete's relatively low tensile strength and ductility are counteracted by the inclusion of reinforcement having higher tensile strength and/or ductility. The reinforcement is usually, though not necessarily, steel reinforcing bars (rebar) and is usually embedded passively in the concrete before the concrete sets. Reinforcing schemes are generally designed to resist tensile stresses in particular regions of the concrete that might cause unacceptable cracking and/or structural failure. Modern reinforced concrete can contain varied reinforcing materials made of steel, polymers or alternate composite material in conjunction with rebar or not.

For a strong, ductile and durable construction the reinforcement needs to have the following properties at least:

- High relative strength
- High toleration of tensile strain
- Good bond to the concrete, irrespective of pH, moisture, and similar factors
- Thermal compatibility, not causing unacceptable stresses in response to changing temperatures.
- Durability in the concrete environment, irrespective of corrosion or sustained stress for example.

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1 Adapted from Wikipedia entry: [https://en.wikipedia.org/wiki/Reinforced_concrete](https://en.wikipedia.org/wiki/Reinforced_concrete)
As mentioned steel bars are added to concrete to increase its mechanical resistance, so that the steel reinforced concrete has higher tensile strength than concrete alone.

A fundamental part in the science of calculation of structures is to determine the characteristics of the reinforcing “skeletons” which are added to concrete. These “skeletons” are usually formed by welded steel reinforcing bars (or rebars). The position and thickness of the bars are calculated to provide the structure with a tensile strength enough to withstand (with a safety margin) the loads imposed on the building structure. Some example of steel reinforcing structures are shown on the following images:

![Image of steel reinforcing structures](image1.jpg)

![Image of steel reinforcing structures](image2.jpg)

![Image of steel reinforcing structures](image3.jpg)

Fig. 1. Various steel structures used for reinforcing concrete pillars and beams
For the purposes of this discussion, we can differentiate two main types of reinforced structures: “flat structures” (fig 2.) and beams and pillars (fig 1.).

![Fig. 2. Various steel structures (meshes) used for reinforcing concrete floors and walls](image)

We have seen that steel, usually in the form of welded corrugated rods, is used to reinforce concrete. As mentioned, we propose the use of the old LPG to partially substitute those steel rods.

The most basic requirement for reinforcement is that the reinforcing material meets certain mechanical resistance conditions, in particular high tensile strength, to complement the high compression strength of concrete. The used LPG cylinders are made of relatively thick steel which means they fulfill that basic requirement to be used as reinforcements.

**How to use the LPG cylinders as reinforcement:**

To be usable as concrete reinforcements the LPG cylinders need to be transformed first. This transformation consists in cutting off the top and bottom of the cylinders, in order to obtain a short metallic tube and two curved plates (top and bottom). It is the metallic tube that will be used, welded to other tubes and/or to steel rebars, to construct steel reinforcing structures with similar
uses as those shown in Figure 1. The top and bottom cutoffs can be repurposed for other uses or be sold as steel scrap. We will call LGP tubes to the result of removing (cutting off) the top and bottom of the LPG cylinders.

While it is possible to fabricate many types of reinforcing structures combining LPG tubes and steel rods, we believe that the tube geometry is more suited for the fabrication of beams and pillars with shapes as shown on Fig. 1.

**Structures resulting for combining LPG steel tubes and rebar rods are shown on figure 3.**

![Diagram](image)

Fig. 3. two examples of assemblies of steel tubes and rebar rods usable as concrete reinforcements (to be filled with concrete). Front and top views.
Examples of similar uses:

An application comparable to the one proposed (although based in using steel tubes, instead of using modified LPG cylinders) are Concrete-filled steel tubes.

Concrete-filled steel tubes

Concrete-Filled Steel Tubes (CFTs, see Fig. 3) are composite members consisting of an steel tube filled with concrete. In current international practice, CFT columns are used in the primary lateral resistance systems of both braced and unbraced building structures. There exist applications in Japan and Europe where CFTs are also used as bridge piers.

Fig. 3. Transversal section of a Concrete-Filled Steel Tube

Our reference, Concrete-Filled Steel Tubes, has various advantage that directly translate to our proposal:

Advantages of Concrete-Filled Steel Tubes

The CFT structural member has a number of distinct advantages over an equivalent steel, reinforced concrete, or steel-reinforced concrete member. The orientation of the steel and concrete in the cross section optimizes the strength and stiffness of the section. The steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moment. Also, the stiffness of the CFT is greatly enhanced because the steel, which has a much greater modulus of elasticity than the concrete, is situated farthest from the centroid, where it makes the

2 Adapted from: http://www.northeastern.edu/compositesystems/wiki/Concrete-Filled_Steel_Tubes
greatest contribution to the moment of inertia. The concrete forms an ideal core to withstand the compressive loading in typical applications, and it delays and often prevents local buckling of the steel. Additionally, it has been shown that the steel tube confines the concrete core, which increases the compressive strength for circular CFTs. Therefore, it is most advantageous to use CFTs for the columns subjected to the large compressive loading. In contrast to reinforced concrete columns with transverse reinforcement, the steel tube also prevents spalling of the concrete and minimizes congestion of reinforcement in the connection region, particularly for seismic design. Numerous tests have illustrated the increase in cyclic strength, ductility, and damping by filling hollow tubes with concrete. Recent applications have also introduced the use of high strength concrete combined with high strength thin-walled steel tubes with much success. When high strength concrete and thin-walled steel tubes are used together, the more brittle nature of high strength concrete is partially mitigated by the confinement from the steel tube, and local buckling of the thin steel tube is delayed by the support offered by the concrete. Progress in concrete technology has made it possible to utilize concrete strengths over 15 ksi in CFT beam-columns.

A number of additional economical benefits stem from the use of CFTs. The tube serves as formwork in construction, which decreases labor and material costs. In moderate- to high-rise construction, the building can ascend more quickly than a comparable reinforced concrete structure since the steelwork can precede the concrete by several stories. The cost of the member itself is much less than steel and roughly equivalent to reinforced concrete on a strength per dollar basis for low to medium strength concrete (Webb, 1993). In addition, the steel tube and concrete act together to provide natural reinforcement for the panel zone, which reduces the material and labor costs of the connections. With the use of high-strength concrete, CFTs are stronger per square foot than conventional reinforced concrete columns (Webb, 1993). In high-strength applications, smaller column sizes may be used, increasing the amount of usable floor space in office buildings. The smaller and lighter framework places less of a load on the foundation, cutting costs again. These advantages have secured an expanding role for this versatile structural element in modern construction.

**Limitations of Concrete-Filled Steel Tubes**

A primary deterrent to widespread use of CFTs is the limited knowledge regarding their behavior. A number of factors complicate the analysis and design of concrete-filled steel tubes. A CFT member contains two materials with different stress-strain curves and distinctly different behavior. The interaction of the two materials poses a difficult problem in the determination of combined properties such as moment of inertia and modulus of elasticity. The failure mechanism depends largely on the shape, length, diameter, steel tube thickness, and concrete and steel strengths. Parameters such as bond, concrete confinement, residual stresses, creep, shrinkage, and type of loading also have an effect on the CFT’s behavior. Axially loaded columns and, in more recent years, CFT beam-columns and connections, have been studied worldwide and to some extent many of the aforementioned issues have been reconciled for these types of members. However, researchers are still studying topics such as the effect of bond, confinement, local buckling, scale effect, and fire on CFT member strength, load transfer mechanisms and
economical detailing strategies at beam-to-CFT column connections, and categorization of response in CFTs and their connections at all levels of loading.

List of all the benefits (economic, societal, and environmental) that the solution will bring to sub-Saharan African countries and how it meets all the Solution Requirements.

**BENEFITS.**

- **Creation of employment**: the used LPG cylinders will have to be transformed into hollow tubes. This will be done by cutting off the top and bottom of the cylinder to obtain a hollow tube. This task will be performed at local workshops equipped with tools to cut metal.

- **Foster the construction sector**: reinforced concrete structures that use hollow steel tubes derived from the LPG cylinders can complement the use of steel rebar rods, as shown in the section “Advantages of Concrete-Filled Steel Tubes”, thus potentially resulting in lower building costs with comparable or higher safety results.

- **Environmental**: construction using concrete structures usually “require” large amounts of steel, used as rebars and solid beams. This steel has to be fabricated from iron, which has to be extracted\(^3\) from nearby or faraway sources (mines and steel foundries), sometimes with large economical and environmental cost accumulated from the many steps (mining-transformation-transportation) required to have it available at the construction site. Steel foundries producing the steel for the rebars consume large amounts of energy (coal/coke and electricity). Recycling of the steel LPG cylinders into steel tubes that partially replace steel rebars should result in a reduced demand/consumption of steel rebars, which also means that available resources (fresh steel) can be used in higher value products.

- **Low-tech solution**: transforming the LPG cylinders into hollow steel tubes that will be welded together and/or to steel rebars is a task that can be performed using relatively inexpensive equipment (main tasks required are the cutting off the top and bottom). For an added value, the obtained hollow tubes can be welded together (and with rebars) to fabricate tubes as long as desired.

\(^3\) The author is a Mining Engineer.
The operations that has to be performed on the cylinders include:

**Classification:**

- As directly reusable or repairable for use to store LPG, repairable
- As non reusable and non-repairable
  - To be scrapped, if it’s heavily damaged (e.g. highly corroded or very deformed)
  - To be converted into (hollow) tubes.

We will focus now on the operations to be performed on the cylinders that have been classified as to be converted into tubes.

**Degassing:**

Cylinders need to be degassed. This process is already known and will not be discussed here.

**Cutting off top and bottom:**

The bottom and top parts of the cylinders are cut off, to obtain a tube. The best techniques to cut the cylinders (e.g. mechanical or other) would need to be evaluated and tested separately.

**Soldering of assemblies:**

The hollow tubes that result of cutting the top and bottom of the LPG cylinders are already a sellable item that can find uses different to the one currently proposed (as reinforces of concrete).

The metal workshop that transforms the LPG cylinders can sell the resulting hollow tubes, or can transform them into larger reinforcing structures, joining various tubes and rods, as required by its clients.
Work plan:

Actors and resources involved in the proposed solution include:

- **Providers** of the used LPG cylinders. They will fulfill the function of gathering used LPGs and classifying them (and possibly also degassing them)

- **Metal Workshop** to transform the selected LPGs cylinders into tubes, and optionally solder them together and combined with steel rods to build “cylinders and rods” structures to be sold used as concrete reinforcement. The shapes and characteristics of these steel structures can be fabricated (the tubes and rods soldered together) as custom designs for each specific construction need.

- **Arquitects**: the architect/s and/or engineers responsible for the design of a specific structure (e.g. building) would need to be aware of the particular characteristics of the steel tubes obtained from LPG cylinders (thickness and mechanical properties) to be able to include them in the structure calculation in substitution of steel bars. Because nowadays calculation of structures is done mainly with a computer and specialized Software, it seems advisable to design/integrate a software capable of using cylinders, in addition to usual rebars (rods) for the calculation of the structure.

- **Professional associations**: the use of steel tubes obtained from modified LPGs can be promoted by professional associations. These associations could also develop and give practical courses on the various tasks related to the proposed solution:
  - How to classify the LPG cylinders
  - How to degas them
  - How to transform the cylinder into a tube
  - Welding operations applied to the steel tubes
  - Calculations of structures using steel tubes as reinforcement (based in CAD/architectural software).

- **Normalization entities**: may assist by recommending or developing an Standard (ASTM or other) applicable to the use of steel tubes (derived from LPGs) as building materials.
ITEMIZED COSTS:
The solution would need to be further developed in order to define the preferred cylinder cutting methods and also tested, and if successful, promoted. All these steps have associated costs. There are various ways in which the solution could be implemented.

DEVELOP AND TEST CUTTING METHOD AT METAL WORKSHOP
A second step could be to design and test in a metal workshop various methods to convert the LPG cylinders into tubes. The selected method will take into account which metal-working tools are more widely available in developing countries.

DEVELOP AND TEST JOINING (WELDING) METHODS AT METAL WORKSHOP
Another task is to develop and test simple welding procedures to join together various steel tubes (obtained from LPG cylinders) and steel rods. Costs for this task include the services of a metalworking workshop and an educative entity. As deliverable product, an illustrated manual and/or a demonstrative video about the methods for cylinder cutting and welding of the tubes and rods would be produced. Additional educational material (preferably audiovisual) can be developed about the classification of used LPG containers and degassing.

SOFTWARE DEVELOPMENT. We suggest to develop software (or a module for existing commercial software) that will allow to calculate a structure that includes steel cylinders (from modified LPGs) as reinforcement of concrete.

DEMONSTRATIVE KIT WITH VIDEO AND CUTTING AND WELDING TOOLS.
Demonstrative kit/s can be formed that will include workshop tools required for cutting and welding of the steel cylinders. These kits, together with an illustrated (or audiovisual demonstrative video) manual can be provided to the expected users (existing or newly created local metal workshops, which could be for example local car repair facilities).

Other costs would include the promotion of the solution, local tests, language adaptation of educational material, costs of coordination activities, etc.
PROFITS:

The current price of steel rebar, which is the material that would be (partially) replace by the steel tubes obtained from the LPG cylinders is about 400 USD Tm, or about 0.4 USD Kg.

For a rough estimation, we can consider that around a 40%-60% of the steel of the empty cylinder can be recovered to be used/sold as a concrete reinforcing tube (the other 50% being the top and bottom cut-offs, sellable as steel scrap). This means that we can recover about 4-6 kgs of steel from a cylinder weighing 10 Kgs, giving each converted LPG cylinder (converted to an steel tube) (as same price as steel rebar per kg) a sell value of about 0.5×5= 2.5 USD. If we add the sellable value of the scrapped top and bottom and give it a much lower value (about 0.05 USD Kg), the total sell value of the converted cylinder plus the scrap would add to about 3 USD per transformed LPG cylinder.

This 3 USD per converted cylinder value can be considerably increased (probably at least two fold) if the steel tubes are further transformed into larger steel support structures formed by joining the steel tubes with steel rebars and supplying/selling this preformed structures to the construction site. This working method (building the steel structures at metal workshops instead of joining them at the construction site) will allow faster construction rates resulting in overall lower construction costs.

The operations of converting the cylinders into tubes and the further workshop operations of welding the tubes and cylinders at metal workshops (such as local vehicle repair facilities) is expected to result in faster building and associated lower costs in the public and private construction sector (buildings, bridges and others) which may derive into an increased economic growth of the country.

• A statement of your willingness, in principle, to work further in this opportunity and describe their expertise if they are indeed interested.

I’m an engineer, and although I’m participating in this challenge as an individual, I also own a small R&D company with partners and various associated individuals that together have the skills required to further develop this project, for example by designing software for structures calculation, design and perform the cylinder cutting tests and developing the associated educational material. We offer the participation of my company to pursue this project. Further details about ourselves cannot be provided at this stage, because of the anonymity requirements set in the Challenge.

The reference used for current Prices of rebar is www.Alibaba.com suppliers, such as:
