GRE Pipe
Green Energy that Powers the World

A Pipe Comparison Carbon Footprint Study

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"Glass-reinforced epoxy (GRE) pipe can challenge metallic piping systems in today's eco-environment due to the lower energy requirements needed for manufacturing and the lower energy use throughout the pipes' service life. In the face of global warming, the use of GRE pipe, relative to carbon steel pipe, produces less carbon dioxide in the atmosphere and thus makes it an attractive piping choice."

Climate change affects our competitive landscape in many ways. Businesses are facing higher raw material prices, rising energy costs, and increasing awareness of manufacturers' and suppliers' environmental records. Companies that manage and mitigate their exposure to climate change risks can have a competitive advantage over rivals in a carbon-constrained future, as well as being able to sustain their operations in an environmentally sensitive time.

The focus of this paper is to compare glass-reinforced epoxy (GRE) pipes with carbon steel (CS) pipes, to illustrate the relative energy necessary to manufacture and use the pipes. The critical success factors of GRE on eco-environment will be highlighted to advance the case for GRE in the marketplace.

Contents

1 Global Warming and Pipe Use

By now, almost everyone is aware of global warming and knows it is the result of the gradual warming of the earth's surface due to increasing levels of greenhouse gases (GHG) trapped within our atmosphere. Out of the four major global greenhouse gases emitted, fossil fuels such as coal, oil, and natural gas are responsible for about three-quarters of total emissions. Carbon dioxide (CO_2) is one of the main culprits. The emission of CO_2 is primarily from the combustion of fossil fuels for industrial activities. An accelerated pace of economic growth and the continuing dependency on fossil fuels are the main causes of global warming. World energy consumption at present can be seen in Figure 1. The consequence of energy production and consumption of that energy is the major source of anthropogenic GHG.

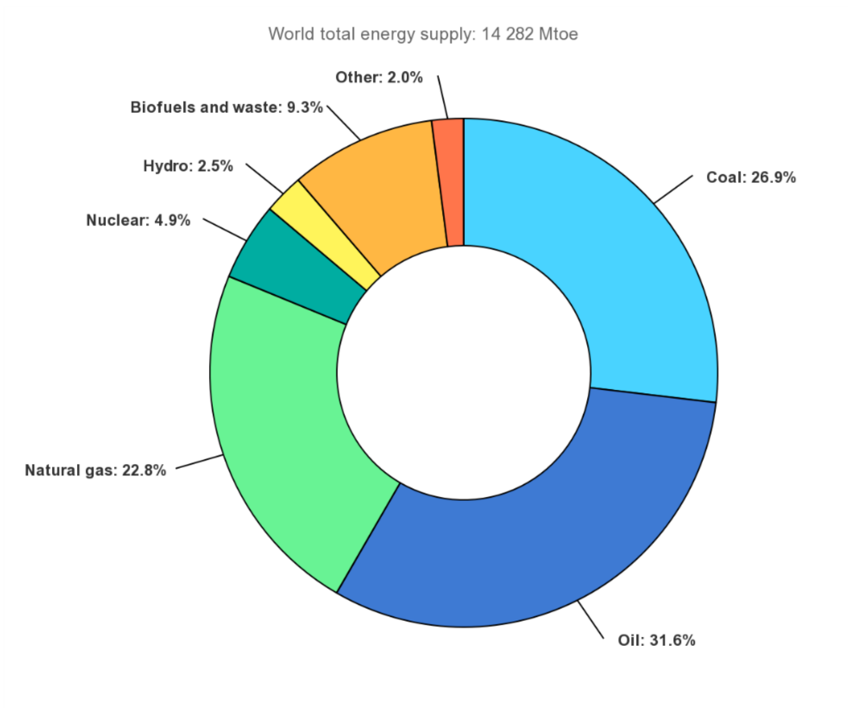


Figure 1[1]

In the pipe manufacturing industry, the process of making the pipes and piping systems requires energy. In addition, energy is consumed in the usage of pipes and piping systems. Pipes play an important role in everyday life, delivering our drinking water, supplying cooking gas, and removing our sewage. Pipes are also used industrially to transport oil, natural gas, chemicals, and industrial feed stocks. Therefore, the design of pipes and piping systems plays an equally important role in maintaining an eco-friendly environment.

[1] *Global share of total energy supply by source (2018)*

The need to address global climate change is a vital but long-term challenge confronting our planet in the twenty-first century. The characteristics of climate change create unique global challenges, necessitating an international response.

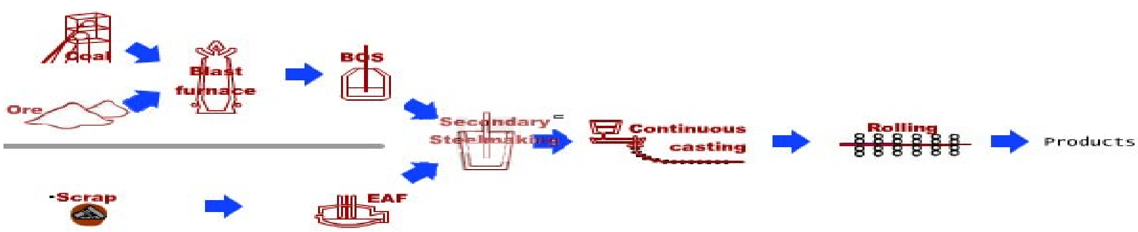
To reduce the harmful effects of CO_2 emission in the long run, it is necessary to seek alternative energy sources. Shifting to these new energy sources will take considerable time, as the technology needed is mostly in the development stages. In the meantime, companies need to do their part by becoming greener. Energy efficiency can be applied across the board, and pipe manufacturing is no exception.

2 Energy Required for GRE Versus CS Pipes

The manufacturing processes for composite pipe and metallic pipe are complex. Both processes consume and emit different levels of energy and CO_2. Raw material requirements, specifications, and manufacturing processes need to be considered when comparing GRE with CS pipes.

The majority of pipe production is CS, and it is very energy intensive to produce. CS pipes, as the name suggests, are produced by forming and welding steel plates or sheets, or by piercing a billet and rolling to the final dimension, resulting in a seamless pipe. The complex pathway to produce steel, which is also needed to produce CS pipes, is shown in Figure 2.

Figure 2 Steel Production Process[2]



[2] Source: Steel data are based on Berkeley Lab (World Best Practice Energy Intensity Values for Selected Industrial Sectors).

Today, there are two main routes to make steel. One is the conventional route, which uses blast furnace and basic oxygen furnace (BOF). The second is the modern route, which uses an electric arc furnace (EAF) and recycled steel. Both processes yield molten steel. In a series of subsequent steps, the molten steel is poured and solidified in a continuous caster, where liquid steel is cast into shapes (slabs, billets, or blooms). These semi-finished products are then transformed, or rolled, into finished products. Some of these semi-finished products undergo a heat treatment known as hot rolling. More than half the hot rolled sheets are subsequently rolled again at ambient temperatures (cold rolling).

In contrast, GRE pipes are essentially made from glass fiber roving in an epoxy resin matrix around a rotating mandrel. The glass fibers are oriented to provide the mechanical strength in the intended orientation, while the thermosetting resin provides the physical and chemical barrier of the finished product. After building the GRE pipe layer by layer, the pipe is typically cured for a few hours at temperatures between ambient and 200°C.

2.1 Density of Pipes

To illustrate the energy impact between the two materials, a common pipe was selected for comparison. A 12-in., 25-bar rated GRE 2425 pipe was compared to a schedule 40, 12-in. CS pipe. This CS pipe was selected because it also has a rated pressure of about 25 bar.[3] Schedule 80 and XXS CS pipes are also included for comparison purposes.

One material property that should be noted is the material density. This is because the weight of the pipe greatly influences the amount of energy used in its respective manufacturing. The dimensions, density, and weight of the various pipes can be found in Table 1.

Table 1 Dimensions, Density, and Weight of GRE and CS Pipes[2,4,5,6]

	GRE	Schedule		
	2425 Fiber/Resin	40	80	XXS
Nominal Diameter [cm] (in)	30.5 (12)	30.5 (12)	30.5 (12)	30.5 (12)
Pressure Rating [bar] (psi)	25 (362)	25.5 (370)	33.7 (490)	87.6 (1270)
O.D. [cm] (in)	33.05 (13.01)	32.39 (12.75)	32.39 (12.75)	32.39 (12.75)
I.D. [cm] (in)	31.37 (12.35)	30.33 (11.94)	28.89 (11.37)	27.31 (10.75)
Wall Thickness [cm] (in)	0.84 (0.33)	1.03 (0.406)	1.75 (0.688)	2.54 (1.00)
Area [cm^2] (in^2)	85.0 (13.1)	101.6 (15.7)	168.3 (26.1)	238.2 (36.9)
Density [g/cm^3] (lbs/in^3)	2.6/1.19 (0.09/0.043)	7.85 (0.284)		
Weight [Tonnes/km] (lbs/in)	18.5 (1.04)	79.7 (4.46)	132.1 (7.41)	187.0 (10.5)

It should be noted that the weight of the GRE pipe is based on a nominal 70% fiberglass content.

3 *Wrought Steel Pipe – Bursting Pressures* (2008)

4 *Pipe Schedules* (June 2019)

5 *Fiberglass Systems* (June 2017)

6 *Metals Handbook Desk Edition* (1998)

2.2 Energy of Pipe Production

The processes used in transforming raw or intermediate materials into final products require different energy levels. Table 2 shows the energy that is needed to produce a kilometer of each pipe as well as the subsequent CO_2 emission.

Table 2 Primary Energy Requirements and Specifications for GRE Versus Carbon Steel Pipe Production

	GRE	Schedule		
	2425	40 {BOF/EAF}	80 {BOF/EAF}	XXS {BOF/EAF}
Raw Material Energy [GJ/km] (kwh/in)	432 (3.05)	N/A	N/A	N/A
Manufacturing Energy [GJ/km] (kwh/in)	99.9 (0.705)	N/A	N/A	N/A
Total Energy [GJ/km] (kwh/in)	532 (3.75)	769 (5.42) {864/524}	1275 (9.00) {1433/868}	1804 (12.7) {2028/1228}
Total Emissions [Tonnes CO2/km] (lbs CO2/in)	104 (5.82)	151 (8.46) {170/103}	250 (14.0) {281/170}	354 (19.8) {398/241}

To calculate these values, two different methods were used. For CS pipe, the CO_2 emissions per metric ton of steel, along with the weight of each pipe per kilometer, were used. For GRE pipe, the energy to produce the raw material and convert to the finished pipe, along with the weight of the pipe per kilometer, were used. To convert between energy and emissions the conversion factor of $7.07 * 10^{-4}$ [Metric tons CO_2/kWh] was used.[7]

There are two different amounts of CO_2 emitted, depending on the process of how the CS pipe is made. Using the BOF method, 2.13 tons of CO_2 are emitted per ton of steel.[6] For the EAF method, only 1.29 tons of CO_2 are emitted per ton of steel.[8] To get an estimate of the energy and emission of CO_2 in CS pipe production, a weighted average of the two methods was used. This average was calculated assuming 71% of steel is produced using BOF.[9]

The energy required to make GRE pipes was split into two sections. The first part was the energy required to produce resin and fiberglass. It takes about 32.5 gigajoules to produce one metric ton of the liquid epoxy resin and fiberglass.[10] The second part was the energy used to manufacture the pipe from the raw materials. This was determined by studying energy usage of several manufacturing locations versus the amount of material produced. It was found that it takes about 5.4 gigajoules to manufacture one metric ton of pipe.

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[7] *AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2018 data (2019)*

[8] *Inventory of Carbon and Energy* (2019)

[9] *BOF and EAF Steels: What are the Differences?* (March 2016)

[10] *Bandwidth Study U.S. Glass Fiber Reinforced Polymer Manufacturing* (September 2017)

When the weight of the pipe was factored into the above values, the energy consumption and emission of CO_2 per kilometer of pipe had significantly different levels. It was found that GRE pipes take about 31% less energy to produce and subsequently produce about 31% less CO_2 than schedule 40 CSP.
In all cases, GRE pipe has a substantial advantage in terms of energy consumption, because it helps companies reduce their carbon footprint, whereas CS pipe does not.

3 Life Cycle Energy Balance

Besides consuming energy in manufacturing, piping systems consume energy while in service. Understanding the overall energy consumption during a piping system's life cycle helps one understand the extent of the benefit of GRE. The more fossil energy required to produce a product, the less desirable the product.

3.1 Pumping Energy Savings of GRE Versus CSP

When considering energy use in operations, the obtained savings or wastages become a crucial ecological and economical factor. With energy savings throughout its life cycle, the GRE pumping system benefits make it the energy saving choice.

The environmental impact of GRE and CS pipe can be evaluated based on the energy requirements to pump any liquid (e.g., water) through the system. A comparison of their energy saving capabilities will help to evaluate the material within its operation.

Assuming a 12-in. line is delivering 646,000 gallons of water (density of 8.34 lb/gal) per day, the energy usage per mile of pipe can be determined. This assumes the typical flow rate of about 10 ft per second to avoid erosion.

The Hazen-Williams "C" factor over a 10-year service life for GRE and CS pipe is 150 and 100, respectively.[11] Equations 1 and 2 are used to calculate the energy demand for a flow through a pipe.[12]

Equation 1 Hazen-Williams Friction Loss[12]

$$H_L = 10.46L\left(\frac{flow\ rate}{CID^{2.63}}\right)^{1.852}$$

Equation 2 Horsepower Requirement[12]

$$HP = \frac{flow\ rate\ [gpm]*8.34[\frac{lb}{gal}]*H_L[ft]}{33{,}000\ [\frac{ft*lb*hp}{min}]}$$

[11] Hazen-Williams Coefficients Table (December 2014)

[12] *Fiberglass Pipe Design* (2005)

Using Equation 1 and 2, the horsepower demand for a 12-in. GRE piping system is about 40% that of a 12-in. CS schedule 40 piping system. Assuming 80% pump efficiency on a 1-year full-time operation, the energy required can be calculated using Equation 3.

Equation 3 Energy Requirements for Full Time Operation[12]

$$\frac{hp * 24[\frac{hr}{day}] * 365[\frac{day}{year}]}{0.8\ (efficiency)} = hp - hr/year$$

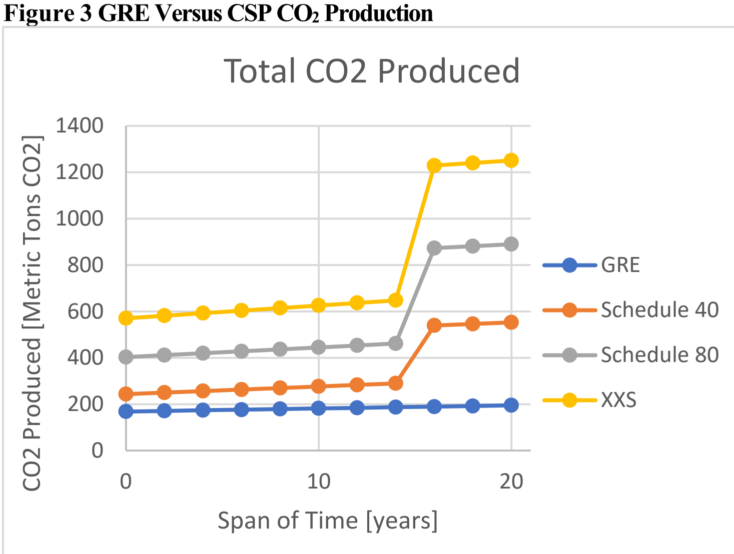
Using Equation 3, the GRE pipe would take about 2,515 [hp-hr/year] (6.75 [GJ/year]), whereas the schedule 40 pipe would take about 6,282 [hp-hr/year] (16.9 [GJ/year]).

3.2 Life Cycle of 20-Year Project

The examination of CO_2 emissions requires a look into life-cycle energy analysis. The life-cycle energy balance is one of many considerations when selecting the most suitable piping system. It quantifies the total energy demands and the overall energy efficiencies of the processes and products. The life-cycle efficiency estimates help to determine how much additional energy must be expended in a pipe's life cycle for it to become a useful operational product. Incidentally, a saving or wastage criterion for composite versus metallic piping systems is put into place.

Take the example of a 20-year water transmission pipeline project with the same system mentioned in the previous section. Figure 3 shows that the emissions for GRE pipe are significantly less than that of CS pipe. Using a GRE piping system instead of a CS piping system will result in 65% less emissions.

Figure 3 GRE Versus CSP CO_2 Production



This is due to the limited life of carbon steel (e.g., in corrosive environments). Because CS pipe systems will need to be replaced at least once before the end of the field life, there are higher operating expenditures and replacement costs.[13,14] Because GRE requires a smaller amount of fossil energy, substituting GRE for CS pipe is beneficial for applications requiring long service life.

4 Effects of Weight of Pipe Systems

Something else to consider when focusing on the environmental impact of GRE versus CS is weight. As seen in section 2, CS is significantly heavier. In fact, 2425 GRE is about 23% the weight of a schedule 40 CS pipe. This is important because weight directly influences the amount of emissions produced when transporting material.

4.1 Transporting Pipes Via Trucks

Trucks are commonly used when transporting piping inland. The effects of the weight discrepancy between the two types of pipe causes a substantial difference in CO_2 emissions. To further understand the varying emission levels, a standard US semi-truck with a flatbed trailer will be used as an example of transportation.

There are two different methods to show the difference in emissions. The first method is when only weight is a consideration and the overall dimensions of the load are neglected. The only consideration, in this scenario, is the permitted cargo load of 48,000 lb.[15] Using the weight per kilometer of each pipe (see section 2), the truck would be able to hold 1.18 kilometers and 0.273 kilometers of GRE and CS piping, respectively. When only considering the weight, the CS piping would need to have approximately 4.32 times the number of trips to deliver the same system.

Using the 12-in, 25 bar piping system as an example, if a system with a line length of 1 mile needs to be delivered, two loads of GRE and six loads of CS will need to be transported. All but one load of each type will be at the maximum cargo weight of 48,000 lb. Using the average truck emissions factor of 161.8 grams of CO_2 per short ton-mile, it was found that CS delivery would emit 0.0458 metric tons of CO_2 per mile, while the GRE delivery would only emit 0.0106 metric tons of CO_2 per mile.[16] Therefore, using a GRE piping system instead of a CS piping system will result in about 77% less CO_2 emitted into the atmosphere during transportation.

The second limitation to consider is the permitted dimensions of the load, along with the weight. For a standard flatbed trailer, the total load dimensions can be 53 x 8.5 x 8.5 ft.[15] Using the outside diameters of the pipes (see section 2), an allowable amount of pipe per truck can be determined. A trailer could fit seven

[13] *Process Piping Materials* (n.d.)

[14] *Corrosion Prediction for Corrosion Rate of Carbon Steel in Oil and Gas Environment* (2018)

[15] *Types of Semi Trailers* (2020)

[16] *Green Freight Math: How to Calculate Emissions for a Truck Move* (2015)

rows and seven columns of pipe. Approximately 0.79 kilometers (0.49 miles) of piping would fit on a trailer. CS pipe will exceed the weight limit, which will be reached at 0.273 kilometers (0.169 miles) of piping, before reaching this dimensional limit. The dimensional limit does make a difference for the GRE piping. Because the amount of pipe that will fit within these dimensions is smaller than the weight previously discussed, it can increase the number of loads.

In fact, the 1-mile line length would require an additional load. There are still three less loads required than with CS pipe, though. Along with that, because each of the GRE loads would be lighter than the maximum allowable load, the emissions of each trip will lower, causing it to emit the same amount of CO_2 as before.

With both weight and dimensional limitations considered, transporting GRE piping will reduce the amount of CO_2 emitted by about 77% compared to CS pipe.

4.2 Piping Systems in Ships

The weight savings of an onboard piping system can also greatly influence the emission of CO_2. In 2015, the shipping industry contributed about 3% (932 million metric tons) of the total annual emissions of CO_2,[17] making the shipping industry the sixth largest contributor when compared to all countries.[17] One way that this number can be reduced is by changing the weight of the ship. This can be done by replacing any CS piping systems with GRE. The savings related to fiberglass pipes use in the container shipping industry was examined. Container shipping is the biggest contributor of CO_2 in the shipping industry, at 23% of the emissions (214.36 million metric tons).[17]

First, the weight saving capabilities need to be estimated. A recent study showed that replacing only five seawater piping systems lead to 23-ton weight savings when compared to schedule 40 CS pipe.[18] To put the potential weight savings into perspective, there are more than 80 different piping systems on a ship.[19] The average deadweight of a container ship is about 40,000 metric tons.[20] With a deadweight-to-displacement ratio of 3:5, the average displacement is about 66,500 metric tons.[21] The displacement of the T45 ship used in the study is only 7350 metric tons, making the average container ship approximately 5.42 times the weight.[22] This suggests that the weight of all the piping systems would be significantly higher as well. Although the weight savings may be much greater for container ships than those used in the study, a savings of 23 tons will be used for this example.

[17] *Greenhouse Gas Emissions from Global Shipping, 2013–2015* (2017)
[18] *6 New Royal Navy Type 45 Anti-Air Warfare Destroyers*
[19] *The Great Soviet Encyclopedia, 3rd Edition. (1970-1979).*
[20] *Review of Maritime Transport (2011)*
[21] *SMK 3522 SHIP DESIGN I (2013)*
[22] *Daring Class (n.d.)*

To calculate the effects of this weight change, Equation 4 will be used.

Equation 4 Fuel Consumption of a Ship[23]

$$\frac{Fuel\ Consumption}{day} = \lambda v^3 \nabla^{\frac{2}{3}}$$

Where λ is a constant, v is the speed, and ∇ is the displacement weight of the ship. Since the only factor that is changing between the two piping systems is the weight, a relationship between weight and fuel consumption can be formed. Since fuel consumption directly relates to emissions, the amount of decreased emission can be estimated.[24] Given the previous relationships, the annual emissions of the container ship industry, the average weight of a container ship, and 23 tons of weight savings, the emissions would be reduced by approximately 49,000 metric tons of CO_2 per year. When considering the drastic weight difference between the T45 and the average container ship, along with the possibility of replacing all piping systems, these emission savings would be even greater.

5 Carbon Sink Effect

Carbon sink is a repository of organic carbon in the environment. The increase in anthropogenic carbon, caused by the higher demand of fossil energy, is so extensive that the natural carbon cycle becomes imbalanced. The terrestrial ecosystem (e.g., forests, oceans, soils), known as the natural carbon repository, stores carbon instead of allowing it to be present in the atmosphere as a GHG.

In the natural ecological carbon-cycle, trees are a means to help reduce atmospheric carbon by removing it from the atmosphere and storing the carbon in its tissue. This sequestration gives trees a status of “carbon sink”.

Along with natural carbon repositories, artificial methods of carbon capture and sequestration can be a solution to decrease CO_2 emissions. One method is to permanently store sequestered CO_2 in finished products.[25] Storing CO_2 in various products will prevent the CO_2 from entering the atmosphere and exacerbating the greenhouse effect.

With its specific composition of material, GRE piping systems are made of 70% glass and 30% resin. Resin is composed of 74% carbon by weight. This means GRE piping systems have approximately 22% carbon content. This is important to note since the GRE resin is made from crude oil sources. Although, this does not make GRE pipe production a technical sinking method, it does lock up carbon in a permanent product and prevents it from potentially becoming carbon dioxide in a combustion cycle. Hence, GRE pipes allow us to return carbon into the ground by storing the carbon in the finished product during its service life.

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[23] *Ship design and performance for masters and mates (2004)*

[24] *Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations*

[25] *Putting CO2 to Use (2019)*

On the other hand, CS pipes only have approximately 0.3% carbon by weight and principally add more carbon to the atmosphere when fossil fuels are burned to make steel. Since pipes are essential needs in an industrial society, it is best to have as close to a carbon neutral product as possible. In short, the GRE pipe function is partly like a tree in the context of carbon storage. Thus making GRE pipes a candidate material to serve a "carbon sink" role.

6 Conclusions

As mentioned earlier, the consumption of fossil fuel is the main cause of global warming However, in the wake of industrialization, the use of fossil fuel has become a necessity, especially when there is not a viable alternative. While popular belief in greener manufacturing means finding more energy-efficient ways to produce goods, many people are unaware of the fact that energy efficiency also needs to be considered in the use of the product. When we talk about pipe manufacturing, there is a distinct difference between the total energy required to make and maintain GRE pipes versus pipes made from CS.

This paper highlighted three advantages of GRE piping systems over CS piping systems with regards to limiting climate change. They were:

1. Energy Use in Manufacturing

On a per kilometer basis, GRE piping systems require 31% less energy to produce than that made from CS.

2. Energy Use in Operation

GRE can produce 65% energy savings throughout a 20-year life cycle. This is due to the smaller amount of energy required to manufacture, a smoother inner pipe surface which significantly reduces the pumping energy required, and the corrosion-resistant nature of GRE.

3. Effects of Weight of Piping System

Due to the lightweight nature of GRE pipes, the emissions caused by travel can be greatly reduced. While shipping pipe via semi-trucks, GRE can reduce the CO_2 emissions by up to 77%. Along with this, changing current container ship piping systems to fiberglass can reduce the annual CO_2 emission by 49,000 tons at a minimum.

4. Carbon Sequestration Effect

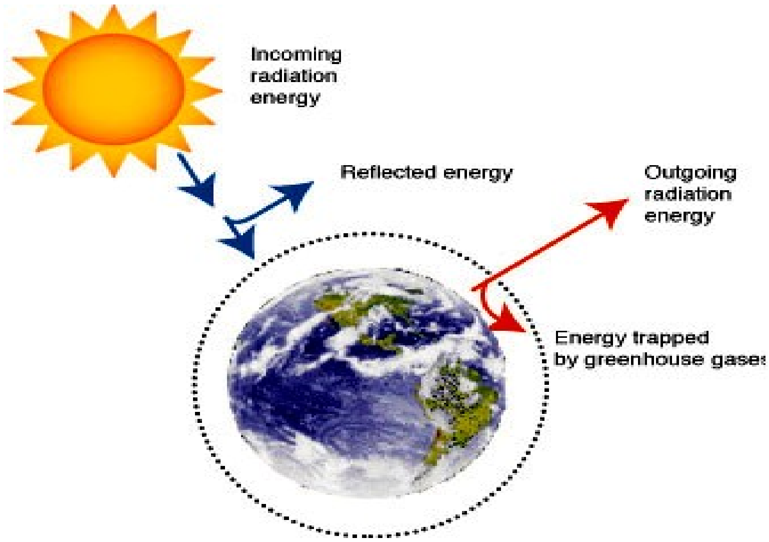
The carbon stored in GRE piping systems prevents the same carbon from being emitted into the atmosphere as CO_2 and causing the greenhouse effect.

Interestingly, one might think that an industrial man-made product produced from a natural material like iron should be more eco-friendly. On the contrary, it is a proven fact that steel piping systems create more harm to the earth and have a shorter life span than GRE piping systems. Hence, GRE is an effective alternative to reduce the environmental impact of industrialization.

<u>APPENDIX</u>

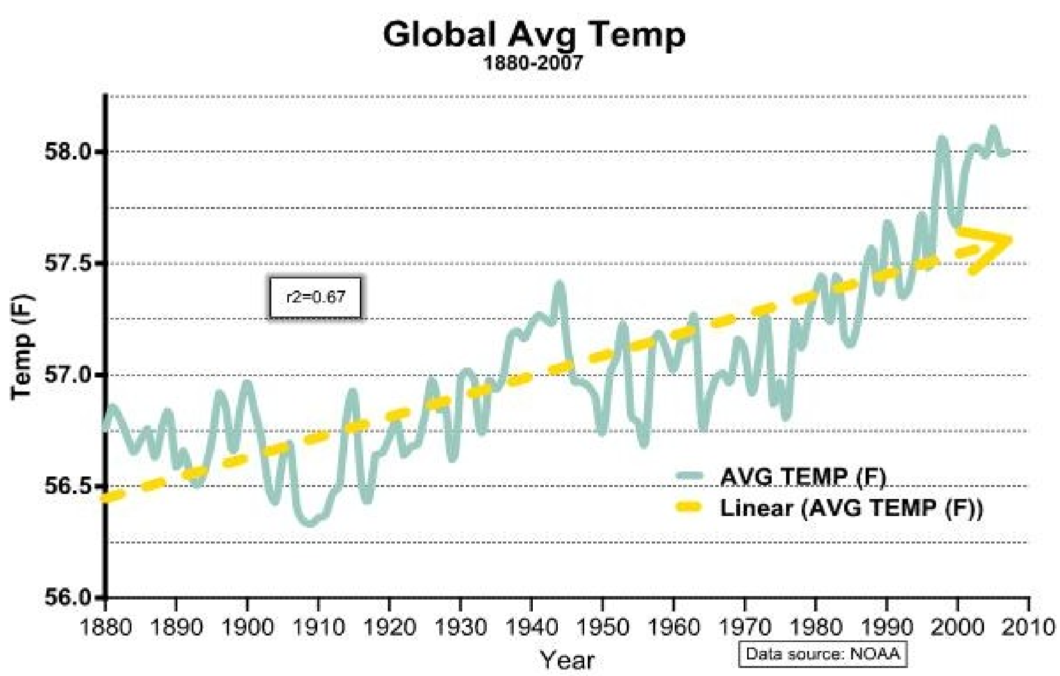
<u>1.</u>

Earth Greenhouse Effect



<u>2.</u>

Global Mean Temperature Over Land and Ocean



Source: NCDC/NESDIS/NOAA

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