GF Piping Systems

Marine

Efficiency boost for passenger ships

How pre-insulated plastic piping systems help to reduce CO_2-emissions and costs for shipowners and operators.

Abstract

The right material for the job

Why pre-insulated polyethylene pipes in air conditioning chilled water systems make passenger ships more efficient

How can shipbuilders reduce fuel consumption and greenhouse gas emissions, while saving costs at the same time? The entire maritime sector is currently facing this question, as the pressure rises to make shipping more sustainable. While the biggest challenge in the long term is the development of carbon-neutral fuels, shipowners and shipbuilders also need effective solutions that can be implemented today. In this context, one area particularly suited for improvement is HVAC on passenger ships: These systems are highly energy intensive and require extensive piping networks that are traditionally made of post-insulated steel - a heavy material that is susceptible to corrosion and requires frequent maintenance due to the degradation of the rubber cell insulation material. Modern pre-insulated plastic piping systems, on the other hand, overcome the many problems of steel: They are light, durable, efficient as well as cost-effective. These properties mean that this comparatively small optimization onboard ships has the potential to noticeably reduce their carbon footprint.

In 2021 GF Piping Systems, the leading flow solutions provider worldwide, and Foreship, the internationally renowned ship design and engineering company, collaborated on an energy efficiency study that verifies these claims. Basing their calculations on a 150.000 GT cruise ship, the partners analyzed the performance of different piping solutions in an air conditioning chilled water system. The main focus of the study was a comparison between a baseline steel post-insulated piping system and the pre-insulated COOL-FIT 2.0 and 4.0 systems by GF Piping Systems. The simulated piping networks had a total length of approximately 600 meters.

The study consisted of three phases: During the first phase, the performance of the two piping systems was measured by comparing the electrical power draw of the chillers and pumps within the air conditioning system. In the second phase, these results were used to calculate fuel savings, emissions reductions and cost-effectiveness. Finally, the study quantified the effect of these savings on the Energy Efficiency Existing Ship Design Index (EEXI) and the Carbon Intensity Indicator (CII).

GF Piping Systems and Foreship were able to show that pre-insulated plastic piping systems do indeed have significant benefits over traditional steel systems. Due to better insulation and material properties, COOL-FIT could operate at a lower pressure and experienced less temperature rise.

This increased efficiency led to improvements in the key areas of fuel consumption, GHG emissions, cost-effectiveness and IMO indices. In the simulation, the 150.000 GT cruise ship was able to save between 80 and 112 metric tons of fuel every year and reduce the estimated total annual greenhouse gas emissions of around 175.455 m tons by up to 351 m tons - these are improvements of around 0,2% compared to steel. Financially, COOL-FIT can save around $2,3 million over the course of 25 years – or up to $3,8 million when taking into account that COOL-FIT is maintenance-free. Finally, COOL-FIT had small, but measurable impacts on both EEXI and CII, showing that marginal improvements such as piping material can have positive overall effects, especially when they are part of a larger optimization strategy.

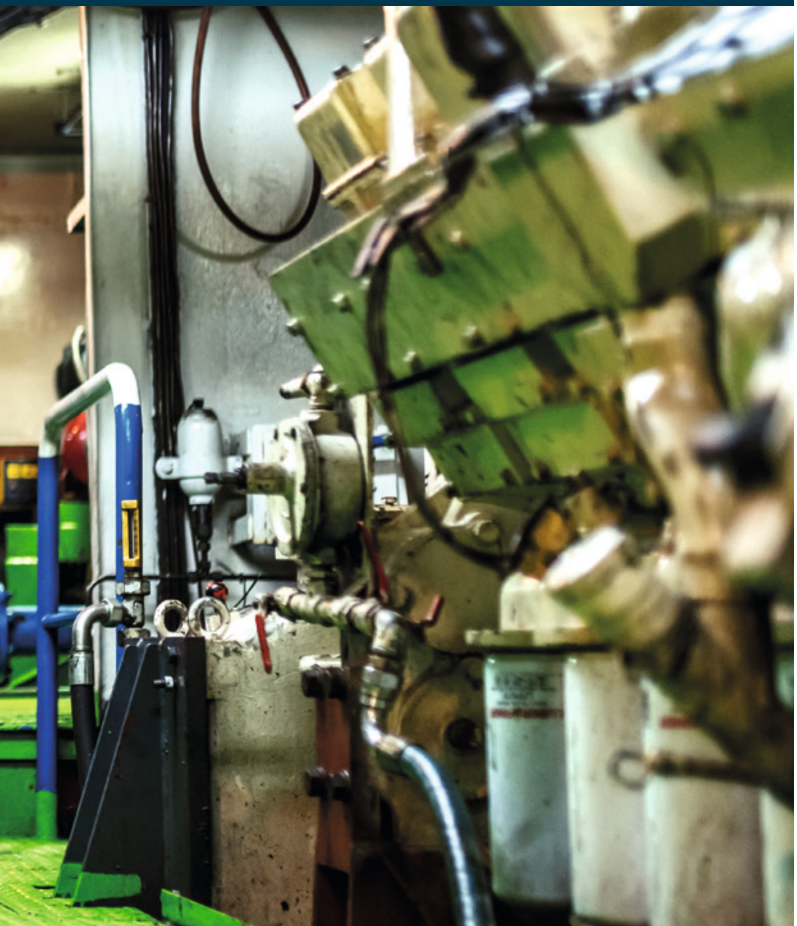

Table of content

Contents

Abstract 2
- The right material for the job

Sustainability 4
- The challenges facing the global maritime industry

What does the future hold 5
- Pre-insulated plastic vs. post-insulated steel

The Study Design 6

Question 1 8
- Polyethylene vs. steel
  Which configuration performs best?

Question 2 10
- How much energy can plastic piping systems save?

Question 3 13
- Can pre-insulated plastic piping systems impact EEXI and CII values?

The Results 14
- Better performance, higher efficiency, lower costs

Summary 18
- How can GF Piping Systems help you?

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The challenges facing the global maritime industry

How can shipbuilders and shipowners lower their CO_2 emissions while saving fuel and lowering costs at the same time?

The biggest long-term challenge facing the maritime sector is sustainability. Currently, international shipping causes around one billion tons of CO_2 each year, or 2,5% of global greenhouse gas emissions. If the sector were a country, this would make it the sixth largest emitter in the world – slotting in between Japan and Germany in fifth and seventh place respectively. As a result, more and more international standards require shipbuilders, owners and dockyards to find solutions that reduce greenhouse gas (GHG) emissions as quickly as possible.

Several of the most important guidelines for achieving this goal are defined by the International Maritime Organization (IMO) who's strategy stipulates, among other things, that the marine industry must reduce annual GHG emissions by at least 50% by the year 2050, compared to 2008. In order to achieve this goal, the IMO has put a number of guidelines in place. The first is the "Energy Efficiency Design Index" (EEDI), introduced in 2011, which is aimed at new ships. EEDI establishes an energy efficiency level per capacity mile, or grams of CO_2 per ton-mile.

The second guideline is the Energy Efficiency Existing Ship Index (EEXI) which aims to improve the efficiency of maintenance-free, and cheaper ships. In addition, the Carbon Intensity Indicator (CII) is another important factor, as the IMO strategy states that the carbon intensity of ships (the CO_2 emissions per transport work) should be reduced by at least 40% by the year 2030. Crucially however, these guidelines are only focused on the end result – as long as the required energy efficiency level is met, shipowners, shipbuilders and dockyards are free to find their own technical solutions for their application.

On the one hand this means that engineers and technicians can express their creativity with new and innovative ship designs. But at the same time, they also have to rely on their many suppliers to develop cutting-edge technical solutions. As a result, the combined goals of sustainability, efficiency and financial viability have to be the main focus of every manufacturer that contributes components during the build process.

Pre-insulated plastic vs. post-insulated steel

In the context of energy efficiency, the piping systems onboard ships play an important role. However, many of the systems onboard large vessels such as cruise ships are still made of steel. This material has a number of crucial drawbacks as it is energy-intensive to produce, heavy, and susceptible to corrosion. These properties mean that the use of steel negatively affects the overall weight of the vessel which in turn has a negative effect on fuel efficiency, GHG emissions as well as operational and maintenance costs. In addition, these metal piping systems are often post-insulated with a rubber-based foam. During the post-insulation process there is a risk of human error, as the rubber cell is delicate and can easily be damaged. Further complications can arise when gaps form between the pipe and insulation material, leading to the formation of ice and condensation. This condensation is then often absorbed by the foam which deteriorates and loses its thermal insulation properties. In extreme cases, the formation of ice can also damage components such as valves, which impacts the functionality of the piping system.

Plastic piping systems, on the other hand, negate many of these shortcomings. The various forms of plastic currently available offer significant improvements compared to steel. This already becomes apparent in the production process, as materials such as polyethylene require less energy to make and are recyclable. Furthermore, plastics are lightweight, corrosion- and maintenance-free as well as cheaper. Cutting edge pre-insulation technologies and smoother surfaces also make this type of piping system more efficient. On ships, where every detail matters on the path to more sustainability, plastic piping solutions therefore have the potential to significantly improve the overall efficiency of the vessel while simultaneously reducing costs.

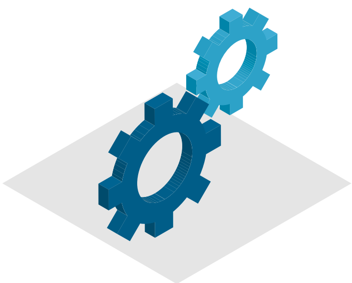
The Study Design

The Study Design

In 2021, GF Piping Systems, the Swiss expert for plastic piping systems, and Foreship, a company consisting of international ship designers and engineers, decided to conduct a joint energy efficiency study.
The goal: To quantify the benefits of plastic piping solutions onboard large ships. Together, the partners determined the parameters of the study as follows:

1. The Ship

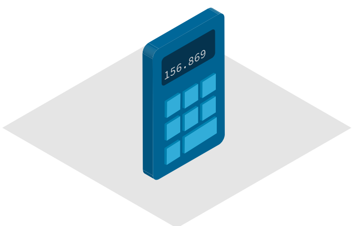
Passenger ships rely heavily on many different piping systems with functions such as water and wastewater transport, or HVAC. On very large vessels like cruise ships, the expansive network of pipes reaches a combined length of several hundred kilometers. Therefore, a 150.000 GT cruise ship was chosen as a basis for the study, as the cruise industry stands to gain most from more efficient piping solutions.



2. The System

On passenger ships in general, and cruise ships in particular, HVAC plays an important role within the piping systems onboard. On the one hand, HVAC adds comfort and a more luxurious experience for passengers, especially in the many popular tropical locations visited by cruise ships. On the other hand, HVAC is a highly energy intensive system that impacts both fuel consumption and GHG emissions.

For this reason, the decision was made to compare plastic and steel piping as part of a simulated air conditioning chilled water system. The piping systems chosen for the study were the pre-insulated COOL-FIT 2.0 and 4.0 by GF Piping Systems and a baseline post-insulated steel system. With a length of around 600 meters, the systems were modelled with four chiller units and four centrifugal supply pumps.



3. The Calculations

In an effort to obtain the best possible results in the comparison between plastic and steel piping systems in air conditioning chilled water systems onboard cruise ships, Foreship divided the calculations into three steps:

- Comparing the performance of the piping systems in the HVAC application
- Determining the overall energy savings for the ship
- Determining the effects on the EEXI and CII indices

Question 1

Polyethylene vs. steel

Which configuration performs best?

Pressure drops within the piping network

In order to make the pressure comparison between plastic and steel as meaningful as possible, calculations were based on pressure drops from the pumps to the furthest Air Handling Unit (AHU). Due to the system being a closed loop, the return side from the AHU cooling coil back to the chiller unit was also considered.

$$\Delta_{p\ total}\ [pa] = \Delta_{p\ friction} + \Delta_{p\ fitting}$$

Pump power

The second important parameter within the study was the power required to run the pumps in the HVAC system, both in constant flow and variable flow. During constant flow, the pumps continuously run at full speed. In this scenario, the AHU is equipped with a three-way valve which diverts surplus chilled water back to the chiller. During variable flow, the pumps run according to the demands of the cooling coil of the AHU and the flow is directly proportional to the enthalpy of the air before and after the cooling coil. The calculations also took head of pump and pump shaft power into account.

$$H_{dyn}\ [m] = \frac{\Delta_{p\ total}\ [pa]}{\rho \left[\frac{kg}{m^3}\right] * g \left[\frac{m}{s^2}\right]}$$

$$P_{Shaft}\ [W] = \frac{Q_v \left[\frac{m^3}{s}\right] * \rho \left[\frac{kg}{m^3}\right] * g \left[\frac{m}{s^2}\right] * H\ [m]}{\eta}$$

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Question 1

Temperature

Temperature rises of the chilled water were calculated at three points from the chiller unit to the AHU cooling coil and back. The cooling coils in question were located furthest, mid-range and closest in relation to the chiller units. The temperature rises were calculated both during constant and variable flow. For the final results, the average temperature rise across the locations was used.

$$\Delta T_{H_2O}\,[°C] = (T_v - T_s)\,[°C] * e - \frac{U'\left[\frac{W}{mK}\right] * L\,[m]}{C\left[\frac{W}{°C}\right]} - \Delta T_0\,[°C]$$

Heat load by the surrounding environment

$$\Phi\,[kW] = Q_v\left[\frac{m^3}{s}\right] * \rho\left[\frac{kg}{m^3}\right] * \Delta T_{H_2O}\,[°C] * C_p\left[\frac{kJ}{kg°C}\right]$$

Electrical power reduction, where COP of 6.0 was used as annual average for the chillers.

$$P_{chiller}\,[kW] = \frac{\Phi\,[kW]}{COP_{chiller}}$$

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Question 2

How much energy can plastic piping systems save?

All savings were calculated according to six scenarios:

Scenario	Description of energy savings
Original	MGO ship base line
with constant flow pump	Constant flow AC-chilled water pumps and AC-chillers
with variable flow pump	Variable flow AC-chilled water pumps and AC-chillers
Original	LNG ship flow line
with constant flow pump	Constant flow AC-chilled water pumps and AC-chillers
with variable flow pump	Variable flow AC-chilled water pumps and AC-chillers

Constant Flow =
The pumps continuously run at full speed

Variable Flow =
The pumps run according to the demands of the cooling coil of the AHU

Question 2

Energy Savings

The calculations for energy savings considered both water pump and chiller power consumption on an annual basis.

$$E_{\text{savings total}} = (P_{\text{reduction, pumps}} + P_{\text{reduction, chillers}})\ [MW] * \left[\frac{8760h}{a}\right] = \left[\frac{MWh}{a}\right]$$

Fuel Savings

The consumption of marine gas oil (MGO) and liquefied natural gas (LNG) was modeled using an average specific fuel consumption (SFC), specific gas consumption (SGC) and specific pilot fuel consumption (SPFC) for a 4-stroke medium speed engine.

$$m_{\text{MGO fuel}} = \frac{E_{\text{saving}} \left[\frac{MWh}{a}\right] * 1000 * SFC \left[\frac{g}{kWh}\right]}{10^6} = \left[\frac{m\ ton}{a}\right]$$

$$m_{\text{LNG fuel}} = \frac{E_{\text{saving}} \left[\frac{MWh}{a}\right] * 1000 * SGC \left[\frac{g}{kWh}\right] + E_{\text{saving}} \left[\frac{MWh}{a}\right] * 1000 * SPFC \left[\frac{g}{kWh}\right]}{10^6} = \left[\frac{m\ ton}{a}\right]$$

Question 2

Financial Savings

Potential financial savings were determined using average prices for both MGO and LNG between April and September 2021 at the port of Rotterdam. Using this data, the study determined the financial savings on an annual basis.

$$USD_{savings} = LNG_{saving}\left[\frac{m\ ton}{a}\right] * LNG_{corr.}\left[\frac{\$}{mt}\right] + MGO_{saved}\left[\frac{m\ ton}{a}\right] * MGO_{price}\left[\frac{\$}{mt}\right] = \left[\frac{\$}{a}\right]$$

Emissions Savings

The reduction of greenhouse gas (GHG) emissions was determined using Well-to-Wake (WtW) analysis which looks at the entire life-cycle of the MGO and LNG fuels considered in the study. In addition, emissions such as Nitrogen Oxide (NOX), Sulphur Oxide (SOX) and Particulate Matter (PM) were included in the calculations.

Well to Tank (WtT)

$$CO_2\left[\frac{ton}{a}\right] = \frac{\text{Fuel savings}\left[\frac{kg}{a}\right] * \text{Lower Heating Value}\left[\frac{MJ}{kg}\right] * CO_2\ \text{Well to Tank}\left[\frac{g\ CO_2\ eq}{MJ}\right]}{10^6}$$

Tank to Wake (TtW)

$$CO_2\left[\frac{ton}{a}\right] = \text{Fuel savings}\left[\frac{ton}{a}\right] * \text{Carbon Factor}\left[\frac{g\ CO_2}{g\ fuel}\right] = \left[\frac{m\ ton}{a}\right]$$

$$\text{Methane Slip} = \left(\frac{E_{savings}\left[\frac{kWh}{a}\right] * \text{Methane Slip}\left[\frac{g}{kWh}\right]}{10^6}\right) \text{Methane } CO_{2e}\ \text{factor} = \left[\frac{ton}{a}\ CO_{2e}\right]$$

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Question 3

Can pre-insulated plastic piping systems impact EEXI and CII values?

EEXI

As of January 2023, the Energy Efficiency Design Index for Existing Ships (EEXI) will go into effect in accordance with IMO guidelines. As a result, the study took CO_2 emissions per ship capacity-nautical mile into account.

$$\frac{\left[\prod_{i=1}^{M} fi\right]\left[\sum_{i=1}^{nME} P_{ME\,(i)} * C_{FME\,(i)} * SFC_{ME(i)}\right] + (P_{AE} * C_{FAE} * SFC_{AE}) + \left\{\left[\prod_{i=1}^{M} fi * \sum_{i=1}^{nPTI} P_{MTT\,(i)} - \sum_{i=1}^{neff} f_{eff\,(i)} * P_{AEeff\,(i)}\right] * C_{FAE} * SFC_{AE}\right\} - \left[\sum_{i=1}^{neff} f_{eff\,(i)} * P_{MTT\,(i)} * C_{FME} * SFC_{ME}\right]}{f_i * f_e * f_i * Capacity * V_{ref} * f_w}$$

CII

Along with the EEXI, the Carbon Intensity Indicator (CII) also comes into effect in January 2023. In an effort to encourage the development of new technologies and sustainable fuels, the Carbon Intensity Indicator is designed to lower GHG emissions on ships. The indicator is calculated by considering the actual fuel consumption and the distance travelled by a ship on an annual basis. For this study, a seven-night cruise profile in the Caribbean Sea with a length of around 2.000 n.m. was simulated.

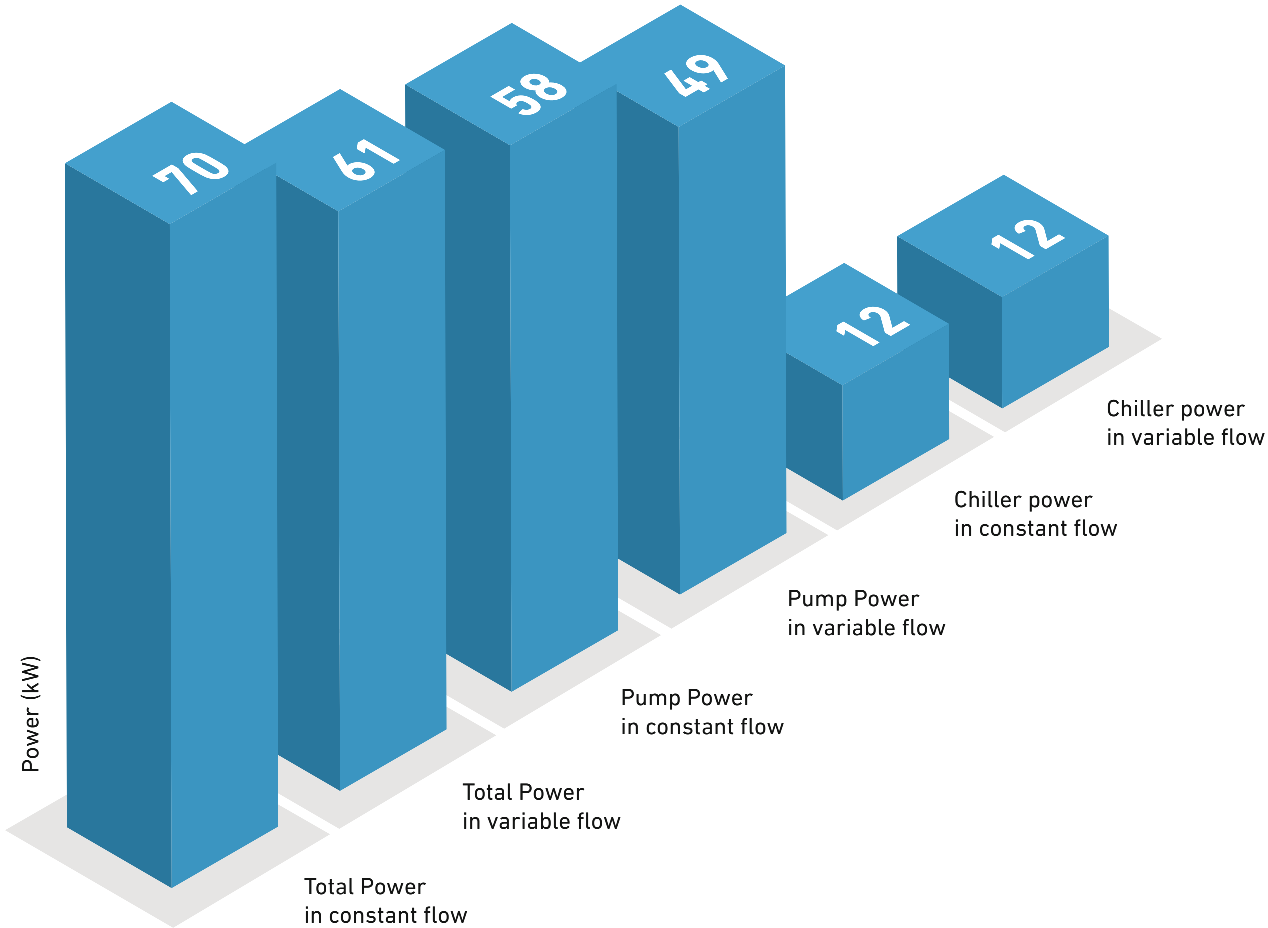
$$CII = \frac{\sum\left(\text{each fuel type consumed [m ton]} * \text{carbon factor acc. fuel}\left[\frac{\text{g } CO_2}{\text{g fuel}}\right]\right)}{\sum\left(\text{gross Tonnage [GT]} * \text{distance travelled [n.m.]}\right)} = \left[\frac{\text{g of } CO_2}{\text{GT n.m.}}\right]$$

Better performance, higher efficiency, lower costs

1. Piping performance

Overall, the COOL-FIT 2.0 and 4.0 piping systems proved to be noticeably more efficient than the steel baseline system. Looking at electrical power, for example, plastic consumed 60kW less energy in the variable flow setting. This translates to an energy saving of 2%.

Electrical power reduction of pumps and chiller with COOL-FIT pipe (kW)



In addition, the plastic COOL-FIT systems also performed better in the context of heat and temperature losses. Their modern pre-insulated construction resulted in 30% less temperature rise in a constant flow scenario, while operating with 0,6 bar less pressure than steel. This corresponds to a 11% pressure decrease.

2. Savings

The higher energy efficiency of the pre-insulated plastic COOL-FIT piping systems translated to a measurable environmental impact for the entire 150.000 GT cruise ship. Due to the lower power requirements, fuel savings range between 82,1 m tons/year (for an LNG ship with variable flow pumps which also saves 2,0 m tons of pilot fuel) and 112,5 m tons/year (for an MGO ship with constant flow pumps).

Moreover, the lower fuel consumption leads to measurable financial savings. Over the course of 25 years, pre-insulated plastic piping in air conditioning chilled water systems can save an average $2,3 million, considering an annual inflation rate of 2,5%. However, shipowners can expect a total of around $3,8 million in savings as COOL-FIT is maintenance-free which drastically lowers operational costs. But since these maintenance costs can vary, this larger sum can only be regarded as an estimation.

At the same time, the lower fuel consumption also results in a reduction of greenhouse gas emissions. Depending on the configuration of the ship, 306,8 m tons to 373,7 m tons of CO_2 can be saved every year by using pre-insulated plastic piping systems. Other pollutants such as Nitrogen Oxides (NOX), Sulfur Oxides (SOX) or Particulate Matter (PM) can be reduced by 1,1 m tons to 6,1 m tons per year. Together, these reductions equate to 0,2% fewer emissions for the entire ship.

Financial Savings		COOL-FIT versus steel with cellular rubber in Constant Flow	COOL-FIT versus steel with cellular rubber in Variable Flow
MGO	USD/a	64.210 $	55.996 $
MGO	USD/ 25 years	2.193.265 $	1.912.690 $
LNG	USD/a	78.088 $	68.099 $
LNG	USD/ 25 years	2.667.324$	2.326.105 $

Comparison of the cumulative savings for COOL-FIT per year and over the course of 25 years in USD.

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Indices

Regarding the EEXI and CII indices, the study found some measurable but small improvements. For example, the modelled cruise ship in an MGO configuration with steel pipes achieved an EEXI value of 8,48 grams of CO_2 per ship capacity-nautical mile, while plastic piping achieved a value of 8,47. Similarly, fitting an MGO-powered ship with COOL-FIT and a constant flow pump improved the CII value from 11,19 g CO2/ GT n.m. to 11,17.

Comparison of EEXI and CII values

	Scenario	EEXI value with 19.7 MW hotel load [g CO_2/ GT n.m.]	CII value with 19.7 MW hotel load [g CO_2/ GT n.m.]
	with steel pipes	8,48	11,19
	with constant flow pump and COOL-FIT	8,47	11,16
	with variable flow pump and COOL-FIT	8,47	11,17
	with steel pipes	7,48	8,26
	with constant flow pump and COOL-FIT	7,48	8,24
	with variable flow pump and COOL-FIT	7,47	8,24

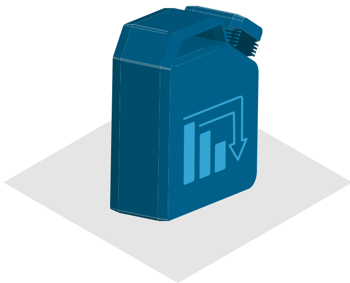
What do these results mean for the maritime industry?

In the face of many looming sustainability goals, shipowners, shipbuilders and dockyards require light, durable, efficient and cost-effective technical solutions that they can implement throughout their vessels. In this context, HVAC systems are an area with a lot of potential as they often still rely on traditional steel piping systems with insulation techniques that do not reflect the state-of-the-art technologies currently available. It was therefore the goal of this study conducted by GF Piping Systems and Foreship to compare pre-insulated plastic and post-insulated steel piping systems in air conditioning chilled water systems onboard cruise ships.

The data taken from the simulation of a 150.000 GT cruise ship showed significant improvements across the board. Compared to steel, the pre-insulated plastic piping system with a carrier pipe made of PE HD was more efficient, as it used less power, operated at a lower pressure, and caused less temperature rise. This increased efficiency translated into improvements in four key areas: Installing the polyethylene components reduced the fuel consumption by up to 112 metric tons per year, GHG emission by up to 373 metric tons per year, and lowered costs by up to $3,8 million over a period of 25 years. Furthermore, the simulation resulted in small improvements for the EEXI and CII values.

The entire maritime industry is currently searching for sustainable technologies. But while large-scale solutions such as sustainable fuels are on the horizon, it is equally important to find the many marginal gains that can be made. This study demonstrates that even small actions such as installing pre-insulated plastic piping in the HVAC system can have far-reaching positive effects throughout the entire ship. Beginning with the production process, plastics are much less energy intensive to produce when compared to steel. Once installed onboard, they combine high performance with better efficiency and lower costs. And, after a considerably longer operational lifetime than steel, many plastic materials can be recycled which extends their use. Looking towards the future, pre-insulated plastic solutions can therefore be an important part of a larger strategy to make shipping more sustainable.

The key benefits of pre-insulated polyethylene pipes

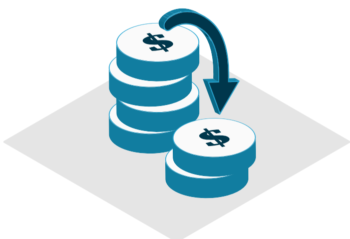


Fuel reductions of up to

-112 m tons

GHG emissions

- 373 m tons



Cost savings of up to

$3,8 million

over 25 years

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How can GF Piping Systems help you?

As an expert for the safe and reliable transport of fluids, GF Piping Systems has been a proponent of plastics as a piping material for over 60 years. As a result, our products are currently being used by customers in more than 100 countries around the world. No matter whether they are applied in buildings, utilities, production facilities or on ships, we believe that plastic piping systems are superior to equivalent systems made from materials such as metal or steel: They are lightweight, corrosion-free and require little maintenance, which makes them easy to handle and cheaper to operate. In addition, our broad spectrum of products and services offers the right solution for every application, from new projects to retrofits.

COOL-FIT in the marine sector

The COOL-FIT product line is a mainstay in the GF Piping Systems portfolio. It is a plastic water-chilled piping system designed for various applications. Its construction combines the low thermal conductivity of plastic with modern insultation technologies, as the media pipe, insulation and shell are permanently connected during the manufacturing process. This means that COOL-FIT boasts a 30% better energy efficiency, 50% faster installation time and up to 65% less weight than its steel competitors.

After having gathered 30 years of experience as a partner of the global marine industry, we believe that COOL-FIT is ideally suited for maritime applications, where improved energy efficiency, easy handling and low weight are valuable benchmarks. By using COOL-FIT onboard large vessels such as cruise ships, owners and shipbuilders can maximize performance and efficiency in their HVAC systems. The study conducted by GF Piping Systems and Foreship now demonstrates that the use of pre-insulated plastic piping systems also improves the overall energy efficiency of ships. Lightweight plastic piping solutions are therefore an important solution on the way to a more sustainable future in the marine industry.

About GF Piping Systems Ltd.

GF Piping Systems is the leading flow solutions provider worldwide, enabling the safe and sustainable transport of fluids. The company specializes in plastic piping systems and system solutions plus services in all project phases. GF Piping Systems has its own sales companies in 31 countries, which means it is always by its customers' side. Production sites in 36 locations in America, Europe, and Asia ensure sufficient availability and quick, reliable delivery. In 2020, GF Piping Systems generated sales of CHF 1,70 bn and employed 6'893 people. GF Piping Systems is a division of Georg Fischer AG, which was founded in 1802, and is headquartered in Schaffhausen, Switzerland.

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