Circular Economy Initiatives Advancing Construction in Gas Increment Projects

Feras Alfosail[1]; Soo-youn Kim[2]; Khaled Alaboud[3]; Abdulaziz Alomrani[4]; Abdulrahman Alghunaim[5]; Ahmed Alahmed[6]; Hassan Hobani[7]; Mohammad Dossary[8]; Abdullah Agili[9]; Sultan Alankari[10]; Made Darmawan[11]

[1,3,4,5,6,7,8,9,10,11]Fadhili Gas Increment Project, Saudi Aramco, Dhahran, 31311, Saudi Arabia
[2]GSE&C, Gran Seoul, Seoul, 31311, South Korea

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Abstract: This report highlights several circular economy initiatives there were implemented during the detailed design phase with the EPC contractor for a sulfur recovery gas increment project. Capitalizing on the concept of cloning the existing plant, the initiatives targeted Reduce and Remove principles to optimize the existing design and advance the project milestone resulting in sustainable project execution and operation. These initiatives vary between material optimization, introducing alternative non-metallic materials, optimizing equipment power loads, utilizing pre-assembled structures, enhancing equipment shipments, and improving fabrication practices. The deployment of these initiatives under the different key circular economy principles ensures that the company has an effective and sustainable performance for the future. In addition, it resulted into reducing CO2 by more than 182,000 tonnages.

Keywords: *Circular Economy; Gas Increment Project; CO2 Emissions; Optimizations;Sustainability.*

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I. INTRODUCTION

Saudi Aramco, as a global leader in energy and chemicals, is committed to advancing sustainable development through innovation, operational excellence, and environmental responsibility. In alignment with its corporate vision—to be the world's preeminent integrated energy and chemicals company—Aramco has embraced the principles of the circular economy to reduce environmental impact and enhance resource efficiency across its operations.

Gas Increment Program (GIP), one of Aramco's flagship initiatives, is designed to expand the Kingdom's gas production capacity to meet rising domestic and international demand. As part of this expansion, Aramco is pioneering the integration of circular economy methods into construction and infrastructure development, with the objective of minimizing waste and reducing the carbon footprint associated with large-scale industrial projects.

➢ *Circular economy strategies within the GIP focus on several key areas:*

- Material Reuse and Recycling: Construction activities are being optimized through the reuse of excavated materials, recycled aggregates, and reclaimed steel, reducing the need for virgin resources and lowering emissions from material production and transport.
- Design for Deconstruction: Infrastructure is being designed with modularity and future adaptability in mind, enabling components to be reused or repurposed at the end of their lifecycle.
- Energy Efficiency and Emissions Reduction: Advanced technologies and construction methodologies are being deployed to reduce energy consumption and greenhouse gas emissions during both the construction and operational phases.
- Waste Minimization and Resource Recovery: On-site waste segregation, recovery of valuable materials, and closed-loop systems are being implemented to divert waste from landfills and promote circular flows of resources.

These initiatives are not only contributing to the sustainability of the GIP but also reinforcing Aramco's role in supporting the Kingdom's Vision 2030, which emphasizes economic diversification, environmental protection, and the transition to a low-carbon future. By embedding circular economy principles namely Reduce, Reuse, Recycle and Remove into its gas infrastructure projects, Aramco is setting a benchmark for responsible industrial development and demonstrating how energy companies can lead in climate-conscious innovation.

➢ *While in the context of the GIP, Scope 1 and Scop 2 emissions are related to large scale implementations, Scope 3 emissions are primarily associated with:*

- Procurement and transportation of construction materials
- Manufacturing and fabrication of equipment and components
- Contractor and supplier operations
- End-of-life treatment of construction waste and materials

To mitigate these emissions, Aramco is implementing a range of circular economy initiatives that aim to reduce material demand, extend product lifecycles, and promote reuse and recycling across the construction value chain.

➢ *These include:*

- Sourcing low-carbon and recycled materials to reduce embodied carbon in construction.
- Collaborating with suppliers to adopt sustainable manufacturing practices and improve logistics efficiency.
- Designing for modularity and disassembly, enabling reuse of components and minimizing waste.
- Implementing digital tools for material tracking and lifecycle assessment to optimize resource use and reduce emissions hotspots.

This report provides an overview of the circular economy initiatives undertaken within the GIP with case studies addressing scope 3 emissions, evaluates their environmental and operational impacts, and explores how these efforts align with Aramco's broader sustainability and strategic objectives.

II. APPROACHES

This study focused on the Reduce and Remove principles of elements based on the design requirement during development stage. As such, the categories mentioned afterwards that have been considered include one or both of circular economy initiatives. In this paper report, consideration has been given to major contributions which can be grouped in one of the following:

- Reduce Steel Material Requirement
- Improving Civil Construction Works and Building Materials
- Optimizing Electrical and Miscellaneous Requirements

➢ *Reduce Steel Material Requirement*

There are several methods in which the material requirement i.e. steel of the equipment can be optimized during the detailed engineering phase of a project. This can be accomplished via optimizing material thickness, use of alternative materials, and/or eliminate their use/ function and thus can be removed from service.

As an example, on material thickness optimization, we illustrate how the use of optimized values for the Design code for external loads on carbon steel flanges of Heat Exchangers following the requirements of ASME VIII Division 1 UG-44. The governing equation is written as

$$16M_E + 4F_E G \leq \pi G^3[(P_R - P_D) + F_M P_R] \tag{1}$$

where M_E is the external moment, F_E is the external axial force, F_M is the moment factor, G is the gasket reaction diameter, P_D is the vessel MAWP at design temperature, and P_R is the flange pressure rating at design temperature. The application of the code case 2901 in the updated version of the code allows the designer to consider reducing the allowable factor FM if the loading is primarily sustained in nature, and the bolted flange joint operates at a temperature where gasket creep/relaxation will be significant. This allowed the rating of the vessels and heat exchangers to be retained and optimized, avoiding the need to have higher rated flanges. Table 1 shows the rating for different equipment before and after the optimization.

Table 1 Table Showing the Flange Class Rating for the Different Equipment

Equipment	Flange Rating Before Optimization	Flange Rating After Optimization
Heat Exchangers	Class 900	Class 600
Vessels	Class 600	Class 150
Columns	Class 600	Class 150
Reaction Furnace	Class 1500	Class 600
Incinerator	Class 900	Class 300

The results after optimizing the flanges resulted in reducing the weight of the carbon steel flanges by 3580 kg which is equivalent to 6623 kg of CO2 emissions that have been reduced based on the study of sustainable ship reports [1].

Another considered example is the optimization of the external corrosion allowance on the surface of the high temperature incinerator stack which is made of carbon steel. The stack is made of dual carbon steel materials with internal lining and outer and inner shells as shown in Fig. 1. The outer shell has a diameter of 4.8 to 3.8 meters and 90 meters in length. Since the annular space (gap between the inner and outer shell) provided in order to maintain the inner shell range of required temperature (above 320 FO and less than 617 FO), then atmospheric corrosion of no concern and external corrosion allowance will not be required. In addition, the removal of the corrosion allowance does not affect the thermal performance of the stack while in operation. Thus, this resulted in reducing carbon steel weight by 81,114 kg which contributes to 150,060.9 kg of CO2 emissions.

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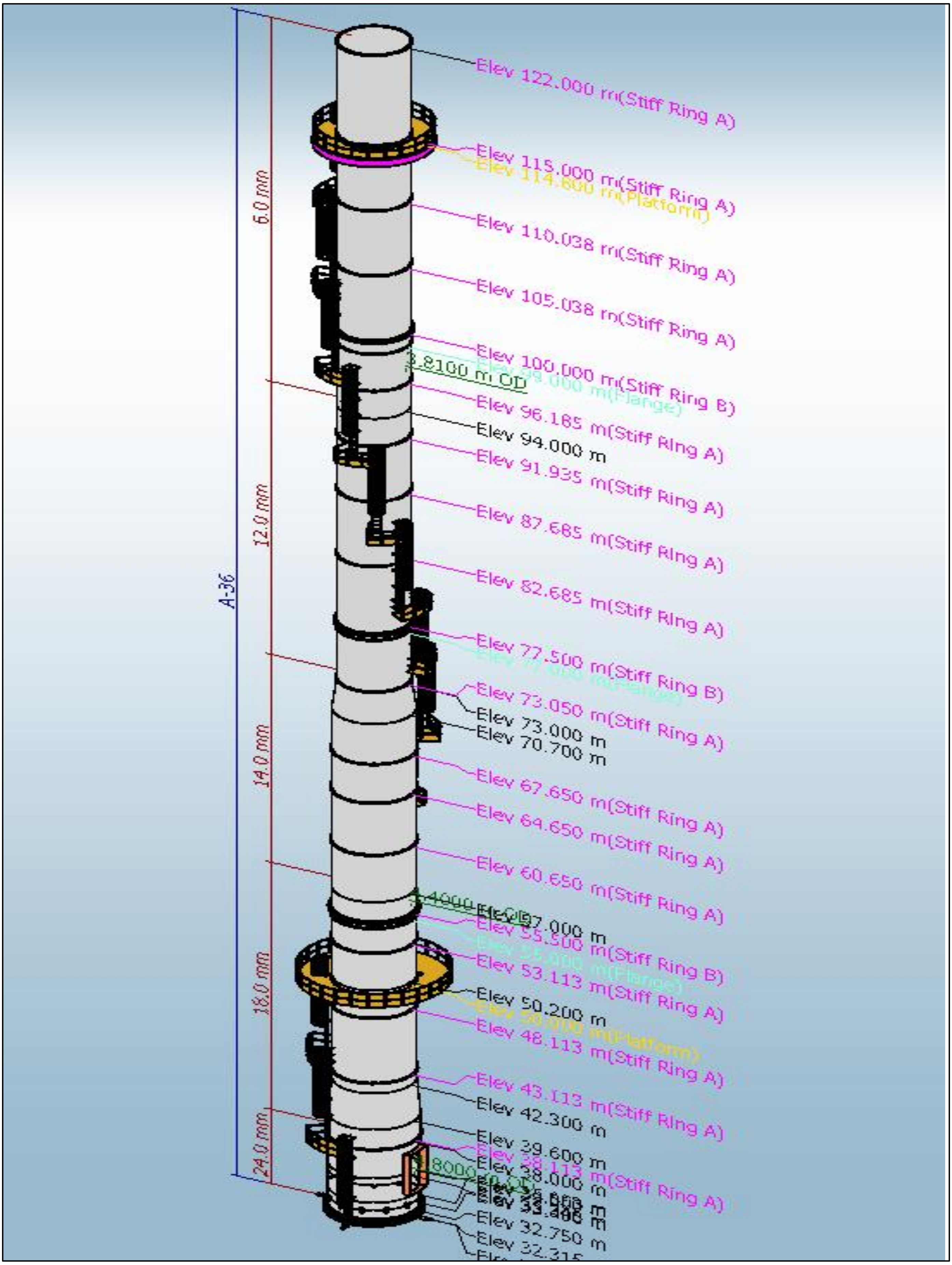

Fig 1 Schematic of Incinerator Stack

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An additional improvement in the corrosion area is to enhance the number of corrosion probes in the sulfur loading gas system. This has been achieved utilizing two conditions:

- First, the steam tracing is installed with temperature maintained above the
- Condensation Range
- An adequate process control monitoring system is installed with notification in place of exceeding below the temperature i.e. 330 Fo.

Provided the two conditions are met, aquas phase corrosion types are avoided, and the design team were able to eliminate a total of 7 probes on the loading system. The total avoided steel weight of the corrosion probes is nearly 472.5 kg which contributes to 874.125 kg of CO2 emissions. It is to note that the total weight include probe, pipe fitting, and attachment accessories required for the installation and mounting of the corrosion probe as shown in the schematic in figure 2.

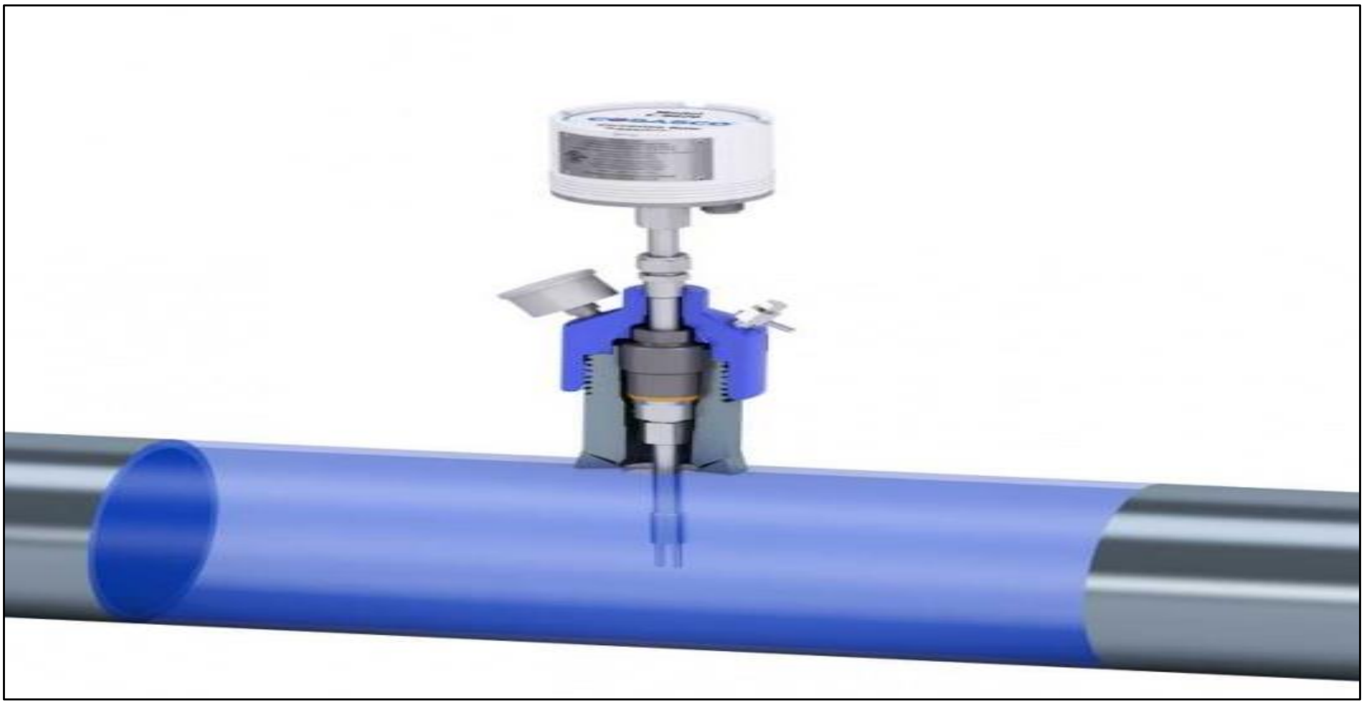

Fig 2 Schematic of a Typical Corrosion Probes Utilized in the Process

Moreover, the use of alternative alloys can contribute to either increasing or decreasing the amount of CO2 emissions. As an example, we illustrate the use of unplasticized polyvinyl chloride i.e. uPVC conduits fittings and supports instead of steel coated with PVC for paved transitions and buried underground encased concrete. The application of the PVC for cables prevents induced current from power cables in conduits while ensuring the availability of concrete encasement for fire rating protection purposes having a minimum modulus of elasticity of 500,000 psi per NEMA specification. In addition, the use of non-metallic crude oil-based materials such as polymers offers more potential to promote the conversion of oil products. The total length of PVC conduit that replaces the steel one is 910 meters contributing to reducing the CO2 emissions by 74.803 tonnages of CO2. It is worth mentioning that the emission per weight for PVC materials is almost equivalent to that of steel [2]; however, the density of steel is five times that of PVC which allows it to cover more volume and lengths.

In another example related to optimization, the design team were able to apply innovative engineering analysis to enhance and improve the cooling water system of the plant. Driven by the approach temperature of the cooling water steam and the low duty of the heat exchangers, it has been observed via thermal design that the single stage heat exchanger can be utilized in lieu of a multi-stage heat exchanger for water cooling system. This resulted in optimizing the number of heat exchangers, circulation pumps and related piping and packaged equipment. The optimization resulted in eliminating 139,603 kg of steel and eliminated an annual power consumption of 21,385,087 kW/year considering all the trains in the plant. By considering a 15-year life cycle of the plant operation, this can be estimated to reduce CO2 emissions by 182,459,207 kg over the life cycle of the plant for all the trains. The schematic in figure 3 shows the process diagram before and after the optimization.

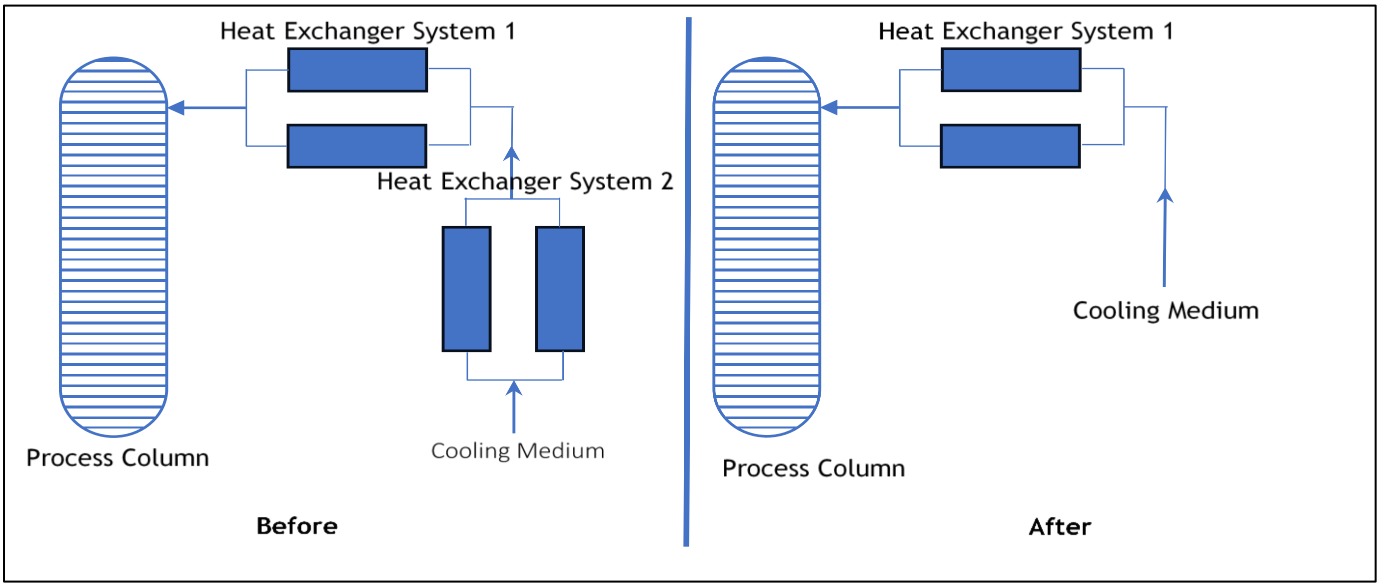

Fig 3 Schematic of The Chiller Package Optimization for The Water-Cooling System

To summarize, the contribution of reducing steel reduced the carbon footprint due to the steel production by 182,691.568 tonnages of CO2. The chart in figure 4 shows the contribution in this category from each initiative. Thus, this resulted in reducing carbon steel weight by 81,114 kg which contributes to 150,060.9 kg of CO2 emissions.

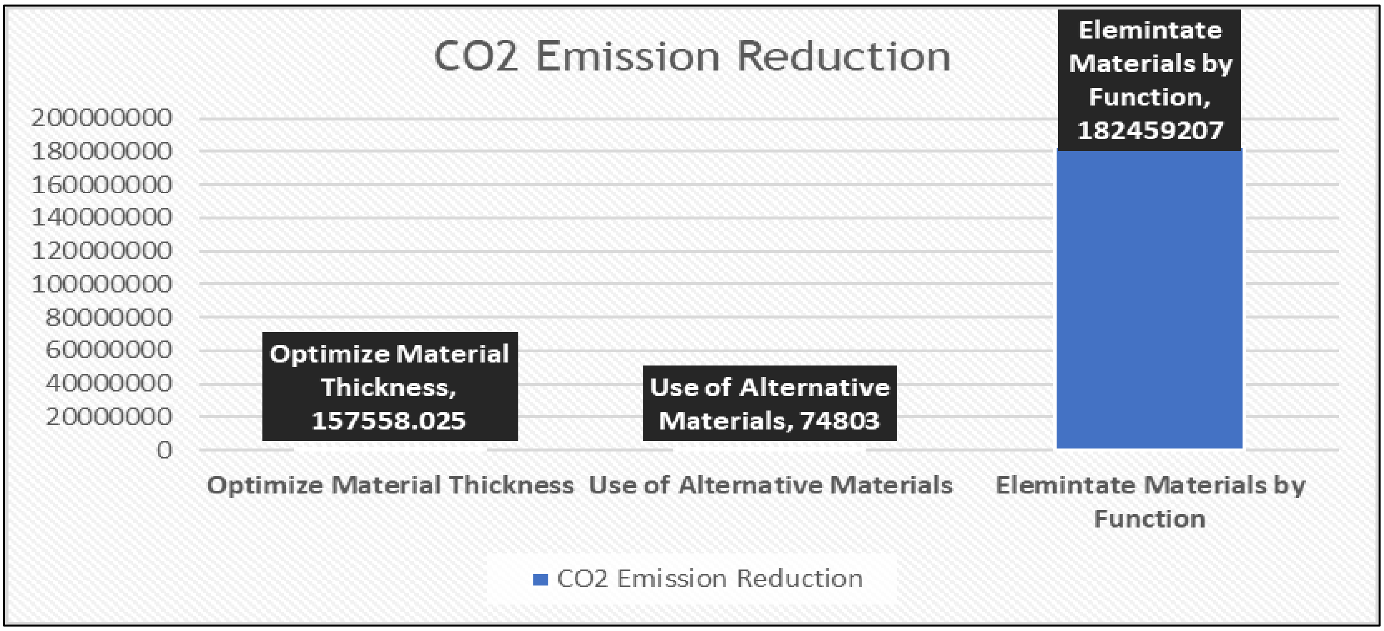

Fig 4 The contribution of the initiatives in CO2 emission reduction for material optimization

➢ *Improving Civil Construction Works and Building Materials*

To capitalize on the cloning concept framework for project design deliverable and construction activities, three innovative initiatives have been considered in this sector that contributes to the reduction of CO2 emissions. This has been achieved considering the following: First, removing the requirement of trenching and electrical duct bank for future expansion, optimizing the asphalt pavement thickness and optimizing RTR piping thrust block requirements.

The first example that the design team has considered is to eliminate the provision required to connect the 115KV power cable for future expansion. Due to the limitation in crossing the boundary of the battery limit and electrical cable route is not required within the design life of the plant, the design team eliminated the duct bank and the trench required for the electrical cable. This eliminated the need to have 338.84 m3 of concrete and 25.94 tonnage of steel. In addition, the trench volume would require 24 hours of operating a 30-tonnage excavator and 46 truck trips from the ready-mix batch plant to the project site. The total reduction in CO2 emissions yield 161.840 tonnage of CO2 material wise based on concrete production average around 0.14 kg CO2 per kg of concrete [3] and 1.437 tonnage of CO2 logistics and transportation wise considering the emission from a typical diesel engine of a truck [4].

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The second example considered is the optimization of the asphalt pavement thickness for plant areas. In the design of pavement, aggregates in the wearing course are combined with asphalt base to form the entire thickness of the road pavement. Typically, class B asphalt aggregates are utilized based on ASTM specification because it is more economical and can be suitable for applications where the demands on the asphalt are less. However, for installation purposes class B aggregates resulted in thicker concrete than when aggregates of class A are being utilized. Since class A aggregates are finer than class B ones, and with proper engineering analysis the design team were able to optimize the asphalt course from 140 mm to 120 mm with a coverage are of not less than 110,649 m2. This resulted in reducing the carbon footprint by 296,827 kg of CO2 materials wise and 6.435 tonnage of CO2 considering the logistics to transport the aggregates to the project site with an average two-hour trip. The schematic in figure 5 shows a typical layout of the design of the asphalt pavement.

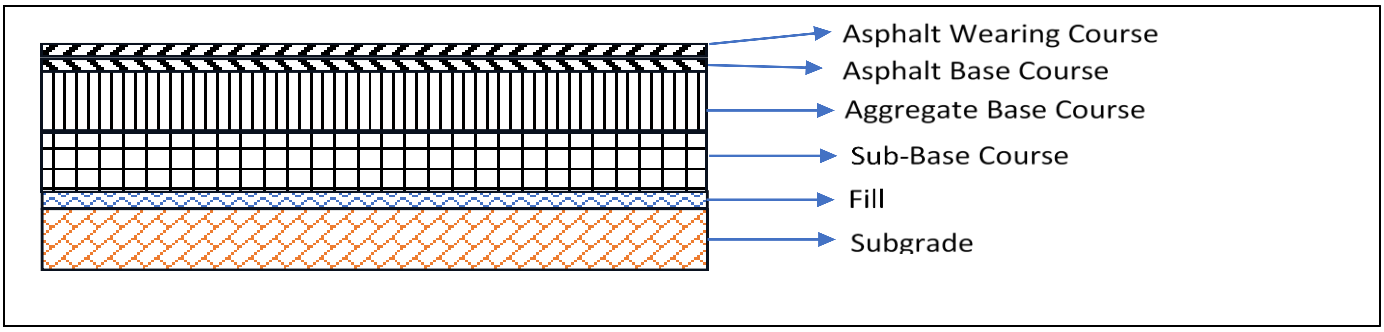

Fig 5 Schematic of a Typical Pavement Design

The last example in this category is the optimization of the non-metallic underground RTR piping thrust blocks. Thrust blocks are utilized in piping systems to suppress and counteract the forces generated by the fluid in the piping system. Early design specifications required the installation of the blocks at every bends, tees, and reducers where momentum can affect the pipe regardless of the stresses on the piping system. Therefore, a stress analysis was performed on the piping system for utilities and oily drainage systems to determine the structural capacity and integrity of the underground piping system. The results revealed that for most cases the stress levels are acceptable and below the allowable stresses per ISO code 14692. The stress levels were based on the manufacturer diagram shown in figure 6.

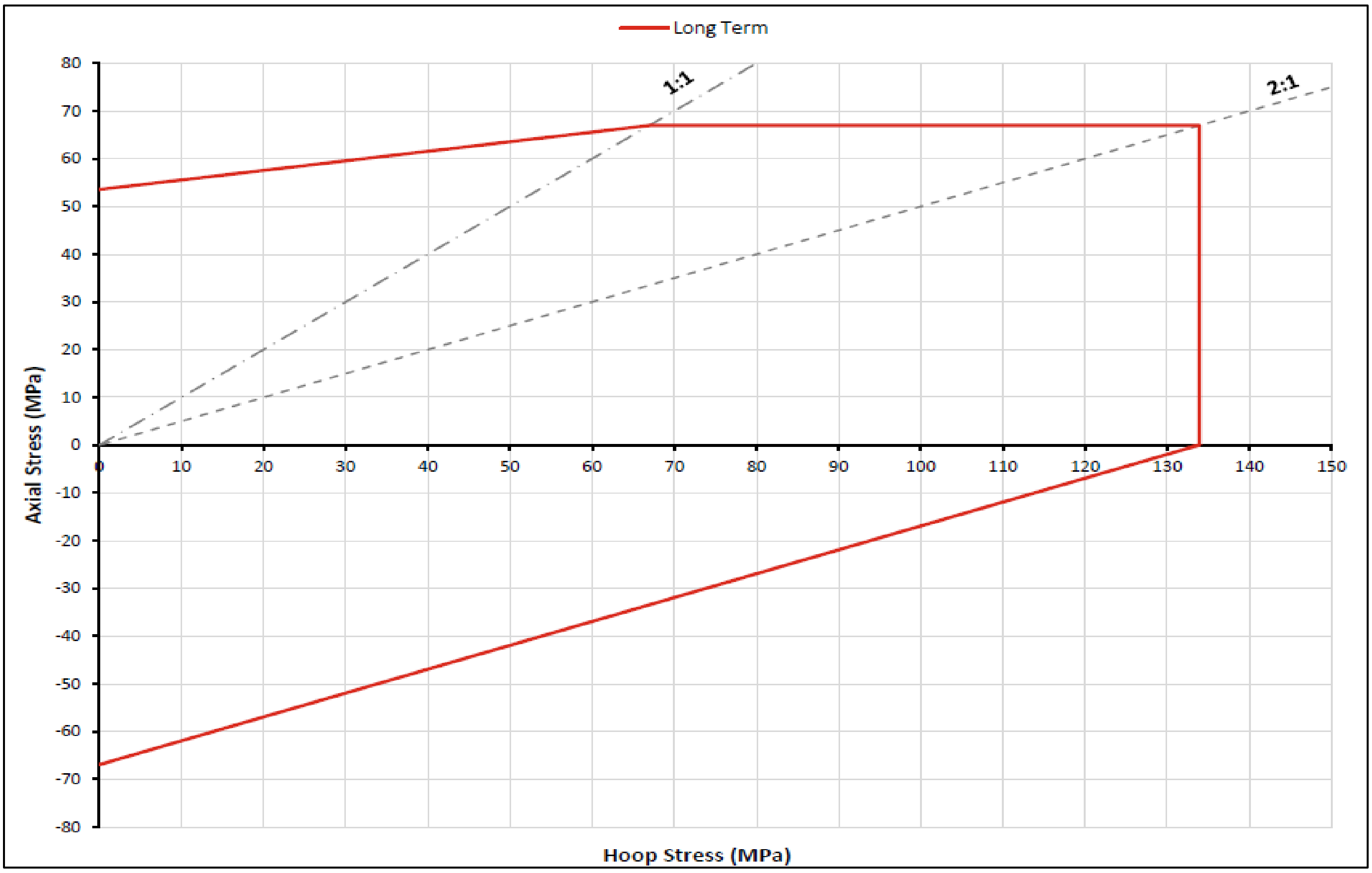

Fig 6 RTR Piping Stress Diagram Utilized in The Stress Analysis Showing the Boundaries

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The outcome reduces a total of 153 concrete thrust blocks for the RTR piping system. This can be estimated to contribute to 21.235 tonnage of CO2 emissions by materials and 1.11 tonnage of CO2 via logistics by transporting the ready-mix concrete require to cast in place the mix.

The outcome in civil and construction activities resulted in reducing carbon footprint by a total of 487.77 tonnage of CO2. The chart in figure 7 shows a summary of the initiatives conducted in this category.

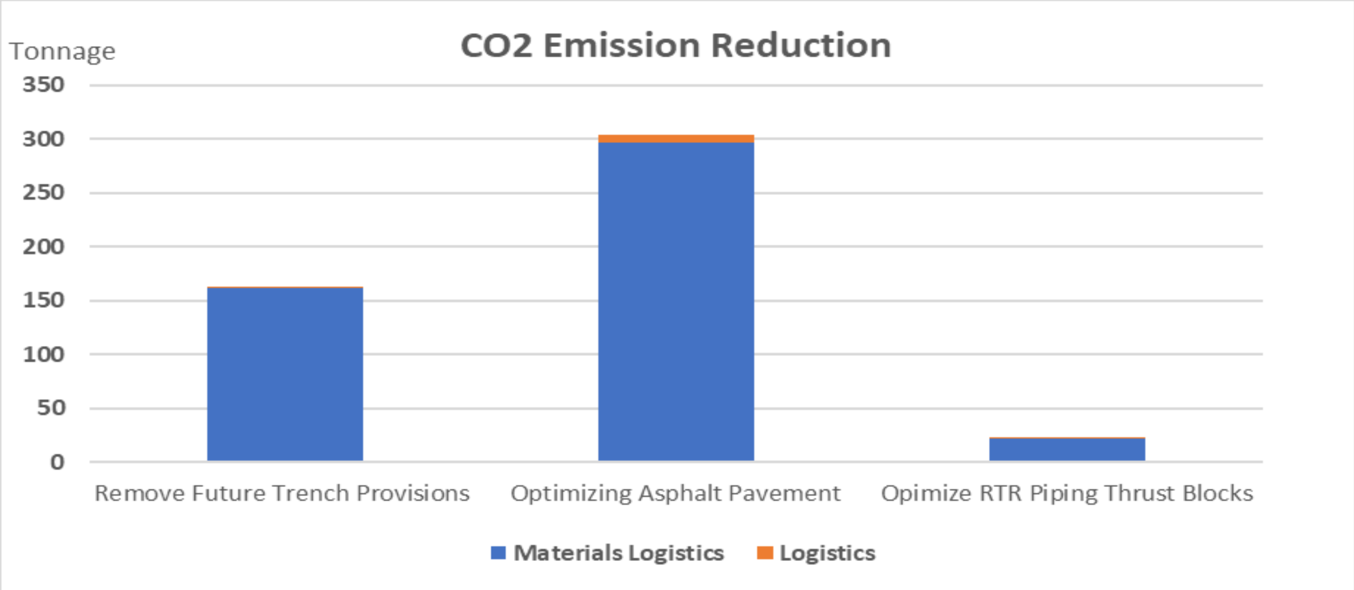

Fig 7 The contribution of the initiatives in CO2 emission reduction for civil and construction

➢ *Optimizing Electrical and Miscellaneous Requirements*

The last category that was considered during the phase of the design is the opportunity to optimize and reduce the consumption of electrical equipment and optimize the logistic requirements during procurement activities. Under this category, three initiatives were considered namely optimizing the post-weld heat treatment (PWHT) requirements, optimize the operation and requirements of the automatic doors, and enhancing the testing requirements of pump components.

The post weld heat treatment is a step required post welding activities for welding of pressure vessels subject to sour service as per the ASME code. For that reason, all the welds in the columns, vessels and drums will be subjected to post weld heat treatment. The optimization for this initiative is recognized in two forms: first, utilize local heating elements instead of inserting the equipment inside a furnace to soak for two hours at temperature of 650oC. Secondly, identifying equipment that is required to be treated for sour service with exception cases per the applicable code. Considering an equipment such as degassing drums in the process, performing the localized PWHT for the sulfur degassing drum can save up to 465 GJ of electricity. This has been calculated based on equipment weight of 138,200 kg, steel specific heating value of 0.5 kJ/kg.C and furnace efficiency of 30%. Additionally, considering the code case of ASME VIII UW-2 and Table UCS-56-1 which permits and allows welding without applying post-weld heat treatment reduced the electrical requirements in this case by 14.1 GJ. By using a grid emission factor of 0.568 tons of CO2 per MWh in Saudi Arabia, the reduced CO2 emissions are calculated to be 75.59 tonnages [5].

The second initiative is optimizing the power requirement to operate blast resistant doors for manned and unmanned operating buildings. The optimizing from automatic to manual considering the manning requirement and the escape routes of personnel. As a result, a total of 43 doors have been optimized to operate manually with an estimated total electrical load of 147, 168 kW/yr to operate these doors. Considering the life cycle of the plan of 15 years, it yields 2,207.52 MW of electricity which contributes to 1253.576 tons of CO2.

The third initiative is to optimize shipping and test the requirements of centrifugal pumps which require performance certification of certain components at their own facilities to provide warrantee as per the applicable code. In our case, the pump casing and materials were procured from a manufacturer in Saudi Arabia while major components such as the seals are procured from India. The design specification states that seal testing to be conducted at the seal manufacturing facility. After careful examination with the procurement team and manufacturers, approval has been obtained to conduct the seal performance test at the pump manufacturer after assembly. This prevents shipping the pump back to the seal manufacturer for testing purposes. This way, shipping the pump train which contains six pumps and weight 30114 kg through 5600 km from Saudi to India has been prevented. Considering an average emission factor of 0.01614 kg CO2 per tonnage per km, the total emission reduction is 5,443.64 tonnage of CO2 [6].

Other initiatives in this category include the utilization of pre-assembled structure as a pipe rack. The carbon footprint in this case is reduced by eliminating the unnecessary construction and transportation activities. Due to the complexity nature of the process quantifying the reduction in CO2 emissions has not been considered in this report. Figure 8 showed an in-progress installation of the pre-assembled structure.

Fig 8 Pre-Assembled structure during installation

In a summary, the total emission reduction contributing to this initiative in the electrical and miscellaneous category contributed to 6772.81 tonnages of CO_2. The chart in figure 9 illustrates the contribution of each initiative.

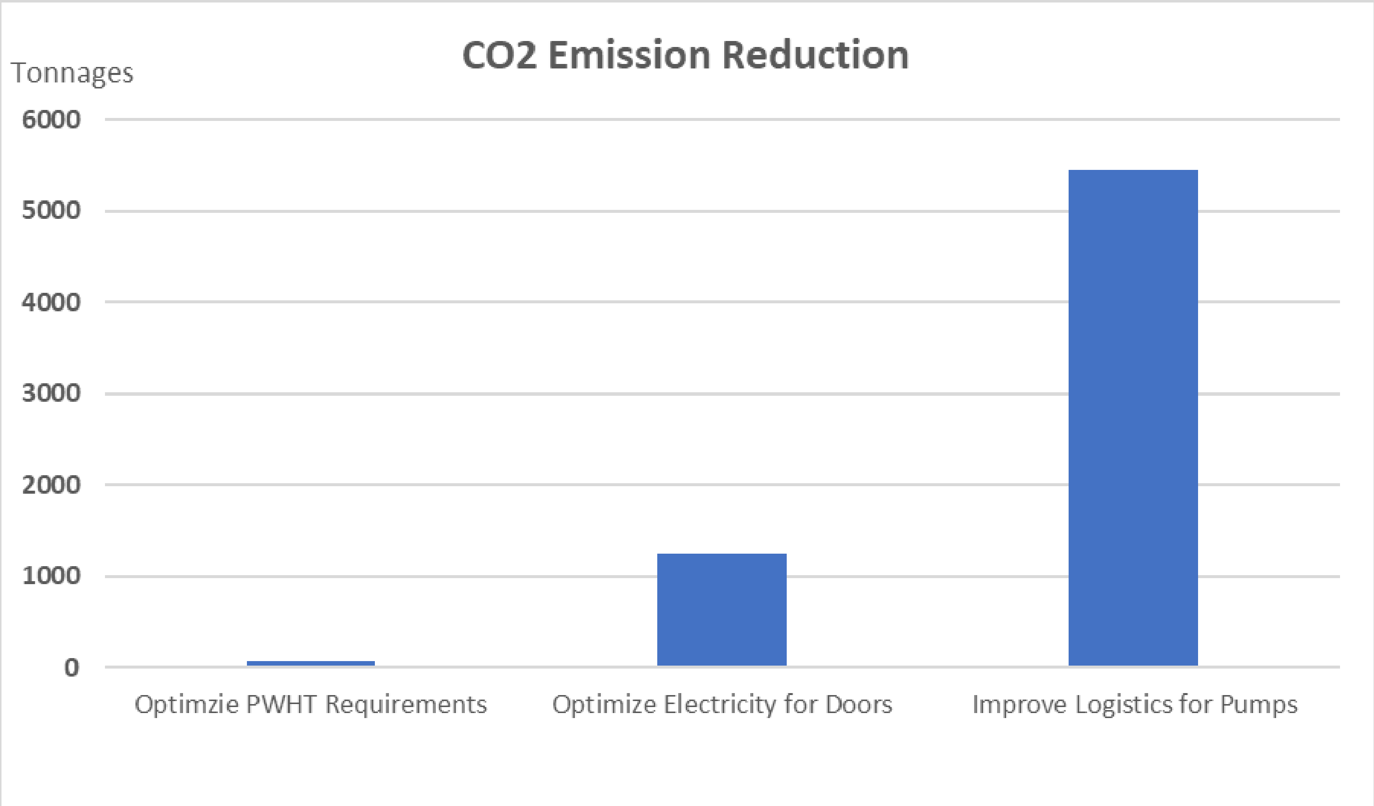

Fig 9 The Contribution of the Initiatives in CO_2 Emission Reduction for Electrical and Miscellaneous

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III. CONCLUSIONS

In conclusion, this report highlights several circular economy initiatives under materials, civil, logistic and electrical categories targeting Reduce and Remove principle. These were conducted GSE&C design team aiming to enhance project schedule, improve cost and reduce carbon footprint. Applying these initiative resulted in reducing CO2 emissions by a total of 189952.15 tonnage. In this regard, Saudi Aramco will continue to work with its EPC contractors to enhance environmental impact by minimizing waste and maximize resources utilization.

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