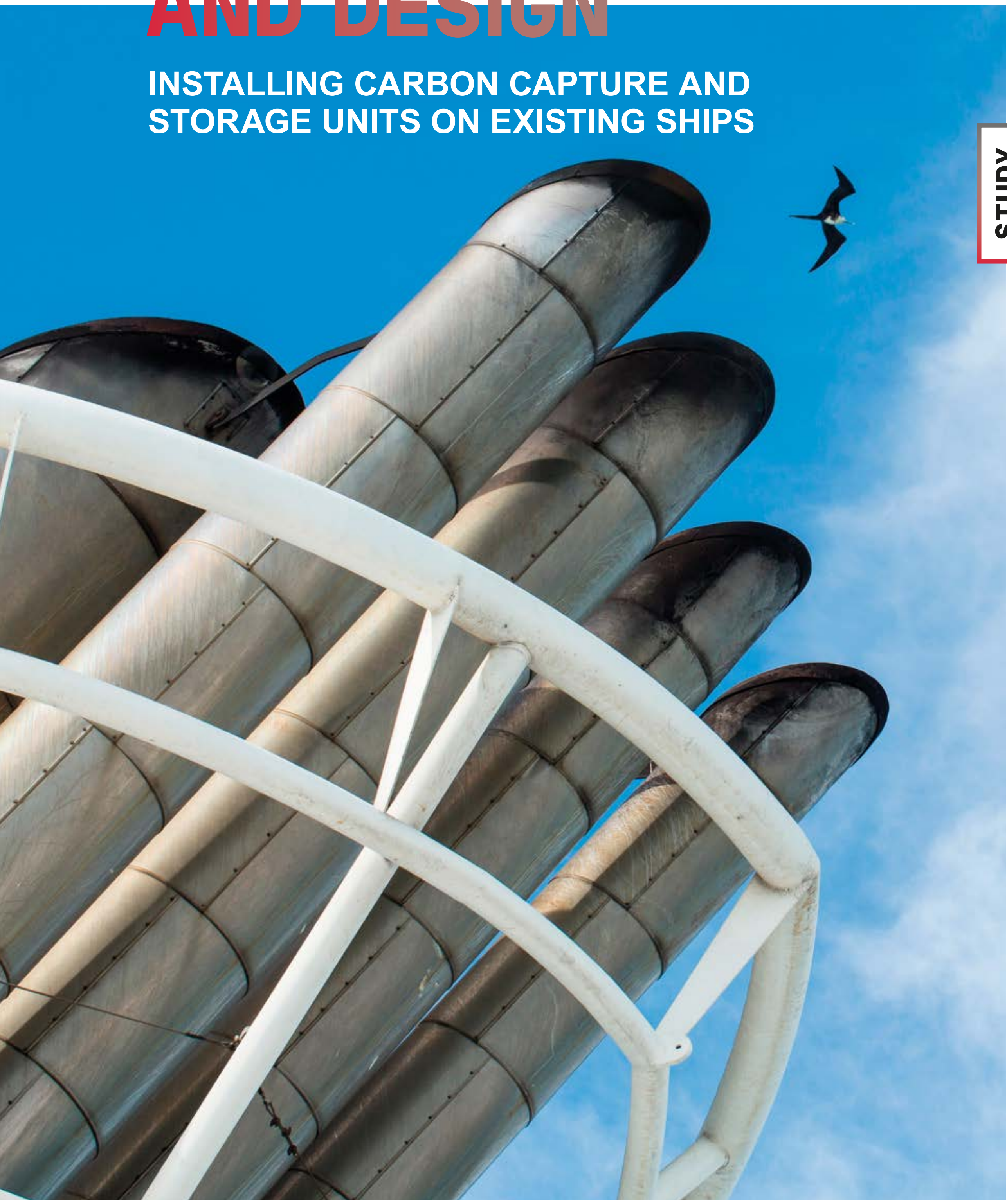
JUNE, 2023

FEASIBILITY STUDY AND DESIGN

INSTALLING CARBON CAPTURE AND STORAGE UNITS ON EXISTING SHIPS

STUDY



BUREAU VERITAS

CONTENT

EXECUTIVE SUMMARY

Carbon capture and storage (CCS) technology has enormous potential to help hard-to-decarbonize industries minimize their CO_2 emissions. In 2021, CCS technology captured 40 million tons of CO_2, notably from onshore industrial projects. Now in 2023, it offers a promising solution for reducing greenhouse gas (GHG) emissions from shipping.

This will be crucial to meeting climate targets set by the International Maritime Organization (IMO), including a minimum 50% reduction in GHG emissions from shipping by 2050(1). This target, and its accompanying legislation, have created a prime opportunity for CCS technology to decarbonize the marine industry.

COMPARING IN-SERVICE SHIPS AND NEWBUILDS

Achieving decarbonization is somewhat easier for ships being designed or constructed today, which can determine their fuel and emissions profiles from scratch. Newbuilds have the opportunity to integrate alternative fuels onboard, such as liquefied natural gas (LNG), methanol, biofuels, and ammonia.

However, most ships in the global fleet are already in service, with lifespans of 25-30 years. This makes complying with decarbonization legislation – like the IMO's Carbon Intensity Indicator (CII) or the EU Emissions Trading System (EU ETS) – challenging, and potentially expensive.

DESIGNING A STUDY FOR CCS ONBOARD IN-SERVICE VESSELS

To address this, Bureau Veritas set out to study the feasibility of integrating CCS technology onboard in-service vessels. We partnered with Wah Kwong and QIYAO Environmental Technology(2) (here called QIYAO ENVIRON TEC), installing CCS units onboard two in-service ships.

Wah Kwong provided two vessels from their fleet: a 53,000 DWT bulk carrier *(Tianjin Venture)* and a 176,000 DWT bulk carrier *(CSSC Wan Mei)*. Using vessel-specific parameters, QIYAO ENVIRON TEC then developed customized CCS units, which were submitted to Bureau Veritas for approval. Bureau Veritas assessed the units' compliance with existing Rules and regulations, and evaluated the technology's ability to reduce CO_2 emissions from operations.

To design the units, QIYAO ENVIRON TEC used guidance from the Intergovernmental Panel on Climate Change (IPCC). The IPCC defines three approaches to capturing CO_2: pre-combustion, oxy-fuel combustion and post-combustion capture. QIYAO ENVIRON TEC used post-combustion capture for its units, as this is the most mature technology and the easiest to implement onboard.

To ensure the study could apply to all vessels, the bulk carriers selected to comply with ever-stricter CII requirements and continue operating until 2030, the ship would need to improve to a C rating.

Finally, two further parameters were considered. First, to create a complete energy profile, the study assessed the quantity of additional fuel required to power the CCS units. Second, the effects of the EU ETS – a cap-and-trade mechanism for taxing CO_2 emissions – were used to run a cost analysis.

ADDRESSING CHALLENGES, FINDING RESULTS

Our study looked at the following challenges for integrating CCS technology onboard:

- **Onboard installation:** unit arrangement and available space.
- **CCS dry weight:** installation of CCS equipment and LCO_2 tanks.
- **Shaft alignment:** hull deformation assessment.
- **Stability:** intact and damage stability assessments.

Our study found that from 2023-2030, with CCS technology onboard, the *Tianjin Venture* could save ~$305,000 USD(3). The ship's carbon capture rate would begin at 10.2%, then rise to 29.5% by 2030. Similarly, the *CSSC Wan Mei* could save ~$555,000 USD(4), with a maximum carbon capture rate of 26.3%.

This suggests that applying CCS to in-service vessels is not only feasible, but a potentially economically attractive option for shipowners. However, customized design of CCS units would be required to ensure each ship reaches the maximum possible CO_2 reduction on an economically viable basis.

(1) Compared to 2008 levels.
(2) A subsidiary of Shanghai Marine Diesel Engine Research Institute.
(3) Assuming the vessel sails in EU waters. This number rises to ~$6.8 million USD if LCO_2 is sold.
(4) Assuming the vessel sails in EU waters. This number rises to ~$11 million USD if LCO_2 is sold.

Through this collaboration, Bureau Veritas's expertise in supporting CCS projects combined with Wah Kwong' and QIYAO's technical and strategic capabilities, will help to accelerate the implementation of CCS technology in the shipping industry.

VALUE AND SUPPORT WHY BUREAU VERITAS? - THE VALUE AND SUPPORT BUREAU VERITAS CAN BRING TO CLIENTS

As a classification society, Bureau Veritas works with industry players across the maritime industry, from offshore operators to ship owners and port authorities. We are committed to reducing our industry's environmental impact and supporting stakeholders through their unique sustainability journey. We help clients comply with environmental regulations, implement green solutions onboard, measure decarbonization progress, and more.

As a Business to Business to Society Services Company, Bureau Veritas is committed to embedding sustainability into our strategy and across our businesses. Our BV Green Line of services and solutions empowers organizations to implement, measure and achieve their sustainability objectives.

The transition to a greener shipping industry is critical. Carbon capture, and storage (CCS) technology captured a total of 40 million tons of CO_2 in 2021 according to the International Energy Agency (IEA), notably in industrial projects on shore. This makes CCS one of the options available today that could significantly contribute to achieving carbon neutrality, as well as a promising avenue for reducing emissions from shipping. We are much honored to collaborate on this study. BV's expertise in supporting CCS projects, combined with Wah Kwong' and QIYAO's technical and strategic capabilities, will help to spur the implementation of CCS technology in the shipping industry.

Acknowledgements

We would like to thank the following partners for their participation in the project.

WAH KWONG
MARITIME TRANSPORT HOLDINGS LIMITED

CSSC 中国船舶集团有限公司第七一一研究所
SHANGHAI MARINE DIESEL ENGINE RESEARCH INSTITUTE

1. INTRODUCTION

1.1. IMO GHG STRATEGY

The initial IMO GHG strategy envisages a reduction in the carbon intensity of international shipping by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008 levels. Total annual GHG emissions from international shipping should be reduced by at least 50% by 2050 compared to 2008 levels.

The Committee recalled that the initial IMO GHG Strategy on reduction of GHG emissions from ships foresaw the adoption of a revised strategy in 2023. To that purpose, MEPC 78 recognized the need to strengthen the ambition of the initial strategy and agreed to revise it with a final draft revised strategy to be decided by MEPC 80, with a view to adoption(5).

1.2. CII INTRODUCTION

CII, Carbon Intensity Indicator, is calculated as the ratio of the total mass of CO_2 emitted to the total transport work undertaken in a given calendar year.

CII came into force on January 1, 2023, for existing vessels over 5,000 GT, which means that all qualified vessels need to calculate their annual attained CII by the end of the year and compare that with the required CII value to get a rating of A, B, C, D or E, indicating the vessel's operational efficiency.

For vessels that receive a D rating for three consecutive years, or an E rating, corrective actions must be taken to raise the CII rating to an acceptable level in the following year, and this needs to be written into the Ship Energy Efficiency Management Plan (SEEMP) for verification. Thus, CII is combined with the enhanced use and auditing of the SEEMP.

1.3. INNOVATION TECHNOLOGY

While alternative fuels, such as methanol, hydrogen and ammonia, show long-term promise, they are still undergoing technical development, and the production timeline of renewable alternative fuels for the marine industry will probably be long.

Carbon Capture and Storage technology has been available for several decades, but it has only recently become a hot topic in the marine industry. The 2021 United Nations Climate Change Conference notably featured two CCS-focused events, and governments throughout northern Europe have begun generously funding CCS projects. CCS is an important emission-reduction technology that can be applied across the energy system.

According to the International Energy Agency (IEA), carbon capture and storage technology captured a total of 40 million tons of CO_2 in 2021, notably in industrial projects on shore. This makes CCS one of the options available today that could significantly contribute to achieve carbon neutrality, as well as a promising solution for reducing emissions from shipping(6). The report of the twelfth meeting of the Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG 12)(7) also supports the inclusion of carbon capture and storage system to contribute to the reduction of GHG emissions.

(5) The Marine Environment Protection Committee on its seventy-eighth session.
(6) International Energy Agency.
(7) Report of the twelfth meeting of the Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG 12).

2. CARBON CAPTURE AND STORAGE (CCS)

2.1. CCS TECHNOLOGY OVERVIEW

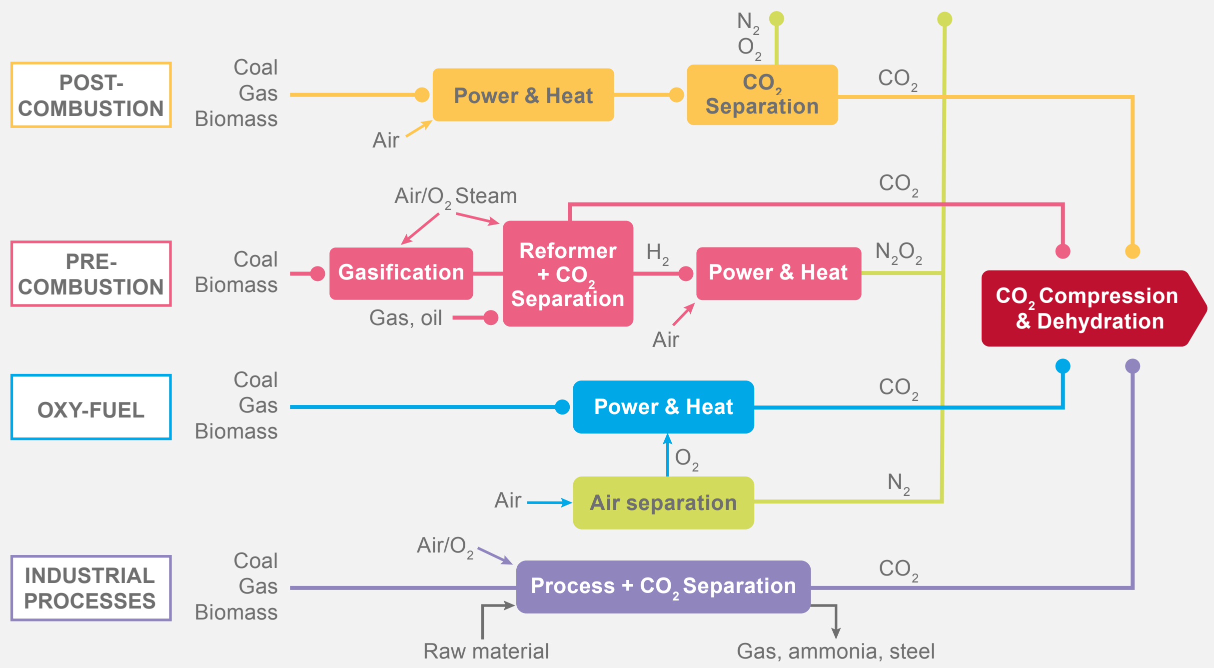
According to the Intergovernmental Panel on Climate Change (IPCC) special report on carbon capture and storage, there are three main approaches to capture CO_2 generated from primary fossil fuels, as shown in figure 2.1:

- **Pre-combustion capture:** processing the primary fuel in a reactor with steam and air or oxygen to produce a mixture consisting mainly of carbon monoxide and hydrogen (synthesis gas). Additional hydrogen, together with CO_2, is produced by reacting the carbon monoxide with steam in a second reactor (shift reactor). The resulting mixture of hydrogen and CO_2 can then be separated into a CO_2 gas stream, and a stream of hydrogen.
- **Oxy-fuel combustion capture:** using oxygen instead of air for combustion of the primary fuel to produce a flue gas that is mainly water vapor and CO_2. This results in a flue gas with mainly CO_2 and H_2O[8].
- **Post-combustion capture:** capturing CO_2 from flue gases produced by the combustion of fossil fuels in air. These systems normally use a liquid solvent to capture CO_2 in a flue gas stream.

For the detailed characteristics of the different CCS technologies, please refer to table 2.1.

To summarize: the post-combustion carbon capture system requires the least alteration to existing ship designs and retrofitting options.

FIGURE 2.1: OVERVIEW OF CO_2 CAPTURE PROCESSES AND SYSTEMS



Source: IPCC, 2005

(8) The Intergovernmental Panel on Climate Change (IPCC), 2005 – Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Eds.) Cambridge University Press, UK. pp 431. Available from Cambridge University Press, The Edinburgh Building Shaftesbury Road, Cambridge CB2 2RU ENGLAND.

TABLE 2.1: CAPTURE TOOLBOXY

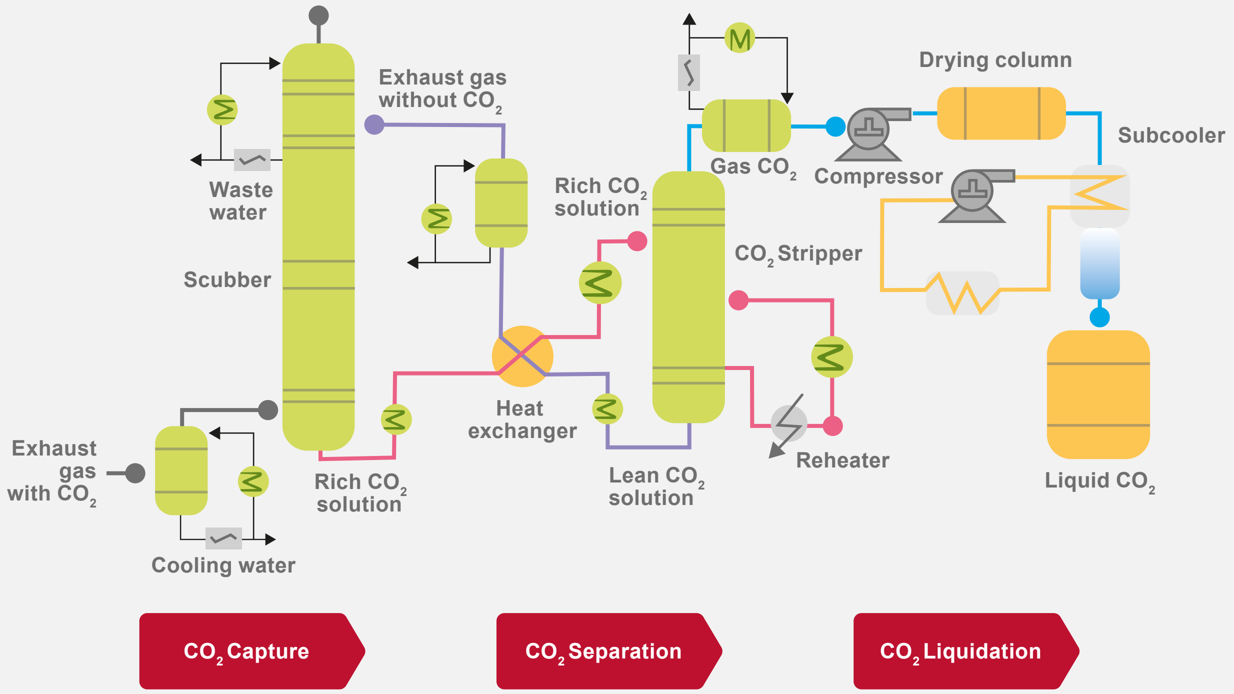
Separation task	Post-combustion capture		Oxy-fuel combustion capture		Pre-combustion capture	
Capture Technology	Current	Emerging	Current	Emerging	Current	Emerging
Solvents (Absorption)	Chemical solvents	Improved solvents Novel contacting equipment Improved design of processes	N/A	Biomimetic solvents, e.g., haemoglobin derivatives	Physical solvent Chemical solvents	Improved chemical solvents Novel contacting equipment Improved design of processes
Membranes	Polymeric	Ceramic Facilitated transport Carbon Contactors	Polymeric	Ion transport membranes Facilitated transport	Polymeric	Ceramic Palladium Reactors Contactors
Solid sorbents	Zeolites Activated carbon	Carbonates Carbon-based sorbents	Zeolites-Activated carbon	Adsorbents for O_2/N_2 separation, Perovskites Oxygen chemical looping	Zeolites-Activated carbon Alumina	Carbonates Hydrotalcites Silicates
Cryogenic	Liquefaction	Hybrid processes	Distillation	Improved distillation	Liquefaction	Hybrid processes
Feature	It is the easiest of the three methods to implement and the most mature, but its operating costs are equally high and need to be controlled.		Combustion at high oxygen concentration places higher demands on combustion chamber material quality. This method of oxygen production is more costly and the operation and maintenance costs are relatively high.		A complete retrofit design of the entire system would require significant initial investment, and the technology for hydrogen-engines is not mature.	

2.2. QIYAO ENVIRON TEC CARBON CAPTURE AND STORAGE UNIT PRINCIPLE

As shown in figure 2.2, the QIYAO ENVIRON TEC CCS system consists of an absorption unit, a separation unit, a compression unit, a refrigeration unit and a storage unit. The main principle is that the organic amine compound solution reacts with the CO_2 in the scrubber, separating it from exhaust gas. The dissolved CO_2 compound solution is desorbed at high temperature in the stripper, and extracted CO_2 is compressed, purified and cooled into liquid CO_2 and stored in a low-temperature storage tank.

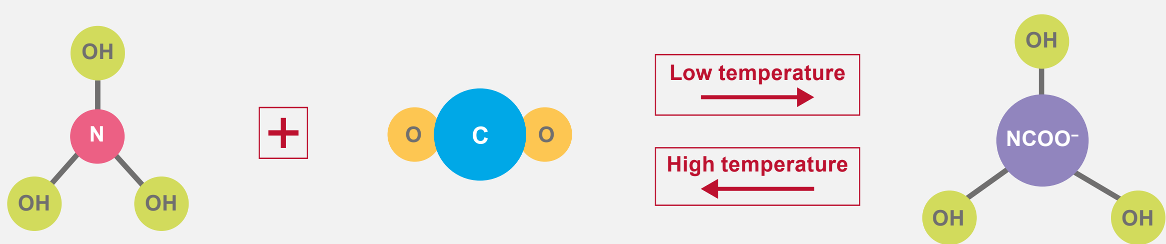
The absorption and separation process of CO_2 is showing in figure 2.3. At low temperatures, an organic amine compound will selectively react with CO_2 in exhaust gas to form ionic $R_1R_2N^+HCOO^-$, while at high temperatures, $R_1R_2N^+HCOO^-$ will react in reverse to regenerate CO_2 and R_1R_2NH.

FIGURE 2.2: QIYAO ENVIRON TEC CCS SYSTEM



Source: QIYAO ENVIRON TEC

FIGURE 2.3: ABSORPTION AND SEPARATION PROCESS OF CO_2



The operating conditions and limitations of the QIYAO ENVIRON TEC CCS system is shown in table 2.2.

The CO_2 capture rate of the CCS system could achieve 85% from the exhaust gas flow according to QIYAO ENVIRON TEC, and the system can be customized according to vessel type and size. The organic amine solution's effectiveness will degrade when system operation time increases, the loss of organic amine absorbent based on the 30% organic amine solution will be about 5% per liter per day.

TABLE 2.2: CCS SYSTEM CONDITION

Parameter	Value
Inlet exhaust gas temperature range	0~350°C
Inlet exhaust gas pressure range	0~10 kPa
Outlet exhaust gas temperature range	≤ 100°C
Outlet exhaust gas pressure range	0~10 kPa
Pressure loss (100% working condition)	≤ 3,200 Pa
Absorbent inlet pressure	2~2.5 bar
Inlet alkalinity of absorbent	pH=14
Absorbent type	Organic amine solution
System operation control parameters and settings	Temperature in absorption tower: 40°C~60°C Absorption liquid density: 1~1.02 kg/L Scrubber pressure loss ≤ 1,000 Pa pH in absorption tower ≥ 11
Applicable maximum fuel sulfur content	1.0%

3. CCS METHODOLOGY FOR CII CALCULATION

3.1. INTERNATIONAL REGULATION BACKGROUND

Refer to "MEPC 76/7/44 – Reduction of GHG emissions from ships - Comments on document MEPC 76/7/5 (Submitted by the Republic of Korea)"[(9)]. Since other capture systems, including the post-combustion system, directly capture CO_2 from flue gas produced after the combustion process, the equation for the calculation of the mass of CO_2 emissions (M) in CII should be modified to cover all CO_2 capture systems as follows:

FIGURE 3.1: FORMULA WITH CCS

$$M = \sum_j (FC_j - FE_j)\, C_{F_j} - CC$$

Term	Explanation
j	Fuel oil type
FC_j	The total mass (in grams) of consumed fuel oil of type j in the calendar year, as reported under IMO DCS
FE_j	The mass (in grams) of consumed fuel oil of type j, which should be excluded from CII calculation and which has been captured and stored rather than having been emitted to the atmosphere
C_{F_j}	The fuel oil mass to CO_2 mass conversion factor for fuel oil type j, in line with those specified in the 2018 Guidelines on the method of calculation of the attained EEDI for new ships (resolution MEPC.308(73)), as may be further amended
CC	The mass (in grams) of CO_2 captured from flue gas measured; taking into account the guidelines developed by the Organization

Please note that the FEj default value is zero in this study.

3.2. TENTATIVE METHODOLOGY FOR CCS

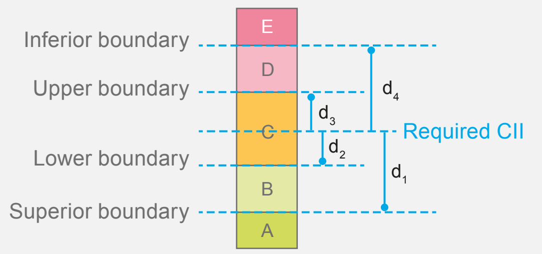
3.2.1. General principle

In order to comply with the CII annual minimum requirement, existing ships must work to decrease their CO_2 emissions. The formula is as follows:

$$Attained\ CII = (FC_j \times C_{F_j} - CC) / W \qquad \textbf{(1)}$$

Attained CII should equal to or lower than the upper boundary per year to ensure existing ships comply with the minimum CII requirement in each year (hereafter referred to as "Target CII").

FIGURE 3.2: CII RATING



3.2.2. Carbon capture calculation methodology

Using the above equation (1), we can calculate below:

$$CC = FC_j \times C_{F_j} - W * Target\ CII \qquad \textbf{(2)}$$

Please note that current CC is the CO_2 emissions from the entire ship without considering CCS in operation at this point. This is because CO_2 emission produced by CCS will be fully captured by the process itself.

Please note that FCj is ship operation data without CCS. CCS's fuel consumption will be calculated according to the equation (3) below.

Since CCS will need additional fuel consumption to generate power during the CO_2 capture process, and will therefore create additional CO_2 emissions, we assume that the additional amount produced by CCS will be captured by the process itself.

(9) MEPC 76/7/44 – Reduction of GHG emission from ships Comments on document MEPC 76/7/5 (Submitted by the Republic of Korea).

Prior to calculating the CCS CO_2 emission amount, we must know the CCS CO_2 capture capacity–power consumption curve. The formula is as follows:

$$B_k = f(A_k) \qquad (3)$$

- A: CCS capture amount.
- B: CCS CO_2 emission amount.
- f: CCS capacity–power consumption factor.
- k: Counting number, from 1 to n.

Iterative computations as follows:

Refer to equation (2), $A_1 = CC, B_1 = f(A_1), B_2 = f(B_1)...,$ $B_n = f(B_{n-1})$

Calculation will complete when B_n approaches zero or is negligible.

We will then know CCS CO_2 emission total amount is $B_1 + B_2 + ... + B_n$.

The final amount of total CO_2 emissions the ship will capture is:

$$CC = FC_j \times C_{F_j} - W * Target\ CII + B_1 + B_2 + B_3 + ... + B_n \qquad (4)$$

The ship complies with CII requirements when the CCS and capture CO_2 amount is greater than CC (CCS should have sufficient design margin).

3.3. MEASUREMENT AND VERIFICATION OF CO_2 EMISSION CAPTURE

According to section 3.2, we will know the theoretical amount of CO_2 to be captured during ship operation. However, to ensure the ship will fulfill the CII rating to an acceptable level, the amount of CO_2 captured should be reported in a measurable and verifiable way, and be adequately documented, taking into account detailed guidelines, including measurement methodologies and standards, and quality assurance of measuring systems developed by the organization.

4. EXISTING SHIPS PARAMETER AND CII CALCULATION

BV and Wah Kwong worked together to assess the CII ratings of Wah Kwong's fleet according to vessels' 2021 operating data. The study selected two different size bulk carriers with the estimated CII ratings as the study focus: *Tianjin Venture* with DWT is 53,413 tons, and *CSSC Wan Mei* with DWT is 176,460 tons.

Based on the specific design parameters of the vessels, QIYAO ENVIRON TEC developed a customized design for CCS units and submitted relevant drawings to BV for approval.

4.1. *TIANJIN VENTURE*

4.1.1. Ship overview

Tianjin Venture is a Supramax bulk carrier, built in 2009, the deadweight tonnage of which is 53,413 tons.

Engines data as follows in table 4.1.

Tianjin Venture

TABLE 4.1: ENGINE DATA

Main engine maker	HHM
Engine type	MAN B&W 6S50MCC
Number of main engine	1
Power @ SMCR (kW)	9,480@127RPM
Exhaust gas flow @ SMCR (kg/hr)	~84,850
Exhaust gas temperature @ SMCR (Celsius)	~350
Number of main engines connected to the scrubber	1
Auxiliary engine maker	**DAIHATSU**
Engine type	6DK-20
Number of auxiliary engines	3
Power @ MCR (kW)	680@720RPM
Exhaust gas flow @ MCR (kg/hr)	-
Exhaust gas temperature @ MCR (Celsius)	~350
Number of auxiliary engines connected to the scrubber	0

The main design parameters of CCS are listed in the table 4.2.

TABLE 4.2: MAIN DESIGN PARAMETERS

CCS parameter	
Maximum main engine load % of SMCR	100%
Number of main engine in operation	1
Maximum auxiliary engines load % of MCR	100%
Number of auxiliary engines in operation	0
Maximum exhaust gas flow at inlet (kg/hr)	~84,850
CO_2 capture rate (kg/h)	~1,000
Maximum temperature of exhaust gases at inlet (Celsius)	~330
Maximum sulphur content on fuel oil	0.1%
Target of CO_2 equivalent	29.5%
Maximum ambient temperature (Celsius)	45
Maximum relative humidity	60%
Maximum sea water temperature (Celsius)	32
Minimum alkalinity of sea water (μmol/lt)	2,300
Maximum exhaust gas back pressure along scrubber (mm WC)	250

4.1.2. CII calculation

According to the DCS 2021 data, and following the business-as-usual scenario, the CII ratings of *Tianjin Venture* from 2023 to 2030 has been estimated.

According to MEPC.346/78, for ships rated as D for three consecutive years or rated as E, the SEEMP shall be reviewed to include a plan of corrective actions to achieve the required annual operational CII.

For *Tianjin Venture*, if the ship is to continue operating until 2030, it needs to take some measures to increase its annual CII rating to an acceptable level which means at least a C rating from 2023 until 2030. With CCS considered as the measure, we need to calculate exactly how much CO_2 needs to be captured onboard year by year for the ship to achieve a C rating from 2023 to 2030, as shown in table 4.3.

According to the CCS design of QIYAO ENVIRON TEC for *Tianjin Venture*, capturing one ton CO_2 will consume 268 kWh of electrical power and 70 kg of fuel oil for the boiler to produce the extra steam.

Based on the CCS methodology descripted in chapter 3, the required CO_2 capture amount is shown in table 4.4. In 2023, the CCS needs to capture a total of 1,442 m^3 (1,661,068,065 g) CO_2 when stored at 7 barg, –46°C conditions. The corresponding annual CO_2 capture rate is about 10.2%.

Since the CII requirement will get stricter each year starting from 2023, the CCS capture rate will need to increase each year accordingly, and the capture rate will reach 29.5% in 2030.

TABLE 4.3: CII TARGET VALUE AND RATING WITH CCS

	Existing ship with CCS							
	CII Attain (2023)	CII Attain (2024)	CII Attain (2025)	CII Attain (2026)	CII Attain (2027)	CII Attain (2028)	CII Attain (2029)	CII Attain (2030)
Tianjin Venture	5.48	5.36	5.25	5.13	5.02	4.90	4.79	4.67
	C	C	C	C	C	C	C	C

TABLE 4.4: CO_2 CAPTURE AMOUNT AND FUEL CONSUMPTION

	2023	2024	2025	2026	2027	2028	2029	2030
Estimate Annual Minimum CO_2 Capture Amount (g)	1,661,068,065	2,168,997,029	2,676,925,992	3,184,854,956	3,692,783,919	4,200,712,883	4,708,641,846	5,216,570,810
Estimate Annual LCO_2 Amount (m^3) (LCO_2 density is 1,152kg/m^3 @ 7barg-46°C)	1,442	1,883	2,324	2,765	3,206	3,646	4,087	4,528
Estimate Annual Minimum Extra Fuel Consumption Amount (mt)	204	266	329	391	453	516	578	640
Preliminary CO_2 Capture Net Percentage	10,2%	13,2%	16,0%	18,9%	21,6%	24,3%	26,9%	29,5%

4.2. *CSSC WAN MEI*

4.2.1. Ship overview

CSSC Wan Mei is a Capesize bulk carrier, built in 2012 with a deadweight tonnage of 176,460 tons.

Engine data as following in table 4.5:

The main design parameters of CCS are listed in the table 4.6.

CSSC Wan Mei

TABLE 4.5: ENGINE DATA

Main engine maker	CMD
Engine type	MAN B&W 6S70MC-C Mark 8.1
Number of main engine	1
Power @ SMCR (kW)	16,860@91RPM
Exhaust gas flow @ SMCR (kg/hr)	~137,915
Exhaust gas temperature @ SMCR (Celsius)	~330
Number of main engines connected to the scrubber	1
Auxiliary engine maker	**YANMAR**
Engine type	6N21ALEW
Number of auxiliary engines	3
Power @ MCR (kW)	970@900RPM
Exhaust gas flow @ MCR (kg/hr)	7350
Exhaust gas temperature @ MCR (Celsius)	355
Number of auxiliary engines connected to the scrubber	0

TABLE 4.6: MAIN DESIGN PARAMETERS

CCS parameter	
Maximum main engine load % of SMCR	100%
Number of main engine in operation	1
Maximum auxiliary engines load % of MCR	100%
Number of auxiliary engines in operation	0
Maximum exhaust gas flow at inlet (kg/hr)	~137,915
CO_2 capture rate (kg/h)	~1,640
Maximum temperature of exhaust gases at inlet (Celsius)	~330
Maximum sulphur content on fuel oil	0.1%
Target of CO_2 equivalent	26.3%
Maximum ambient temperature (Celsius)	45
Maximum relative humidity	60%
Maximum sea water temperature (Celsius)	32
Minimum alkalinity of sea water (μmol/lt)	2,300
Maximum exhaust gas back pressure along scrubber (mm WC)	250

4.2.2. CII calculation

Like the *Tianjin Venture*, according to the DCS 2021 data, the CII ratings of *CSSC Wan Mei* has been estimated and the target CII values by applying CCS has been calculated as shown in table 4.7. The CCS design for *CSSC Wan Mei* to capture one ton of CO_2 will consume 538kWh of electric power and 112 kg of fuel oil for the boiler to produce the extra steam.

The CCS capture rate will be 5.8% in 2023 and increase to 26.3% in 2030, as shown in table 4.8.

TABLE 4.7: CII TARGET VALUE AND RATING WITH CCS

	Existing ship with CCS							
	CII Attain (2023)	CII Attain (2024)	CII Attain (2025)	CII Attain (2026)	CII Attain (2027)	CII Attain (2028)	CII Attain (2029)	CII Attain (2030)
CSSC Wan Mei	2.61	2.55	2.50	2.44	2.39	2.33	2.28	2.22
	C	C	C	C	C	C	C	C

TABLE 4.8: CO_2 CAPTURE AMOUNT AND FUEL CONSUMPTION

	2023	2024	2025	2026	2027	2028	2029	2030
Estimate Annual Minimum CO_2 Capture Amount (g)	1,885,729,422	2,957,303,183	4,028,876,944	5,100,450,704	6,1720,24,465	7,243,598,226	8,315,171,986	9,386,745,747
Estimate Annual LCO_2 Amount (m^3) (LCO_2 density is 1,152kg/m^3 @ 7barg-46°C)	1,637	2,567	3,497	4,427	5,358	6,288	7,218	8,148
Estimate Annual Minimum Extra Fuel Consumption Amount (mt)	232	363	495	627	758	890	1,022	1,153
Preliminary CO_2 Capture Net Percentage	5,8%	8,9%	12,0%	15,0%	17,9%	20,8%	23,6%	26,3%

5. CCS ONBOARD FEASIBILITY STUDIES

The CCS required CO_2 capture rates for *Tianjin Venture* and *CSSC Wan Mei* calculated by BV in chapter 4 are shown in table 4.4 and 4.8.

The corresponding CCS units based on each maximum CO_2 capture rate in 2030 were designed by QIYAO ENVIRON TEC.

5.1. *TIANJIN VENTURE*

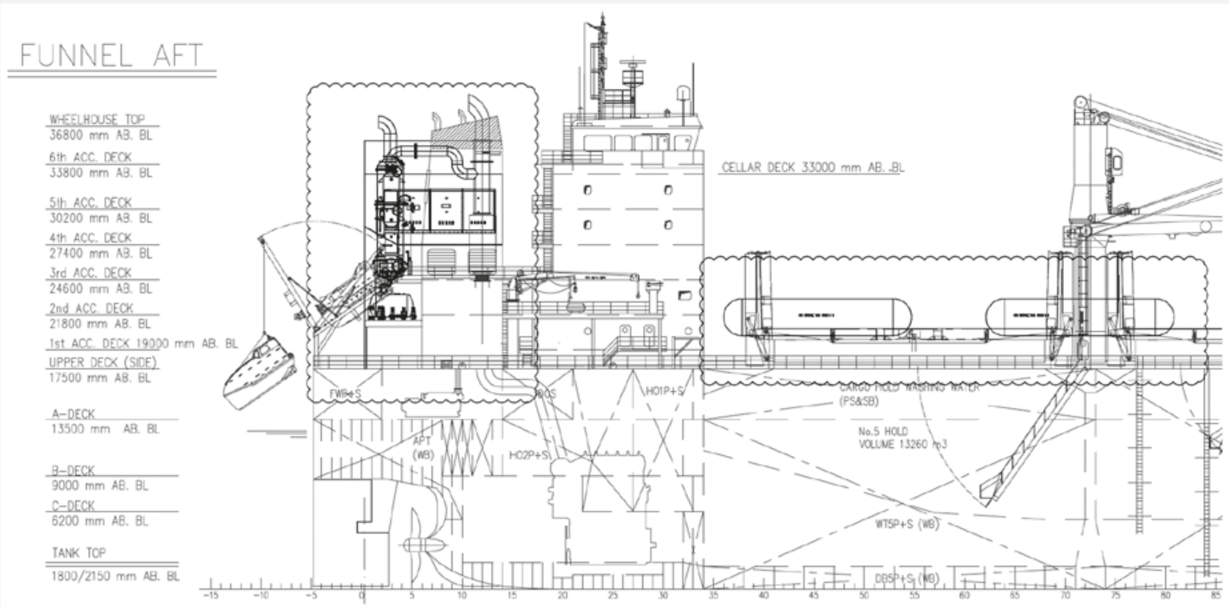
5.1.1. CCS installation onboard

For an existing ship, the biggest obstacle to applying CCS is the onboard installation arrangement, especially for a small bulk carrier that does not have much space available to install the CCS equipment and LCO_2 storage tank(s).

For *Tianjin Venture*, based on the ship type, size and existing design, the CCS equipment will be installed on the accommodation decks after the funnel, as shown in figures 5.1, 5.2 and 5.3.

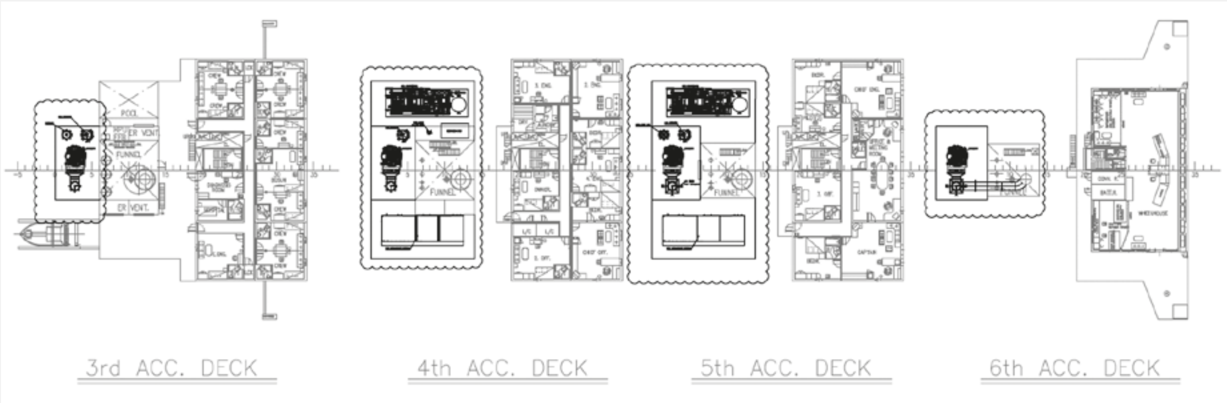
Regarding the LCO_2 tank, due to the limited space onboard, it is difficult install one big storage tank. So, after investigations made by BV, Wah Kwong and QIYAO ENVIRON TEC, it was decided that storage should be split between four small tanks, each with the capacity of 100 m^3. And the arrangement onboard is shown in figures 5.1 and 5.3, two of the tanks are installed on the port side and the other two are installed on the starboard side, just next to the No.5 cargo hatch.

FIGURE 5.1: CCS INSTALLATION ARRANGEMENT ON *TIANJIN VENTURE*



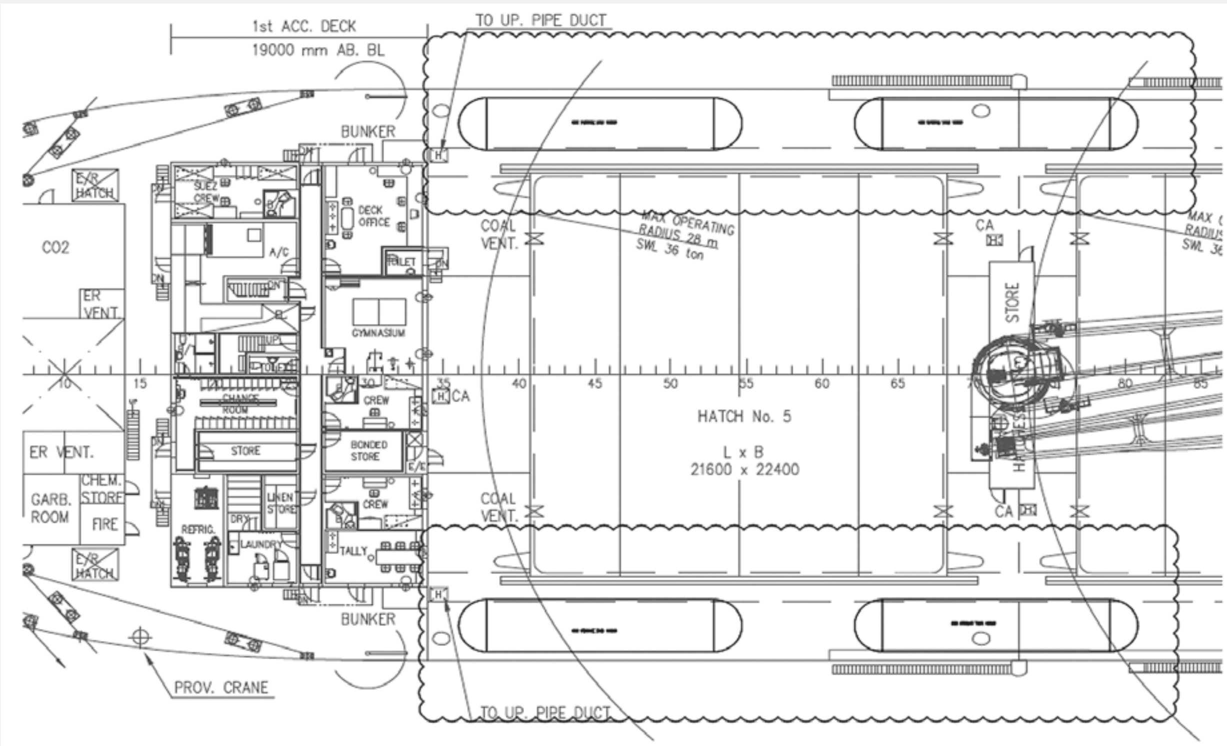
Source: QIYAO ENVIRON TEC

FIGURE 5.2: CCS INSTALLATION ARRANGEMENT ON THE ACCOMMODATION DECK



Source: QIYAO ENVIRON TEC

FIGURE 5.3: LCO_2 TANKS ARRANGEMENT ON *TIANJIN VENTURE*



Source: QIYAO ENVIRON TEC

5.1.2. CCS dry weight

The installation of CCS equipment and LCO_2 tanks will increase the weight of the ship. Depending the design, the dry weight of CCS equipment and LCO_2 tanks is about 289.3 tons, so there will be an inevitable loss of cargo carriage.

5.1.3. CCS power and amine consumption

Power, steam and organic amine solution consumption, etc., are shown in table 5.1.

5.1.4. Electric and steam balance

In this scheme, CCS capacity is 1 t/h, using 0.7MPa steam, and the steam volume is 1 t/h.

The total capacity of the existing boiler is 3.1 t/h (oil-fired boiler is 2 t/h, exhaust boiler is 1.1 t/h), considering CCS operation and steam consumption at sea when cold conditions are revised to 2,544.3 kg/h (1,000 + 1,544.3). No extra boiler is needed.

Electric load analysis as shown in table 5.2.

TABLE 5.1: POWER AND AMINE CONSUMPTION

Description	Quantity	Unit	Item	Sub-items descriptition	Quantity
Organic amine consumption	1	kg/h	1	Absorption and regeneration	1
Organic amine replacement	8,000	kg	2	Replacement by per half year	8,000
Electricity consumption	267.8	kWh	1	Absorption and regeneration	55
			2	Compressor	90
			3	Refrigeration	85
			4	Control system and CEMS	30
			5	Re-liquefaction	7.8
Steam consumption	1,000	kg/h	1	Rich liquid desorbing CO_2	1,000
Sea water consumption	213	m^3/h	1	Pressure loss (100% working condition)	97
			2	Absorbent inlet pressure	36
			3	Inlet alkalinity of absorbent	0
			4	Absorbent type	80
Compressed air consumption	5	m^3/h	1	Start and stop some valves	5

TABLE 5.2: ELECTRIC LOAD ANALYSIS

Item	Running at Sea	Maneuvering	Break down	Stay in Harbor	Loading & Unloading
Total (Original) (kW)	536.1	930.56	800.4	386.4	1,164.3
GE (kW)	680	680	680	680	680
NO. of GE	1	2	2	1	2
Load Factor (%)	78.8	68.4	58.9	56.8	85.6
CCS 29.5%	268	268			
Total with CCS 29.5% (kW)	804.1	1,198.56			
NO. of GE	2	2			
Load Factor (%)	59.13	88.1			

5.1.5. Shaft alignment analysis

Normally, the addition of large equipment on board can cause hull deformation. If the deformed area affects the shafting installation area, it can cause changes in the bearing load of shafting and put stress on the shaft. The CCS installation area of this ship is about ~FR0-FR15, ~FR35-FR80 (see figure 5.1) above the main deck, with dry weight ~300 t and wet weight ~760 t. The shafting installation area is ~FR5-FR20 above the double bottom. From experience, it is similar to the installation of the scrubber, and there is no need to re-align shafting. To perform quantitative analysis, the deformation effect of CCS on the shafting installation area must be considered within the calculation.

5.1.6. Stability analysis

For LCO_2 tanks and major CO_2 equipment, total dry weight is approximately 300 tons in the current design. This will affect stability.

According to a rough estimation of added lightweight and corresponding VCG (21,800 mm):

- Intact stability: intact stability is made acceptable by selecting the worst case scenario after retrofit based on the approved final loading manual.
- Damage stability: damage stability is affected if the NO.1 CH zone is damaged, the critical point being the hatch coaming corner top of NO.2 CH, below final water line at 20 mm.

Possible solutions:

- Decrease the summer draught to 12.52 m, so that the coaming corner top of NO.2 CH will be above the final water line at 27 mm (original summer draught was 12.54 m). All drawings/documents related to stability need to be updated and submitted to class for approval.
- Increase the hatch coaming plate: this be a solution but feasibility studies are required.
- With the agreement of the flag administration:
  - Master can consider the added weight (i.e., the added part of lightweight) as constant (cargo) weight when assessing stability and longitudinal strength of a loading condition (i.e., by using the approved loading instrument or using relevant forms included in the approved Trim and Stability Booklet).
  - The lightweight estimation report shall be duly agreed and signed by the owner, and this shall be used as supplementary to the approved Loading Instrument, Trim and Stability Booklet (including Longitudinal Strength Calculations).
  - Please note this needs to be accepted by the flag administration, which should be approached for approval right from the earliest stages.

5.2. *CSSC WAN MEI*

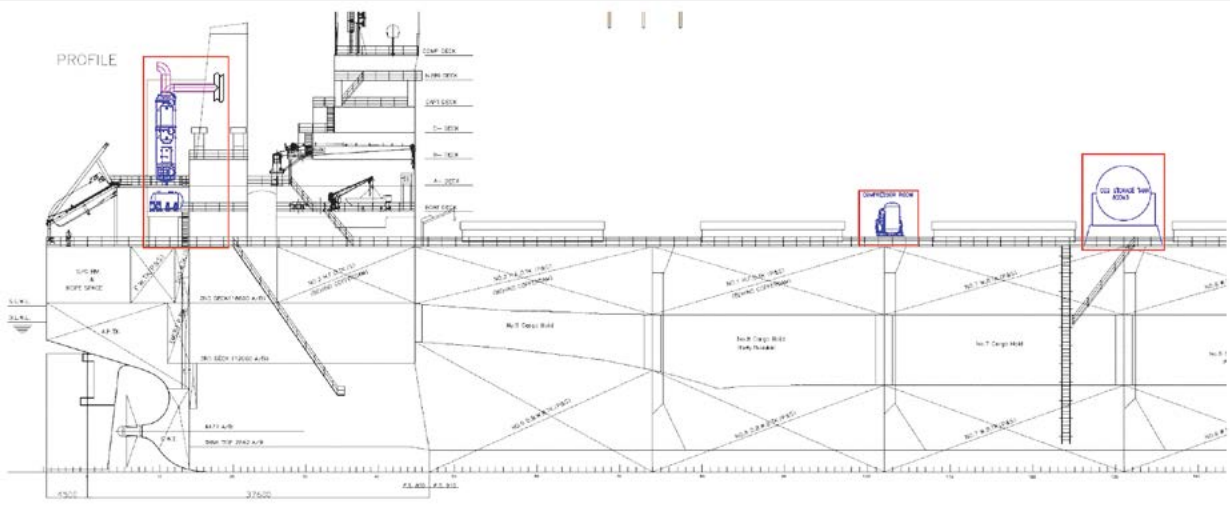
5.2.1. CCS installation onboard

For *CSSC Wan Mei*, depending on ship size and existing design, the onboard CCS equipment and LCO_2 tank installation are shown in figures 5.4 and 5.5.

5.2.2. CCS dry weight

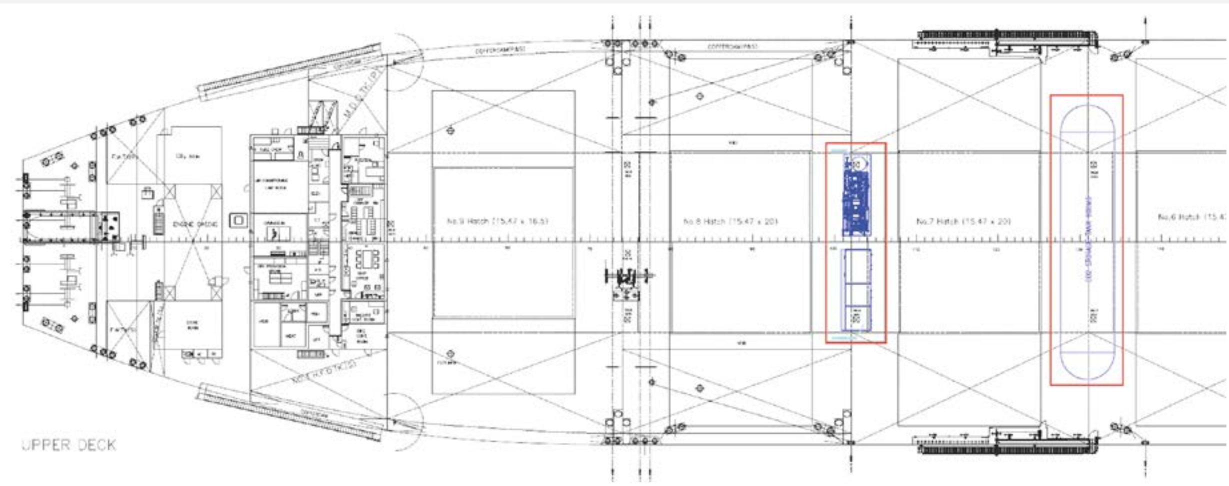
The dry weight of CCS equipment and LCO_2 tank for *CSSC Wan Mei* is about 364.9 tons, which will result in inevitable loss of cargo carriage.

FIGURE 5.4 CCS INSTALLATION ARRANGEMENT ON *CSSC WAN MEI*



Source: QIYAO ENVIRON TEC

FIGURE 5.5: LCO_2 TANK AND COMPRESSOR AND LIQUEFACTION UNIT ARRANGEMENT INSTALLATION ON *CSSC WAN MEI*



Source: QIYAO ENVIRON TEC

5.2.3. CCS power and amine consumption

The power, steam and organic amine solution consumption etc., are shown in table 5.3.

5.2.4. Electric and steam balance

In this scheme, CCS capacity is 1.64 t/h, using 0.7 MPa steam, with a steam volume of 1.6 t/h.

Total capacity of the existing boiler is 4.2 t/h (oil-fired boiler is 2.5 t/h, exhaust boiler is 1.7 t/h), considering CCS operation, the steam consumption at sea when cold conditions are 4,498 kg/h (1,600 + 2,898).

In principle, the capacity of existing boilers is insufficient.

We would like to recommend checking operational steam consumption at sea, to ensure there is a 300 kg/h margin.

Electric load analysis as shown in table 5.4.

TABLE 5.3: POWER AND AMINE CONSUMPTION

Description	Quantity	Unit	Item	Sub-items descriptition	Quantity
Organic amine consumption	1.64	kg/h	1	Absorption and regeneration	1.64
Organic amine replacement	8,000	kg	2	Replacement by per half year	8,000
Electricity consumption	538	kWh	1	Absorption and regeneration	80
			2	Compressor	195
			3	Refrigeration	220
			4	Control system and CEMS	30
			5	Re-liquefaction	13
Steam consumption	1,600	kg/h	1	Rich liquid desorbing CO_2	1,600
Sea water consumption	280	m^3/h	1	Absorption regeneration module	160
			2	Lean solution cooling	40
			3	Compression module	0
			4	Refrigeration module	80
Compressed air consumption	10.5	m^3/h	1	Start and stop some valves	10.5

TABLE 5.4: ELECTRIC LOAD ANALYSIS

Item	Running at Sea	Maneuvering	Emergency	Rest in port	Loading & Unloading
Total (Original) (kW)	800.8	1,221.5	143	501.3	1,115
GE (kW)	900	900	200	900	902
NO. of GE	1	2	1	1	2
Load Factor (%)	89.0	67.9	71.5	55.7	61.9
CCS 26.3%	538	538			
Total with CCS 26.3% (kW)	1,338.8	1,759.5			
NO. of GE	2	2			
Load Factor (%)	74.38	97.8			

5.2.5. Shaft alignment analysis

Like with the *Tianjin Venture*, from experience, this is similar to the installation of the scrubber, so there is no need to re-align shafting. To perform quantitative analysis, the deformation effect of CCS on the shafting installation area must be considered within the calculation.

5.2.6. Stability analysis

Since *CSSC Wan Mei* is a large bulk carrier with DWT at 176,460 tons, the weight increase of CCS is 364.9 tons. This is a small percentage of the DWT so, according to a rough estimation, there will be no impact on the stability of such a big ship.

Tianjin Venture

6. CAPEX AND OPEX ANALYSIS

The CAPEX and OPEX analysis of *Tianjin Venture* and *CSSC Wan Mei* are shown in figures 6.1 and 6.2.

Notes:

- Shipyard retrofit fee is not included.
- Fuel oil and amine costs will change according to market price.
- When ship CII rating is D or better, CCS will not need to operate.

FIGURE 6.1: CAPEX OF CCS

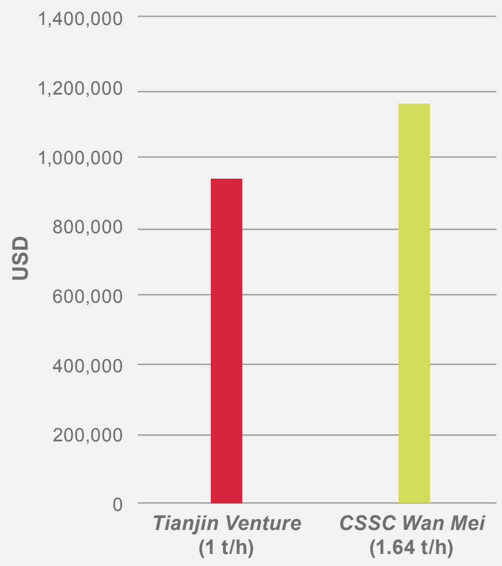
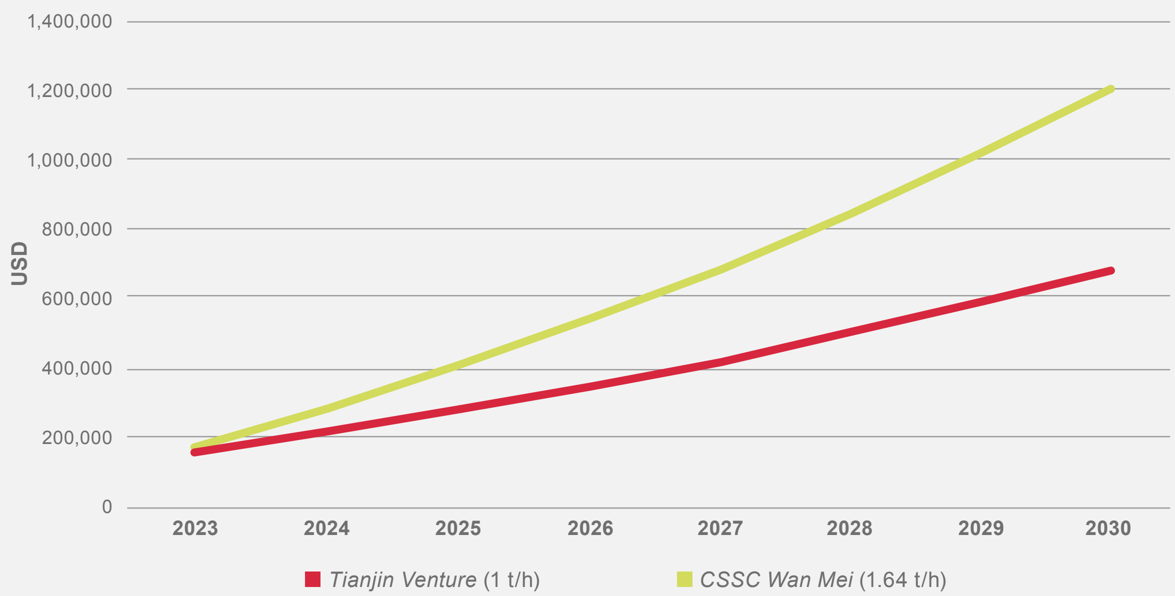


FIGURE 6.2: OPEX OF CCS



7. EU ETS EFFECT FORECAST

In July 2021, the European Commission adopted a proposal aiming to cut greenhouse gas emissions by at least 55% by 2030, putting the EU on a sustainable path to becoming climate neutral by 2050.

The Fit for 55 package is the proposed framework for transforming the Green Deal into reality. These measures are the most ambitious legislation the EU has ever used to combat climate change and create a sustainable economy. It will include both revisions to existing regulations and new measures, goals and tools.

The Commission puts forward a combination of tools, consisting of carbon pricing, rules, targets and support measures. The proposals include adjustments to existing measures (e.g., carbon market, energy taxation) as well as proposals for new legislation, including the EU Emissions Trading System (ETS).

7.1. WHAT IS EU ETS?

The EU ETS Directive will incentivize the shipping industry to reduce GHG emissions in line with the EU's targets. EU ETS uses CO_2 pricing and revenue redistribution to achieve these aims. It is a "cap and trade" mechanism, in which CO_2 allowances are allocated and traded within a certain restricted level.

If you want to emit CO_2, you must obtain permit to do so by buying certain allowances. EU Allowances (EUAs) are made available every year. EUAs can be obtained via auction by governing authorities or other players, such as banks, financial institutions or companies. Participants can only emit up to the amount covered by their allowances. If they do not have enough to cover their needs, they can:

- Reduce their carbon emissions to allowable levels, or;
- Purchase additional allowances.

Putting a price on carbon creates an incentive to de-carbonize. It will stimulate innovation, adaptation, and accelerate the development of new technologies.

EU ETS impacts shipping in the following instances:

- Ships are 5,000GT+;
- Emissions are covered by the system;
- 100% of CO_2 emissions from voyages intra-EU ports;
- 100% of CO_2 emissions at berth in EU ports;
- 50% of CO_2 emissions from extra-EU voyages to or from an EU port.

There will be a phase-in period (or Introduction Path) [2024: 40%], [2025: 70%], [2026: 100%].
This is a learning period to identify shortcomings.

7.2. EU ETS ESTIMATION

A cost saving has been estimated for both ships, taking the ETS into consideration. Assuming the ships will only sail within EU waters, if the ship installs the CCS and the EU's ETS legislation accepts CCS as a countermeasure to reduce the ship's CO_2 emission, the ship will achieve costs savings for the amount of CO_2 captured by CCS and therefore not emitted into the atmosphere.
Of course, CCS operating costs also need to be taken into account.

The calculation is based on the following conditions:

- Assuming the ship CII will obtain C rating;
- CCS OPEX is as per the QIYAO ENVIRON TEC analysis;
- EU ETS EUA price is 98.01 EUR per metric ton on August 19, 2022, assuming the EUA price increases 5 EUR each year;
- LCO_2 price is as per the Asia-Pacific market price, which in in Japan was 246 USD per metric ton, FOB Tokyo on September 2022, and assuming the LCO_2 price remains constant in the coming years.

For *Tianjin Venture*, in an overview of 2023 to 2030, the cost saving is 304,639 USD in total when the ship sails in EU waters, making payback 6,767,952 USD in total if the LCO_2 can be sold.

For *CSSC Wan Mei*, in an overview of 2023 to 2030, the cost saving is 554,942 USD in total when ship sails in EU waters, making payback 11,092,140 USD in total if LCO_2 can be sold.

FIGURE 7.1: EU ETS COST SAVING WITH CCS

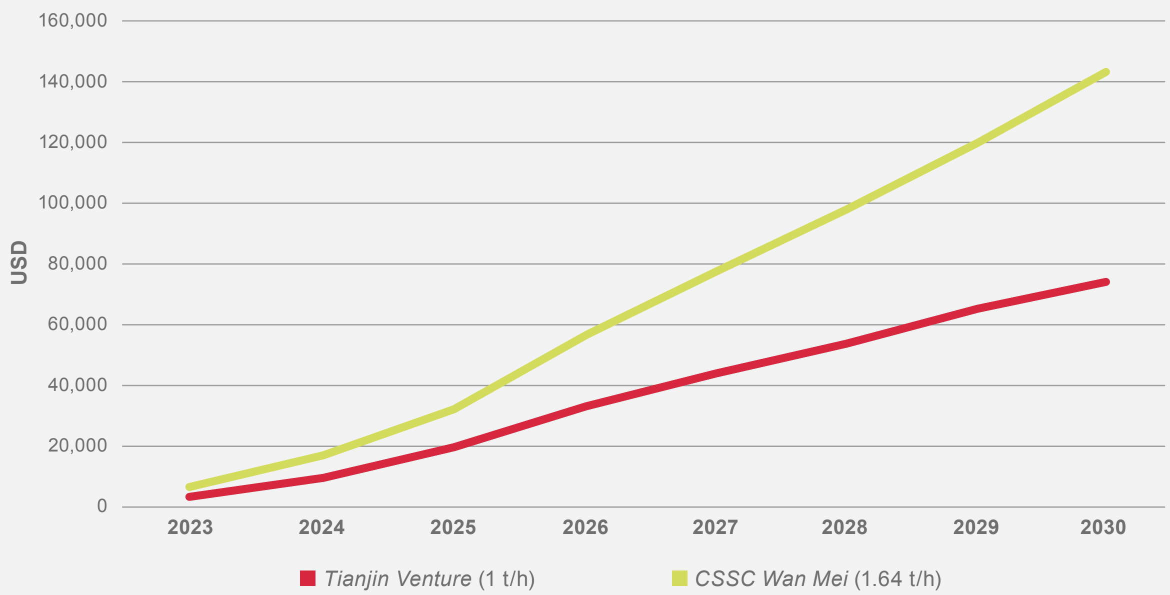
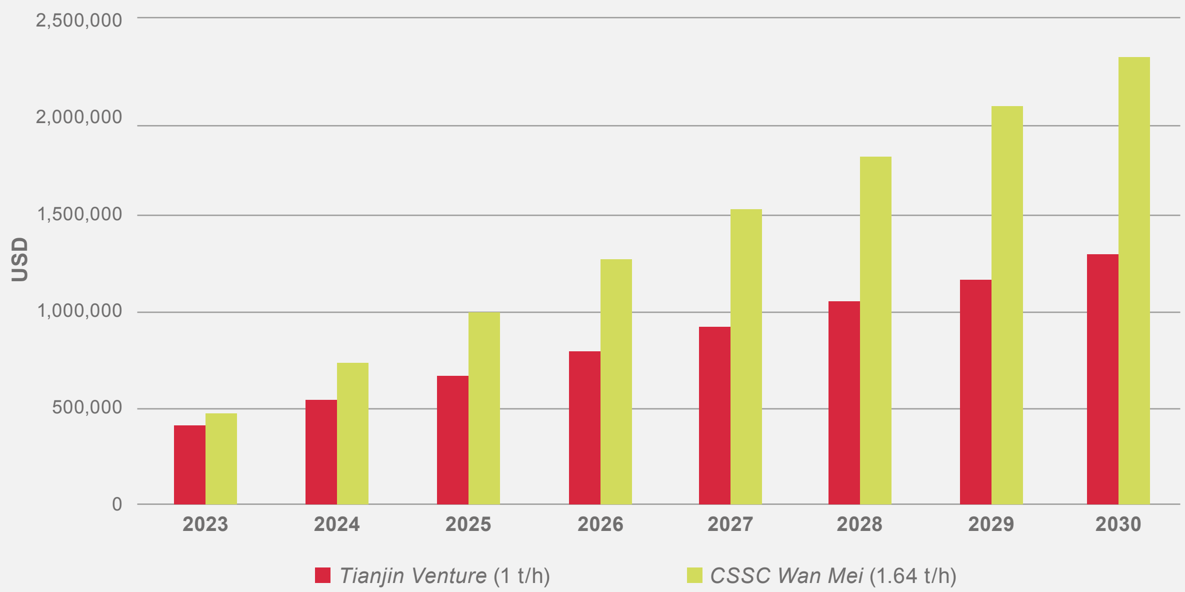


FIGURE 7.2: PAYBACK WHEN LCO_2 IS SOLD



8. CONCLUSION

This report analyzes the feasibility of applying CCS technology on existing ships with the aim of meeting the CII requirements for from January 2023, and fully considers the far-reaching impact of the EU's upcoming implementation of "Fit for 55" (ETS).

Three main aspects were analyzed: technical feasibility, regulations, and cost.

TECHNICAL FEASIBILITY

QIYAO ENVIRON TEC CCS technology has been approved by BV. CCS technology has been used in the industry for years, and the technology is mature. This analysis of CCS uses the absorption and analysis method of amine solution to capture CO_2 from the exhaust pipe, and then compresses and liquefies it and stores it in a low-temperature tank. QIYAO ENVIRON TEC and BV have performed a lot of analysis on the pre-design, operating conditions and maintenance of the system. They have also completed analysis of the installation of CCS on the ship, calculating the electrical load, the interface design of the ship's auxiliary system, etc., to ensure that the installation of CCS on the ship meets the premise of CII requirements and has a high degree of feasibility.

REGULATIONS

Both the IMO and EU have reiterated their carbon ambitions in recent meetings and formulated various policies and regulations to promote the decarbonization of the marine industry.

COST ANALYSIS

CAPEX and OPEX were analyzed, along with a preliminary analysis of the EU ETS, for the period of 2023 to 2030. The cost saving for *Tianjin Venture* is 304,639 USD in total when the ship travels only in EU waters, with payback of 6,767,952 USD in total when LCO_2 is sold. The cost saving for *CSSC Wan Mei* is 554,942 USD in total when the ship travels only in EU waters, with payback of 11,092,140 USD in total when LCO_2 is sold.

This analysis illustrates that the application of CCS technology in ships is feasible and creates certain economies under increasingly strict regulations in the future. However, we must take into account the difficult process of industry chain establishment, such as how to handle collected CO_2, the subsequent development of carbon tax, whether non-EU countries will propose similar regulations, etc. All of these factors require careful consideration. That said, there is no doubt that CCS is already an effective technical solution to decarbonize ships, and a customized design for specific ships will ensure the best savings while meeting regulations.

9. REFERENCES

The Marine Environment Protection Committee at its seventy-eighth session.

MEPC.352 (78) - 2022 Guidelines on Operational Carbon Intensity Indicators and the Calculation Methods (CII Guidelines, G1).

MEPC.353 (78) - 2022 Guidelines on the Reference lines for using with operational Carbon Intensity Indicators (CII Reference line Guidelines G2).

MEPC.338 (76) - 2021 Guidelines on the Operational Carbon Intensity Reduction Factors relative to Reference lines (CII Reduction Factors Guidelines G3).

MEPC.354 (78) - 2022 Guidelines on the Operational Carbon Intensity Rating of Ships (CII Rating Guidelines, G4).

MEPC.355 (78) - 2022 Interim Guidelines on Correction Factors and Voyage Adjustments for CII Calculations (CII Guidelines, G5).

Report of the twelfth meeting of the Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG 12).

International Energy Agency (IEA), Global pipeline of commercial CCUS facilities operating and in development, 2010-2021.

The Intergovernmental Panel on Climate Change (IPCC), 2005 – Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Eds.) Cambridge University Press, UK. pp 431. Available from Cambridge University Press, the Edinburgh Building Shaftesbury Road, Cambridge CB2 2RU ENGLAND.

Proposal for a Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC.

ABBREVIATIONS

BV Bureau Veritas
CAPEX Capital expenditure
CCS Carbon Capture and Storage
CO_2 Carbon Dioxide
CH Cargo hold
CII Carbon Intensity Indicator
DCS Fuel oil Data Collection System
ETS Emissions Trading System
EU European Union
EUA European Union allowances
FR Frame
GHG Greenhouse Gas
IEA International Energy Agency
IMO International Maritime Organization
IPCC Intergovernmental Panel on Climate Change
ISWG Intersessional Working Group
MCR Maximum Continuous Rating
MEPC Maritime Environment Protection Committee
OPEX Operating expenditure
RPM Revolutions Per Minute
SEEMP Ship Energy Efficiency Management Plan
SMCR Specific Maximum Continuous Rating
VCG Vertical Center of Gravity

KEY CONTACTS AT BUREAU VERITAS

Julien BOULLAND
Global Market Leader – Sustainable
+33 7 79 86 26 15
julien.boulland@bureauveritas.com
marine-offshore.bureauveritas.com

Pierre CHAUVIERE
Regional Offshore General Manager of NAZ
pierre.chauviere@bureauveritas.com
marine-offshore.bureauveritas.com

Benoit GROVEL
Directeur, Expertise Gaz / Gas Expertise Director
+33 6 72 55 74 74
benoit.grovel@bureauveritas.com
marine-offshore.bureauveritas.com

Patrick JAN
Expertise Leader –
Environment, Innovative Engine and Alternative fuels
+33 1 55 24 75 51
patrick.jan@bureauveritas.com
marine-offshore.bureauveritas.com

Ernest MENG
Project Manager of Expertise Center –
Sustainability, I&TD
+86 21 2319 0032
ernest.meng@bureauveritas.com
marine-offshore.bureauveritas.com

Georgios RAPTAKIS
Manager, Marine Sustainable & Energy Transition
Development
+86 21 2319 0593
georgios.raptakis@bureauveritas.com
marine-offshore.bureauveritas.com

Daniel SONG
Head of Expertise Center, I&TD
+86 21 2319 0667
daniel.song@bureauveritas.com
marine-offshore.bureauveritas.com

Steven WANG
CPO Mach Section Manager
+86 21 2319 0616
steven-yq.wang@bureauveritas.com
marine-offshore.bureauveritas.com

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FOR MORE INFORMATION,
CONTACT BUREAU VERITAS MARINE & OFFSHORE

8 cours du triangle
92937 Paris La Défense Cedex - France
+33 (0)1 55 24 70 00

marine-offshore.bureauveritas.com

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