Image 1

M/V Lee A. Tregurtha

REPORT DETAILING THE INSTALLATION AND OPERATION OF MARINE EXHAUST GAS SCRUBBING EQUIPMENT ABOARD THE GREAT LAKES SELF-UNLOADING *MOTOR VESSEL LEE A. TREGURTHA*

PREPARED BY
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FOR THE
U.S. DEPARTMENT OF TRANSPORTATION
MARITIME ADMINSTRATION

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Terminology and Acronyms

AOR	Agreement Officer's Representative
ECA	Emission Control Area
IFO280	Intermediate Fuel Oil
IMO	International Maritime Organization
MARAD	U.S. Department of Transportation Maritime Administration
MDO	Marine Diesel Oil
META	Maritime Administration's Maritime Environmental and Technical Assistance Program
UPS	Uninterruptible Power Supply
VGP	Vessel General Permit

ACKNOWLEDGEMENTS

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INTRODUCTION

The Interlake Steamship Company is a privately held company headquartered near Cleveland, Ohio in Middleburg Heights. Interlake and is predecessor companies trace their history back more than 100 years on the Great Lakes. The Company, which employs about 400 people, owns and operates a fleet of eight (8) self-unloading bulk carrying ships on the Great Lakes. It manages and operates a ninth vessel. Interlake's ships range in size from 690 feet in length with a per trip capacity of 24,800 tons, to the largest ship on the Great Lakes at 1,013.5 feet in length with a per trip capacity of 68,000 tons. Interlake's modernized, state of the art ships carry over 20 million tons of bulk cargo throughout the Great Lakes annually. Those cargoes include iron ore that feeds steel mills throughout the Midwest, low-sulphur coal used by electric power generating plants throughout the region, limestone aggregates used by the construction industry, flux for steel mills, and grain for the milling industry. Interlake's customers rely on Interlake vessels to provide reliable and affordable transportation of raw materials.

By virtue of its operation, Interlake's vessels trade exclusively in fresh water. Consequently, their useful life is decades longer than vessels operating in the corrosive salt water of the world's oceans. It is not uncommon for vessels operated on the Great Lakes to be more than fifty years old. The keel for Interlake's newest ship was laid in 1979, and its oldest ship – the M*/V Lee A. Tregurtha* which is the subject of this report – was built in 1942. In contrast, it would be rare to find a salt water vessel built in the 1970's that was still in service, and ships built in the 1980's are routinely being retired from service. As a consequence, freight rates on the Great Lakes have remained low because ships do not have to be replaced as often, and new ships are rarely built. However, hull longevity on the Great Lakes lends itself to the development of programs to renew vessels, and the Cooperative Agreement between MARAD and Interlake relates to the renewal and upgrading of the *M/V Lee A. Tregurtha.*

VESSEL'S STORIED HISTORY

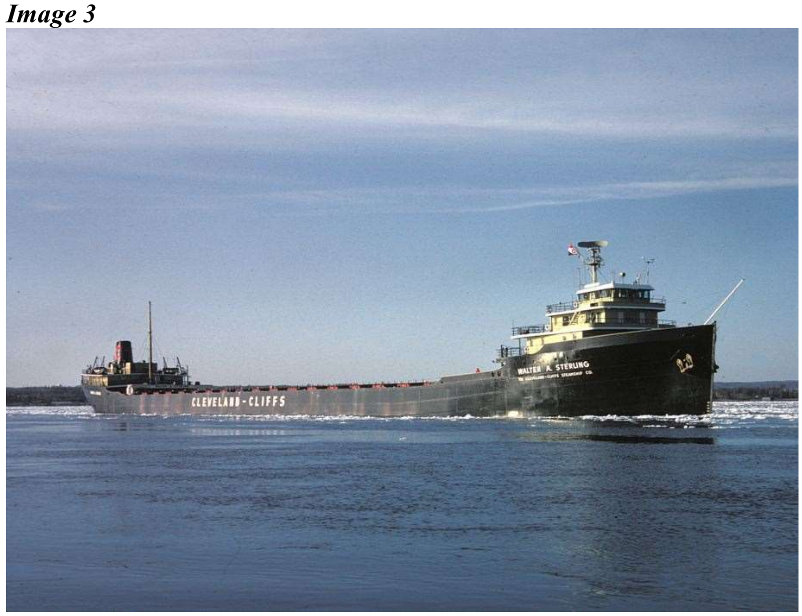
The *M.V. Lee A. Tregurtha* is Interlake's oldest vessel, and has an interesting history. She was designed as an oil tanker for Mobil Oil and her keel was laid at Bethlehem Shipbuilding and Drydock Company, Sparrows Point, Maryland in the early 1940's, just as World War II was breaking out. The United States Maritime Commission assumed construction of the vessel and renamed it *Samoset* upon its launch in June of 1942. Less than six months later in December of that year, the vessel was transferred to the United States Navy for use as an oiler, was renamed the *USS Chiwawa,* and joined the Atlantic Fleet. The *USS Chiwawa* participated in convoy

Image 2

USS Chiwawa (AO-68) was a T3-S-A1 Kennebec-class oiler

operations, and the convoy came under attack in the Atlantic Ocean. Several other vessels were lost to German fire, but the *USS Chiwawa* returned safely. The vessel was eventually awarded two Battle Stars for her service with the Atlantic Fleet before transferring to the Pacific Fleet in July of 1945. Following convoy operations and voyages to Hawaii and Japan, the *USS Chiwawa* was awarded the "Navy Occupation Service Medal – Asia" before she was decommissioned in May of 1946 and subsequently transferred to the reserve fleet.

Image 3



Walter A. Sterling, 1971

The *Chiwawa* was sold in 1947 and entered service as a tanker on the east coast of the United States throughout the Caribbean and in the Gulf of Mexico, where it operated for thirteen years. In 1960, the *Chiwawa* was purchased by Cleveland-Cliffs Steamship Co. of Cleveland, Ohio for lengthening and conversion to a Great Lakes iron ore carrier. The extensive work was completed at American Shipbuilding in Lorain, Ohio, lengthening the vessel by 228' and increasing its beam by 7'. In May of 1961, the vessel was christened the *Str. Walter A. Sterling* (after the President of Cleveland-Cliffs Iron Company).

In 1976, the *Sterling* was lengthened by an additional 96', increasing her cargo carrying capacity to more than 30,000 tons and making her the largest steam powered vessel on the Great Lakes. In 1978, the *Sterling* was converted to a self-unloading ship, slightly reducing her cargo carrying capacity.

In 1984, the *Sterling* was sold to Rouge Steel Co., a subsidiary of the Ford Motor Company and a year later, the vessel was renamed *William Clay Ford*.

THE *LEE A. TREGURTHA*

In 1989, the entire Rouge Steel Co. fleet including the *William Clay Ford* was sold to Lakes Shipping Company, an affiliate of The Interlake Steamship Company. In May of 1989, the vessel was rechristened the *Str. Lee A. Tregurtha*, taking its name from the wife of one of the owners and the Vice-Chairmen of Interlake. In 2015, Lakes Shipping Company was merged into The Interlake Steamship Company, which now owns the *Tregurtha*.

In an effort to increase efficiency and reduce emissions, in 2005 Interlake embarked on an aggressive engine replacement program nearly ten years ago. It converted three steam powered vessels to diesel power, and replaced the diesel engines in a fourth vessel with newer and more efficient diesel engines all at a total cost of more than $75,000,000. That capital investment program to convert its steam turbine powered vessels to diesel power started with the conversion of the *Str. Lee A. Tregurtha.* After much consideration of available engines, the Company chose to install two Rolls Royce Bergen B32-40L6P diesel engines with a power rating of 4,020 horsepower each. Vessel specifics for the *Tregurtha* are shown below in Table 1 with the vessel profile show in Figure 1.

Table 1: Existing Vessel Information

Lee A. Tregurtha	
OFFICIAL NUMBER:	251505
CARRYING CAP.	29,360 Gross Tons
LENGTH OVERALL	826 Ft.
BEAM	75 Ft.
DEPTH	39 Ft.
TYPE VESSEL	Bulk Carrier
MAIN ENGINE	Rolls Royce Bergen B32-40L6P
TOTAL HP	8,040

Image 4: Vessel Profile

The *M.V. Lee A. Tregurtha* is an important vessel in Interlake's fleet. Its self-unloading system includes five cargo holds as well as a 250-foot boom, and the vessel is capable of self-discharging her full cargo in about eight hours. The *M.V. Lee A. Tregurtha* operates for approximately 300 days per year during the Great Lakes navigation season, which typically runs from late March through early January. The Great Lakes traditionally experience winter ice closures of several months, from January through March, during which time vessels like the *Tregurtha* enter the shipyard for annual maintenance and repair. Following its conversion from a steamer to a diesel powered ship in 2005, the *Lee A. Tregurtha* began operating on Intermediate Fuel Oil (IFO280) Residual Marine Grade, with an average sulphur content of 20,000 ppm (2.0%). The engines that were chosen and installed were designed to operate most efficiently on IFO280, and equipment designed to handle the transfer and use of IFO280 was installed at a significant cost during the conversion.

THE IMPACT OF NEW REGULATIONS

The conversion of three steam powered vessels to diesel ships, and repowering of the fourth vessel, had a significant positive impact by reducing stack emissions from those Interlake vessels. However, not long after the expensive engines and related equipment were purchased and the projects had commenced, changes in emissions regulations threatened the projects' viability. Neither the diesel engines installed during the conversion of Interlake's steam powered vessels to diesel powered vessels, nor the replacement engines installed in the repowering of the largest ship on the Great Lakes, when operated on IFO280, would comply with the fuel sulphur limits of the North American ECA.

A significant unintended consequence of the North American ECA sulphur limit regulations was that fleets like Interlake's, if forced to converted from IFO280 to Marine Diesel Oil (MDO), would significantly increase their fleet fuel consumption and resulting greenhouse gasses. After making significant strides to reduce its environmental impact with the voluntary projects that it has undertaken starting in 2005, the new regulations would have had Interlake's fuel consumption increasing by approximately 1 million gallons per year if it modified its vessels to operate on MDO to comply with those new regulations. Over ten years, Interlake's vessels would consume an additional 10 million gallons of MDO.

While Interlake invested significant time and financial resources in trying to develop a liquefied natural gas solution and was optimistic that there would be an LNG solution in place on the Great Lakes for the 2015 implementation of the new regulations, natural gas suppliers abruptly postponed development of LNG in the Great Lakes region in June of 2014.

Exhaust Gas Scrubbing Technology as the Answer

Interlake immediately turned its focus to investigating and engineering closed-loop exhaust gas scrubbing technology that would bring its vessels' stack emissions into full compliance alternative to switching to low sulphur diesel. Interlake believed that once closed-loop exhaust gas scrubbing technology was designed for installation on Great Lakes vessels, and a safe and reliable infrastructure was developed to support the technology, closed-loop exhaust gas scrubbers would provide Great Lakes vessels with a system that would be at least as effective as the ECA fuel requirements at reducing stack emission. The Company's vision was to pioneer the use of closed-loop exhaust gas scrubbing technology on Great Lakes vessels. That technology would qualify as an alternative ECA compliance method that would result in emissions that were equal to or less than those that emitted from the use of MDO. Ultimately, the technology would be eligible for recognition as ECA Equivalent Controls under MARPOL Annex VI, Regulation 4.

The intent of the ECA and MARPOL regulations is to reduce acid rain, which is believed to be caused or contributed to by sulphur from stack emissions. During the combustion process, sulphur oxides form when the sulphur in fuel oxidizes. Sulphur oxides dissolve in water. Therefore, when they are released into the atmosphere as combustion engine emissions, they dissolve in the moisture in the atmosphere and return to ground in the form of acid rain.

Taking advantage of the soluble properties of sulphur oxides, exhaust gas scrubbing technology developed years ago for use at shore side refineries. The basic scrubber design has alkaline water spraying through exhaust gas to dissolve and neutralize the sulphur oxides in the exhaust stream. As emissions regulations developed, shore side exhaust gas scrubbing technology was implemented on vessels that operate on the oceans. Salt water is alkaline in nature, and was the logical choice to use as the reactive agent for those vessels and open loop scrubbers were developed. Those systems are typically referred to as sea to sea systems, as the saltwater that is used in the scrubber is taken from and returned to the sea.

Interlake's vessels operate in an enclosed freshwater system, so saltwater systems were not an option. Additionally, overboard discharge regulations make the open loop concept impractical. Consequently, Interlake's ships required closed loop exhaust gas scrubbing systems in which a reactive agent is added to fresh water to clean the exhaust gasses, and then the wash water is treated to remove contaminates before being discharged overboard.

Prior to Interlake commencing its exhaust gas scrubber program, closed loop systems had not been implemented aboard vessels on the Great Lakes. To develop this technology, Interlake partnered with BELCO Technologies Corporation, a subsidiary of DuPont™ that designs and builds closed-loop scrubbers throughout the world. Interlake worked diligently with BELCO to design, install and test closed loop systems on its vessels. At the same time, Interlake needed to develop a reliable caustic soda supply throughout the Great Lakes for use in the scrubbers. Finally, Interlake needed to understand and develop scrubber waste stream cleaning technology and disposal logistics throughout the Great Lakes.

The Interlake vessels that were candidates for closed-loop exhaust gas scrubbing technology, like many other vessels that operate exclusively on the Great Lakes, fell into one of two classes depicted below.

Table 2

Vessel Classes	
Class 1 690’-826’ Vessels, 6,000 SHP - 8,000 BHP, 1950’s “Vintage”	
Class 2 1,000’ Vessels, 16,000 BHP, 1980’s “Vintage”	

Class 1 vessels are mid-size traditional Great Lakes vessel sometimes referred to as “Lakers” with forward pilot houses and aft engine rooms. Vessels in Class 1 first entered service in the 1950’s as steam turbine powered vessels, and range in overall length between 690’ and 826’. Interlake was the first company to convert and repower to state-of-the-art diesel engines in Class 1 vessels, starting with the repowering of the *M.V. Lee A. Tregurtha* in 2006. Following the *Tregurtha* conversion, Interlake converted and repowered three other Class 1 vessels – the *M.V. Hon. James L. Oberstar*, the *M.V. Kaye E. Barker* and the *M.V. Herbert C. Jackson*.

Class 2 vessels are the 1,000’ class of vessels, sometimes referred to as “thousand footers.” Vessels in Class 2 first entered service in the late 1970’s and early 1980’s, and were all constructed as diesel powered vessels. Again, Interlake was the first to repower a Class 2 vessel to more efficient diesel engines with the *M.V. Paul R. Tregurtha* in 2012.

DuPont™ Marine Scrubbers from Belco Technologies Corp.

After significant investigation and analysis, Interlake chose to partner with BELCO Technologies Corp., a DuPont™ company, to develop and install single-inlet, closed-loop DuPont™ Marine Scrubbers on its impacted vessels.

The BELCO scrubber units are attached to the exhaust system of each of the ship's two engines. Their design has exhaust gas from the engines traveling through a series of absorption sprays that "wash" and remove impurities, specifically sulphur and particulate matter. That washed exhaust gas then travels through a droplet separator before a clean plume of white steam is discharged into the atmosphere. Specifically, the scrubber system relies on an injection of sodium hydroxide to neutralize and remove sulphur from the exhaust gas.

Image 5: Sectional View of DuPont™ Belco Marine Scrubber

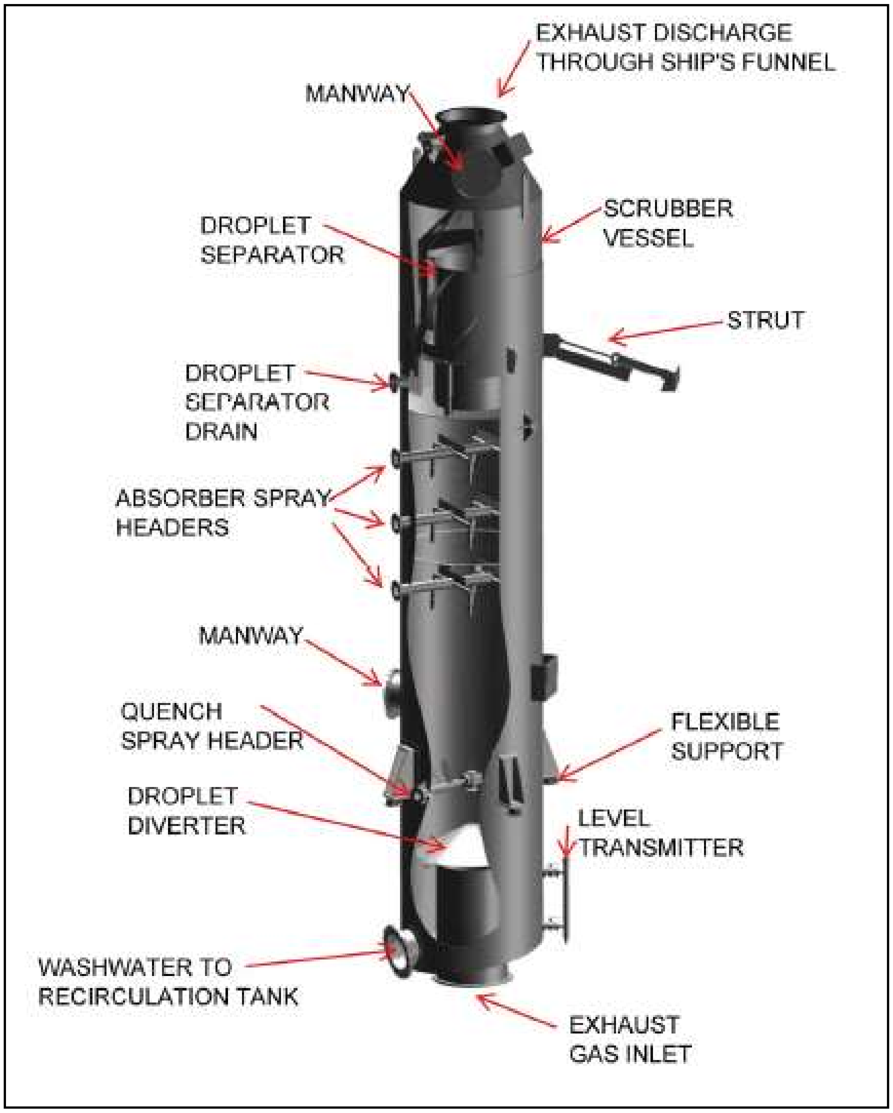


Image 6

Scrubber vessel during fabrication

BELCO's scrubber vessels are nearly 5' in diameter and are constructed out of highly corrosion-resistant alloys. Exhaust gas enters through the gas inlet at the bottom of the scrubber vessel and passes vertically through the scrubber vessel, exiting the discharge at the top of the scrubber vessel. Safety devices and alarms are built into the scrubber vessel protect the engines against backflow of wash water. In the lower section of the scrubber vessel, referred to as the Quench Section, wash water that is dosed with caustic soda as the reactive agent is sprayed through several spray nozzles designed to maximize contact with exhaust gasses. In this section of the scrubber vessel, exhaust gasses become saturated, gas temperatures are reduced, and SO2 absorption begins. In the second level of the scrubber vessel, referred to as the Absorber Section, the exhaust gasses are sprayed with wash water by several more spray nozzles. In this section, SOx is dissolved into the wash water, making it acidic. The instruments measuring the acidity of the wash water activate the two caustic metering pumps, which control the amount of caustic soda being added to the wash water recirculating tank. The caustic soda and water mix neutralizes the acidity. The instruments measuring the acidity of the wash water recirculating tank function to maintain the wash water at a neutral pH of 7. The top level of the scrubber vessel is referred to as the Droplet Separator section. The droplet separators are chevron style structures that remove water droplets from the exhaust gas before it is discharged from the scrubber vessel. Those droplets are returned to the wash water recirculating tank through a droplet separator drain. A level indicator in the wash water recirculating tank activates a make-up water pump, which is designed to add water to the system as the level drops.

Image 7

A view into the Scrubber vessel during fabrication

The exhaust gasses are monitored by a Continuous Emission Monitoring System (CEMS) provided by Martek Marine and installed as part of the BELCO system. The CEMS monitors various exhaust gas emissions including SO_2 and CO_2, and calculates the SO_2/CO_2 ratio. The unit extracts sample gas from the top of the scrubber vessel after it has passed through the scrubber. The sample is brought into a panel through a heated sample line for analysis. The sample line is heated so as not to condense water from the sample. Non-dispersive infrared technology is used to measure the emissions.

From time to time, some of the wash water needs to be purged and processed to remove contaminates before being discharged, requiring a peripheral effluent treatment system. For the original installation on the *M.V. Hon. James L. Oberstar,* the only available technology to treat effluent at the time was the Enscrub unit manufactured by Ensolve. That unit is designed to function much the same way that an oily water separator functions, in order to produce effluent that meets regulatory standards for overboard discharge. While the Enscrub unit functioned, it required significantly more manpower, and cost significantly more to operate than, what was anticipated and budgeted for. Many of the issues relate to the unit's filters, which were expensive and required frequent changes. While improvements were made to the Ensolve system throughout the *Oberstar's* first season operating with a scrubber system, the filter costs, maintenance costs and overall operational costs of the Ensolve system far exceed the original expectations and budget. Consequently, Interlake opted to replace the Ensolve unit with a new centrifugal separator scrubber effluent treatment system manufactured by GEA Westfalia called a Scrubber Master.

That same Scrubber Master system was then installed as part of the original equipment on the *Tregurtha*.

The BELCO system is equipped with an effluent water monitoring system with instruments that measure pH, temperature, PAH, turbidity and oil content of the effluent stream. If the measurements conform to the limits permitted by regulation, the effluent stream can be discharged overboard. However, the system is designed to prohibit overboard discharge of the effluent water if any of those parameters exceed the limits allowed by regulation, at which time the effluent is sent back to the waste water tank.

INSTALLATION ABOARD *M/V LEE A. TREGURTHA*

The *M.V. Lee A. Tregurtha* was the second of Interlake's Class I vessels to be equipped with scrubbers. The first installation was made aboard Interlake's *M.V. Hon. James L. Oberstar* in early 2015 at Fincantieri Bay Shipbuilding in Sturgeon Bay, Wisconsin. The same yard was chosen for the *Tregurtha* installation, and plans were implemented to order and install two single-inlet, closed-loop DuPont™ Marine Scrubbers from Belco Technologies Corp., a DuPont™ company, in early 2016.

In order to satisfy the first testing requirement of the requirements of the Cooperative Agreement with MARAD – baseline pre-scrubber installation testing, Interlake secured the services of SGS, the world's leading inspection, verification, testing and certification company, to conduct baseline emissions testing. A little more than a month before the vessel's arrival in the shipyard, on December 14th and 15th, 2015, SGS boarded and rode the vessel and conducted testing in order to determine the emissions of the *Tregurtha's* two Rolls Royce B32:40L6/6m engines. Measurements were performed according to Marpol Annex VI.

Table 3: Engine Data for M.V. Lee A. Tregurtha

Component		Engine port side	Engine Starboard
Supplier		Rolls Royce	Rolls Royce
Type		B32 40L6/6M	B32 40L6/6M
Serial number		15080	15081
Cilinders		6	6
Line / V		Line	Line
Charging		Turbo	Turbo
Intercooler		Yes	Yes
Rated power	kW	3000	3000
Rated speed	rpm	750	750

To conduct its baseline testing, SGS sampled flue gasses, which were processed in a flue gas cooler to remove moisture. The dried flue gasses were subsequently tested with SGS's measuring equipment. The results of the measurements are summarized in tables 4 and 5 below.

Table 4: Results of the 95% load measurement Port side December 2015

Engine		
Manufacturer		Rolls Royce
Type		B32 40L6/6M
Number		15080
Location		MS Lee Tregurtha
Cycle		E2: 3000 kW @ 750 rpm
Emissions		**Measured**
CO2 relative emisson	(g/kWh)	***580***
CO relative emisson	(g/kWh)	***0.34***
SO2 relative emisson	(g/kWh)	***4.81***
NOx relative emisson	(g/kWh)	***10.00***
Particle relative emission	(g/kWh)	***0.45***
Particle relative emission	(mg/m03 dry flue gas)	***67***

Table 5: Results of the 95% load measurement Starboard side December 2015

Engine		
Manufacturer		Rolls Royce
Type		B32 40L6/6M
Number		15081
Location		MS Lee Tregurtha
Cycle		E2: 3000 kW @ 750 rpm
Emissions		**Measured**
CO2 relative emisson	(g/kWh)	***586***
CO relative emisson	(g/kWh)	***0.38***
SO2 relative emisson	(g/kWh)	***4.64***
NOx relative emisson	(g/kWh)	***9.61***
Particle relative emission	(g/kWh)	***0.43***
Particle relative emission	(mg/m03 dry flue gas)	***69***

Image 8

Scrubber vessel being lifted for installation

The BELCO scrubber system was scheduled for installation during the 2015/2016 winter layup period. Prior to the vessel's arrival at the Fincantieri Bay Shipbuilding in Sturgeon Bay, Wisconsin, project equipment was arriving on a regular basis and a great deal of work was being done in anticipation of the *Tregurtha's* arrival. The first of two scrubbers arrived in the shipyard on December 23, 2015 and the second arrived shortly thereafter. Due to an uptick in customer cargo requirements right at the end of the shipping season, the vessel did not arrive at its layup berth at Bay Shipbuilding until January 24, 2016.

The shipboard work promptly began upon its arrival into the shipyard. Due to significant space constraints, the engineering as it related to fitting all of the equipment onto the *Tregurtha* was significantly more challenging than it was for the other vessels in Interlake's fleet. Other vessels in the Interlake fleet afforded significantly more room in which to install the scrubber vessels and peripheral equipment. As space on the *Tregurtha* was extremely limited, it took significant effort to engineer and design components that would fit into the very limited spaces in the engine room and in the stack. For example, the narrow stack on the *Tregurtha* was modified by adding bolsters to each side to accommodate the actual scrubber vessels. One of the more challenging engineering issues was fitting the caustic tank an associated pumps into the engine room. Engineering took longer than expected and cost more than budgeted, and Bay Engineering had to work very hard to complete the engineering for timely delivery to the shipyard.

Image 9

Scrubber Master Installed

The *Tregurtha* project included the installation of a GEA Westfalia Scrubber Master, installed as a peripheral effluent treatment system for the purpose of removing contaminates from the wash water so that it could be discharged overboard. When Interlake first began installing scrubber systems on its vessels, the only available effluent treatment system was the Enscrub unit manufactured by Ensolve. While the Enscrub unit functioned, it was far from optimal. Shortly after the Enscrub unit was installed on Interlake's *M.V. Hon. James L. Oberstar*, and prior to the equipment specifications being finalized for the *Tregurtha* project, GEA Westfalia began selling its Scrubber Master for peripheral effluent treatment system. The centrifugal design of Westfalia's Scrubber Master is similar to other centrifugal Westfalia equipment that Interlake employs in the fuel supply systems aboard its vessels.

Given the difficulties that Interlake experienced with the Ensolve unit, Interlake decided to replace that unit on the *Oberstar* with a GEA Westfalia Scrubber Master, and to specify the Scrubber Master equipment as original equipment in all future scrubber projects including the *Tregurtha* project. One of the engineering challenges relating to the *Tregurtha* project was the design and installation of two entirely new decks inside of the engine room to accommodate all of the associated equipment, including the Scrubber Master equipment.

Image 10

Vessel stack removed

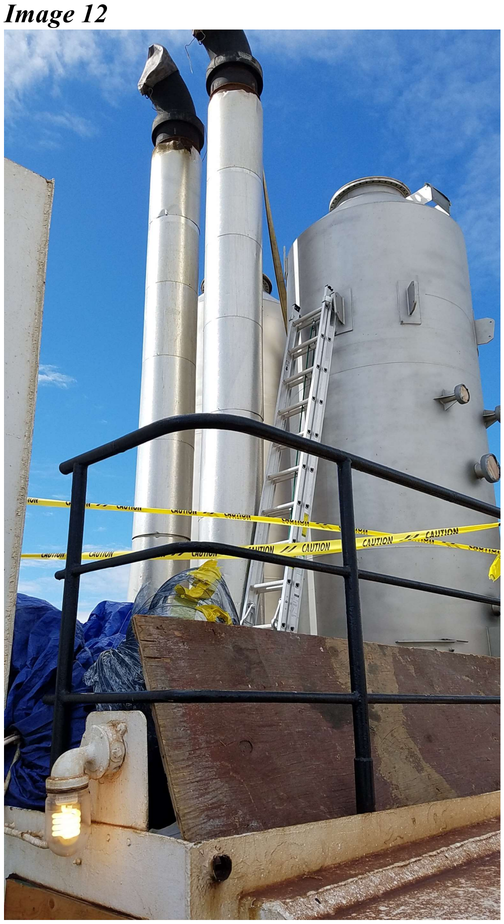
In addition to the change in specification of the effluent treatment system from the *Oberstar* project to the *Tregurtha* project, there were other changes to the scrubber system and peripheral equipment between the two projects to adapt the project for "lessons learned" following the *Oberstar* installation and operation. The exhaust gasses in the system are monitored by a CEMS provided by Martek Marine. The original specification as installed on the *Oberstar* provided for one CEMS unit with one sample pump and one set of sensors. As the vessel has two engines, the CEMS unit on the *Oberstar* was configured to alternate taking emissions samples from the port and starboard engines. Following the opportunity to operate the Oberstar's scrubber system for a season, it was determined that for future scrubber system installations, including the system planned for the *Tregurtha*, the CEMS system would be modified to install a sample pump and a set of sensors for each of the two engine exhaust streams so that the exhaust gasses from each engine could be continuously monitored.

Image 11

Chevron style droplet separators

Another change in design and specification of equipment between the *Oberstar* project and subsequent scrubber projects including the *Tregurtha* project was a change to the design of the droplet separators in the scrubber vessels. The original droplet separator design was not efficiently catching and removing enough moisture from the exhaust as it passed through the system. That resulted in sodium and sulfate residue being carried by moisture in stack emissions, where it immediately precipitated from the stack emissions and settled on the vessel. The change in design to the chevron-style separators, which provided more surface area over which the emissions would pass, was effective at removing that moisture and solving the carry-over issue.

Image 12



Scrubber before stack reinstalled

Overruns in installation increased the total cost of the system by more than $560,000. The overruns were attributed to the difficulty in fitting components into tight spaces, the complexity of the stainless steel piping systems, American Bureau of Shipping requirements for inspection and x-ray of welds on caustic recirculation piping, and overtime labor with respect to all of those components of the project.

COMMISSIONING AND OPERATION OF THE VESSEL

As a result of the lessons learned during the commissioning of the *Oberstar's* exhaust gas scrubbing system a year earlier, and commissioning of the *Oberstar's* Scrubber Master system several months earlier, commissioning of both the exhaust gas scrubbing system and the Westfalia system on the *Tregurtha* went much more smoothly. The *M/V Lee A. Tregurtha* departed the shipyard on June 22, 2016, 182 days after entering the yard, with a fully functioning exhaust gas scrubbing system. For the first several weeks, BELCO commissioning engineers, Westfalia representatives and Interlake seamen worked on solving what were minor commissioning issues with the performance of the various systems. Those issues were quickly and easily worked through. For example, the day after the vessel sailed, the crew and BELCO commissioning engineers determined that splashing within the scrubber vessels themselves was causing the stilling well sensors to read inaccurate high level readings, sounding an erroneous alarm. BELCO was able to engineer and implement a permanent solution to that problem.

FIRST ROUND OF SCRUBBER EMISSIONS AND WASH WATER TESTING

In order to satisfy the second testing requirement of the Cooperative Agreement with MARAD, Interlake once again secured the services of SGS to conduct the first round of post-scrubber installation emissions testing to verify that the newly installed equipment was functioning properly. Measurements were performed according to Marpol Annex VI. Approximately six weeks after the *Tregurtha*'s scrubber system was commissioned, BELCO boarded the vessel on August 12, 2016 to conduct performance testing of both the marine scrubbers.

Image 13

Sampling ports before Scrubber

Image 14

Sampling ports after Scrubber

Table 6: Measurement Program Starboard Exhaust Stream August 2016

Engine	Location	Measurement	Date	Period	Load / % MCR
Star board	Before scrubber O_2-CO_2-CO-NO_x-SO_2	1	2016-08-12	12:30 – 13:00	2580 kW / 86%
		2		13:00 – 13:30	
		3		13:30 – 14:00	
		4		14:00 – 14:30	
		5		14:30 – 15:00	
		6		15:00 – 15:30	
		7		15:30 – 16:00	
Star board	Before scrubber PM	1	2016-08-12	13:16 – 13:27	2580 kW / 86%
		2		13:45 – 13:54	
Star board	After scrubber O_2-CO_2-CO-NO_x-SO_2	1	2016-08-12	12:30 – 13:00	2580 kW / 86%
		2		13:00 – 13:30	
		3		13:30 – 14:00	
Star board	After scrubber PM	1	2016-08-12	13:10 – 13:25	2580 kW / 86%
		2		13:49 – 13:59	

Table 7: Measurement Program Port Exhaust Stream August 2016

Engine	Location	Measurement	Date	Period	Load / % MCR
Port side	Before scrubber O_2-CO_2-CO-NO_x-SO_2	1 2 3 4 5 6 7	2016-08-12	07:30 – 08:00 08:00 – 08:30 08:30 – 09:00 09:00 – 09:30 09:30 – 10:00 10:00 – 10:30 10:30 – 11:00	2580 kW / 86%
Port side	Before scrubber PM	1 2	2016-08-12	09:21 – 09:30 09:47 – 09:58	2580 kW / 86%
Port side	After scrubber O_2-CO_2-CO-NO_x-SO_2	1 2 3 4 5	2016-08-12	07:30 – 08:00 08:00 – 08:30 08:30 – 09:00 09:00 – 09:30 09:30 – 09:48	2580 kW / 86%
Port side	After scrubber PM	1 2	2016-08-12	09:48 – 09:58 10:05 – 10:15	2580 kW / 86%

Table 8: Summary of Results Port Exhaust Stream August 2016

Location / components		Before scrubber	After scrubber
O_2	vol%	11.7	11.8
CO_2	vol%	7.0	6.9
CO	vppm	80	77
NO_x	vppm	807	855
SO_2	vppm	451	14
PM	mg/m_0^3	248	106
CO_2	g/kWh	607	6.7
CO	g/kWh	0.44	0.43
NO_x	g/kWh	7.96	8.52
SO_2	g/kWh	5.69	0.17
PM	g/kWh	1.10	0.47
SO_2/CO_2	-	64.4	2.0

Table 9: Summary of Results Starboard Exhaust Stream August 2016

Location / components		Before scrubber	After scrubber
O_2	vol%	11.8	11.9
CO_2	vol%	6.9	6.9
CO	vppm	83	81
NO_x	vppm	834	876
SO_2	vppm	446	19
PM	mg/m_0^3	128	58
CO_2	g/kWh	607	607
CO	g/kWh	0.46	0.46
NO_x	g/kWh	8.30	8.8
SO_2	g/kWh	5.68	0.24
PM	g/kWh	0.57	0.26
SO_2/CO_2	-	64.6	2.8

The results of SGS's August 2016 testing revealed that both the port side and starboard side scrubbers demonstrated performance significantly better than the allowable maximum SO2(ppm)/CO2 (vol %) ratio of 4.3, and were 2.0 and 2.8 respectively. In addition, the results also showed that the DuPont™ Marine Scrubbers removed 54-57% of the inlet PM. The testing also showed that the pH, PAH and Nitrates measurements were well within the allowable limits. On-line measurements of turbidity were also found to be within allowable limits.

On November 23, 2016, SGS again boarded the *Tregurtha* – this time to test the washwater from four separate locations: Sea suction; port side scrubber purge; starboard side scrubber purge and overboard discharge downstream of common washwater treatment unit. The parameters measured include the 10 dissolved and total metals, 16 PAHs, Nitrates-Nitrites and pH that are required by section 2.2.26.2.2 of the 2013 Vessel General Permit (VGP). Although the VGP only mandates results at the ship's overboard discharge, the expanded test results also show that the pH of all collected samples is greater than the minimum allowable pH of 6.0. Similarly, the total PAHs and Nitrates-Nitrites are well below the allowable limit of 2250 μg/L and 2700 mg/L respectively.

In summary, the first round of testing of both emissions and wash water following the installation of the DuPont™ Marine Scrubbers and related equipment aboard the *Tregurtha* demonstrate performance in accordance with the VGP and International Maritime Organization (IMO) requirements, and the entire system is in compliance with both the gaseous and water discharge emissions regulations set forth by both the VGP and the IMO.

THE FIRST SEASON OF OPERATION

Throughout the fall and into the winter of 2016, the scrubber system continued to function well. However, as with any innovating project, Interlake engineers were challenged from time to time. For example, they experienced issues with turbidity sensors in the system. Air bubbles in the washwater caused the sensors to give erroneous readings as it mistook the bubbles for turbidity in the washwater. The sensor is a light refractive sensor, and when light from the sensor contacted the bubbles, it did not reflect back accurately and would give a false reading of high turbidity when the turbidity was within the tolerable limits. In order to reduce the air bubbles, the system back pressure was increased to compress the air bubbles out of the system. However, the increased back pressure caused valve issues, cavitation and premature wearing. Representatives from Westfalia were consulted, and worked with Interlake engineers and BELCO representatives to develop a new sensor to replace the problematic ones, allowing the system backpressure to be returned to normal. This bypass turbidity meter was installed as a test on another Interlake vessel and has worked well, so another has been ordered for installation on the *Tregurtha* after this operating season. That problem was not unique to the *Tregurtha*, and affected all of Interlake's vessels with exhaust gas scrubbing equipment.

Another issue that Interlake engineers worked through was the premature failure of probe heaters. Probes within the system are heated so that they are not impacted by condensation. The probe heaters in many instances failed prematurely, requiring frequent maintenance. Tests were conducted of various other brands of probe heaters until a suitable alternative was found.

While these and other similar issues required and in some instanced continue to require attention, Interlake was pleased that from an operational standpoint, the *Tregurtha* experienced the smoothest operation of all of our vessels with exhaust gas scrubbing equipment. Consequently, very little work was required to be done to the *Tregurtha's* scrubber system over the 2016/2017 winter layup period. The most significant project on the system that winter was the permanent installation of the Chevron style droplet separators. Interlake's first vessel to receive exhaust gas scrubbing equipment had an alternate design of droplet separators instead of the Chevron type that is now specified as original equipment in each installation. The original droplet separators were not efficiently catching and removing enough moisture from the exhaust as it passed through the system, so it was determined that they should be replaced with Chevron type separators. Consequently, the original equipment for the *Tregurtha* was equipped with chevrons. However, the Chevrons, while installed in the fabrication shop, were not permanently affixed inside of the scrubbers. The units were shipped on their sides and when they were raised vertically to move them into the ship, the Chevrons shifted. A more permanent Chevron installation was accomplished over the 2016/2017 winter layup period.

With approximately six months of operations utilizing the scrubber system in 2016, Interlake was able to gather emissions data, which when contrasted against the vessel's actual fuel sulphur position, was another indication of how efficiently the exhaust gas scrubbing equipment was performed. The fuel sulphur position for the *Tregurtha* was established as of January 1, 2016, and the "Average Annual Fuel Sulphur Content" was then carried forward each month, taking into account additions and consumption, to calculate the vessel's running fuel sulphur content. The calculated fuel sulphur position was then checked twice by laboratory testing during the period (analytical). Variances between the calculated fuel sulphur position and actual fuel sulphur position determined by laboratory testing were determined to be .0968% or less. The fuel sulphur position for the *Tregurtha* for the period from July 1, 2016 through December 30, 2016 was as follows:

Table 10: Actual Fuel Sulphur Position, July 2016 through December 2016

7/1/2016 calculated	8/1/2016 calculated	9/1/2016 Analytical	9/30/2016 calculated
1.0946%	1.2400%	1.4074%	1.3468%

9/30/2016 analytical	11/1/2016 calculated	12/1/2016 Analytical	12/1/2016 analytical
1.2500%	1.5151%	1.2579%	1.2600%

For the period from July 1, 2016 through September 30, 2016, the vessel's actual fuel sulphur position was 1.2722%. For that same period of time, scrubber system CEMS data established the port and starboard main propulsion engines averaged 19.541 PPM and 19.869 PPM respectively. Their average SO2/CO2 ratio were 3.154 and 3.143 respectively, which would have an equivalent fuel sulphur content level of .0728% and .0726% respectively. For the period from October 1, 2016 through December 30, 2016, the vessel's actual fuel sulphur position was 1.3410% for that same period of time, with the vessel in constant service, CEMS data established that the port and starboard main propulsion engines averaged 19.262 PPM and 18.230 PPM respectively. Their average SO2/CO2 ratio were 3.143 and 2.780 respectively, which would have an equivalent fuel sulphur content level of .0726% and .0642% respectively. Consequently, the exhaust gas scrubbing equipment on the *M/V Lee A. Tregurtha* was effectively and significantly reducing sulphur in the vessel's emissions to levels well below the regulatory requirements.

RETURN TO SERVICE AFTER FIRST WINTER LAYUP

When the *Tregurtha* returned to service in the spring of 2017, the scrubber system continued to function well but with minor problems from time to time – primarily with the peripheral equipment. For example, the uninterruptible power supply initially provided with the CEMS unit was not marine rated. That caused an issue

Image 15

Scrubbed exhaust – a plume of steam

with the CEMS that was remedied once identified and the UPS was replaced. Additionally, as part of the original equipment with the *Tregurtha's* installation, Interlake installed a centrifugal GEA Westfalia "Scrubber Master" system for the purpose of scrubber washwater treatment. While that system works significantly better than the Ensolve unit that was installed on the first vessel upon which a gas scrubbing system was installed, it has not been without some minor issues. However, GEA has been a good partner and is working with Interlake to solve those minor issues, one of which relates to centrifugal pump cavitation. The system also required a high frequency of cleaning maintenance required for the turbidity monitor, and Interlake worked with the equipment manufacturer to reduce maintenance intervals on that system. A bypass turbidity meter modification is scheduled for the *Tregurtha* at the end of this season. Perhaps the best evidence that all of those issues were minor, and that the effluent treatment and monitoring systems were working properly, is that the vessel has not been required to hold any effluent in its holding tanks since commissioning in 2016. All of the scrubber water used in the system has been treated, the sludge removed and sent to a sludge tank, and the effluent discharged in conformity with the applicable regulations.

During the period, Interlake continued to gather emissions data and contrast it against the vessel's actual fuel sulphur position to monitor the efficiency of the exhaust gas scrubbing equipment. The fuel sulphur position for the *Tregurtha* was established as of March 1, 2017, prior to commencement of the sailing season, and the "Average Annual Fuel Sulphur Content" was then carried forward each month, taking into account additions and consumption, to calculate the vessel's running fuel sulphur content (those values shown below as "calculated"). The calculated fuel sulphur position was then checked by laboratory testing in September (that value shown below as “analytical”). The variance between the calculated fuel sulphur position as of October 1, 2017, and the actual fuel sulphur position determined by laboratory testing done two days earlier was determined to be .0514%. The fuel sulphur positions for the *Tregurtha* (both calculated and analytical) for the period from March 1, 2017 through October 1, 2017 was as follows:

Table 11: Actual Fuel Sulphur Position, March 2017 through October 2017

3/1/2017 calculated	4/1/2017 calculated	5/1/2017 calculated	6/1/2017 calculated	7/1/2017 calculated
1.1246%	0.9719%	1.2188%	1.3691%	1.5353%

8/1/2017 calculated	9/1/2017 calculated	9/28/2017 Analytical	10/1/2017 calculated
1.4042%	1.5252%	1.3000%	1.3514%

For the period commencing April 1, 2017 and ending June 30, 2017, there was a malfunction of the CEMS data logging computer that impacted the capture of and analysis of data pertaining to exhaust gas (see comment above concerning power supply issue). Once the malfunction was discovered, the CEMS was reset and returned to normal operation. During that quarter, the CEMS unit logged 23,629 records for both main engines. It logs data every 4 minutes for both engines simultaneously. The data was reviewed and analyzed, and revealed quarterly average SO2/CO2 ratio for both main engines of 3.424. The quarterly average SO2 reading for both main engines was 19.372ppm. The average fuel sulphur equivalent for the period was 0.0749. For the period commencing July 1, 2017 and ending September 30, 2017, the CEMS unit logged 33,114 records for both main engines. It logs data every 4 minutes for both engines simultaneously. The data was reviewed and analyzed, and revealed a quarterly average SO2/CO2 ratio for both main engines of 3.023. The quarterly average SO2 reading for both main engines was 17.024ppm. The average fuel sulphur equivalent for the period was 0.0674. Once again, the data confirmed that the exhaust gas scrubbing equipment on the *M/V Lee A. Tregurtha* was effectively and significantly reducing sulphur in the vessel’s emissions to levels well below the regulatory requirements.

SECOND ROUND OF SCRUBBER EMISSIONS TESTING

In order to satisfy the third testing requirement of the Cooperative Agreement with MARAD, Interlake once again secured the services of SGS to conduct the second round of post-scrubber installation emissions testing to verify that the scrubber equipment was continuing to function properly. Measurements were performed according to Marpol Annex VI. BELCO boarded the vessel on December 21, 2017 to conduct this second round of performance testing of both the marine scrubbers.

Table 12: Measurement Program Starboard Exhaust Stream December 2017; 3000kW @ 750 rpm

Test	load	95%	95%	95%	95%
Date		11/07/17	11/07/17	11/07/17	11/07/17
Start	(hh:mm)	10:50	11:20	11:50	12:20
End	(hh:mm)	11:20	11:50	12:20	12:50

Table 13: Measurement Program Port Exhaust Stream December 2017; 3000kW @ 750 rpm

Test	load	95%	95%	95%	95%
Date		11/07/17			
Start	(hh:mm)	13:35	14:05	14:35	15:05
End	(hh:mm)	14:05	14:35	15:05	15:35

Table 14: Summary of Results Port Exhaust Stream December 2017

Location / components		Before scrubber	After scrubber
O_2	vol%	12.6	12.6
CO_2	vol%	6.3	6.4
CO	vppm	53	43
NO_x	vppm	1331	1223
SO_2	vppm	405	19
PM	mg/m_0^3	97	29
CO_2	g/kWh	680	694
CO	g/kWh	0.4	0.3
NO_x	g/kWh	15.1	13.9
SO_2	g/kWh	6.4	0.3
PM	g/kWh	0.5	0.2
SO_2/CO_2	-	64.3	3.0

Table 15: Summary of Results Starboard Exhaust Stream December 2017

Location / components		Before scrubber	After scrubber
O_2	vol%	12.5	12.5
CO_2	vol%	6.4	6.5
CO	vppm	72	60
NO_x	vppm	1296	1201
SO_2	vppm	388	21
PM	mg/m_0^3	53	20
CO_2	g/kWh	686	699
CO	g/kWh	0.5	0.4
NO_x	g/kWh	14.5	13.9
SO_2	g/kWh	6.0	0.3
PM	g/kWh	0.3	0.2
SO_2/CO_2	-	60.6	3.15

The results of SGS's December 2017 testing revealed that both the port side and starboard side scrubbers demonstrated performance significantly better than the allowable maximum SO2(ppm)/CO2 (vol %) ratio of 4.3, and were 3.0 and 3.15 respectively. In addition, the results also showed that the DuPont™ Marine

Scrubbers removed 62-70% of the inlet PM. The testing also showed that the pH, PAH and Nitrates measurements were well within the allowable limits. On-line measurements of turbidity were also found to be within allowable limits.

In summary, the second round of emissions testing following the installation of the DuPont™ Marine Scrubbers and related equipment aboard the *Tregurtha* demonstrate performance in accordance with the VGP and International Maritime Organization (IMO) requirements.

CONCLUSION

Having recently converted the *M/V Lee A. Tregurtha* from a steam powered vessel to a diesel powered vessel operating on IFO280, new regulations that were to become effective on January 1, 2015, limiting sulphur emissions in the North American ECA threatened the economics of that project. As a means of alternative compliance, Interlake chose to install closed-loop exhaust gas scrubbing equipment on its vessels – something that had not yet been done on the Great Lakes where its ships operated. The fresh water environment and discharge regulations posed unique challenges, but Interlake was confident that it could assist in the development and implementation of this technology on the Great Lakes. Faced with an anticipated project cost of $5,187,000, Interlake turned to MARAD for assistance. MARAD answered the call, allowing the *Tregurtha* installation to go forward as a demonstration project that was performed under a Cooperative Agreement with MARAD as part of its META Program. While the final project cost came in approximately one million dollars over the initial estimate, the project was a great success. The goals of the project: Deploying scrubber technology on the *M/V Lee A. Tregurtha*; adding to a growing body of in-use data to prove that closed-loop exhaust gas scrubbing technology will work in fresh water on the Great Lakes; expanding implementation of scrubber technology on Interlake's Great Lakes vessels; further developing a reliable caustic soda supply throughout the Great Lakes; and developing a greater understanding of scrubber waste stream cleaning technology and disposal logistics throughout the Great Lakes including establishing infrastructure to offload and dispose of the small amount of sludge waste product generated from the closed-loop system were all met. The project demonstrated the ability to retrofit an existing and otherwise serviceable vessel with closed-loop exhaust gas scrubbing technology, without the need to repower. Interlake has shared its experience with other Great Lakes operators, and has allowed numerous vessel visits by those operators and their representatives to help advance the technology. The scrubbers have proven effective at reducing stack sulphur emissions well below where they would have been had the vessel simply switched to MDO, while at the same time removing particular matter.