Ministry of Environment and Energy

Male', Republic of Maldives.

Progress Report

Demonstration Project for Fisheries Sector

April, 2018

Submitted for the consideration of the 81st Meeting
of the Executive Committee of
the Multilateral Fund for the implementation of the Montreal Protocol

Contents

List of Tables

List of Figures

Abbreviations

DPND	Department of Planning and National Development
GWP	Global Warming Potential
HCFC	Hydrocholorofluorocarbon
HFC	Hydroflourocarbon
MIFCO	Maldives Industrial Fisheries Company
UNEP	United Nations Environment Program
MIT	Maldives Institute of Technology
UNDP	United Nations Development Program
RSW	Refrigerated Sea Water Systems

1. HCFC phase-out in the Maldives

The Maldives is a small island country and consumes HCFC-22 in refrigeration and air-conditioning applications. The consumption of HCFC-22 in the year 2017 was approximately 43.6 MT, which was a 35% reduction from the baseline. Of this total consumption, fisheries sector applications make for approximately 15-20% of the total consumption.

Fisheries sector plays an important role in the Maldives economy. It is the second largest contributor to Maldives' economy and employs a significant population of the country. The fish catch of Maldives is stored, processed, and exported globally. HCFC-22 is consumed in fisheries sector in a range of applications and predominantly in fishing vessels, processing and storage applications. Many of this equipment still have an economic life, although old and require continued use of HCFCs for their operations. Given that fishing vessels operate in sea and many times under rough sea and/or weather conditions, it is difficult to control leakage and adopt good servicing practices like in other equipment such as refrigeration equipment using HCFCs in land.

Stage I of HPMP, included retrofitting HCFC based equipment in the fisheries sector. Due to technological constraints and the need for compliance of the country, ODS free alternatives were selected as retrofit/drop-in substitutes. Due to high GWP of the selected refrigerant, the further usage was not advised to fishing sector. Based on these experiences, UNDP in May 2016 submitted a "Demonstration project for HCFC-free low-global warming potential alternatives in refrigeration in fisheries sector" to the 76th ExCom, got approval to find out the low GWP alternatives for fisheries sector. Fishing industry has agreed with the Government of the Maldives to continue their efforts to convert to low GWP alternatives that are technically feasible and economically viable, as and when such alternatives become available in the market. Hence, in order to help the fishing industry, particularly sea-borne vessels that use HCFCs, this project aims to demonstrate low-GWP HCFC free alternatives for use by fishing industry in the Maldives.

2. Maldives Fisheries sector

The fisheries sector plays a critical part in the country's economic development, with the fisheries sector contributing a significant contribution to food security, as fish is the primary source of protein in the local diet (FAO, 2016). It is one of the most important primary economic activity in almost all of the country's inhabited islands.

Maldives benefits from access to high quality fisheries stock, but a large share of its value is lost through export of fish as commodities to intermediary markets. Previously, Maldives shipped 90 percent of its fishing catch of tuna in dried form to Sri Lanka. In 1979, Maldivian government created the Maldives Fisheries Corporation.

As opposed to tourism, fisheries accounts for a very small contribution to GDP (1.7 percent) but a larger share of employment (10.5 percent). Currently the fisheries sector generates USD 110 million in export revenue.

The fisheries sector includes local fishing communities and enterprises developed for collection and processing of the catch. As shown in **Table 1**- **Table 5**, there are about 17 fisheries enterprises in operation, 4 facilities not in operation at the moment, 4 enterprises under construction, 7 facilities planned and 1 facility construction delayed.

Table 1: Fisheries Enterprises/Facilities in Operation

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
1	R	Dhuvaafaru	MWSC	50	Operating
2	K	K. Atoll (Barge)	IOF Cooperation Pvt Ltd. FV	100	Operating
3	K	Hura	Blue Line - Euro Global Maldives Pvt ltd	60	Operating
4	K	Gaagandu	Marine Coral Fish Processing Factory	15	Operating
5	K	Hulhumaale	Ensis Fisheries Pvt Ltd	110	Operating
6	Aa	Ukulhas	United Regional Corperative Society	32	Operating
7	V	Thinadhoo	Ilyas Ibrahim / Ufanveli / N. Holhudhoo	10	Operating
8	Dh.	Meedhoo	Beach Builders Pvt Ltd	25	Operating
9	Dh	Kudahuvadhoo	Bright Brother's Pvt Ltd	12	Operating
10	Ga	Kooddoo	Kooddoo Fisheries Maldives Ltd	2000	Operating
	Gdh	Thinadhoo		100	Operating
	Gdh	Faresmaathoda		10	Operating
11	Gn	Fuvahmulah	Big Fish South Pvt. Ltd	40	Operating
12	S	Hithadhoo	Addu Fresh Pvt. Ltd.	40	Operating
13	K	Hulhumale	Umar Jamaal	-	Operating
14	Laamu Maandhoo	Maandhoo Fisheries Complex	Horizon Fisheries	3500	Operating
15	Lh. Felivaru	Felivaru Fish Processing	STO	750	Operating
16	Hulhumale	Maldives Marine Products	Maldives Marine Products	80	Operating
17	K. Kandu Oiygiri	Kandu Oiygiri Maldives	STO	120	Operating

Table 2: Fisheries Enterprises/Facilities not in operation

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
17	Sh	Keekimini	Island Enterprises Pvt. Ltd.	50	Not operational
18	K	K. Atoll (Barge)	Alize (FV)	10	Not operational
19	Th	Tha. Atoll (Guraidhoo)	IOF Cooperation	50	Repairing
20	Th	Funadhoo	Funnadhoo Tuna Products Pvt. Ltd.	15	Not operational

Table 3: Fisheries Enterprises/Facilities under Construction

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
21	K	Himmafushi	Bigfish Pvt Ltd	40	Under Construction
22	F	Nilandhoo	Kooddoo Fisheries Maldives Ltd	25	Under Construction
23	GDh	Fiyoree	Kooddoo Fisheries Maldives Ltd	25	Under Construction
24	GDh	Gahdhoo	Kooddoo Fisheries Maldives Ltd	25	Under Construction

Table 4: Fisheries Enterprises/Facilities Planned

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
25	N	Lhohi	Felivaru Fisheries Maldives Ltd	20	Requested for land
26	R	Alifushi	Felivaru Fisheries Maldives Ltd	20	Requested for land
27	B	Thulhaadhoo	Felivaru Fisheries Maldives Ltd	20	Land allocated
28	Th	Hirialndhoo	Kooddoo Fisheries Maldives Ltd	20	Land allocated
29	Ga	Kolamaafushi	Kooddoo Fisheries Maldives Ltd	20	Land allocated
30	Ga	Dhehvadhoo	Kooddoo Fisheries Maldives Ltd	20	Land allocated
31	Ga	Dhaandhoo	Kooddoo Fisheries Maldives Ltd	20	Requested for land

Table 5: Fisheries Enterprises/Facilities delayed

No	Atoll	Island	Company Name	Cooling Capacity (Tons)	Status
32	K	Male' (barge)	Ocean Fresh Pvt. Ltd.	50	delayed Construction

The government of Maldives strongly focus on development of solutions with low GWP alternatives and energy efficient systems while phasing out HCFCs. In this regard, the facilities planned/under construction will definitely be with low GWP refrigerants as these facilities are land based where ammonia are predominant.

2.1 Technologies used in sea-borne refrigeration applications

An assessment was carried out to find out the refrigeration technologies used across the fisheries vessels by the fisheries enterprises of the Maldives. Most commonly used systems are Refrigerated Sea Water (RSW) Systems that are used both at Mother Vessels as well as the collector vessel. Figure 1 shows a general RSW system and Figure 2 shows a collector vessel of Maldives. Figure 3 shows a RSW system used in the Maldives.

Referred RSW systems are used to cool down the fish being collected and stored across the tanks and are currently installed for usage in the mother vessel and fish collector vessels of the fisheries enterprises.

Refrigerated Sea Water (RSW) systems chill fish through a mechanical process that pulls heat from the catch within the fish into an evaporator, and then discharges that heat overboard through a condenser. Most RSW units require between 5hp and 15hp, and this energy is supplied to the unit through auxiliary diesel generators installed in the vessel.

Figure 1: Refrigerated Sea Water (RSW) System

(Available at https://www.teknotherm.no/fisheries/fisheries-systems/rsw-systems/)

Figure 2: Collector Vessel

Figure 3: Vessels and their RSW systems

2.2 *Technologies used in land based storage and processing*

The review of the land based refrigeration systems revealed that the following technology applications are in use across the fish processing and transportation enterprises of the Maldives.

These technology options contribute to the various process of applications of fisheries sector operations of the Maldives.

Table 6: Commonly used Shore-based refrigeration equipment

No	Name of the Equipment	Image of the Equipment	Purpose
1	**Freezer Containers**		A **refrigerated container** or **reefer** is an intermodal container (shipping container) used in intermodal freight transport that is refrigerated for the transportation of fish. As per the use in the fisheries sector, enterprises use them as additional storage for the fish processing activities.

2	**Transport Trucks**		A **refrigerator trucks** are used to carry fish at specific temperatures. Refrigerator trucks used in the fisheries sector are ice-cooled, equipped with mechanical refrigeration systems powered by small displacement diesel engines. These trucks transport the fish to various locations such as to the airport or other locations.
3	**Ice Plants**		**Ice plants** are used for the production and storage of ice, including the icemaker itself that is the unit that converts water into ice together with the associated refrigeration machinery, harvesting and storage. Ice plants used in the fisheries sector include block and flake ice plants used across various enterprises
4	**Cold Rooms**		All the fisheries enterprises in the Maldives possess refrigerated **cold rooms** as a storage facility attached to the fisheries enterprises. They are designed as a 'walk-in' facility and are used for various functions within the stated enterprises. Besides storing fish, these cold rooms are used as a processing room, waste room, for provisions, sorting room, packing room-glazing room, receiving room, offal room and for storing ice.
5	**Blast Freezers**		Fisheries enterprises in the Maldives also use **blast freezers** also known as shock freezers. Such freezers are intended to rapidly lower temperature of fish catch down, freezing them extremely quickly. These specialized freezers are used across the fisheries enterprises in the Maldives.
7	**Air conditioners**		Besides the aforementioned equipment, several **air-conditioning units** are also used across the fisheries sector.

8	**Refrigeration Complexes**		The refrigeration complexes use industrial cold rooms within the fisheries enterprise and as such investments are high, there are only limited numbers of such refrigeration complexes in the Maldives.

2.3 Review of refrigerant usage across Fisheries Sector

The fisheries sector consumes approximately 20% (MEE, 2016) of the HCFC imported into the country. With the review of the technology options present in the fisheries sector and the amount of HCFC still being used there is a considerable effect on the ongoing phase out activities of HCFC across the fisheries sector, as the Government of Maldives has committed to completely phase out HCFCs across the country by 2020. The Figure 4 shows usage of HCFCs in fisheries applications.

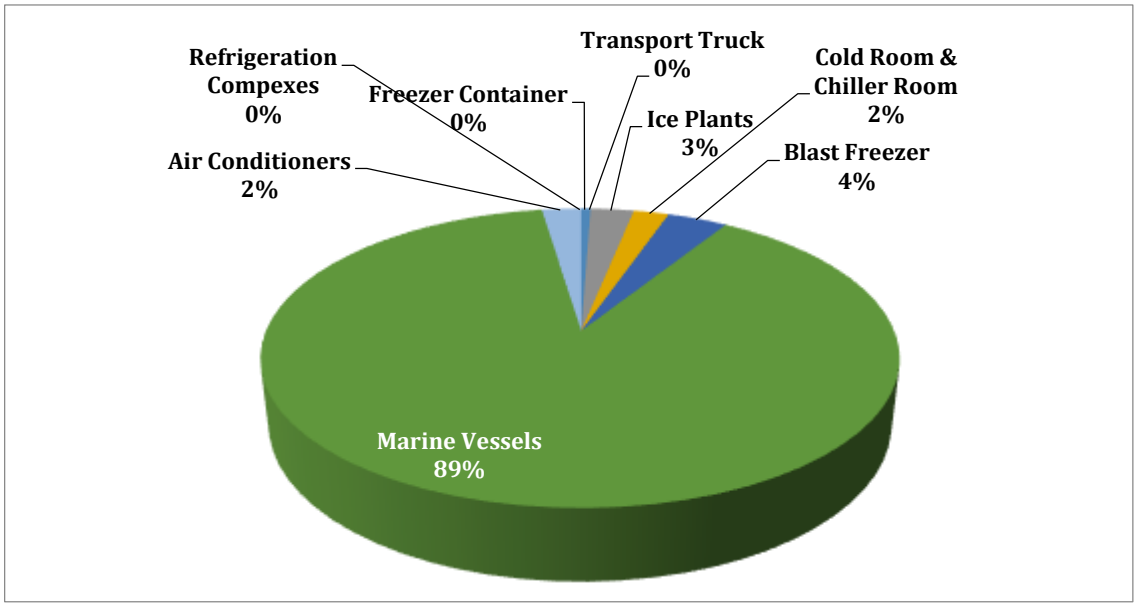

Figure 4 Presence of HCFC across Fisheries Enterprises of the Maldives

With the import control on HCFCs accompanied with the ban on HCFC based equipment, a significant increase in the import of Hydroflourocarbons (HFCs) has been observed in the recent years. The ODS survey carried in the Maldives in 2016 shows that with the start of HPMP implementation in 2010 and subsequent enforcement of regulations, the percentage

of HCFC consumption has gradually decreased and consumption of ODS alternative refrigerants has increased.

The ODS report shows that the consumption level of HCFCs at the end of 2015 was at 40% while ODS alternatives account for 60% of the total refrigerant consumed in the country. According to the ODS Alternative Survey, the commonly used HFC blends in the Maldives are R-404A, R407C, R410A, R417A; while occasionally consumed HFC blends are R-507C and R-438A. HFC 134a is reported as the most commonly used HFC, accounting for 13% of the total refrigerant consumed; and 31% of the total ODS alternatives consumed in the Maldives.

The projection shows overall growth of ODS alternatives use in the Maldives is 15% per annum for the period 2016-2030. R-410A is projected to have the highest annual growth followed by R-407C, 48% and 18% respectively. R134a and R-404A is projected to grow over 200% by 2030 and R-407C and R-410A is expected to grow over 380% by 2030 from the consumption levels in 2015. Consumption of all ODS alternatives are projected to grow more than 250% during 2016-2030 period.

The tourism sector is found to be the largest consumer of R&AC equipment and refrigerant in the Maldives. More than 13% of the total ODS alternatives imported into the country is directly imported by the tourist establishments and a large amount imports by the local suppliers are also consumed in tourism sector. The fisheries sector seems to the largest consumer of HCFC as most of the fishing vessels are still using HCFC based equipment. Furthermore, 16% of the ODS alternative refrigerant imported into the county is for use in fisheries sector. Most commonly used ODS alternatives in fisheries and food processing sectors are R-134a, R-404A and R-410A (ODS inventory report, 2016). Some of the fisheries related facilities use Ammonia especially in cold storages. However, as shown in Table 7, except for Ammonia, all the other refrigerants used in the fisheries sector are high GWP options.

Table 7: common refrigerants used in the fisheries sector of the Maldives

#	Refrigerant	Common Applications	GWP
1	R-22	Filled within Freezer Containers, Ice Plants, Blast Freezers, RSW Systems of Fish Collector and Mother Vessels, Cold Rooms and Chillers and Air-conditioners	1810
2	R-134 A	Freezer Containers	1430
3	R-404 A	Transport Trucks, Ice Plants, Cold Rooms and Chillers, Ice Plants, Blast Freezers and land based refrigeration complexes.	3922

4	R-418A	Air Conditioners	1500
5	R- 410 A	Air Conditioners	2088
6	R-438 A	Air Conditioners, RSW Systems of Fish Collector and Mother Vessels	2265
7	Ammonia	Ice Plants, RSW Systems of Fish Collector and Mother Vessels and land based refrigeration complexes.	0

As is evident, it is important to find a low GWP alternative option to the fisheries sector and mostly to the sea-borne applications.

2.4 Technology options versus refrigerants used across fisheries enterprises

The Table 8 below summarizes the various refrigeration technologies used across the fisheries enterprises of the Maldives. HCFCs are used in almost all the applications except in transport trucks and refrigeration complexes.

Table 8: Common Refrigerants and their Applications

#	Name of the Equipment	Equipment Functions	Types of Refrigerants
1	Freezer Containers	Often used for storing fish and fish products	**R-22 (62%)** **R-134 (38%)**
2	Transport Trucks	For Transportation of Fishery products	**R-404 A (100%)**
3	Ice Plants	Used for making Ice	**Ammonia (88%)** **R-22 (4%)** **R-404A (8%)**
4	Cold Rooms/Chiller Rooms	Processing Room/Semi Processing Room/Waste Room/Storing Fish/Provision Room/Packing Room/Finished Products/ Sorting Room/Glazing Room/ Cooling Room	**R-22 (59%)** **R-404 A (41%)**
5	Blast Freezers	To freeze fish within a short duration	**R-22 (81%)** **R-404 A (19%)**
6	Fish Collector/ Mother Vessels and Burges	Marine vessels are used for both collection and sometimes processing	**Ammonia(15%)** **R-22 (85%)**

7	Air conditioners	Like other sector sectors Air conditioners are also used within the Fisheries Sector	**R-22 (70%)** **R-410 A (20%)** **R-418 A (10%)**
8	Refrigeration Complexes	Limited refrigeration complexes are also used in the Maldivian Fisheries Sector	**Ammonia (99%)** **R-404 A (1%)**

3. Overview of the demonstration project

This Demonstration project was approved at the 76th ExCom in May 2016, for a 24 month period. The demonstration project is to identify low-GWP alternative technologies to HCFCs for use in refrigeration equipment with a charge of 150 kg to 200 kg of refrigerant in the fisheries sector.

With the implementation of the Demonstration Project, it is envisaged that the following will be attained.

a. The demonstration project will lead to: (i) research and analyse existing technology options used in both sea-borne refrigeration equipment and in land storage and processing applications; (ii) undertake a technical assessment of low-GWP options in terms of their feasibility as drop-in refrigerants as well as replacement options; (iii) test the performance of substitutes including optimization of drop-in or replacement systems; and (iv) demonstrate the use of the selected substitutes.

b. The project proposes to convert the HCFC-22-based refrigeration equipment in three fishing vessels to low-GWP technologies, by assessing alternative technology performance, and evaluating the suitability of the selected technology based on the cost of retrofitting and maintaining best possible performance of the equipment without much hassle to the client. Based on the evaluation, suitable technologies will be disseminated to the fishing industry during HCFC phase-out. The project will eliminate the use of 0.6 MT of HCFC-22 in fishing vessels.

The demonstration project also includes;

- ✓ Undertaking a detailed technology research and analysis of existing options available and technology choice and retrofit options
- ✓ Conducting Information sessions to the stakeholders

- ✓ Preparation of bid documents for the purchase of refrigerants and other spare parts if required
- ✓ Assisting selected enterprises on retrofitting of the selected equipment
- ✓ Preparation of manuals for all three retrofitted equipment applications
- ✓ Trainings for the technical staff on both retrofitting and their maintenance

Keeping in view the above mentioned outputs, to find a suitable HCFC free and low-GWP refrigerant to be used across the fisheries sector in different applications and on shore based applications, the public fisheries company, Maldives Industrial Fisheries Company Limited (MIFCO) was selected for this assessment. This is the largest fisheries enterprise in the country. MIFCO was mainly selected because of the uncertainties involved in the project along with the unavailability of alternatives for this sector. Hence, a Memorandum of Understanding (MOU) was signed between the Ministry of Environment and Energy (MEE) and MIFCO to undertake the assessment and to provide three vessels for the demonstration.

4. Review of technology options

Various consultative processes were carried out to carryout the assessments and selection of three vessels. Some of the parameters considered in selecting the vessels include the age, refrigerant use, willingness to participate in the project and possible risks associated with the implementation. The government of Maldives alonwith their technical experts participated in an "International Conference on Sustainable Management of Refrigeration Technologies in Marine and offshore Fisheries Sector" held at Bangkok from 6-8 April 2017 to understand the global scenario on fisheries sector. Further to carry forward the message on low GWP available technologies as technology roadshow was organized by UN Environment on 14-15 August 2017, where large number of manufacturer and refrigerant suppliers were present. A special focus group meeting during the technology roadshow held in August 2017 provided an excellent platform to discuss some of the challenges in finding and retrofitting new refrigerants. The fisheries sector owners were present and round table discussions session was organized. It was found that industry is not willing to move to A2L refrigerants. To understand the difficulties faced by fisheries vessels an expert team who was present at the roadshow a trip was made to different locations where MIFCO enterprises are located. The team included experts from MIT, Honeywell, UNDP and Johnson Controls (Anshu Kumar, UNDP, Bangkok, Alex Cohr Pachai, Johnson Controls, Denmark, Nitin Karwa, Sr. R&D Engineer, Honeywell, India, Anand Joshi, Ex-President Association of Ammonia Refrigeration, India, Musthafa Rafeeu, Manager Business development, MIFCO (Felivaru fisheries complex, kaduoiygiri fish village , kooddoo fish complex and addu fish complex). Main purpose of the visit was to analyse the retrofitting options and possible vessels that could be selected for

the project. Meetings were carried out with other fisheries vessel owners who were reluctant to move toward to flammable and toxic refrigerants.

The following section provides details of the three vessels selected for the demonstration project.

4.1 Overview of the Vessels selected

The Maldives Industrial Fisheries Company (MIFCO), is a public company engaged in the production, processing and marketing of fish and fish products. Established in 1993, MIFCO was relocated as a subsidiary of State Trading Organization (STO) in September 2016. As the key manufacturers and exporters of frozen fish and fish products, Maldives Fisheries Corporation (MFC) has a history dating back to 1979 when Maldives Nippon Corporation was formed, in partnership with Marubeni Corporation of Japan, to process and can fresh tuna. MFC was renamed as the Fisheries Projects Implementation Department (MFID), which was transformed into MIFCO in 1993. At present, MIFCO have no partnership with Japan, and are a 100% indigenous company.

MIFCO manages the largest fish procuring operation in Maldives, collecting Pole and Line and Handline caught Yellowfin and Skipjack Tuna. MIFCO owns three EU standard factories namely, Felivaru Fisheries, Kooddoo Fisheries and Kandu Oiygiri Maldives which process canned, chilled, frozen and value added tuna which is exported to International markets and sold locally.

For the purpose of the demonstration project, the equipment from MIFCO and Maandhoo Fisheries were assessed (Table 9). The main focus was to assess the capacity of vessels, compressors used in these installations, and the refrigerant quantities used in applications of both Mother and Collector Vessels that use RSW systems to store chilled catch.

Table 9: details of the refrigeration systems across some of the fisheries enterprises of the Maldives

No	Name of the company	Equipment category	Model/ additional details	No. of compressors / system	Total capacity (HP)	Ref used	Gas weight (kg)
1	**MIFCO**	Randhi-19	Sabroe Compressor	2 Compressors	40	R-22	35
		Randhi-20	Sabroe Compressor	2 Compressors	40	R-22	35

		Randhi-21	Sabroe Compressor	2 Compressors	40	R-22	35
		Randhi-22	Sabroe Compressor	2 Compressors	40	R-22	35
2	**Maandhoo Fisheries Complex**	HF 106/Ship to Chill Fish	Dakin 2x model # 6CX75	2	30x2= 60HP	R-22	45
		HF 107/Ship to Chill Fish	Dakin 3x model # 6CX75	3	30x3= 60HP	R-22	45
		HF 108/Ship to Chill Fish	Dakin 2x model # 6CX75	3	30x3= 60HP	R-22	45
		HF 109/Ship to Chill Fish	Dakin 2x model # 4CX75	2	20x2= 60HP	R-22	45
		HF 110/Ship to Chill Fish	Dakin 2x model # 4CX75	2	20x2= 60HP	R-22	45
		Oivaali 102	Mycom F62B2	4	100x4=400HP	R-22	298.4

After the assessment three vessels from the public company, MIFCO, were selected for the demonstration project. Table 10 provides the details of these vessels.

Table 10: Selected Vessels for the Demonstration Project

#	Name of the Vessel	Brief Description of the Vessel
1	**Randhi-19**	Randhi-19 is a fish collector vessel that is approximately 29 years old. Vessel is now operated from Felivaru Fish Processing Plant.
2	**Randhi-24**	Randhi-24 is a fish collector vessel that is approximately 18 years old. Vessel is now operated from Kooddoo Fisheries Complex
3	**Randhi-30**	Randhi-30 is a fish collector vessel that is approximately 15 years old. Vessel is now operated from Kooddoo Fisheries Complex

These vessels though old are still being operated for the purpose of collecting fish, and include brine tanks that are cooled using the installed Refrigerated Seawater Systems.

Figure 5: Fish collector vessel selected for the project

4.2 Existing refrigeration technology in the selected vessels.

The Maldives Institute of Technology (MIT) is engaged with the above three vessels to study the technology options being used in these vessels, and analyze what alternate technologies can be provided to the end users to preserve the ozone layer.

It was observed that all the selected vessels use Refrigerated Sea Water (RSW) Systems for cooling the brine tank installed in the vessels, which in turn cool the collected fish, before they are transported to the fish processing plants. All three vessels use R-22, and the amount of refrigerant in each RSW system were on average between 60 - 70 kg.

4.3 Overview of the refrigeration systems

Every vessel released for the demonstration project includes the presence of RSW systems with one unit installed on the starboard side, and another installed on the hull side of the vessel. The **Error! Reference source not found.** shows the installed RSM system.

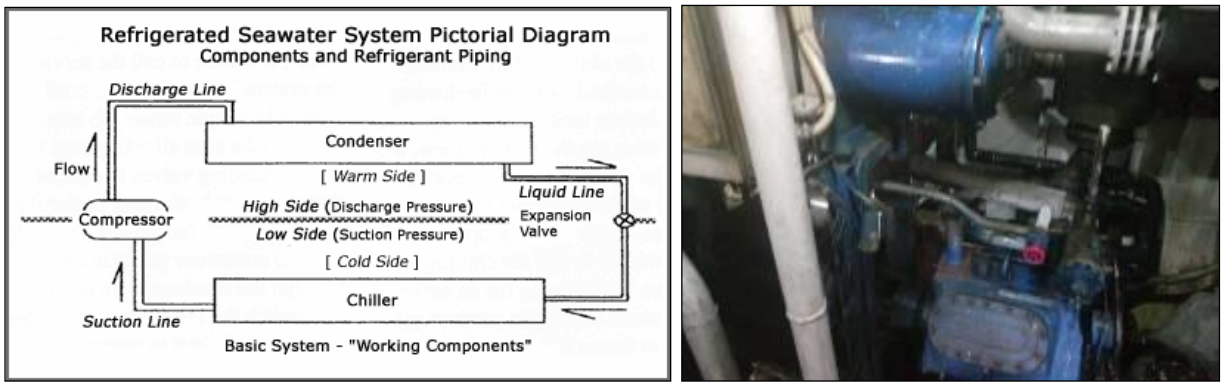

Figure 6 Illustration of installed RSM system

Seawater is re-circulated by pumps through the tanks and the chilling system. The refrigeration machinery chills the seawater before it enters the tanks in the lower layer of the ship, and is distributed evenly over the complete bottom cross-section of the tanks through a set of perforated plates or similar distribution devices. The chilled seawater passes upwards through the tank and layers of fish, thus keeping the fish suspended in the chilled seawater, simultaneously cooling the catch. The water returns through suction screens in the top of the tanks to the chilling unit of the system, passing through this, and repeating the circulation process. To keep the circulating water in good condition, a limited amount of feed water may be added, and “dirty” water bled off. The water circulating system is arranged such that the flow can be reversed by the operation of certain valves in the main water distribution manifold.

4.3.1 Components and their functions

Within all three selected demonstration vessels, there are two individual refrigeration systems installed on both the sides of each vessel, each system including the following main components.

- ✓ Compressors
- ✓ Chillers
- ✓ Condensers
- ✓ Expansion valves

The following sections provide details of these components.

a. Compressors

The purpose of the compressor is to draw the low-temperature, low-pressure vapour from the evaporator via the suction line. Once drawn, the vapour is compressed. When vapour is compressed, it rises in temperature. Therefore, the compressor transforms the vapour from a low-temperature vapour to a high-temperature vapour, in turn increasing the pressure. The vapour is then released from the compressor in to the discharge line.

Table 11: Compressors of the selected vessels

Vessel	Refrigeration System	Compressor Maker	Brand / Model	Type	Manufacture Year	Compressor Capacity	Oil Used	Last Service
Randhi-19	01	Nippon Sabroe	BF0-5	Piston	1996	36160 Kcal/hr	Capella wax	2010
	02	Nippon Sabroe	BF0-5	Piston	1996	36160 Kcal/hr	Capella wax	2010
Randhi-24	01	GRAM	HC-4075	Piston	1998	77KW	Aircol-299	2013
	02	GRAM	HC-4075	Piston	1998	77KW	Aircol-299	2013
Randhi-30	01	GEA	FX-16/1751	Piston	2011	120KW	Aircol-299	Unknown
	02	GRAM	HC-4075	Piston	1998	77KW	Aircol-299	2013

b. Chillers and Condensers

The major function of chiller is to chill the water to the set temperature and circulate to the desired location with the help of external pump. The heat absorbed by the refrigerant during the process of chilling is being discharged by condenser to the atmosphere as the design of condenser is (air-cool/watercool).

The following tables summarize the properties of the chillers and condensers used in the systems selected for the study.

Randhi-24

Chiller (evaporator)			*Condenser*		
Type	Maker	Build Year	Type	Maker	**Build Year**
Details of Heat Exchanger (chiller) Randhi 24, Heat Exchange (Shell and Tube) Tubes, Pure Titanium Sell pp Model# WHC 20- 2EKG Cooling Capacity 93KW	China	2000	HBY 10-150-4CIB		1998

Randhi-19

Chiller (evaporator)			*Condenser*		
Type	Maker	Build Year	Type	Maker	Build Year
Direct expansion	Nippon Sabroe	1996	Water cool shell and tube	Nippon Sabroe	1986

Randhi-30

Chiller (evaporator)			*Condenser*		
Type	Maker	Build Year	Type	Maker	Build Year
Direct expansion	Nippon Sabroe	1996	Water cool shell and tube	Nippon Sabroe	1986

5. Selection of refrigerants

MIT Consulting Team undertook an exhaustive process of identifying a suitable refrigerant to replace the HCFC-22 being used across the RSW systems of the three selected vessels for the Demonstration Project.

In this regard, MIT Consulting Team reviewed the following.

1. **Desk Study of the possible refrigerants available in the Market**

   MIT consulting team conducted a desk study review of the various refrigerants available in the market that could be used as a potential replacement technology for the selected three vessels. The available technical literature and published papers were analysed.

2. **Consideration of potential technologies for Demonstration.**

   Information gathered from the desk study on refrigerant developments across the globe, led to the identification of potential refrigerants for demonstration within the project.

   Available data on the performance of these refrigerants were compared against the current performance parameters of the selected RSW systems, with special consideration of low GWP refrigerant options.

3. **Discussions with the Technical team of the Demonstration Vessels Owner (MIFCO)**

   The technology reviews and potential options were presented to the technical teams of the demonstration vessel owners(s) to foster project ownership and inclusion.

The literature review revealed a number of low GWP refrigerants being made available in the global market place, although many are new with limited trials {eg: HC-600a, HFC-1234-1234yf, HFC-1234ze(E)}. These limited trial alternatives pose challenges as a suitable retrofitting agent for the fisheries sector in the Maldives. Indeed Kauffeld (2012)[1] indicates that apart from Ammonia, there are limited usages for natural refrigerants for seaborne vessels due to its toxicity and size of charge.

[1] Michael Kauffeld, 2012: Availability of low GWP alternatives to HFCs Feasibility of an early phase-out of HFCs by 2020

For potential alternatives that had moved beyond limited trials, there was a summarization of the Material Safety Data Sheet (MSDS) parameters of the potentially feasible, low GWP refrigerants to replace HCFC in the three selected demonstration vessels (see Table 5).

Table 12: Low GWP refrigerants and its characteristics

Name of the Refrigerant	Composition	Mass%**	ASHRAE Safety Class	Boiling T (°C)	Critical T (°C)	Critical P (MPa)	Glide	GWP
R450A	R134a/R1234yf/R1234ze	42/18/40	A1*	-25.6	100.18	3.74	0.1	547
R513A	R134a/R1234yf	44/56	A1*	-27.9	97.51	3.67	-0.3	573
R448A	R-32/R-125/R-134a/R-1234yf	25/25/20/30	A1*	-38.50	84.62	4.47	5.2	1273
L40	R-32/R-152a/R-1234yf/R-1234ze(E)	40/10/20/30	A2L**	-22.00	89.89	4.84	19.5	<300
DR-5	R-32/R-1234yf	72.5/27.5	A2L**	-45.40	83.11	5.40	3.9	500
R444B	R-32/R-152a/R-1234ze(E)	45/20/35	A2L**	-36.70	90.56	5.07	7.60	295
HFC-32		52	A2L**	-51.7				677

** : A1: Non Flammable ** : A2L: Mildly Flammable*

(Source: Atilla Gencer Devecioğlua, Vedat Oruça, 2015)

Further consideration and discussion between MIT Consulting Team and the MIFCO Technical Teams resulted in a joint decision not to proceed with any A2L refrigerant due to the equipment being old and leak prone, risking fear of accidental fire. With this final decision, the following non-flammable refrigerant options remained for demonstration.

Table 13: Short Listed Refrigeration Options

Name of the Refrigerant	Composition	ASHRAE Safety Class	GWP	Application
R448A	R-32/R-125/R-134a/R-1234yf	A1*	1273	Non-flammable HFO blend, used as a replacement for R404A and R22 in low and medium temperature refrigeration applications.
R444B	R-32/R-152a/R-1234ze(E)	A2L**	295	The refrigerant is mildly flammable and works as an excellent replacement for R-22 in Room Air conditioners.
L40/D8	R-32/R-152a/R-1234yf/R-1234ze(E)	A2L**	<300	The refrigerant is mildly flammable and primarily used for low temperature applications.

Prior to locking on a refrigerant for the demonstration project, it is vital to review and refresh again on the three vessels selected for the Demonstration Project and some of the factors that we need to take into account prior to selecting a refrigerant since most of the short listed refrigerants are under class A2L where the industry does not prefer due to equipment being too old and leak prone, risking fear of accidental fire. .

5.1 *Issues associated with the selected vessels and final recommendations for refrigeration selected*

Recalling the characteristics of the selected demonstration vessels, including their age, as laid out previously in Tables (*Table 8: Common Refrigerants and their Applications*) the following factors will further influence selection of a refrigerant for the Demonstration Project.

1. RSW Systems installed in the above Vessels are old and will be resistant to significant system modifications
2. Aged pipelines installed in these vessels make it extremely difficult to provide a 100 percent leak proof system
3. There is increased risk associated with the selection of a flammable refrigerant due to the lack of ventilation within the rooms in which the RSW systems are installed

With the consideration of these additional factors, the Consulting Team for this technical report propose the following options as an alternate to the demo project:-

1. ***Complete Replacement of the RSW Systems installed in the selected vessels using three possible trial replacement technologies.***

    a. Purchase and Install Ammonia based RSW systems
    b. Purchase and Install R32 A RSW Systems
    c. Purchase and Install R-429 A

Options proposed are reviewed against the following.

Name of the Refrigerant	**ASHRAE Safety Class**	**GWP**	**Comments**
Ammonia	B2L (High Toxicity)	0	Sealed ammonia units can be used for complete replacement of the used RSW systems.
R-32 A	A2 (Mildly flammable)	675	It is suitable for new equipment designed for R32 in applications that commonly use R410A. R32 is designated flammable and therefore is not suitable as a drop-in retrofit replacement for R410A.
R-429A	A3(High Toxicity)	14	Sealed RSW systems for 100 percent replacement can be done and is available in the international market. Properties of this exhibit excellent refrigeration qualities to that of R-22.

2. ***Selection of a Drop in Refrigerant Compatible with the RSW systems***

The Consulting Team together with the MIFCO Engineering Team reviewed the options for selecting a possible refrigerant for the demonstration project and compiled the following list.

Selection criteria developed for the selection of the refrigerant using the short listed table of refrigerants in Table-14 are as follows.

a. Flammability

Flammability remains as a crucial safety criterion that need to be reviewed prior to selecting a suitable refrigerant. In this regard, both R-444B and L40/D8 remains mildly flammable while R-448A remains less flammable.

b. Cost of Retrofitting

RSW systems used in these vessels are old and any modifications that need to be brought will be expensive. Retrofitting using R-444B and L40/D8 remains risky and thus may involve significant costs.

c. Performance

It is important that each selected refrigerant doesn't impact performance of the selected three RSW systems. When reviewed it is seen that only R-448A remains the best refrigerant that can be used without impacting much on the performance of the selected RSW systems.

With the above criteria, and based on the desk study undertaken, it is found that the R-448A remains as the best Drop in Refrigerant for replacing R-22 being used in the selected RSW systems of the three vessels as of now

#	Name of the Refrigerant	Refrigerant Information	Rationale for Recommendation
1	R 448A*	ODP: O GWP: 1273	1. Refrigerant performance seemed suitable to retrofit the selected RSW systems without affecting performance of the system. 2. Limited system modification of the RSW systems required to support the planned retrofitting process. 3. Technical Support available for the retrofitting from the refrigerant manufacture is believed to be adequate.

* It should be noted that, in response to the suggestion of the ExCom to liaise with Nordic Council of Ministers, UNDP did indeed send out enquiries to this body on the "Alternatives to HCFCs and High GWP HFCs in marine vessels"; but UNDP came to know that report has not been finalized as of now. The Norwegian Environmental Agency publication "Study on

environmental and health effects of HFO refrigerants" (December 2017) states that HFO blends R448A, R-449A, R-450A and R452-A are commercially available with R448A and R-449A being the most widely used (Page-12 of report)
(Source:http://www.miljodirektoratet.no/Documents/publikasjoner/M917/M917.pdf)

5.2 Implications for selecting a refrigerant

Although the consulting team is proposing the above options, Maldives is aware of the fact that MLF may have issues with the above options.

As per the recommendations made for the project, we understand that the selected refrigerant should have low GWP option at present in A1 category of refrigerants.

However, the Consulting Team together with the MIFCO Engineering Team explored varying avenues for identifying a refrigerant that fits within the above range and is equally suitable to retrofit the RSW systems of the selected three vessels.

6. Retrofitting the selected equipment

6.1 General retrofitting procedure

All the six RSW systems, selected from the three vessels are old and require extreme care and precaution when being retrofitted

A generalized procedure should be followed when retrofitting any refrigeration system with an alternative refrigerant. However, there may well be specific variations according to the particular characteristics of the system under consideration and the refrigerants involved. See the interactive diagram to see how this flow works for a retrofitting of HCFC refrigeration equipment.

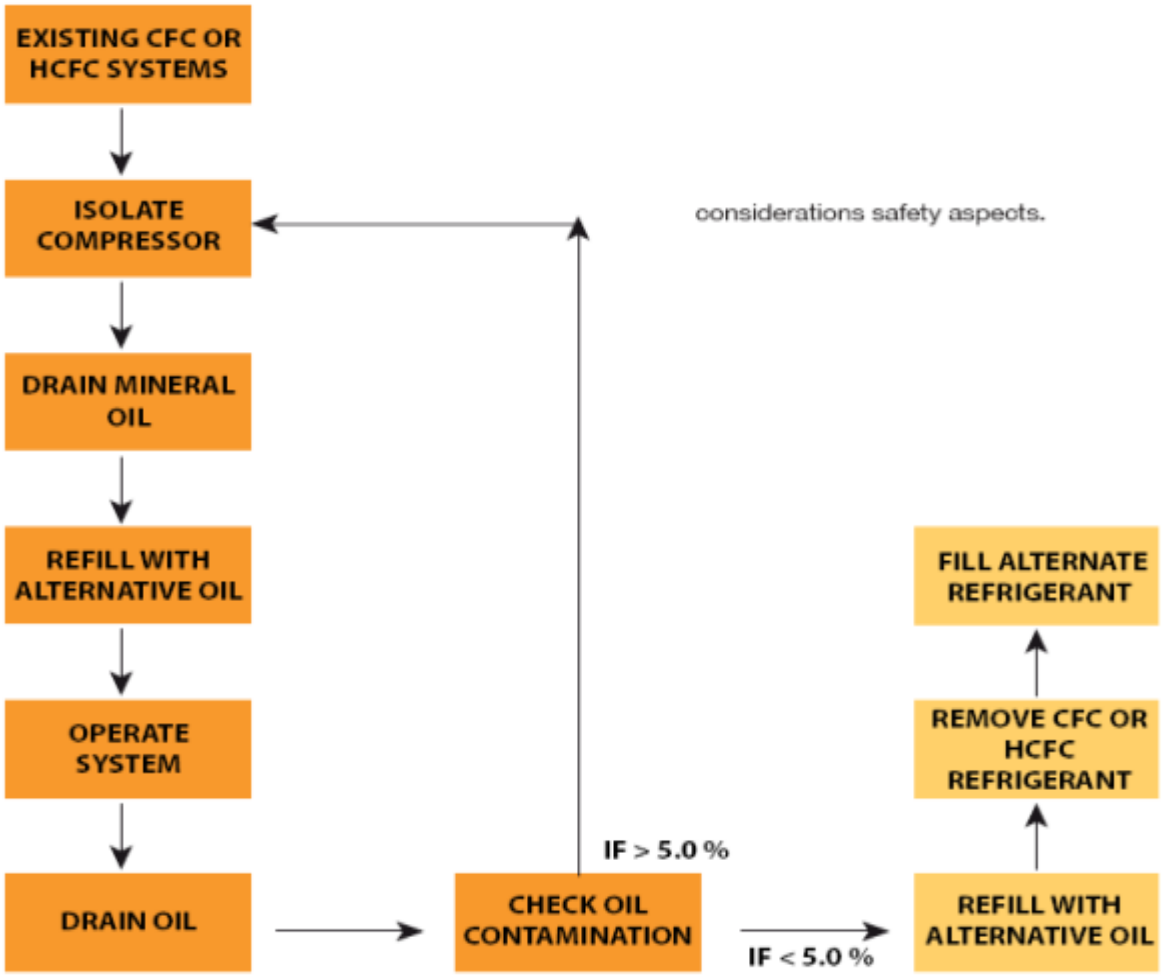

Figure 7 Flow works for a retrofitting of HCFC refrigeration equipment

The procedures to perform this retrofitting are explained below. If the refrigerant replacement is being performed with the use of a “drop- in” refrigerant, some of the steps presented may not be necessary. It is important always to consult the refrigerant manufacturer’s guidelines for retrofitting and the use of “drop-in” refrigerants. The retrofit of flammable refrigerants (such as hydrocarbons) must be executed taking into considerations safety aspects.

7. Lessons learnt

Challenges observed with the Fisheries Equipment Selected for the Demonstration Project
While progressing with the work on identifying a suitable refrigerant that has low GWP and qualifies a good replacement for the currently used R-22.

1. ***Equipment selected for the Demonstration Project is old and fragile***
   All the RSW systems selected for the project are approximately 20 years old and look fragile due to years of operation. Retrofitting with another refrigerant has to be cautiously undertaken as any modification may affect performance of the systems.

2. ***Refrigerant Leakage is Imminent across all the selected systems***
   Due to years of operation, it is difficult and hard to ensure the selected systems are leak proof, making it hard and challenging for any complex retrofitting across this equipment selected for the project.

3. ***Selected RSW systems have undergone modifications***
   It is also observed that all the selected equipment for the project had undergone modifications due to years of operation within the fish collector vessels. Referred modifications need to be carefully reviewed prior to bringing any retrofitting on the selected equipment.

4. ***All the selected equipment are installed in a limited and confined space***
   All the selected equipment for the project is confined to very limited space within the collector vessels. Due to the nature of the installations, it is important that no flammable refrigerant that be used for retrofitting.

5. ***Systems are operated and maintained by semi-skilled technicians***
   While reviewing the selected equipment, it was also noted that the personnel involved with the repair and daily operation of the systems are semi-skilled, making it hard for complex retrofitting.

8. Conclusion and recommendation

This report was developed to present the finding of the research undertaken to find an alternative refrigerant, which are low GWP refrigerant for the phase-out of HCFCs.

Major findings of the research includes;

1. With the review of the technology options being used in the fisheries sector, it is noted that Maldives has a HCFC consumption baseline of 64 metric tonnes , of which approximately 20 percent is consumed in the fisheries sector.

2. MIT consulting Team conducted a detailed desk study to review the refrigerants R-448A as potential refrigerants for the demonstration project. However, as per the recommendation from the 80th ExCom, testing of R448A was stopped because of its high GWP value but at the same time there is no other alternate available in A1 category of refrigerants.

3. A new desk study began in search of a low GWP alternative that are corresponding with R-22. The lower GWP refrigerant R444B has come out tops in the study which further test are needed since the refrigerant is mildly flammable (Safety Class: A2L) and it needs the due consideration of the end users.

4. It has been interacted during the “International Conference on Sustainable Management of Refrigeration Technologies in Marine and offshore Fisheries Sector” with few presenters and it has been found that the shift of technology trend is from R-22 to R404A (GWP 3922) and R-407F (GWP 1824), which is on higher side that R448A (GWP 1273). Ammonia with low charge has been introduced in marine vessels in the last 10 years, but as of 2017 HCFC22 dominates in most of the vessels.

REFERENCE:

Atilla Gencer Devecioğlua, Vedat Oruça, (2015). Characteristics of Some New Generation Refrigerants with Low GWP. The 7th International Conference on Applied Energy – ICAE2015

Michael Kauffeld, 2012: Availability of low GWP alternatives to HFCs Feasibility of an early phase-out of HFCs by 2020 (Accessed at http://www.eia-international.org/wp-content/uploads/EIA_FGas_Report_0412_FINAL_MEDRES_v3.pdf)

Svenn Jacobsen, 2016 : Available at (https://www.wilhelmsen.com/marine-products/refrigeration-solutions/prepare-for-a-low-gwp-future/)

UNDP, 2017: Demonstration Project for HCFC free low GWP alternatives in refrigeration in fisheries sector in the Maldives

FAO, 2016: Maldives and FAO, *Partnering for sustainable agricultural development and food security*

MEE, 2016: ODS Inventory Report

MEE, 2016: HFC Inventory Report