Impact of Hull Material on TCO of Inland Ferry Boats

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Abstract

The article aims to first define and identify the drivers for Total Cost of Ownership (TCO) of Inland Passenger Ferry Boat. It then goes describe the impact of the choice of material - GRP, aluminium and steel on each element of TCO. A case study of 75 passenger ferry is taken and comparison is done on the three hull material. The conclusions clearly point out GRP as preferred choice for hull material of inland passenger ferry.

Introduction

Passenger ferry boats are an essential mode of transportation in many areas of the developing world - India, rest of Asia, Africa and Americas. It is one area where technology modernisation has not penetrated in a significant way. In recent times, as a part of modernisation, GRP catamaran diesel powered boats were introduced. Another entrant is the solar ferry which is also GRP catamaran.

The hull material of conventional diesel ferry boats in earlier times were made of wood and later steel. For modern ferry boats GRP and aluminium, are the preferred options.

The article aims to first define TCO, the various parts of it, and for each part how different drivers influence it. The objective here is to understand the impact of choice of hull material in each of these parts and thereby TCO of the boat. In this analysis the common charges applicable for all boats like crew cost, berthing charges, etc. are avoided.

In next section a case study of 75 passenger ferry is taken and comparison with three possible hull materials is done by actual estimation based on rules and functional needs. In this computation the hull alone is taken as it assumed that in all the three options the superstructure is similar. It is to be noted that the propulsion is taken as diesel engine for ease of comparison and availability of actual project cost. Otherwise for a modern passenger ferry it is economical to be solar powered. [1]

TCO

There are four parts in TCO. They are:

Initial Cost: This is the initial cost of owning the boat.

Energy Cost: It is the cost of fuel for running the boat and its systems i.e., running both main and auxiliary engines. In a diesel ferry, energy cost is the dominant cost in its TCO. In a solar ferry, energy cost is very low since most is supplied by the sun and the remaining is from grid, which again is a cheap energy source.

Maintenance Cost: This include all the other cost of running the boat (except fuel cost) like lubricating oil, filters, engine overhaul etc. In boats made of steel, there is additional cost of steel hull renewal and painting, which is a significant cost. For solar ferry boats the maintenance cost is very low - there are no consumables like lube oil, filters etc. or hull maintenance since hull material is GRP or aluminium and not steel.

Recycling Cost: Most passenger ferries are designed for twenty five years. It is not prudent to design ferry systems for longer period since by then a far better technology would have come to enable replacement. At the end of its life, there is a recycling cost, but the residual value of materials and equipment in the boat may be higher than this and hence there might be a net positive value of the boat.

How Material Affects TCO

Refer the figure 1, the choice of hull material affects the weight of the hull and shape of hull. These then affect the initial cost i.e., CAPEX while energy cost and maintenance cost affect OPEX. Finally the recycling cost is also added, the details are described below.

How hull material affect initial cost of hull

Based on the choice of material, the structure design is done, and that determines the cost of hull as described in four sections below for each of the hull material.
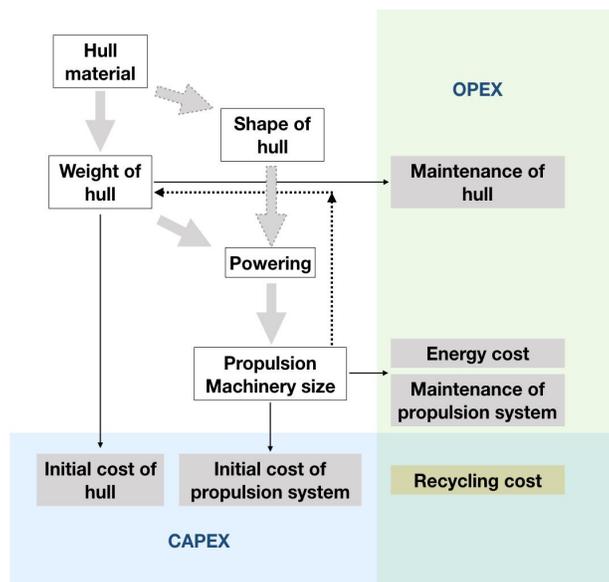

Figure 1: Hull material affecting TCO

(i) Infrastructure: This section covers the basic infrastructure required for manufacturing the hull in a boatyard. Here is assumed that the lease model is taken so as to account for the cost in one boat. In all the choices of material an enclosed shelter that protects the work area from rain and sun is essential, though in case of choice of steel, it is not very sensitive.

	Steel	Aluminium	GRP
Shelter	Simple shelter usually protection from top (rain and sun) is sufficient	The shelter has to be enclosed from sides for Tig welding, which is sensitive to wind.	The shelter has to be enclosed from all sides. Temperature control is not needed in warmer countries (upto 30 deg C)
Machinery	The machinery needed are welding machines, cutting torches. Bending can be done with simple tools.	The welding machines are expensive.	Mould investment is high (but for more than 5 boats this is low). Simple tools are needed.
Summary	total investment is low.	total investment is high	total investment is medium

Table 1: Comparison of infrastructure needs

(ii) Material: This is the major cost after fabrication for all the choices of hull.

	Steel	Aluminium	GRP
Hull material	plates and angles for different thickness and sizes	plates and extrusion for different thickness and sizes.	Mat (woven, chopped strand) of different sizes (gsm), resin
Coating anti-corrosion	Necessary	Not necessary	Not necessary
Coating antifouling	Necessary	Necessary	Necessary
Cost Summary	Cost is low	Cost is highest	Cost is high

Table 2: Comparison on material

(iii) Fabrication: This is the highest group when we take the hull initial cost. This could be 40-60% of the total hull cost.

	Steel	Aluminium	GRP
Labour	Low skilled	High skilled	Medium skilled
Consumable	Welding rod, gas, electricity	Welding rod, gas, electricity	Acetone, catalyst
Summary	Cost is low	Cost is highest	Cost is high

Table 3: Comparison on fabrication

How hull material affect maintenance cost of hull

Based on the hull material the periodic as well as damage repair varies as follows:

	Steel	Aluminium	GRP
Periodic	Removal of rust and coating protection	None	None
Damage	Easy damage repair	Insert piece and welding	Insert piece and joining / layering
Summary	Cost is high	Cost is highest	Cost is low

Table 4: Comparison of hull maintenance

How hull material affect initial cost of propulsion system

(i) Impact of hull material on powering

There are two ways by which hull material affects powering - reduced weight (major), underwater shape constraints (minor).

Steel versus Aluminium or GRP: As far as material selection goes from a single hull steel to aluminium or GRP catamaran there are two levels which reduces the powering. The first is because from a single hull to catamaran the resistance is lower for the same displacement. Refer figure below.
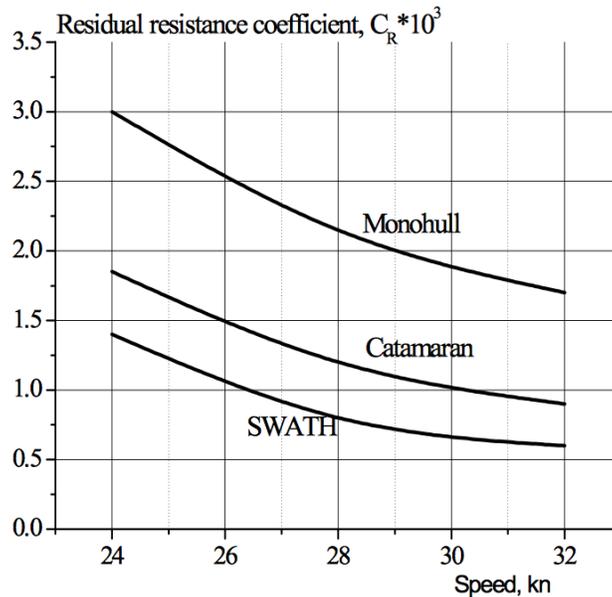
Figure 2: Comparison of Residuary Resistance [2]

The second is because the weight of hull is lower the powering is lower. The above means that from a mono hull to catamaran hull the main propulsion engine size would be reduced by half.

Aluminium or GRP: Between aluminium and GRP there are two reasons for difference in powering. The first one is the difference in weight. An optimised GRP hull is 15% lighter than aluminium hull for inland vessel application (see case study below). Since the hull weight is about 25% of boat weight, it impacts 5-10% in boat weight. For such small difference the increase in powering is about 2/3rd the increase in displacement. So aluminium hull will have 3-6% increase in main propulsion size.

Another factor why aluminium hull have higher drag than GRP is because of smooth shape of GRP. Since GRP hull is taken from a mould and the mould can be made into any given shape unlike aluminium which have limitation in achieving complex shapes by bending. This increase in drag and thereby powering would be around 3-4%.

Hence in total we can expect aluminium to have higher engine power 6-10% more than GRP.

This higher engine power also mean that the engine is heavier and thereby the engine foundation and hull structure associated is heavier. This thereby affects hull weight in above section.

(ii) Initial Cost of Propulsion System

The main propulsion consist of main engine, gear box, shafting, stern tube, seals, propeller, shaft bracket and accessories. The cost of main propulsion system is 12-18% of total boat cost.

How propulsion size affects energy cost and maintenance cost

Once the propulsion size is decided by the above factors, this drives the energy cost and maintenance cost.

(i) Energy Cost

In case of Steel boats which is powered by diesel fuel, daily diesel requirement will vary from 100-150 Liters/day for a passenger capacity of 50-100. This will cost around 6500-10,000 INR (100-150 US$) daily. On long-term basis, the diesel cost is usually projected to increase at 5% annually. For GRP and aluminium catamaran boats since the propulsion machinery size is smaller as drag is lower, the daily fuel consumption and thereby energy cost is nearly half of this.

On the other hand in solar ferry the majority of energy is from sun and few from electric grid if needed. Of course, design can be done in such a way that all the energy requirement can be met from solar by increasing panel and battery capacity but this will increase the initial cost.

ii) Maintenance Cost of Propulsion System

The maintenance of propulsion engines in inland ferries are done every 45 days. At this time engine lube oil is replaced, filters are changed and overhaul is also done. This cost comes to approximately 10% of energy cost annually. This maintenance, total of 8 days in a year, is also loss in revenue.

Case Study of 100 Passenger Ferry

For ease of comparison and to provide quantitative comparison of the three different materials for passenger ferry, case for 100 passenger ferry is considered. Here the four scenarios are taken as follows:

- 100 passenger GRP catamaran - 19 m long, 6.5 m wide, 1.5 m demi-hull, 1.6 m depth
- 100 passenger Aluminium catamaran - same as above
- 100 passenger Steel catamaran - 19 m long, 6.5 m wide, 2 m demi-hull, 1.6 m depth
- 100 passenger Steel mono-hull - 19 m long, 5 m wide, 1.6 m depth

The TCO of the four boats are done first by estimating CAPEX, then OPEX and the Recycling cost.

Initial Cost of Hull

Structure Design: The monohull steel hull structure is done as per Rules and Regulations for the Construction and Classification of Steel Ships, Part 3. Length of the hull is 19 m, Breadth 5 m with frame spacing 500mm and material IS-2062 Grade B.

The catamaran steel and aluminium structure design is done as per IRS Rules for High Speed Crafts, Chapter 6. The plate thickness depends on length of ship and frame spacing. The length of hull is 19 m, width 6.5 m, with 500mm frame spacing and material grade is 5052. The size of extrusion is obtained from same rules Chapter 4 and 6. Here grade considered is 5052 - H32 for aluminium and IS 2062 for steel.

The GRP hull is designed as per IRS rules for High Speed Crafts, Chapter 7. The plate thickness depends on length of ship and local sea pressure. The length of hull is 19 m, width 6.5 m, with 500mm frame spacing and IRS approved GRP material. The size of extrusion is obtained from same rules Chapter 4 and 7.

Type	GRP-Cat	Aluminium-Cat	Steel-Cat	Steel-mono
Bottom plate	6.63 mm	8 mm	6 mm	8 mm
Keel plate	11.6 mm	9 mm	8 mm	10 mm
Side shell plate	5.01 mm	7 mm	6 mm	6 mm
Cross deck plate	10.39 mm	7 mm	6 mm	8 mm
Bulkhead plate	10.03 mm	7 mm	6 mm	6 mm

Table 5: Scantlings of 75 pax boat

Type	GRP-Cat	Aluminium-Cat	Steel-Cat	Steel-mono
Longitudinal	55 (H) * 50 * (B) 3.14	30 x 30 x 2.8 mm	38.1 x 38.1 x 2 mm	(65 x 65 x6)
Bottom girder	100 (H) * 70 (B) * 4.49	38.1 x 38.1 x 3.18 mm	(80 x4) + (60x4) mm	((100 x 6) + (50 x 6))
Web frame	80 (H) * 50 (B) * 2.87	50.8 x 6.35 + 76.2 x 6.35 mm	(50.8 x 6) + (76.2 x 6) mm	(60 x 60 x 5)
Cross deck beam/ Deck Transverse	300 (H) * 120 (B) * 12.23	50.8 x 6.35 + 76.2 x 6.35 mm	(50.8 x 4) +(76.2x 4) mm	(70 x 70 x 8)
Bulkhead stiffener	50 (H) * 40 (B) *2.51	60 x 60 x 6 mm	60 x 60 x4 mm	(50 x 50 x 6)

Table 6: Stiffener/extrusion of 75 pax boat

Hull Weight: The structure design will drive the hull weight and comparison is shown below. The steel mono hull is almost four times the GRP hull.

Grouping	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Demi-hull	1.5	3.2	8.3	10.3
Deck	1.1	2.1	5.3	5.9
Stiffeners	2.4	0.7	2.8	4.4
Hull weight (T)	**5.0**	**6.0**	**16.4**	**20.6**

Table 7: Hull weight (tonnes)

Hull Cost: The cost of the hull - material and services for fabricating the hull is estimated below.

Grouping	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Material	17 (26 K)	33 (51 K)	14 (22 K)	17 (26 K)
Services	29 (45 K)	42 (65 K)	15 (23 K)	12 (18 K)
Hull cost	**46 (71 K)**	**75 (115 K)**	**29 (45 K)**	**29 (45 K)**

Table 8: Hull cost in lakh Rs. (US$)

Initial Cost of Propulsion System

Propulsion Sizing: The boat weight drives the propulsion size as outlined below driven by seize of demi hull and shape of the hull.

Grouping	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Engine + GB	2 x 19 kW	2 x 21 kW	2 x 30 kW	1 x 80 kW
FO tank size (lit)	150	150	200	300

Table 9: Propulsion sizing

Using the structure design, propulsion size and then the other system design, the total weight of the boat is decided.

Grouping		GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Lightship	Hull	5.0	6.0	16.4	20.6
	Machinery	1.1	1.1	1.2	1.0
	Accommodation	5.5	5.5	5.5	5.5
	Outfitting	2.1	1.9	1.9	1.9
	Electrical & Navigation	1.8	1.8	1.8	1.8
Deadweight	Passengers, FW	6.6	6.6	6.6	6.6
	Fuel	0.2	0.2	0.2	0.3
Displacement		**22.2**	**22.9**	**33.6**	**37.6**

Table 10: Boat weight (tonnes)

Propulsion Cost: Using the above propulsion sizing the cost of the system is calculated.

Grouping	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Engine +GB	17 (26 K)	18 (28 K)	21 (32 K)	14 (21 K)
Propulsion system	6 (9 K)	7 (11 K)	8 (12 K)	5 (8 K)
Machinery cost	**23 (35 K)**	**25 (38 K)**	**29 (45 K)**	**19 (29 K)**

Table 11: Machinery cost lakh Rs. (US$)

Initial Cost of Other System

Apart from the hull and machinery, most of the other sections are same for all the four boats. Hence the cost of other system is nearly same.

Grouping	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Accommodation	47 (72 K)	47 (72 K)	47 (72 K)	47 (72 K)
Outfitting	26 (40 K)	26 (40 K)	26 (40 K)	26 (40 K)
Electrical & Navigation	17 (26 K)	17 (26 K)	17 (26 K)	17 (26 K)
Services	25 (38 K)	25 (38 K)	25 (38 K)	25 (38 K)
Other cost	**115 (177 K)**	**115 (177 K)**	**115 (177 K)**	**115 (177 K)**

Table 12: Other system cost lakh Rs. (US$)

CAPEX

The total cost - Hull, machinery and other cost, is totaled to get the CAPEX of the boat.

Grouping	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Hull	46 (71 K)	75 (115 K)	29 (45 K)	29 (45 K)
Machinery (Propulsion)	23 (35 K)	25 (38 K)	29 (45 K)	19 (29 K)
Accommodation	47 (72 K)	47 (72 K)	47 (72 K)	47 (72 K)
Outfitting	26 (40 K)	26 (40 K)	26 (40 K)	26 (40 K)
Electrical & Navigation	17 (26 K)	17 (26 K)	17 (26 K)	17 (26 K)
Services	25 (38 K)	25 (38 K)	25 (38 K)	25 (38 K)
CAPEX	184 (283 K)	215 (331 K)	173 (266 K)	163 (251 K)

Table 13: Boat cost lakh Rs. (US$)

For the two cases there are similar project awarded by Kerala SWTD (State Water Transport Department) to benchmark the cost. A 100 passenger GRP catamaran was recently awarded for 200 lakhs Rs. (308 K US$). This might be on higher side since the hull is not efficient and hence more surface area means higher GRP cost as well as larger engine power. Also a 90 passenger steel monohull was awarded for 150 lakhs Rs. (231 K US$).

Maintenance of hull

Inland vessels are drydocked every two years. The major repairs are hull renewal (relevant for steel) and application of anti-corrosion (not for GRP and aluminium hull) and anti-fouling paint.

in 2 years	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Hull renewal			0.8 (1.2 K)	1.0 (1.5 K)
Anti-corrosion			0.3 (0.5 K)	0.4 (0.5 K)
Anti-fouling	2.0 (3.1 K)	2.0 (3.1 K)	2.2 (3.4 K)	3.6 (5.6 K)
Total	2.0 (3.1 K)	2.0 (3.1 K)	3.3 (5.1 K)	5.0 (7.6 K)

Table 14: Hull maintenance cost lakh Rs. (US$)

Energy Cost

The energy cost is the cost of fuel. For propulsion power, the fuel consumption is taken at SFOC of 225 g/kwh. For a daily operation of 12 hours, with running hours at 8 and idle running at 4 (30% of running hour fuel consumption), the comparison is given below. This is then converted to cost by current diesel price of 65 Rs./litres. The annual cost is calculated by assuming 350 days running.

	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Engine power (kW) @80%MCR	30	33	47	64
FO cons. (l/hr)	8	9	13	17
Running hours	8	8	8	8
Idle running hours	4	4	4	4
FO cons. (l/day)	73	80	115	156
Energy cost daily Rs (US$)	4,749 (73)	5,224 (80)	7,503 (115)	10,131 (156)
Running days	350	350	350	350
Energy cost annual lakh Rs. (US$)	**17 (26 K)**	**18 (28 K)**	**26 (40 K)**	**35 (55 K)**

Table 15: Energy cost

Maintenance of propulsion system

The engine overhaul is done every 45 days and along with this filters and lube oil are changed. This is around 10% of the energy cost.

Annual Cost (Lakh Rs.)	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
Maintenance of propulsion system	1.7 (2.6 K)	1.8 (2.8 K)	2.6 (4 K)	3.6 (5.5 K)

Table 16: Propulsion system maintenance cost lakh Rs. (US$)

Recycling Cost

At the end of its design life cycle of the boat, 25 years, the boat and its equipment will have residual value. It is driven by material value (if it is metal) and equipment value. In case of GRP

boat, there is no value from GRP hull. For steel and aluminium boats the metal hull will get residual value - 50% value for aluminium and 20% for steel. This means that recycling cost will be more than covered by aluminum and to some extend in steel boat whereas there might be small cost for GRP boat. However since metal value is not much these difference is not significant.

Total Cost of Ownership

Bringing the CAPEX and OPEX together the comparison is shown below. The rise in fuel price is assumed to be 5%. The maintenance cost is also assumed to rise at same percentage.

Costs in lakhs		GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
CAPEX	Initial cost of hull	46 (71 K)	75 (115 K)	29 (45 K)	29 (45 K)
	Initial cost of propulsion	23 (35 K)	25 (38 K)	29 (45 K)	19 (29 K)
	Other costs in CAPEX	115 (177 K)	115 (177 K)	115 (177 K)	115 (177 K)
OPEX	Energy cost (annual)	17 (26 K)	18 (28 K)	26 (40 K)	36 (55 K)
	Maintenance hull (every 2 yrs)	2.0 (3 K)	2.0 (3 K)	3.3 (5 K)	5.0 (8 K)
	Maintenance propulsion (annual)	1.7 (2.6 K)	1.8 (2.8 K)	2.6 (4 K)	3.6 (5.5 K)

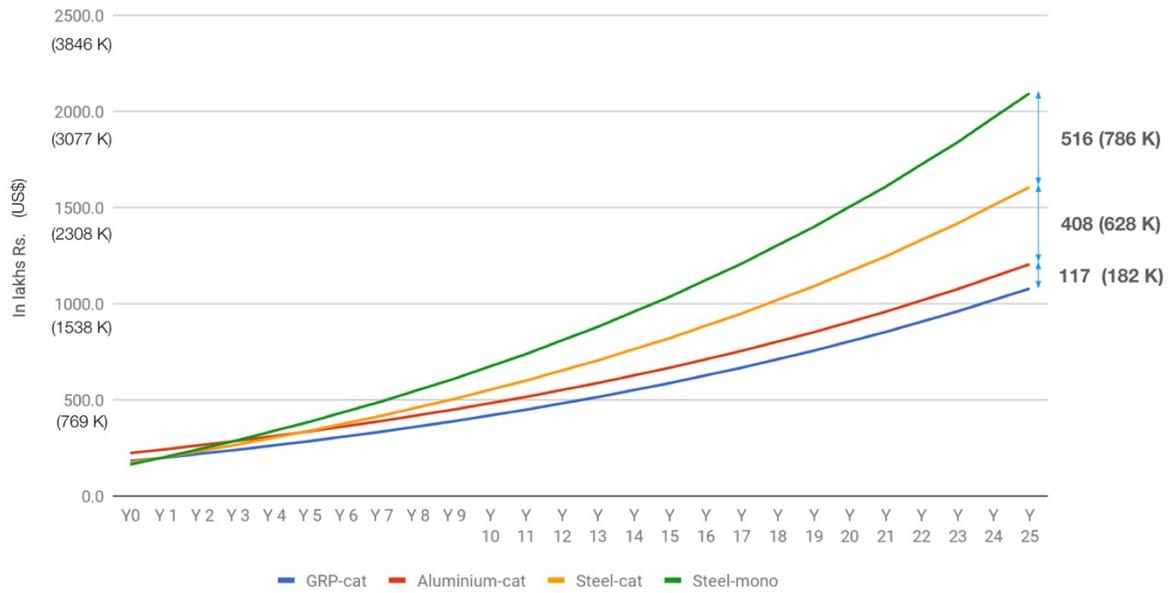Table 17: TCO comparison cost lakh Rs. (US$)

TCO Comparison

Figure 3: TCO comparison

	Year	GRP-cat	Aluminium-cat	Steel-cat	Steel-mono
TCO	Y0	184 (283 K)	215 (331 K)	173 (266 K)	163 (251 K)
	Y 1	202 (311 K)	235 (362 K)	202 (311 K)	202 (311 K)
	Y 2	223 (343 K)	258 (397 K)	236 (363 K)	248 (382 K)
	Y 3	243 (374 K)	280 (431 K)	268 (412 K)	291 (448 K)
	Y 4	266 (409 K)	306 (471 K)	305 (469 K)	342 (526 K)
	Y 5	288 (443 K)	330 (508 K)	340 (523 K)	390 (600 K)
	Y 6	314 (483 K)	358 (551 K)	381 (586 K)	446 (686 K)
	Y 7	339 (522 K)	385 (592 K)	420 (646 K)	498 (766 K)
	Y 8	368 (566 K)	416 (640 K)	465 (715 K)	560 (862 K)
	Y 9	395 (608 K)	446 (686 K)	508 (782 K)	618 (951 K)
	Y 10	426 (655 K)	480 (738 K)	558 (858 K)	686 (1055 K)
	Y 11	456 (702 K)	513 (789 K)	605 (931 K)	750 (1154 K)

Y 12	491 (755 K)	551 (848 K)	660 (1015 K)	825 (1269 K)
Y 13	524 (806 K)	587 (903 K)	712 (1095 K)	895 (1377 K)
Y 14	562 (865 K)	629 (968 K)	773 (1189 K)	978 (1505 K)
Y 15	598 (920 K)	669 (1029 K)	830 (1277 K)	1055 (1623 K)
Y 16	640 (985 K)	715 (1100 K)	897 (1380 K)	1147 (1765 K)
Y 17	680 (1046 K)	759 (1168 K)	960 (1477 K)	1232 (1895 K)
Y 18	727 (1118 K)	810 (1246 K)	1034 (1591 K)	1333 (2051 K)
Y 19	771 (1186 K)	858 (1320 K)	1104 (1698 K)	1427 (2195 K)
Y 20	822 (1265 K)	914 (1406 K)	1185 (1823 K)	1538 (2366 K)
Y 21	871 (1340 K)	967 (1488 K)	1262 (1942 K)	1642 (2526 K)
Y 22	928 (1428 K)	1029 (1583 K)	1352 (2080 K)	1765 (2715 K)
Y 23	982 (1511 K)	1088 (1674 K)	1437 (2211 K)	1879 (2891 K)
Y 24	1044 (1606 K)	1156 (1778 K)	1536 (2363 K)	2014 (3098 K)
Y 25	1103 (1697 K)	1221 (1878 K)	1629 (2506 K)	2140 (3292 K)

Table 18: TCO numbers for 25 years lakh Rs. (US$)

Conclusion

The TCO comparison clearly shows that with comparable functional features, the cheapest inland ferry boat is a GRP catamaran.

Reference

[1] - Sandith Thandasherry, *High fives for solar-powered ferry ops, Ship & Boat International*, Jan/Feb 2018

[2] - Victor Dubrovsky and Konstantin Matveev, "New Types of Sea-Going Multi-Hull Ships with Superior Comfort Level and Safety," *Passenger Vessels for the New Millennium: Joint Meeting of the Pacific Region Sections*, pp. 1- 12, 2005