

Exploring opportunities in marine vessel energy hybridization

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Grid + Battery

H_2 + H_2 H2 fuel + Fuel cell

Fo + Diesel fuel + Engine









Decarbonisation Pathway



Decarbonisation Pathway



Cost of energy





C _G - Cost of grid \$/kWh	CEE-S - Cost of electrical energy fron solar
C _H - Cost of H ₂ \$/Kg	CPE-E - Cost of propulsion energy from engine
CFO - Cost of fuel \$/I	С _{РЕ-м} - Cost of propulsion energy from motor
CEE-B - Cost of electrical energy from battery	CPE - Cost of propulsion energy
CEE-FC - Cost of electrical energy from fuel cell	CAE - Cost of auxiliary energy
CEE-DG - Cost of electrical energy fron D/G	Рв - Brake horse power



100 PAX FERRY

Speed 8-12 knots

Range 75-200 km/day









How cost of diesel/MGO and cost of grid affects electrification

Cost of grid (C Cost of diesel	G) (CFO)	9 US Cents 1.25 USD		
Cast of alas a	` <i>'</i>	10	US Conto	
Cost of elec er	nergy from Da	50	US Cents	
Cost of prop e	nergy from ba	attery	13	US Cents
Cost of prop e	nergy from D(G	55	US Cents
Cost of prop e	nergy from En	41	US Cents	
Countries	CG	CFO	Spread	CEE-B
Countries India	CG 9	CFO 125	Spread 116	СЕЕ-В 12
Countries India HongKong	CG 9 17	CFO 125 290	Spread 116 273	СЕЕ-В 12 21
Countries India HongKong Switzerland	CG 9 17 26	CFO 125 290 221	Spread 116 273 195	CEE-B 12 21 32
Countries India HongKong Switzerland Germany	CG 9 17 26 12	CFO 125 290 221 188	Spread 116 273 195 176	CEE-B 12 21 32 14
Countries India HongKong Switzerland Germany Singapore	CG 9 17 26 12 31	CFO 125 290 221 188 189	Spread 116 273 195 176 158	CEE-B 12 21 32 14 38
Countries India HongKong Switzerland Germany Singapore Canada	CG 9 17 26 12 31 20	CFO 125 290 221 188 189 127	Spread 116 273 195 176 158 107	CEE-B 12 21 32 14 38 25
Countries India HongKong Switzerland Germany Singapore Canada US	CG 9 17 26 12 31 20 15	CFO 125 290 221 188 189 127 103	Spread 116 273 195 176 158 107 88	CEE-B 12 21 32 14 38 25 18
Countries India HongKong Switzerland Germany Singapore Canada US UAE	CG 9 17 26 12 31 20 15 11	CFO 125 290 221 188 189 127 103 82	Spread 116 273 195 176 158 107 88 71	CEE-B 12 21 32 14 38 25 18 18 14

Source : https://www.globalpetrolprices.com/electricity_prices

per kWh per litre		
per kWh per kWh	includes cost of LO, filters & overhaul	
per kWh per kWh		

per kWh includes cost of LO, filters & overhaul

CEE-DG	Prop-B	Prop-DG	CPE-E	E-B spread	E-B ratio
50	13	55	41	28	3.2
116	23	129	94	71	4.1
88	36	98	71	35	2.0
75	16	83	61	45	3.8
76	43	84	61	18	1.4
51	27	56	41	14	1.5
41	20	46	34	14	1.7
33	15	36	26	11	1.7
12	10	14	10	0	1.0
		All in	US Cents		



How cost of diesel/MGO, cost of grid and cost of hydrogen affects shift to hydrogen

Cost of grid (CG)	9 US Cents	per kWh	
Cost of diesel (CEO)	1 25 USD	ner litre	
Cost of hydrogen (CH)	3 USD	per kg	
Cost of elec energy from battery (CEE-B)	12 US Cents	per kWh	
Cost of elec energy from DG (CEE-DG)	50 US Cents	per kWh	includes cost
Cost of elec energy from H2 FC (CEE-FC)	39 US Cents	per kWh	
Cost of prop energy from battery	13 US Cents	per kWh	
Cost of prop energy from DG	55 US Cents	per kWh	
Cost of prop energy from H2 FC	43 US Cents	per kWh	

Cost of prop energy from Engine (CPE-E)

41 US Cents

Countries	CG	CFO	Spread	CEE-B	CEE-DG	Prop-B	Prop-DG	CPE-E	E-B spread	E-B ratio
India	9	125	116	12	50	13	55	41	28	3.2
HongKong	17	290	273	21	116	23	129	94	71	4.1
Switzerland	26	221	195	32	88	36	98	71	35	2.0
Germany	12	188	176	14	75	16	83	61	45	3.8
Singapore	31	189	158	38	76	43	84	61	18	1.4
Canada	20	127	107	25	51	27	56	41	14	1.5
US	15	103	88	18	41	20	46	34	14	1.7
UAE	11	82	71	14	33	15	36	26	11	1.7
Saudi Arabia	7	31	24	9	12	10	14	10	0	1.0
							All in	US Cents		

per kWh

of LO, filters & overhaul

includes cost of LO, filters & overhaul

Cost of hydrogen and energy produced

СН	CEE-FC	Prop-FC
5	39	43
4	31	35
3	23	26
2	16	17
USD/kg	US Cents	US Cents





Inputs

Platform	100 pax ferry	this decide the speed-pov	wer curve (hull and draft)	Scalability of battery				Solar pla	nt production	and degrada
Location	Kochi	for solar production		Low voltage LFP	20 kWh	for aux. battery and sinz	e there are two se	ts of battery Year	Energy (k	Wh Differen
Speed	8 knots	decides the propulsion p	ower required					1	30,8	00
Range per day	75 km	133 km	is 9 hrs disctance	Medium voltage LFP	80 kWh	for prop. battery and sin	ze there are two s	ets of battery 2	30,5	15 (
Max charging range	15 km			Medium voltage LTO	120 kWh	for prop. battery and sin	ze there are two s	ets of battery 3	30,2	33 (
Running time	304 mts	5.1 hrs						4	29,9	53 (
Annual operations	350 days			LTO battery cooling	5 kW	for each 120 kWh scaled	l unit	5	29,6	76 (1,
Air con load	9 kW	for super-efficient based	on the platform					6	29,4	01 (1,
Air con load	12 kW	for efficient based on the	platform	Scalability of fuel cell (size)	70 kW			7	29,1	.29 (1,
Air con load	15 kW	for traditional based on t	he platform	H2 tank scalability	7 kg			8	28,8	59 (1,
Other aux. load	1 kW	based on the platform						9	28,5	92 (2,
Operating time	12 hrs			Efficiency of prop motor (nM)	90%			10	28,3	27 (2,
Aircon running time	9.6 hrs	80% of time		Efficiency of battery (nB)	90%			11	28,0	65 (2,
Power (supere-efficient)	40 kW	from the speed power cu	rve	Efficiency of elec system (nE)	90%			12	27,8	05 (2,
Power (efficient)	56 kW	increase if 40%		Efficiency of alternator (nA)	90%			13	27,5	48 (3,
Power (traditional)	84 kW	increase is 110%		SFC of H2 fuel cell (SFCFC)	70 g/kWh	of electrical energy		14	27,2	93 (3,
Solar plant size	25 kW	based on platform		SFC of Diesel engine (SFCE)	250 g/kWh	of mechanical energy		15	27,0	40 (3,
Insolation	5.5	based on location		SFC of Diesel generator	278 g/kWh	of electrical energy		16	26,7	90 (4)
System efficiency	0.64	3.5 kWh per kW in a day		Density of diesel (rhoFO)	0.85 kg/litre			17	26,5	42 (4,
Daily solar energy	88 kWh	Average production for v	vhole year					18	26,2	96 (4,
Solar plant degradation	0.93% every year	20% degradation in 25 ye	ears	USD Rate	80 Rs/USD			19	26,0	53 (4,
				Cost of grid (CG)	7.5 Rs	9 US Cents	per kWh	20	25,8	12 (4,
Prop solar	70.4 kWh	80% proportion	for propulsion	Cost of hydrogen (CH)	400 Rs	5 USD	per kg	21	25,5	73
Aux. solar	17.6 kWh	20% proportion	for auxiliary	Cost of diesel (CFO)	100 Rs	1.25 USD	per litre	22	25,3	36
LFP design based on	100% average prod	uction for the year		Cost of LO, filters & overhaul in engine (Em	10% of CFO			23	25,1	.02
								24	24,8	70
whole day	super-efficient	efficient		Cost of elec energy from battery (CEE-B)	9.3 Rs	12 US Cents	per kWh	25	24,6	40
Propulsion energy	203 kWh	283 kWh		Cost of elec energy from H2 FC (CEE-FC)	31.1 Rs	39 US Cents	per kWh			
Auxiliary energy	98.4 kWh	127.2 kWh	air con load is for running time and other aux. load is for operating	tin Cost of elec energy from DG (CEE-DG)	39.9 Rs	50 US Cents	per kWh in	cludes cost of LO, filters & o	verhaul	
Max Trip range	super-efficient LTO system	_		Cost of prop energy from battery	10.3 Rs	13 US Cents	per kWh			
Trip distance	15 km			Cost of prop energy from H2 FC	34.6 Rs	43 US Cents	per kWh			
Trip time	61 mts			Cost of prop energy from DG	44.3 Rs	55 US Cents	per kWh			
Propulsion energy	41 kWh									
Auxiliary energy	10 kWh			Cost of prop energy from Engine (CPE-E)	32.4 Rs	41 US Cents	per kWh in	cludes cost of LO, filters & o	verhaul	
CAPEX computation				Battery SOC, DOD and buffer for degradati	ion and replacement			Currency		
Boat without propulsion and drive	2,40,00,000 INR	3,00,000 USD	GRP Boat	DoD for fast charging LTO	60	%		USD		
				DoD for slow charging LFP	80	<mark>%</mark>		INR		
				Degradation and additional capacity LTO	20	%				
		-		Degradation and additional capacity LFP	20	%				





LFP System - Propulsion battery and aux battery separate

Propulsion energy need (mechanical)	203 kWh			Cost with drives and controls	21,67,000 Rs	27,088 USD	
Propulsion energy need (electrical)	226 kWh	loss of electrical t	o mechanical energy				
Prop battery need	338 kWh	battery DOD is 80	0% and additional buddfer of 20% due to degradation replacement	Variable cost of LFP prop battery	70,000 Rs	875 USD	per kWh
Prop battery size	320 kWh	Two sets of	160 kWh batteries	Replacement cost of LFP prop battery	50,000 Rs	625 USD	per kWh
Aux. energy need (electrical)	98 kWh			Cost of prop battery pack	2,24,00,000 Rs	2,80,000 USD	
Aux battery need	148 kWh	battery DOD is 80	0% and additional buddfer of 20% due to degradation replacement	Cost of replacement in 7 yrs	1,60,00,000 Rs	2,00,000 USD	
Aux battery size	140 kWh	Two sets of	70 kWh batteries				
				Variable cost of LFP aux battery	40,000 Rs	500 USD	per kWh
Electrical energy from grid	324 kWh			Replacement cost of LFP aux battery	30,000 Rs	375 USD	per kWh
Consumptionfrom battery annually	1,13,384 kWh			Cost of aux battery pack	56,00,000 Rs	70,000 USD	
OPEX energy cost	10,54,475 Rs.	13,181 USC)	Cost of replacement in 7 yrs	42,00,000 Rs	52,500 USD	
				System cost	25,00,000 Rs	31,250 USD	
				CAPEX of boat	5,66,67,000 Rs	7,08,338 USD	
LFP System - with Solar							
For sizing, total solar production	88 kWh			Cost with drives and controls	21,67,000 Rs	27,088 USD	
Propulsion energy from sun (electrical)	70.4 kWh	80% of energy is	for propulsion				
Propulsion enegy from battery (electrical	155 kWh			Variable cost of LFP prop battery	70,000 Rs	875 USD	per kWh
Prop battery need	233 kWh	battery DOD is 80	0% and additional buddfer of 20% due to degradation replacement	Replacement cost of LFP prop battery	50,000 Rs	625 USD	per kWh
Prop battery size	240 kWh	Two sets of	120 kWh batteries	Cost of prop battery pack	1,68,00,000 Rs	2,10,000 USD	
Aux. energy from sun	17.6 kWh			Cost of replacement in 7 yrs	1,20,00,000 Rs	1,50,000 USD	
Aux. enegy from battery	80.8 kWh	remove solar from	m total aux. energy need (electrical)				
Aux battery need	121 kWh	battery DOD is 80	0% and additional buddfer of 20% due to degradation replacement	Variable cost of LFP aux battery	40,000 Rs	500 USD	per kWh
Aux battery size	120 kWh	Two sets of	60 kWh batteries	Replacement cost of LFP aux battery	30,000 Rs	375 USD	per kWh
				Cost of aux battery pack	48,00,000 Rs	60,000 USD	
% solar contribution	27%			Cost of replacement in 7 yrs	36,00,000 Rs	45,000 USD	
				,,			
Electrical energy from grid	236 kWh			System cost	25.00.000 Rs	31.250 USD	
Consumptionfrom battery annually	82.584 kWh			-,		,	
OPEX energy cost	7.68.035 Rs.	9.600 USE)	Solar plant cost	15.00.000 Rs	18.750 USD	per kW
	.,,	-,	-			,	P
				CAPEX of boat	5.17.67.000 Rs	6.47.088 USD	
					5,27,57,500 113	0,1,000 000	

Propulsion energy need (mechanical)	203 kWh		Cost with drives and controls	21,67,000 Rs	27,088 USD	
Propulsion energy need (electrical)	226 kWh	loss of electrical to mechanical energy				
Prop battery need	338 kWh	battery DOD is 80% and additional buddfer of 20% due to degradation r	replacement Variable cost of LFP prop battery	70,000 Rs	875 USD	per kWh
Prop battery size	320 kWh	Two sets of 160 kWh batteries	Replacement cost of LFP prop battery	50,000 Rs	625 USD	per kWh
Aux. energy need (electrical)	98 kWh		Cost of prop battery pack	2,24,00,000 Rs	2,80,000 USD	
Aux battery need	148 kWh	battery DOD is 80% and additional buddfer of 20% due to degradation r	replacement Cost of replacement in 7 yrs	1,60,00,000 Rs	2,00,000 USD	
Aux battery size	140 kWh	Two sets of 70 kWh batteries				
			Variable cost of LFP aux battery	40,000 Rs	500 USD	per kWh
Electrical energy from grid	324 kWh		Replacement cost of LFP aux battery	30,000 Rs	375 USD	per kWh
Consumptionfrom battery annually	1,13,384 kWh		Cost of aux battery pack	56,00,000 Rs	70,000 USD	
OPEX energy cost	10,54,475 Rs.	13,181 USD	Cost of replacement in 7 yrs	42,00,000 Rs	52,500 USD	
			System cost	25.00.000 Rs	31.250 USD	
			-,		,	
			CAPEX of boat	5,66,67,000 Rs	7,08,338 USD	
LFP System - with Solar						
For sizing, total solar production	88 kWh		Cost with drives and controls	21,67,000 Rs	27,088 USD	
Propulsion energy from sun (electrical)	70.4 kWh	80% of energy is for propulsion				
Propulsion enegy from battery (electrical	155 kWh		Variable cost of LFP prop battery	70,000 Rs	875 USD	per kWh
Prop battery need	233 kWh	battery DOD is 80% and additional buddfer of 20% due to degradation r	replacement Replacement cost of LFP prop battery	50,000 Rs	625 USD	per kWh
Prop battery size	240 kWh	Two sets of 120 kWh batteries	Cost of prop battery pack	1,68,00,000 Rs	2,10,000 USD	
Aux. energy from sun	17.6 kWh		Cost of replacement in 7 yrs	1,20,00,000 Rs	1,50,000 USD	
Aux. enegy from battery	80.8 kWh	remove solar from total aux. energy need (electrical)				
Aux battery need	121 kWh	battery DOD is 80% and additional buddfer of 20% due to degradation r	replacement Variable cost of LFP aux battery	40,000 Rs	500 USD	per kWh
Aux battery size	120 kWh	Two sets of 60 kWh batteries	Replacement cost of LFP aux battery	30,000 Rs	375 USD	per kWh
			Cost of aux battery pack	48,00,000 Rs	60,000 USD	
% solar contribution	27%		Cost of replacement in 7 yrs	36,00,000 Rs	45,000 USD	
Electrical energy from grid	236 kWh		System cost	25,00,000 Rs	31,250 USD	
Consumptionfrom battery annually	82,584 kWh		-,		,	
OPEX energy cost	7,68,035 Rs.	9,600 USD	Solar plant cost	15,00,000 Rs	18,750 USD	per kW
			CAPEX of boat	5.17.67.000 Rs	6.47.088 USD	
					-,,	

LTO System - Propulsion battery and aux battery combined (Between charging)

Propulsion energy need (mechanical)	41 kWh		Variable cost of motors (power rating	g)		
Propulsion energy need (electrical)	46 kWh	loss of electrical to mechanical energy		30 15,00,000 Rs	18,750 USD	
Aux. energy need (electrical)	10 kWh			120 45,00,000 Rs	56,250 USD	
Total energy (electrical)	56 kWh		Interpolation using above rates			
Battery size need	111 kWh	battery DOD is 60% and additional buddfer of 20% due to degradation replacement		50 kW motors		
Battery size	120 kWh		Cost with drives and controls	21,67,000 Rs	27,088 USD	
Battery cooling power	5 kW	for every set of 120 kWh need 5 kW power				
Battery cooling energy	5 kWh	for the trip time	Variable cost of LTO battery	2,00,000 Rs	2,500 USD	per kWh
Total battery cooling energy	60 kWh		Replacement cost of LTO battery	1,80,000 Rs	2,250 USD	per kWh
Check if Total energy + battery cooling < ba	ttery size*0.8		Cost of battery pack	2,40,00,000 Rs	3,00,000 USD	
61	< 72	TRUE	Cost of replacement in 10 yrs	2,16,00,000 Rs	2,70,000 USD	
Final battery size (After cooling check)	120 kWh	Two sets of 60 kWh batteries				
Total electrical energy	384 kWh	propulsion electrical + auxiliary electrical + battery cooling	System cost	4,00,00,000 Rs	5,00,000 USD	
Consumptionfrom battery annually	1,34,384 kWh		CAPEX of boat	9,01,67,000 Rs	11,27,088 USD	
OPEX energy cost	12,49,775 Rs.	15,622 USD				
LTO System - with Solar						
For sizing since the solar production may n	ot be there in the max. trip t	ime, we assume the same battery size as electric mode (can refine with exact schedule and energy	r plot)			
Total electrical energy	384 kWh		Solar plant cost per kW	60,000 Rs	750 USD	per kW
Total solar propduction	88 kWh		Solar plant cost	15,00,000 Rs	18,750 USD	per kW
Electrical energy from battery + grid	296 kWh					
Consumption from battery annually	1,03,584 kWh		CAPEX of boat with solar plant	9,16,67,000 Rs	11,45,838 USD	
OPEX energy cost	9,63,335 Rs.	12,042 USD				

Total electrical energy	384	kWh		
Total solar propduction	88	kWh		
Electrical energy from battery + grid	296	kWh		
Consumptionfrom battery annually	1,03,584	kWh		
OPEX energy cost	9,63,335	Rs.	12,042	USD



Diesel	LTO	LFP	LTO-solar	LFP-solar	H2FC + LFP + Solar	- ``
56	40	40	40	40	40	kW
70	50	50	50	50	50	Propulsion power
16						kW
			70	70	70	kWh
			18	18	18	kWh
	226	226	155	155		kWh
	158	98	141	81		kWh
					155	kWh
					81	kWh
283						kWh
127						kWh
	100%	100%	77%	73%		
	10070	10070	///0	13/0	87%	
100%					0270	
100%			23%	27%	18%	
19.9	11.6	11.6	23 <i>%</i>	2770	21.0	LIS Conts
49.9	12.0	12.0	10.0	0.5	31.9	US Cents
35.4	12.9	12.9	10.0	9.4	33.5	US Cents
40.5	40.5	40.5	40.5	40.5	40.5	US Cents
	100%	100%	100%	100%	100%	
100%						
40.5	12.9	12.9	10.0	9.4	35.5	
83						litres
46						litres
129						litres
					18	kg
	120	320	120	240	80	kWh
		140		120		kWh
	78,944	78,944	54,304	54,304	54,304	kWh
	55,440	34,440	49,280	28,280	28,280	kWh
41	13	13	13	13	43	US Cents
50	12	12	12	12	39	US Cents
351	1127	708	1146	647	1128	
62.1	15.6	13.2	12.0	9.6	32.2	
C	270	253	270	195	50	
3%	3%	3%	3%	3%	3%	
	Diesel 56 70 16 283 127 283 127 100% 49.9 55.4 40.5 83 46 129 100% 40.5 83 46 129 351 62.1 0 3%	Diesel LTO 56 40 70 50 16 226 158 158 283 127 100% 100% 49.9 11.6 55.4 12.9 40.5 40.5 100% 100% 100% 12.9 83 46 129 120 83 46 129 120 351 1127 351 1127 351 1127 351 1127 353 3%	Diesel LTO LFP 56 40 40 70 50 50 16	Diesel LTO LFP LTO-solar 56 40 40 40 70 50 50 50 16 70 10 10 226 226 155 158 98 141 283 127 70 100% 100% 77% 100% 100% 77% 100% 100% 77% 100% 100% 100 49.9 11.6 11.6 9.0 55.4 12.9 12.9 10.0 40.5 40.5 40.5 40.5 100% 100% 100% 100% 100% 100% 100% 100% 12.9 12.9 10.0 100% 100% 100% 100% 100% 1129 12.9 120 120 83 46 12.9 120 120 320 120 <	Diesel LTO LFP LTO-solar LFP-solar 56 40 40 40 40 70 50 50 50 50 16 70 70 70 16 70 70 18 16 70 70 18 16 70 18 18 226 226 155 155 158 98 141 81 283 127 73% 73% 100% 100% 77% 73% 100% 100% 77% 34% 100% 100% 9.0 9.4 40.5 40.5 40.5 40.5 100% 100% 100% 100% 9.4 100% 100% 100% 100% 100% 100% 100% 100% 100% 100% 100% 100% 100% 100% 100% 100% </td <td>DieselLTOLFPLTO-solarLFP-solarH2FC+LFP+Solar56404040404070505050505016</td>	DieselLTOLFPLTO-solarLFP-solarH2FC+LFP+Solar56404040404070505050505016

H2FC with LFP System and Solar

Propulsion power (mechanical) Propulsion power (electrical) Auxiliary power (electrical) Total electrical power need LFP battery size need (1C)

Prop and aux battery size

Fuel cell size No. of fuel cells needed Assumed no. of recharges daily Propulsion energy need (mechanical) Propulsion energy need (electrical) Aux. energy need (electrical) Total electrical energy needed For sizing, total solar production Total electrical energy needed considering SFC of H2 fuel cell Total H2 needed between recharges No. of cylinders

Consumption of H2 annually OPEX energy cost

25,7

Diesel engine + Generator (efficient)

Propulsion energy (mechanical) SFC of Diesel engine (SFCE) Propulsion fuel consumed in engine Auxiliary energy (electrical) Auxiliary energy (mechanical) SFC of Diesel generator Propulsion fuel consumed in generator

Annual fuel consumption

Cost of fuel annually Cost of LO, filter, overhaul OPEX energy cost

45,15,000 Rs. 4,51,500 Rs. 49,66,500 Rs. 56,438 USD

5,644 USD

62,081 USD

40 kW				Cost with drives and controls	21,67,000	Rs	27,088	USD
44 kW								
10 kW				Variable cost of LFP prop battery	70,000	Rs	875	USD
54 kW				Replacement cost of LFP prop battery	50,000	Rs	625	USD
54 kWh				Cost of prop battery pack	56,00,000	Rs	70,000	USD
80 kWh	Two sets of	40 kWh batteries	If the power crosses 80 kW then next set of battery needed	Cost of replacement in 7 yrs	40,00,000	Rs	50,000	USD
70 kW								
1				System cost	25,00,000	Rs	31,250	USD
1				Battery, motors and system cost	1,02,67,000	Rs	1,28,338	USD
203 kWh								
226 kWh	loss of electrical to me	echanical energy		Cost of one 70 kW fuel cell	2,00,00,000	Rs	2,50,000	USD
98 kWh				Cost of fuel cells for the boat	2,00,00,000	Rs	2,50,000	USD
324 kWh				Piping and other fuel cell system cost	150%	of fu	el cell cost	
88 kWh				Piping and other fuel cell system cost	3,00,00,000	Rs	3,75,000	USD
236 kWh				Cost of each 7 kg cylinders	20,00,000	Rs	25,000	USD
70 g/kWh				Cost of 7 kg cylinders	60,00,000	Rs	75,000	USD
18.4 kg	need to take the electr	rical system efficiency since	elec energy is aux consumption					
3 sets of	7 kg	cylinders	Assuming solar	H2 system cost	5,60,00,000	Rs	7,00,000	USD
6440 kg				CAPEX of boat	9,02,67,000	Rs	11,28,338	USD
5,76,000 Rs.	32,200 USD							
283 kWh				Variable cost of engines (power rating)				
250 g/kWh	of mechanical energy			70	20,00,000	Rs	25,000	USD
83 litres				240	60,00,000	Rs	75,000	USD
127 kWh	of electrical energy			Interpolation using above rates				
141 kWh	of mechanical energy			70	kW engines			
278 g/kWh	of electrical energy			Cost Engine, gearbox, tank and accessories	20,00,000	Rs	25,000	USD
46 litres								
				Variable cost of generator (power rating)				
45,150 litres				5	10,00,000	Rs	12,500	USD
				20	25,00,000	Rs	31,250	USD

Interpolation using above rates

CAPEX of boat

Cost generator, tank and accessories

16 kW engines

21,00,000 Rs

2,81,00,000 Rs



26,250 USD

3,51,250 USD



Currency	USD																							
		Effic	ient			Super-e	efficient			Super-e	ficient			Super-	efficient			Super-e	fficient			Super-e	efficient	
Year		Die	esel			LT	0			L	FP			LTO +	Solar			Solar	LFP			H2 + LFI	+ Solar	
	CAPEX	OPEX	Total	Cumulative	CAPEX	OPEX	Total	Cumulative	CAPEX	OPEX	Total	Cumulative	CAPEX	OPEX	Total	Cumulative	CAPEX	OPEX	Total	Cumulative	CAPEX	OPEX	Total	Cumulative
Yr O	351		351.3	351	1,127		1,127.1	1,127	708		708.3	708	1,146		1,145.8	1,146	647		647.1	647	1,128		1,128.3	1,128
Yr 1		62.1	62.1	413.3		15.6	15.6	1,143		13.2	13.2	722		12.0	12.0	1,158		9.6	9.6	657		32.2	32.2	1,161
Yr 2		63.9	63.9	477.3		16.1	16.1	1,159		13.6	13.6	735		12.8	12.8	1,171		10.2	10.2	667		33.3	33.3	1,194
Yr 3		65.9	65.9	543.1		16.6	16.6	1,175		14.0	14.0	749		13.3	13.3	1,184		10.6	10.6	678		34.4	34.4	1,228
Yr 4		67.8	67.8	611.0		17.1	17.1	1,192		14.4	14.4	763		13.7	13.7	1,198		10.9	10.9	688		35.6	35.6	1,264
Yr 5		69.9	69.9	680.8		17.6	17.6	1,210		14.8	14.8	778		14.1	14.1	1,212		11.3	11.3	700		36.7	36.7	1,301
Yr 6		72.0	72.0	752.8		18.1	18.1	1,228		15.3	15.3	794		14.6	14.6	1,226		11.7	11.7	711		38.0	38.0	1,338
Yr 7		74.1	74.1	826.9		18.7	18.7	1,247	253	15.7	268.2	1,062		15.1	15.1	1,241	195	12.1	207.1	919	50	39.2	89.2	1,428
Yr 8		76.4	76.4	903.3		19.2	19.2	1,266		16.2	16.2	1,078		15.6	15.6	1,257		12.5	12.5	931		40.5	40.5	1,468
Yr 9		78.6	78.6	981.9		19.8	19.8	1,286		16.7	16.7	1,095		16.1	16.1	1,273		12.9	12.9	944		41.9	41.9	1,510
Yr 10		81.0	81.0	1,062.9	270	20.4	290.4	1,576		17.2	17.2	1,112	270	16.6	286.6	1,560		13.3	13.3	957		43.3	43.3	1,553
Yr 11		83.4	83.4	1,146.4		21.0	21.0	1,597		17.7	17.7	1,130		17.1	17.1	1,577		13.8	13.8	971		44.7	44.7	1,598
Yr 12		85.9	85.9	1,232.3		21.6	21.6	1,619		18.2	18.2	1,148		17.7	17.7	1,595		14.2	14.2	985		46.2	46.2	1,644
Yr 13		88.5	88.5	1,320.8		22.3	22.3	1,641		18.8	18.8	1,167		18.3	18.3	1,613		14.7	14.7	1,000		47.7	47.7	1,692
Yr 14		91.2	91.2	1,412.0	-	22.9	22.9	1,664	253	19.4	271.9	1,439		18.9	18.9	1,632	195	15.2	210.2	1,210	50	49.3	99.3	1,791
Yr 15		93.9	93.9	1,505.9		23.6	23.6	1,688		19.9	19.9	1,458		19.5	19.5	1,651		15.7	15.7	1,226		50.9	50.9	1,842
Yr 16		96.7	96.7	1,602.6		24.3	24.3	1,712		20.5	20.5	1,479		20.1	20.1	1,671		16.2	16.2	1,242		52.6	52.6	1,895
Yr 17		99.6	99.6	1,702.2		25.1	25.1	1,737		21.2	21.2	1,500		20.8	20.8	1,692		16.7	16.7	1,259		54.3	54.3	1,949
Yr 18		102.6	102.6	1,804.8		25.8	25.8	1,763		21.8	21.8	1,522		21.4	21.4	1,714		17.3	17.3	1,276		56.1	56.1	2,005
Yr 19		105.7	105.7	1,910.5		26.6	26.6	1,789		22.4	22.4	1,544		22.1	22.1	1,736		17.8	17.8	1,294		58.0	58.0	2,063
Yr 20		108.9	108.9	2,019.4		27.4	27.4	1,817		23.1	23.1	1,568		22.8	22.8	1,759		18.4	18.4	1,312		59.9	59.9	2,123

Discount rate 10%

Super-efficient Efficient Super-effi Diesel Year LTO LE OPEX CAPEX CAPEX CAPEX OPEX Total Cumulative OPEX Total Cumulative 351 351 351 1,127 708 Yr 0 1,127 1,127 Yr 1 56.4 56.4 407.7 14.2 14.2 1,141.3 12.0 Yr 2 52.8 52.8 460.5 13.3 13.3 1,154.6 11.2 Yr 3 49.5 49.5 510.0 12.5 12.5 1,167.0 10.5 46.3 46.3 556.4 11.7 1,178.7 9.8 Yr 4 11.7 9.2 43.4 43.4 599.7 10.9 1,189.6 10.9 Yr 5 8.6 10.2 40.6 40.6 640.4 10.2 1,199.8 Yr 6 8.1 38.0 38.0 678.4 9.6 1,209.4 130 Yr 7 9.6 7.6 Yr 8 35.6 35.6 714.0 9.0 9.0 1,218.4 33.4 33.4 747.4 8.4 8.4 1,226.8 7.1 Yr 9 6.6 Yr 10 31.2 31.2 778.6 104.1 7.9 112.0 1,338.7 6.2 29.2 29.2 807.8 7.4 7.4 1,346.1 Yr 11 5.8 27.4 1,353.0 27.4 835.2 6.9 6.9 Yr 12 5.4 25.6 860.9 1,359.4 Yr 13 25.6 6.5 6.5 5.1 Yr 14 24.0 24.0 884.9 6.0 6.0 1,365.5 66 22.5 22.5 907.4 1,371.1 4.8 Yr 15 5.7 5.7 4.5 928.4 21.0 21.0 5.3 5.3 1,376.4 Yr 16 4.2 5.0 19.7 19.7 948.1 5.0 1,381.4 Yr 17 3.9 1,386.0 18.5 18.5 966.6 Yr 18 4.6 4.6 3.7 983.8 1,390.4 17.3 Yr 19 17.3 4.3 4.3 3.4 16.2 16.2 1,000.0 4.1 4.1 1,394.4 Yr 20

	Diesel	LTO	LFP	LTO + Solar	LFP + Solar	H2 + LFP + Solar	
TCO	2,019	1,817	1,568	1,759	1,312	2,123	in 1000 USD
TCO NPV	1,000	1,394	1,042	1,382	904	1,512	in 1000 USD

cient			Super-e	fficient			Super-e	fficient			Super-e	fficient	
			LTO +	Solar			Solar	LFP			H2 + LFP	+ Solar	
Total	Cumulative	CAPEX	OPEX	Total	Cumulative	CAPEX	OPEX	Total	Cumulative	CAPEX	OPEX	Total	Cumulative
708	708	1,146		1,146	1,146	647		647	647	1,128		1,128	1,128
12.0	720.3		10.9	10.9	1,156.8		8.7	8.7	655.8		29.3	29.3	1,157.6
11.2	731.5		10.6	10.6	1,167.4		8.5	8.5	664.3		27.5	27.5	1,185.1
10.5	742.0		10.0	10.0	1,177.4		8.0	8.0	672.2		25.8	25.8	1,211.0
9.8	751.9		9.4	9.4	1,186.7		7.5	7.5	679.7		24.3	24.3	1,235.3
9.2	761.1		8.8	8.8	1,195.5		7.0	7.0	686.7		22.8	22.8	1,258.1
8.6	769.7		8.2	8.2	1,203.7		6.6	6.6	693.3		21.4	21.4	1,279.5
137.6	907.4		7.7	7.7	1,211.5	100	6.2	106.3	799.6	26	20.1	45.8	1,325.3
7.6	914.9		7.3	7.3	1,218.7		5.8	5.8	805.4		18.9	18.9	1,344.2
7.1	922.0		6.8	6.8	1,225.6		5.5	5.5	810.9		17.8	17.8	1,362.0
6.6	928.6	104	6.4	110.5	1,336.1		5.1	5.1	816.0		16.7	16.7	1,378.7
6.2	934.9		6.0	6.0	1,342.1		4.8	4.8	820.8		15.7	15.7	1,394.3
5.8	940.7		5.6	5.6	1,347.7		4.5	4.5	825.4		14.7	14.7	1,409.1
5.4	946.1		5.3	5.3	1,353.0		4.3	4.3	829.6		13.8	13.8	1,422.9
71.6	1,017.7		5.0	5.0	1,358.0	51	4.0	55.3	885.0	13	13.0	26.2	1,449.0
4.8	1,022.5		4.7	4.7	1,362.6		3.8	3.8	888.7		12.2	12.2	1,461.2
4.5	1,026.9		4.4	4.4	1,367.0		3.5	3.5	892.2		11.5	11.5	1,472.7
4.2	1,031.1		4.1	4.1	1,371.1		3.3	3.3	895.5		10.8	10.8	1,483.4
3.9	1,035.0		3.9	3.9	1,375.0		3.1	3.1	898.6		10.1	10.1	1,493.5
3.7	1,038.7		3.6	3.6	1,378.6		2.9	2.9	901.6		9.5	9.5	1,503.0
3.4	1,042.1		3.4	3.4	1,382.0		2.7	2.7	904.3		8.9	8.9	1,511.9







How discount rate affects TCO NPV



Speed-Range	Energy/day	Diesel	LTO	LFP	LTO + Solar	LFP + Solar	H2 + LFP +		
							Solar		
8 kn-75 km	324	1000	1394	1042	1382	904	1512		
@10 % discount rate									

Speed-Range	Energy/day	Diesel	LTO	LFP	LTO + Solar	LFP + Solar	H2 + LFP + Solar		
8 kn-75 km	324	1342	1542	1226	1514	1047	1718		
@5 % discount rate									



TCO NPV for various speeds (8/10/12 knots) and range (75/100/150/200 km)

							5 USD/kg	3 USD/kg
Speed-Range	Energy/day	Diesel	LTO	LFP	LTO + Solar	LFP + Solar	H2+LFP+Sola r (5\$/kg)	H2+LFP+ Solar (3\$/kį
8 kn-75 km	324	1000	1394	1042	1382	904	1512	1371
8 kn-100 km	398	1141	1426	1291	1415	1046	1618	1433
10 kn-75 km	458	1277	1902	1447	1892	1202	1858	1639
8 kn-150 km	548	1422	1490	1573	1480	1438	1882	1610
10 kn-100 km	578	1498	1953	1715	1945	1581	2054	1765
8 kn-200 km	698	1699	1554	1963	1546	1830	2146	1786
12 kn-75 km	772	1912	2517	2285	2512	2044	3254	2851
10 kn-150 km	818	1946	2055	2361	2050	2121	2472	2042
12 kn-100 km	998	2334	2613	2817	2611	2687	3627	3092
10 kn-200 km	1058	2394	2157	2899	2155	2770	2889	2319
12 kn-150 km	1448	3169	2805	3878	2808	3755	4393	3596
12 kn-200 km	1898	4009	2996	5049	3005	4822	5160	4100

Always LFP + Solar < LFP and LTO + Solar < LTO. Hence solar is always cheaper than electric





TCO NPV for various speeds (8/10/12 knots) and range (75/100/150/200 km)



At lower speed and range LFP is cheaper than LTO. However at higher speed and range LTO is cheaper. The key is low trip range (15 km here for each charging).



When is Hydrogen effective?

8 kn-75 km	904	1308
8 kn-100 km	1046	1352
8 kn-150 km	1438	1489
8 kn-200 km	1830	1627

10 kn-75 km	1202	1541
10 kn-100 km	1581	1636
10 kn-150 km	2121	1852
10 kn-200 km	2770	2067

12 kn-75 km	2044	2673
12 kn-100 km	2687	2855
12 kn-150 km	3755	3243
12 kn-200 km	4822	3631



H2 @ 5 USD/kg and 3 USD/kg is more expensive than LFP + Solar. But for 2 USD/kg it is different







100 PAX FERRY

Speed 12 knots

Range 200 km/day







Series



Parallel





What changes with high speed and high trip range?

For long range - 12 knots, 200 km (with 100 km as recharge time) for H2 FC and LTO 100 km is the recharge distance



_						5 USD/kg	3 USD/kg	2 USD/kg	
	Discol	ITO		ITO - Color		H2 + LFP +	H2 + LFP +	H2 + LFP +	
	Diesei	LIU	LFP	LTO + Solar	LFP + Solar	Solar	Solar	Solar	
TCO NPV	4,009	8,985	5,049	9,004	4,822	4,798	3,783	3,336	in 1000 USD





What changes with high speed and high trip range?



Speed-Range	Energy/day	Diesel	LTO	LFP	LTO + Sola
12 kn-200 km	1898	4009	8985	5049	9004



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Thank You



