



Exploring opportunities in **marine vessel energy hybridization**

Sandith Thandasherry

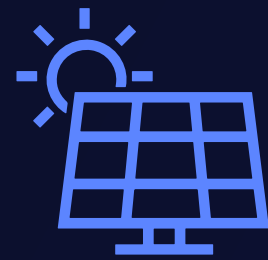


1



Grid + Battery

2



Solar

3

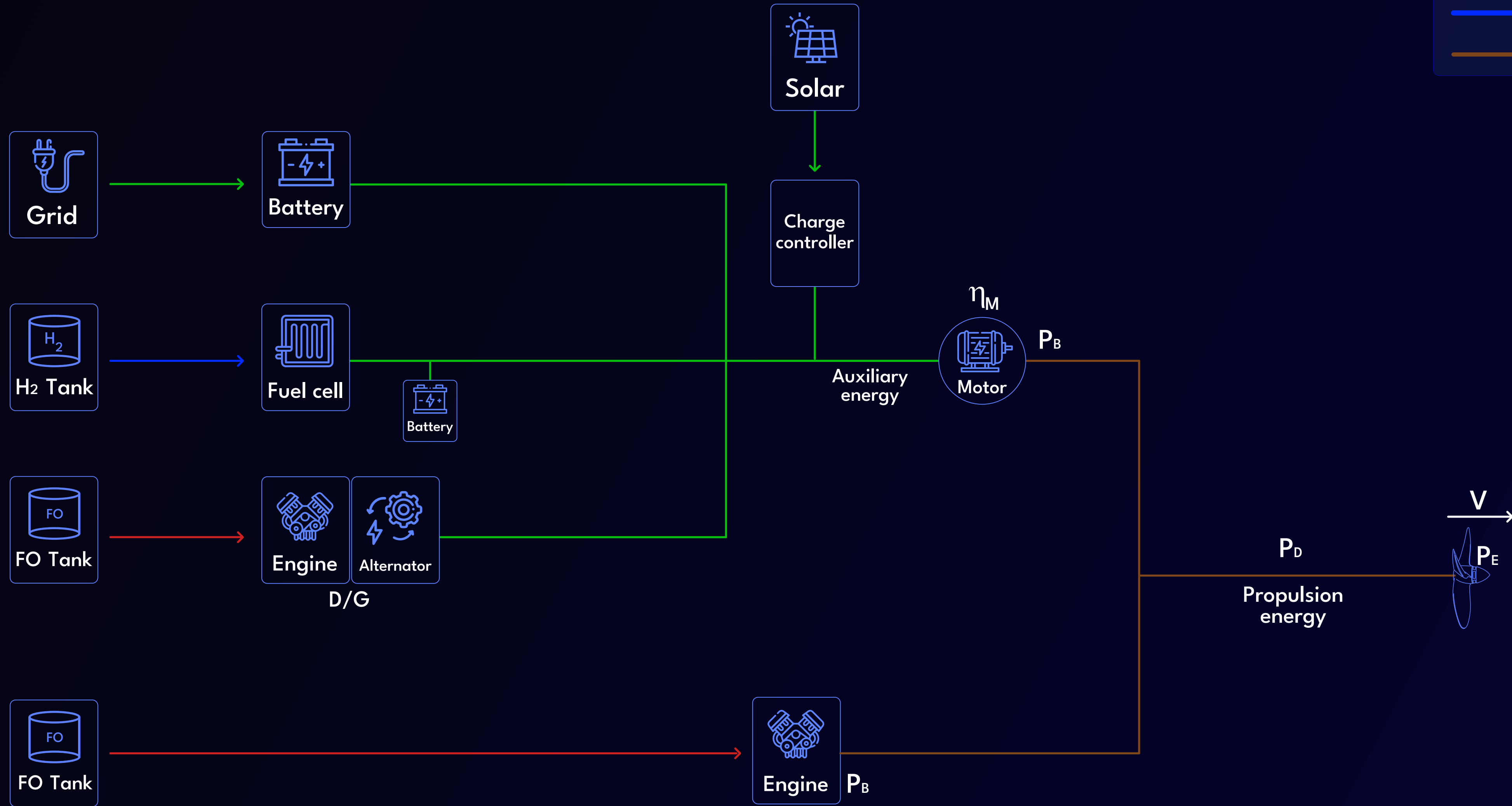
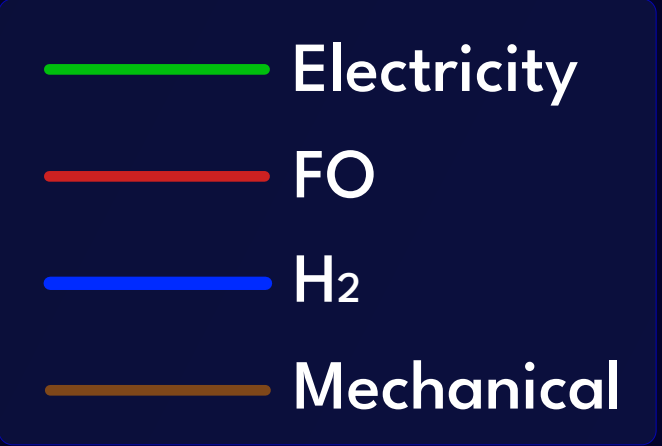


H₂ fuel + Fuel cell

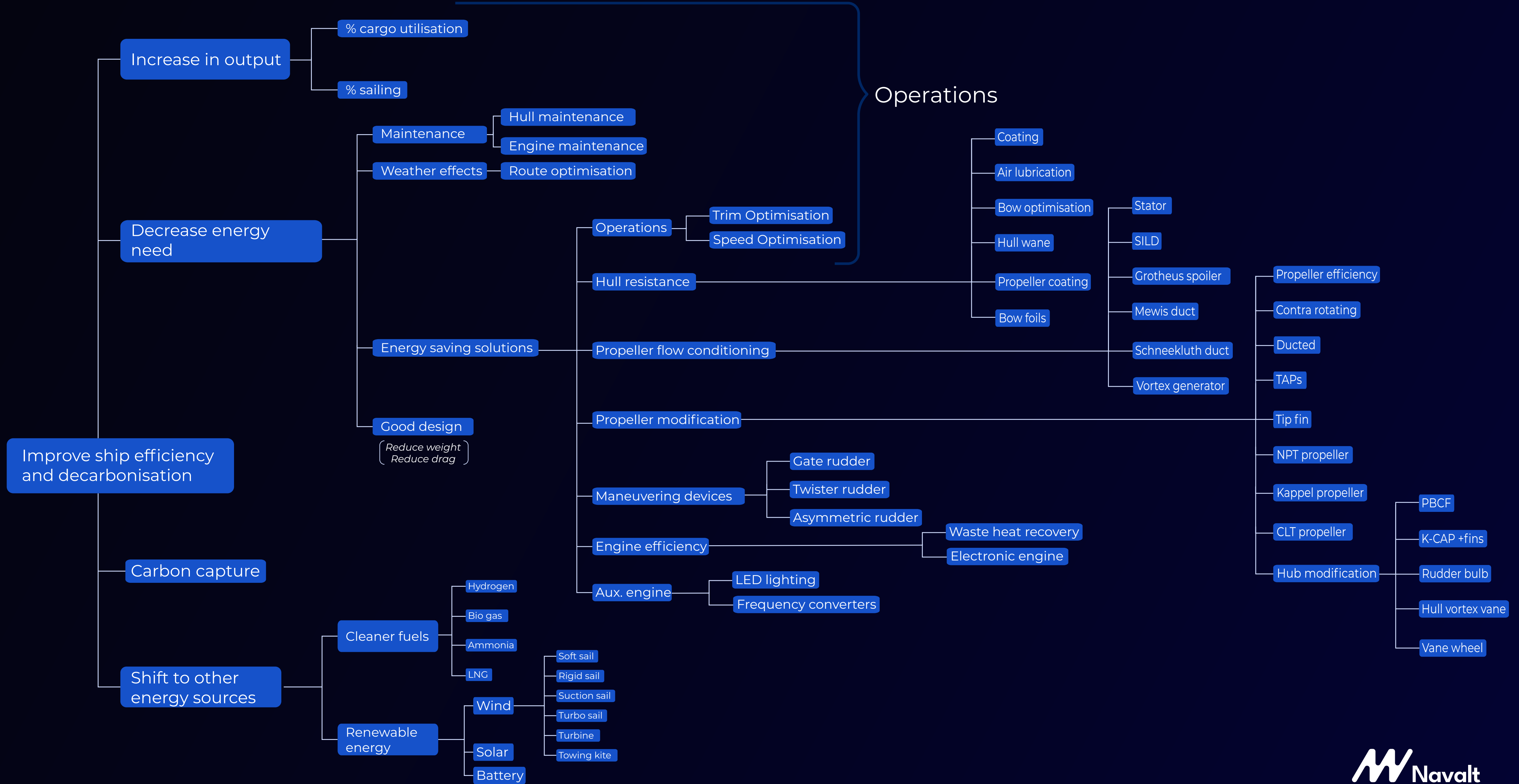
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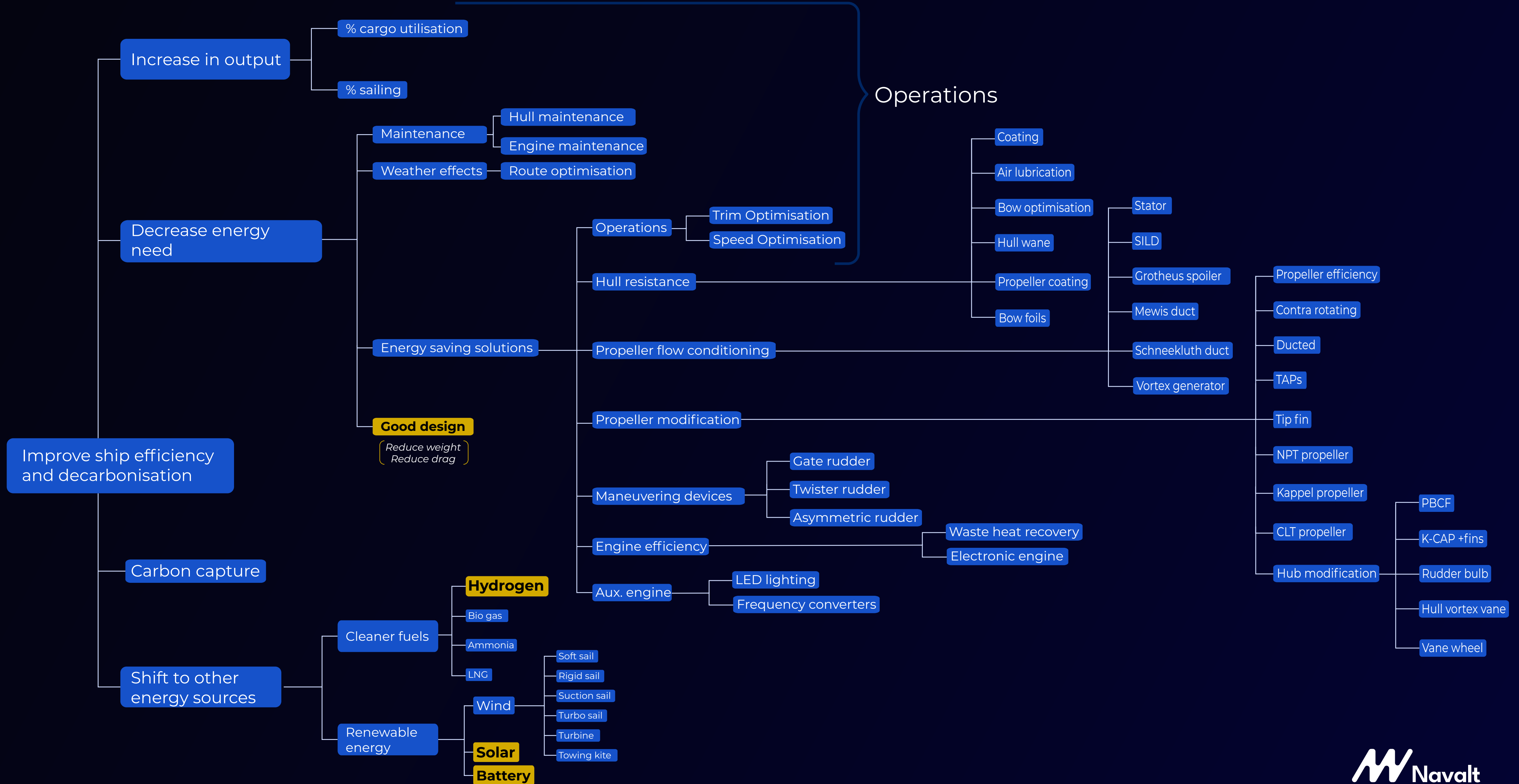
Diesel fuel + Engine



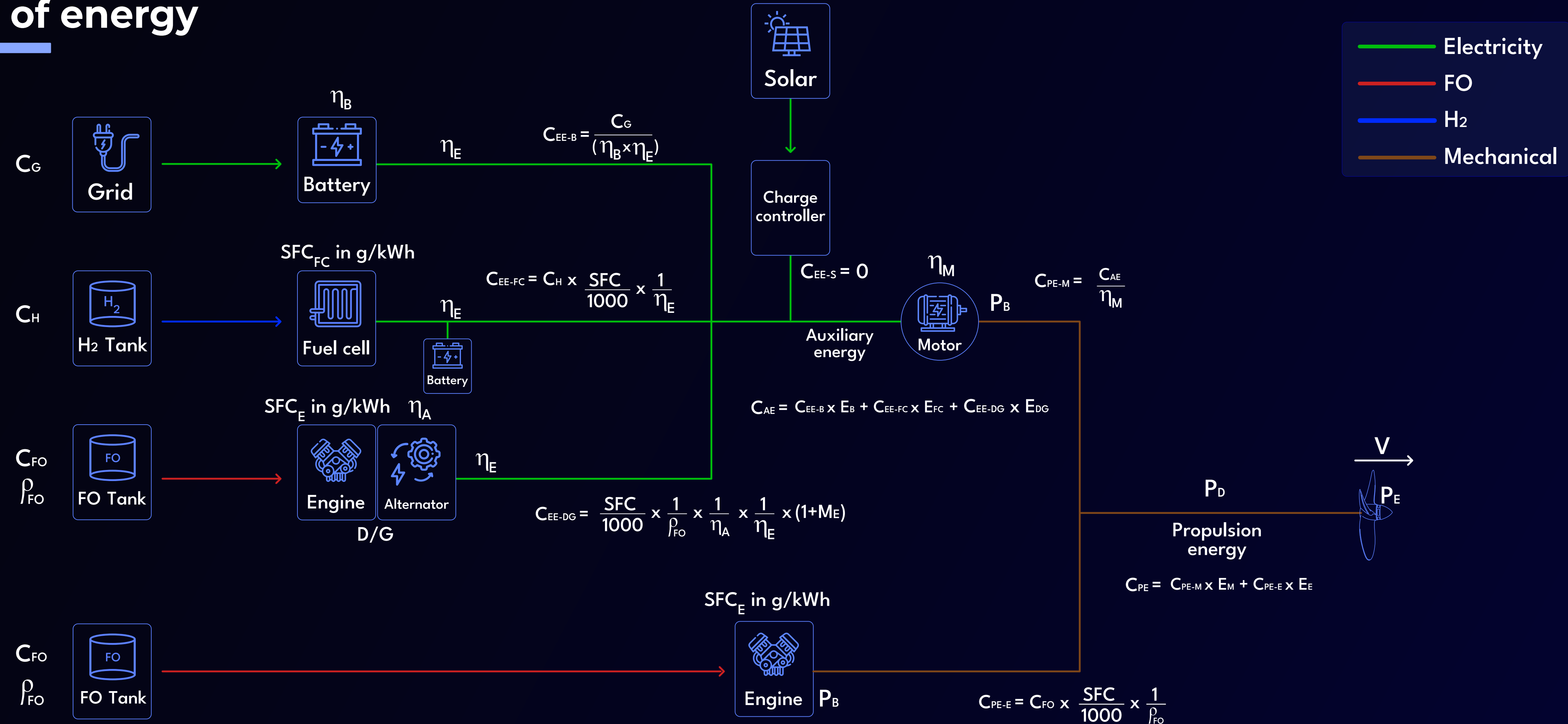
Decarbonisation Pathway



Decarbonisation Pathway

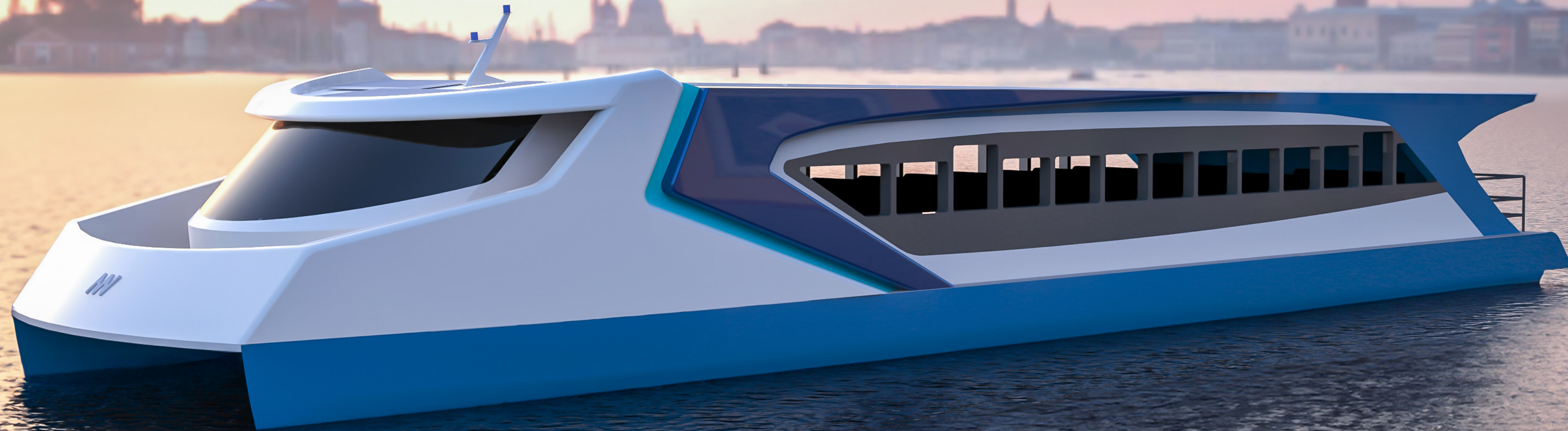


Cost of energy



C_G - Cost of grid \$/kWh	C_{EE-S} - Cost of electrical energy from solar	P_D - Power delivered to propeller	E_B - % Energy from battery	η_M - Motor efficiency
C_H - Cost of H ₂ \$/Kg	C_{PE-E} - Cost of propulsion energy from engine	P_E - Effective power	E_{FC} - % Energy from fuel cell	η_B - Battery efficiency
C_{FO} - Cost of fuel \$/l	C_{PE-M} - Cost of propulsion energy from motor	SFC_E - Specific fuel Consumption engine g/kWh	E_{DG} - % Energy from D/G	η_E - Other system efficiency
C_{EE-B} - Cost of electrical energy from battery	C_{PE} - Cost of propulsion energy	SFC_{FC} - Specific fuel consumption fuel cell g/kWh	E_S - % Energy from solar	η_A - Alternator efficiency
C_{EE-FC} - Cost of electrical energy from fuel cell	C_{AE} - Cost of auxiliary energy		E_M - % Energy from motor	ρ_{FO} - Density of fuel Kg/l
C_{EE-DG} - Cost of electrical energy from D/G	P_B - Brake horse power		E_E - % Energy from engine	ρ_{FO} - Density of fuel Kg/l
			ME - Engine maintenance (LO, filter, overhauling) ~ 10% C_{FO}	

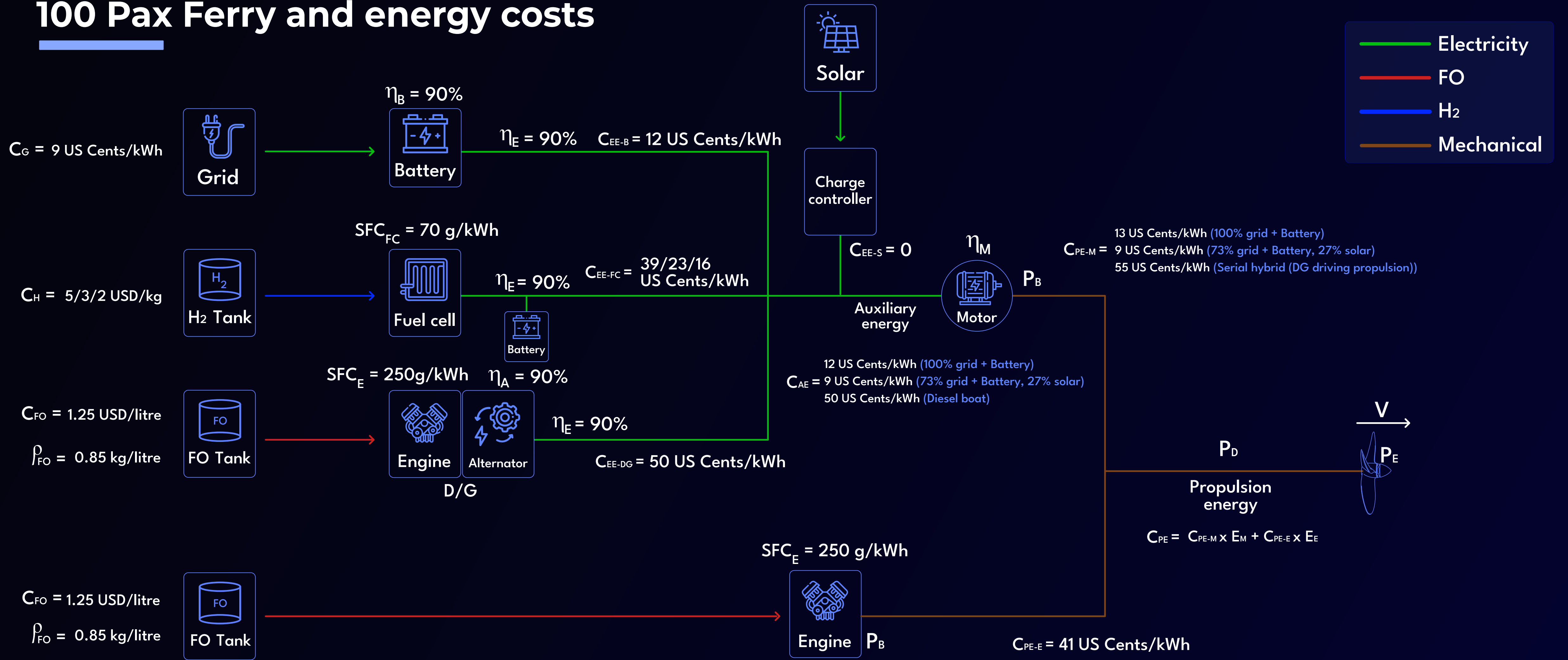
100 PAX FERRY



Speed 8-12 knots

Range 75-200 km/day

100 Pax Ferry and energy costs



C_G - Cost of grid \$/kWh	C_{EE-S} - Cost of electrical energy from solar	P_D - Power delivered to propeller	E_B - % Energy from battery	η_M - Motor efficiency
C_H - Cost of H ₂ \$/Kg	C_{PE-E} - Cost of propulsion energy from engine	P_E - Effective power	E_{FC} - % Energy from fuel cell	η_B - Battery efficiency
C_{FO} - Cost of fuel \$/l	C_{PE-M} - Cost of propulsion energy from motor	SFC_E - Specific fuel Consumption engine g/kWh	E_{DG} - % Energy from D/G	η_E - Other system efficiency
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C_{EE-FC} - Cost of electrical energy from fuel cell	C_{AE} - Cost of auxiliary energy		E_M - % Energy from motor	ρ_{FO} - Density of fuel Kg/l
C_{EE-DG} - Cost of electrical energy from D/G	P_B - Brake horse power		E_E - % Energy from engine	ρ_{FO} - Density of fuel Kg/l
			M_E - Engine maintenance (LO, filter, overhauling) ~ 10% C_{FO}	

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

Cost of grid (CG)	9 US Cents	per kWh	
Cost of diesel (CFO)	1.25 USD	per litre	
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 of LO, filters & overhaul
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 Engine (CPE-E)	41 US Cents	per kWh	includes cost of LO, filters & overhaul

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

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

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 (CFO)	1.25 USD	per 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 of LO, filters & overhaul
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	per kWh	includes cost of LO, filters & overhaul

Countries	CG	CFO	Spread	CEE-B	CEE-DG	Prop-B	Prop-DG	CPE-E	E-B spread	E-B ratio
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Saudi Arabia	7	31	24	9	12	10	14	10	0	1.0

All in US Cents

Cost of hydrogen and energy produced

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

CAPEX, OPEX, TCO and TCO-NPV calculations

Inputs

Platform	100 pax ferry	this decide the speed-power curve (hull and draft)
Location	Kochi	for solar production
Speed	8 knots	decides the propulsion power required
Range per day	75 km	133 km is 9 hrs distance
Max charging range	15 km	
Running time	304 mts	5.1 hrs
Annual operations	350 days	
Air con load	9 kW	for super-efficient based on the platform
Air con load	12 kW	for efficient based on the platform
Air con load	15 kW	for traditional based on the platform
Other aux. load	1 kW	based on the platform
Operating time	12 hrs	
Aircon running time	9.6 hrs	80% of time
Power (supere-efficient)	40 kW	from the speed power curve
Power (efficient)	56 kW	increase if 40%
Power (traditional)	84 kW	increase is 110%
Solar plant size	25 kW	based on platform
Insolation	5.5	based on location
System efficiency	0.64	3.5 kWh per kW in a day
Daily solar energy	88 kWh	Average production for whole year
Solar plant degradation	0.93% every year	20% degradation in 25 years

Prop solar	70.4 kWh	80% proportion for propulsion
Aux. solar	17.6 kWh	20% proportion for auxiliary
LFP design based on	100%	average production for the year

whole day	super-efficient	efficient	
Propulsion energy	203 kWh	283 kWh	
Auxiliary energy	98.4 kWh	127.2 kWh	air con load is for running time and other aux. load is for operating time

Max Trip range	super-efficient LTO system
Trip distance	15 km
Trip time	61 mts
Propulsion energy	41 kWh
Auxiliary energy	10 kWh

CAPEX computation			
Boat without propulsion and drive	2,40,00,000 INR	3,00,000 USD	GRP Boat

Scalability of battery			
Low voltage LFP	20 kWh	for aux. battery and sinze there are two sets of battery	
Medium voltage LFP	80 kWh	for prop. battery and sinze there are two sets of battery	
Medium voltage LTO	120 kWh	for prop. battery and sinze there are two sets of battery	
LTO battery cooling	5 kW	for each 120 kWh scaled unit	
Scalability of fuel cell (size)	70 kW		
H2 tank scalability	7 kg		
Efficiency of prop motor (nM)	90%		
Efficiency of battery (nB)	90%		
Efficiency of elec system (nE)	90%		
Efficiency of alternator (nA)	90%		
SFC of H2 fuel cell (SFCE)	70 g/kWh	of electrical energy	
SFC of Diesel engine (SFCE)	250 g/kWh	of mechanical energy	
SFC of Diesel generator	278 g/kWh	of electrical energy	
Density of diesel (rhoFO)	0.85 kg/litre		
USD Rate	80 Rs/USD		
Cost of grid (CG)	7.5 Rs	9 US Cents	per kWh
Cost of hydrogen (CH)	400 Rs	5 USD	per kg
Cost of diesel (CFO)	100 Rs	1.25 USD	per litre
Cost of LO, filters & overhaul in engine (Em)	10% of CFO		

Cost of elec energy from battery (CEE-B)	9.3 Rs	12 US Cents	per kWh
Cost of elec energy from H2 FC (CEE-FC)	31.1 Rs	39 US Cents	per kWh
Cost of elec energy from DG (CEE-DG)	39.9 Rs	50 US Cents	per kWh includes cost of LO, filters & overhaul
Cost of prop energy from battery	10.3 Rs	13 US Cents	per kWh
Cost of prop energy from H2 FC	34.6 Rs	43 US Cents	per kWh
Cost of prop energy from DG	44.3 Rs	55 US Cents	per kWh
Cost of prop energy from Engine (CPE-E)	32.4 Rs	41 US Cents	per kWh includes cost of LO, filters & overhaul

Battery SOC, DOD and buffer for degradation and replacement

DoD for fast charging LTO	60%
DoD for slow charging LFP	80%
Degradation and additional capacity LTO	20%
Degradation and additional capacity LFP	20%

Solar plant production and degradation		
Year	Energy (kWh)	Difference (kWh)
1	30,800	0
2	30,515	(285)
3	30,233	(567)
4	29,953	(847)
5	29,676	(1,124)
6	29,401	(1,399)
7	29,129	(1,671)
8	28,859	(1,941)
9	28,592	(2,208)
10	28,327	(2,473)
11	28,065	(2,735)
12	27,805	(2,995)
13	27,548	(3,252)
14	27,293	(3,507)
15	27,040	(3,760)
16	26,790	(4,010)
17	26,542	(4,258)
18	26,296	(4,504)
19	26,053	(4,747)
20	25,812	(4,988)
21	25,573	
22	25,336	
23	25,102	
24	24,870	
25	24,640	

Currency

USD
INR

CAPEX, OPEX, TCO and TCO-NPV calculations

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 to mechanical energy	Variable cost of LFP prop battery	70,000 Rs	875 USD	per kWh
Prop battery need	338 kWh	battery DOD is 80% 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	320 kWh	Two sets of 160 kWh batteries	Cost of prop battery pack	2,24,00,000 Rs	2,80,000 USD	
Aux. energy need (electrical)	98 kWh		Cost of replacement in 7 yrs	1,60,00,000 Rs	2,00,000 USD	
Aux battery need	148 kWh	battery DOD is 80% 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	140 kWh	Two sets of 70 kWh batteries	Replacement cost of LFP aux battery	30,000 Rs	375 USD	per kWh
Electrical energy from grid	324 kWh		Cost of aux battery pack	56,00,000 Rs	70,000 USD	
Consumptionfrom battery annually	1,13,384 kWh		Cost of replacement in 7 yrs	42,00,000 Rs	52,500 USD	
OPEX energy cost	10,54,475 Rs.	13,181 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	Variable cost of LFP prop battery	70,000 Rs	875 USD	per kWh
Propulsion enegy from battery (electrical)	155 kWh		Replacement cost of LFP prop battery	50,000 Rs	625 USD	per kWh
Prop battery need	233 kWh	battery DOD is 80% and additional buddfer of 20% due to degradation replacement	Cost of prop battery pack	1,68,00,000 Rs	2,10,000 USD	
Prop battery size	240 kWh	Two sets of 120 kWh batteries	Cost of replacement in 7 yrs	1,20,00,000 Rs	1,50,000 USD	
Aux. energy from sun	17.6 kWh		Variable cost of LFP aux battery	40,000 Rs	500 USD	per kWh
Aux. enegy from battery	80.8 kWh	remove solar from total aux. energy need (electrical)	Replacement cost of LFP aux battery	30,000 Rs	375 USD	per kWh
Aux battery need	121 kWh	battery DOD is 80% and additional buddfer of 20% due to degradation replacement	Cost of aux battery pack	48,00,000 Rs	60,000 USD	
Aux battery size	120 kWh	Two sets of 60 kWh batteries	Cost of replacement in 7 yrs	36,00,000 Rs	45,000 USD	
% solar contribution	27%		System cost	25,00,000 Rs	31,250 USD	
Electrical energy from grid	236 kWh		Solar plant cost	15,00,000 Rs	18,750 USD	per kW
Consumptionfrom battery annually	82,584 kWh		CAPEX of boat	5,17,67,000 Rs	6,47,088 USD	
OPEX energy cost	7,68,035 Rs.	9,600 USD				

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

Propulsion energy need (mechanical)	41 kWh		Variable cost of motors (power rating)	30	15,00,000 Rs	18,750 USD
Propulsion energy need (electrical)	46 kWh	loss of electrical to mechanical energy		120	45,00,000 Rs	56,250 USD
Aux. energy need (electrical)	10 kWh		Interpolation using above rates			
Total energy (electrical)	56 kWh		50 kW motors			
Battery size need	111 kWh	battery DOD is 60% and additional buddfer of 20% due to degradation replacement	Cost with drives and controls	21,67,000 Rs	27,088 USD	
Battery size	120 kWh		Variable cost of LTO battery	2,00,000 Rs	2,500 USD	per kWh
Battery cooling power	5 kW	for every set of 120 kWh need 5 kW power	Replacement cost of LTO battery	1,80,000 Rs	2,250 USD	per kWh
Battery cooling energy	5 kWh	for the trip time	Cost of battery pack	2,40,00,000 Rs	3,00,000 USD	
Total battery cooling energy	60 kWh		Cost of replacement in 10 yrs	2,16,00,000 Rs	2,70,000 USD	
Check if Total energy + battery cooling < battery size*0.8	61 < 72	TRUE	System cost	4,00,00,000 Rs	5,00,000 USD	
Final battery size (After cooling check)	120 kWh	Two sets of 60 kWh batteries	CAPEX of boat	9,01,67,000 Rs	11,27,088 USD	
Total electrical energy	384 kWh	propulsion electrical + auxiliary electrical + battery cooling				
Consumptionfrom battery annually	1,34,384 kWh					
OPEX energy cost	12,49,775 Rs.	15,622 USD				

LTO System - with Solar

For sizing since the solar production may not be there in the max. trip time, we assume the same battery size as electric mode (can refine with exact schedule and energy plot)

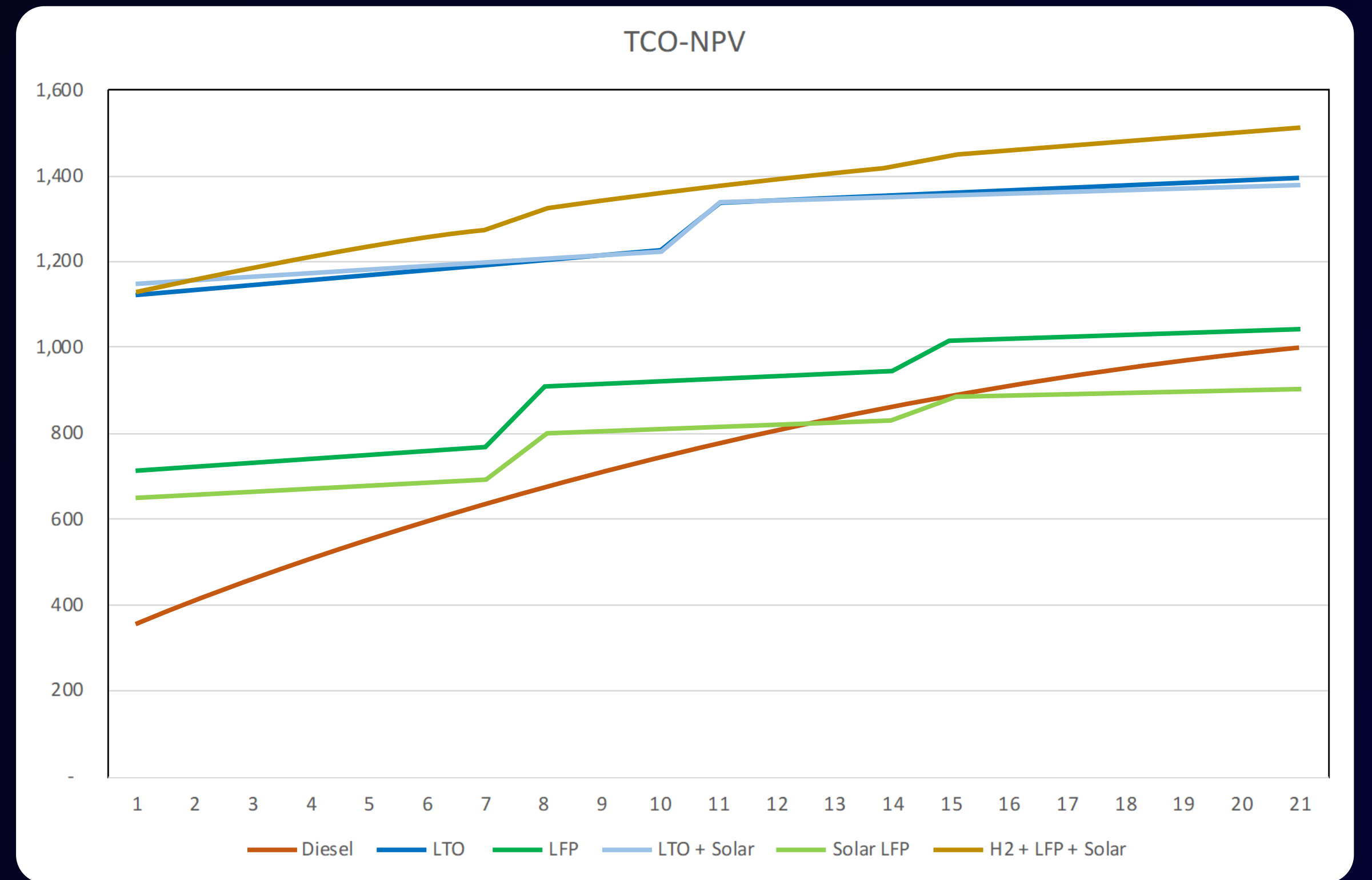
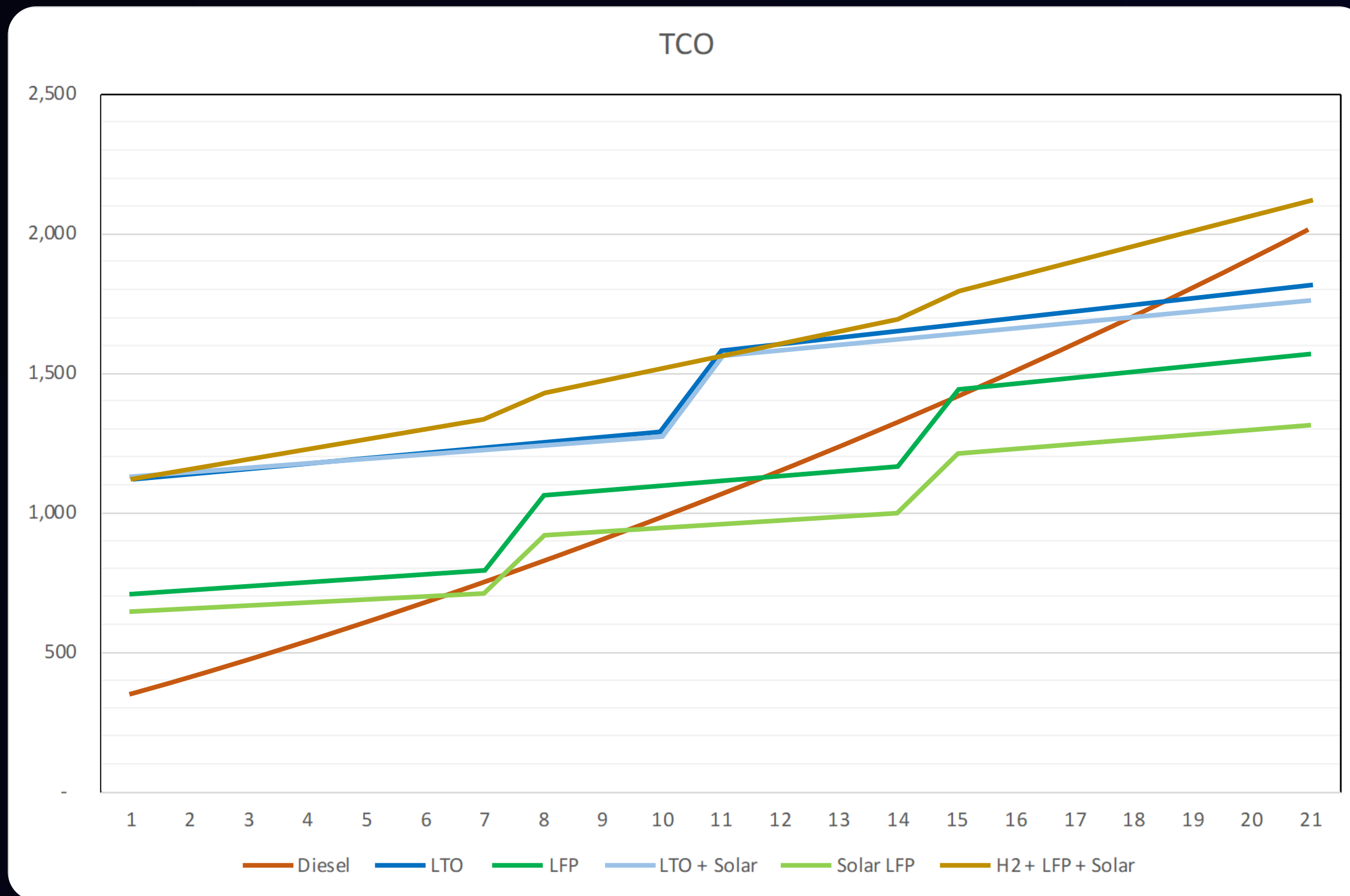
Total electrical energy	384 kWh		Solar plant cost per kW	60,000 Rs	750 USD	per kW
Total solar propduction	88 kWh		Solar plant cost	15,00,000 Rs	18,750 USD	per kW
Electrical energy from battery + grid	296 kWh		CAPEX of boat with solar plant	9,16,67,000 Rs	11,45,838 USD	
Consumptionfrom battery annually	1,03,584 kWh					
OPEX energy cost	9,63,335 Rs.	12,042 USD				

CAPEX, OPEX, TCO and TCO-NPV calculations

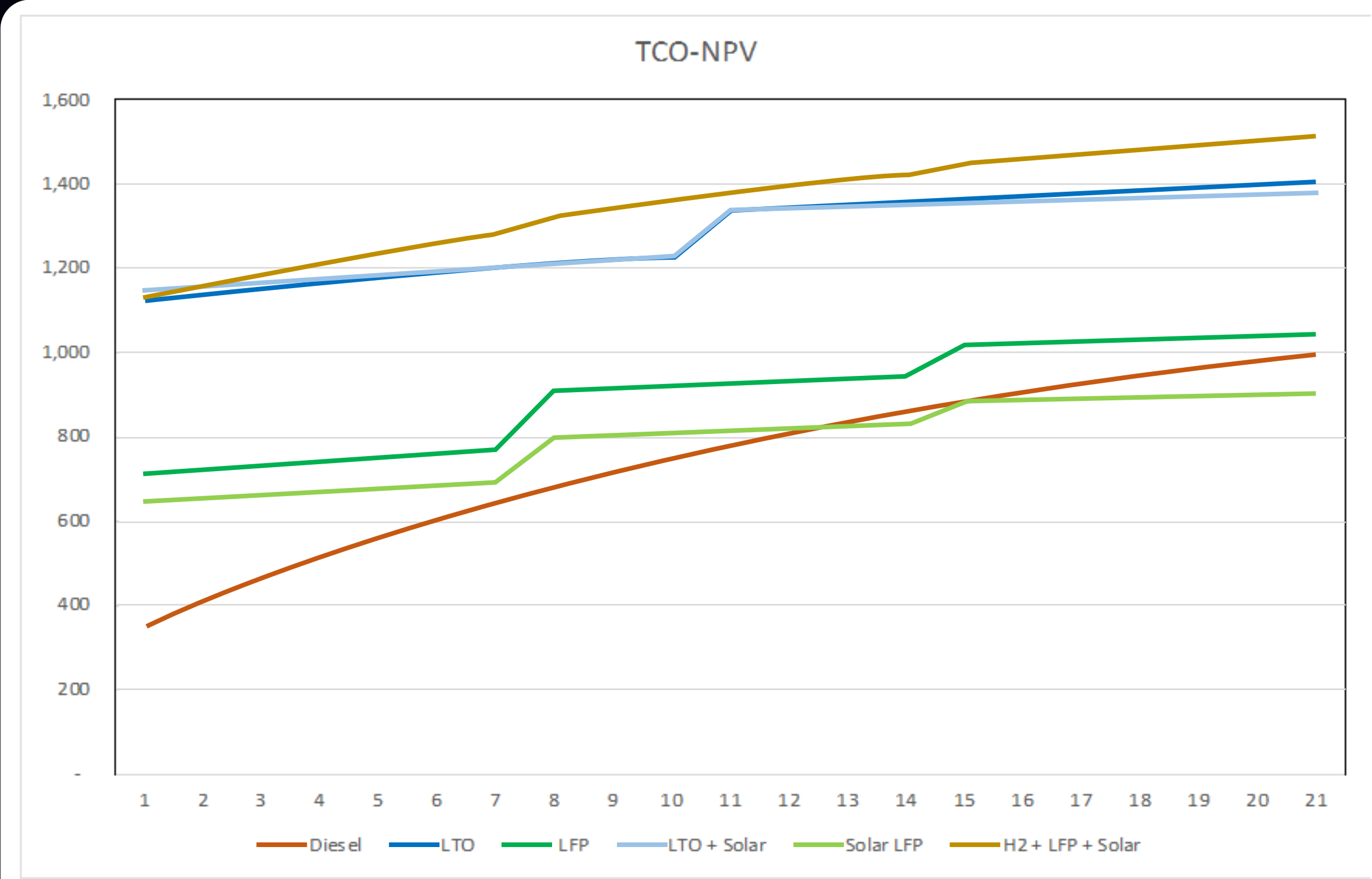
	Diesel	LTO	LFP	LTO-solar	LFP-solar	H2FC + LFP + Solar	
Propulsion power	56	40	40	40	40	40	kW
Motor/Engine size	70	50	50	50	50	50	Propulsion power
Aux. engine size	16						kW
Solar for propulsion (electrical)				70	70	70	kWh
Solar for auxiliary (electrical)				18	18	18	kWh
Propulsion energy from battery		226	226	155	155		kWh
Auxiliary energy from battery		158	98	141	81		kWh
Propulsion energy from fuel cell						155	kWh
Auxiliary energy from fuel cell						81	kWh
Propulsion energy from diesel (mechanical)	283						kWh
Auxiliary energy from diesel (electrical)	127						kWh
% from battery + grid		100%	100%	77%	73%		
% from H2FC						82%	
% from DG	100%						
% from solar				23%	27%	18%	
Cost of Auxiliary energy (CAE)	49.9	11.6	11.6	9.0	8.5	31.9	US Cents
Cost of Propulsion energy from motor (CF)	55.4	12.9	12.9	10.0	9.4	35.5	US Cents
Cost of Propulsion energy (CPE)	40.5	40.5	40.5	40.5	40.5	40.5	US Cents
% from motors		100%	100%	100%	100%	100%	
% from engine	100%						
Cost of Propulsion energy (CPE)	40.5	12.9	12.9	10.0	9.4	35.5	
Fuel consumed in propulsion engine	83						litres
Fuel consumed in DG	46						litres
Fuel consumed daily	129						litres
H2 consumed in prop and aux. daily						18	kg
Propulsion Battery size		120	320	120	240	80	kWh
Auxiliary Battery size			140		120		kWh
Annual propulsion energy from battery/FC		78,944	78,944	54,304	54,304	54,304	kWh
Annual aux. energy from battery/FC		55,440	34,440	49,280	28,280	28,280	kWh
Rate of prop. Energy from diesel/battery/l	41	13	13	13	13	43	US Cents
Rate of aux. energy from diesel /battery	50	12	12	12	12	39	US Cents
CAPEX of boat in 1000 USD	351	1127	708	1146	647	1128	
OPEX of boat in 1000 USD	62.1	15.6	13.2	12.0	9.6	32.2	
CAPEX for battery replacement in 1000 USD		270	253	270	195	50	
	3%	3%	3%	3%	3%	3%	

H2FC with LFP System and Solar				CAPEX of boat	
Propulsion power (mechanical)	40 kW			5,27,000	Rs
Propulsion power (electrical)	44 kW			6,47,000	USD
Auxiliary power (electrical)	10 kW				
Total electrical power need	54 kW				
LFP battery size need (1C)	54 kWh				
Prop and aux battery size	80 kWh	Two sets of	40 kWh batteries		
Fuel cell size	70 kW				
No. of fuel cells needed	1				
Assumed no. of recharges daily	1				
Propulsion energy need (mechanical)	203 kWh				
Propulsion energy need (electrical)	226 kWh	loss of electrical to mechanical energy			
Aux. energy need (electrical)	98 kWh				
Total electrical energy needed	324 kWh				
For sizing, total solar production	88 kWh				
Total electrical energy needed considering	236 kWh				
SFC of H2 fuel cell	70 g/kWh				
Total H2 needed between recharges	18.4 kg	need to take the electrical system efficiency since elec energy is aux consumption			
No. of cylinders	3 sets of	7 kg	cylinders	Assuming solar	
Consumption of H2 annually	6440 kg				
OPEX energy cost	25,76,000 Rs.	32,200	USD		
Diesel engine + Generator (efficient)				CAPEX of boat	
Propulsion energy (mechanical)	283 kWh				
SFC of Diesel engine (SFCE)	250 g/kWh	of mechanical energy			
Propulsion fuel consumed in engine	83 litres				
Auxiliary energy (electrical)	127 kWh	of electrical energy			
Auxiliary energy (mechanical)	141 kWh	of mechanical energy			
SFC of Diesel generator	278 g/kWh	of electrical energy			
Propulsion fuel consumed in generator	46 litres				
Annual fuel consumption	45,150 litres				
Cost of fuel annually	45,15,000 Rs.	56,438	USD		
Cost of LO, filter, overhaul	4,51,500 Rs.	5,644	USD		
OPEX energy cost	49,66,500 Rs.	62,081	USD		
Cost with drives and controls	21,67,000	Rs	27,088	USD	
Variable cost of LFP prop battery	70,000	Rs	875	USD	per kWh
Replacement cost of LFP prop battery	50,000	Rs	625	USD	per kWh
Cost of prop battery pack	56,00,000	Rs	70,000	USD	
Cost of replacement in 7 yrs	40,00,000	Rs	50,000	USD	
System cost	25,00,000	Rs	31,250	USD	
Battery, motors and system cost	1,02,67,000	Rs	1,28,338	USD	
Cost of one 70 kW fuel cell	2,00,00,000	Rs	2,50,000	USD	
Cost of fuel cells for the boat	2,00,00,000	Rs	2,50,000	USD	
Piping and other fuel cell system cost	150%	of fuel cell cost			
Piping and other fuel cell system cost	3,00,00,000	Rs	3,75,000	USD	
Cost of each 7 kg cylinders	20,00,000	Rs	25,000	USD	
Cost of 7 kg cylinders	60,00,000	Rs	75,000	USD	
H2 system cost	5,60,00,000	Rs	7,00,000	USD	
CAPEX of boat	9,02,67,000	Rs	11,28,338	USD	
Variable cost of engines (power rating)	70	20,00,000	Rs	25,000	USD
	240	60,00,000	Rs	75,000	USD
Interpolation using above rates					
Cost Engine, gearbox, tank and accessories	70 kW engines	20,00,000	Rs	25,000	USD
Variable cost of generator (power rating)	5	10,00,000	Rs	12,500	USD
	20	25,00,000	Rs	31,250	USD
Interpolation using above rates					
Cost generator, tank and accessories	16 kW engines	21,00,000	Rs	26,250	USD
CAPEX of boat	2,81,00,000	Rs	3,51,250	USD	

CAPEX, OPEX, TCO and TCO-NPV calculations

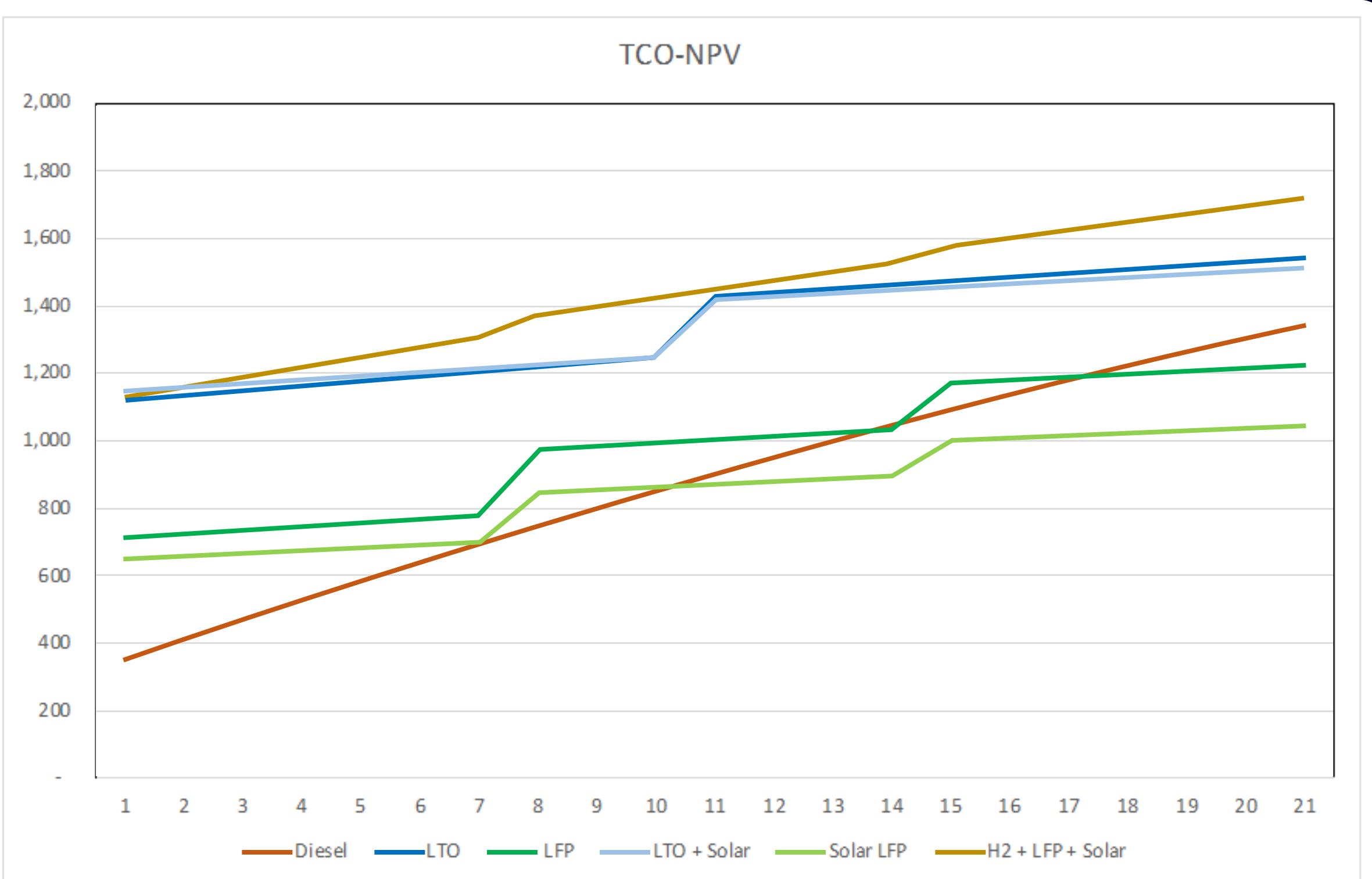


How discount rate affects TCO NPV



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



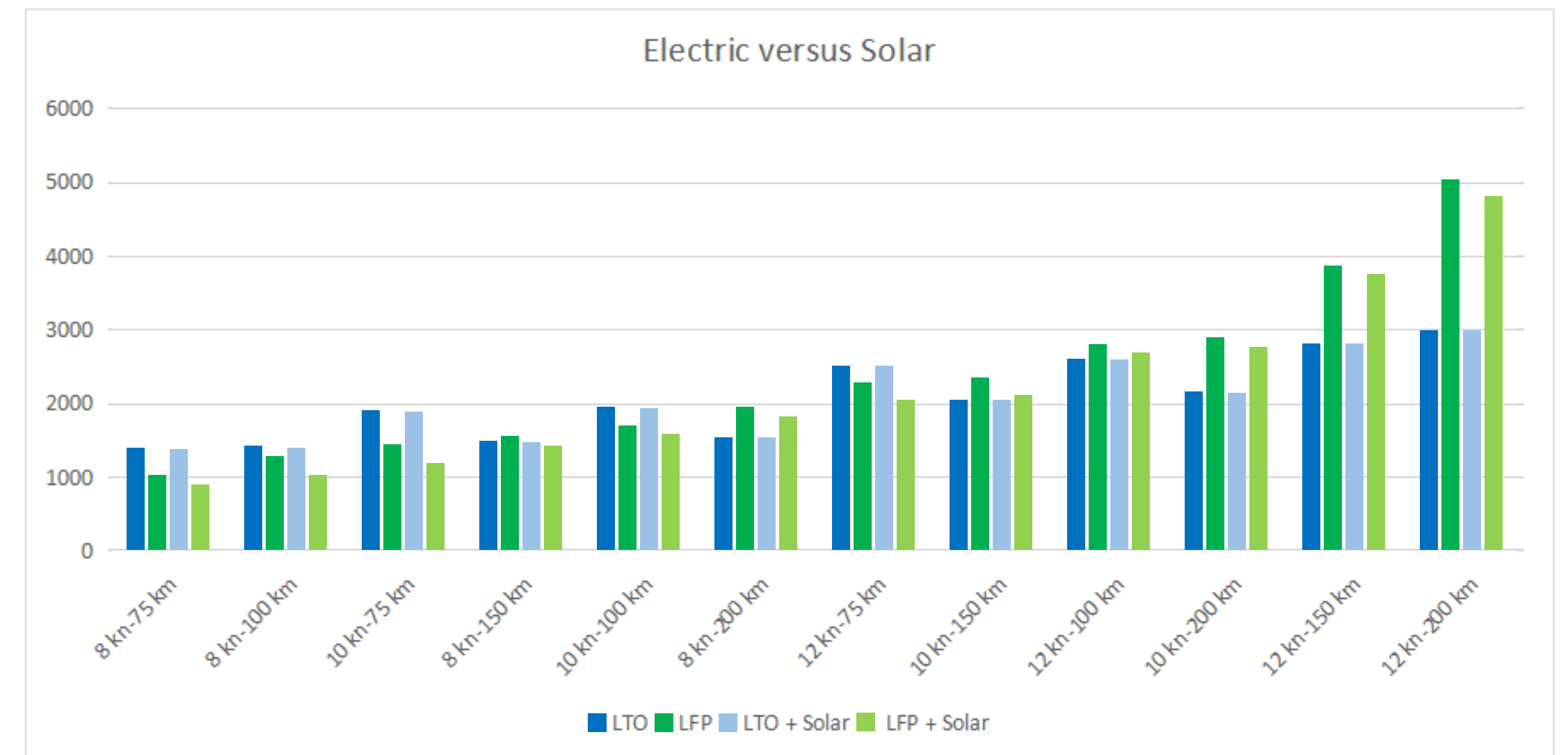
Speed-Range	Energy/day	Diesel	LTO	LFP	LTO + Solar	LFP + Solar	H2 + LFP + Solar
8 kn-75 km	324	1342	1542	1226	1514	1047	1718

@5 % discount rate

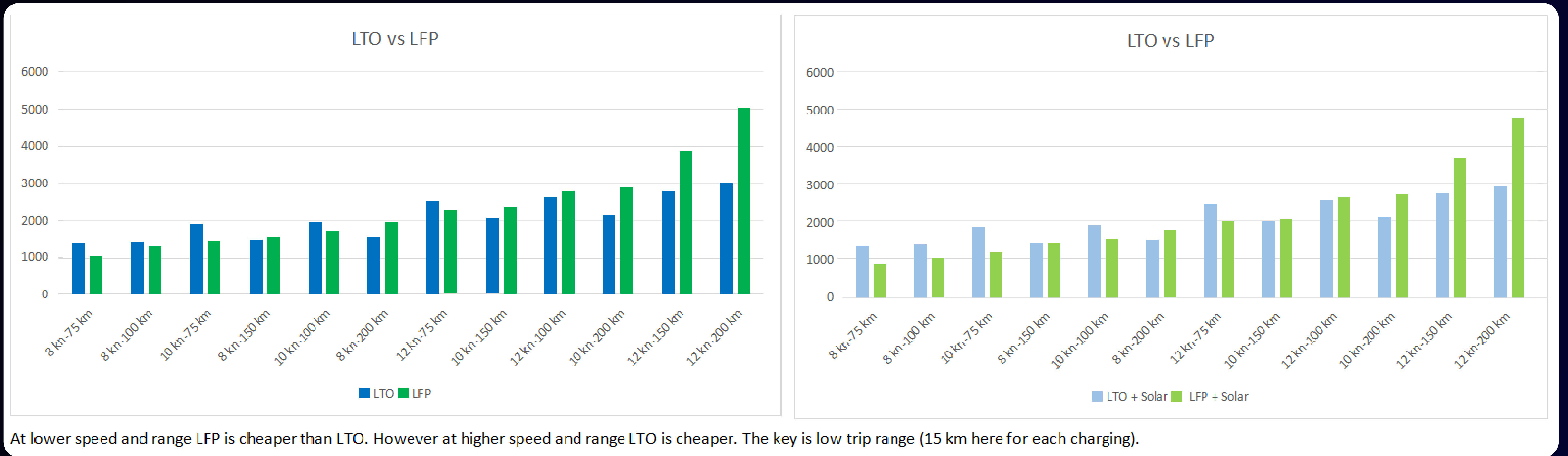
TCO NPV for various speeds (8/10/12 knots) and range (75/100/150/200 km)

Speed-Range	Energy/day	Diesel	LTO	LFP	LTO + Solar	LFP + Solar	5 USD/kg			3 USD/kg			2 USD/kg		
							H2+LFP+Solar (5\$/kg)	H2+LFP+Solar (3\$/kg)	H2+LFP+Solar (2\$/kg)	H2+LFP+Solar (5\$/kg)	H2+LFP+Solar (3\$/kg)	H2+LFP+Solar (2\$/kg)	H2+LFP+Solar (5\$/kg)	H2+LFP+Solar (3\$/kg)	H2+LFP+Solar (2\$/kg)
8 kn-75 km	324	1000	1394	1042	1382	904	1512	1371	1308	1512	1371	1308	1512	1371	1308
8 kn-100 km	398	1141	1426	1291	1415	1046	1618	1433	1352	1618	1433	1352	1618	1433	1352
10 kn-75 km	458	1277	1902	1447	1892	1202	1858	1639	1541	1858	1639	1541	1858	1639	1541
8 kn-150 km	548	1422	1490	1573	1480	1438	1882	1610	1489	1882	1610	1489	1882	1610	1489
10 kn-100 km	578	1498	1953	1715	1945	1581	2054	1765	1636	2054	1765	1636	2054	1765	1636
8 kn-200 km	698	1699	1554	1963	1546	1830	2146	1786	1627	2146	1786	1627	2146	1786	1627
12 kn-75 km	772	1912	2517	2285	2512	2044	3254	2851	2673	3254	2851	2673	3254	2851	2673
10 kn-150 km	818	1946	2055	2361	2050	2121	2472	2042	1852	2472	2042	1852	2472	2042	1852
12 kn-100 km	998	2334	2613	2817	2611	2687	3627	3092	2855	3627	3092	2855	3627	3092	2855
10 kn-200 km	1058	2394	2157	2899	2155	2770	2889	2319	2067	2889	2319	2067	2889	2319	2067
12 kn-150 km	1448	3169	2805	3878	2808	3755	4393	3596	3243	4393	3596	3243	4393	3596	3243
12 kn-200 km	1898	4009	2996	5049	3005	4822	5160	4100	3631	5160	4100	3631	5160	4100	3631

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)

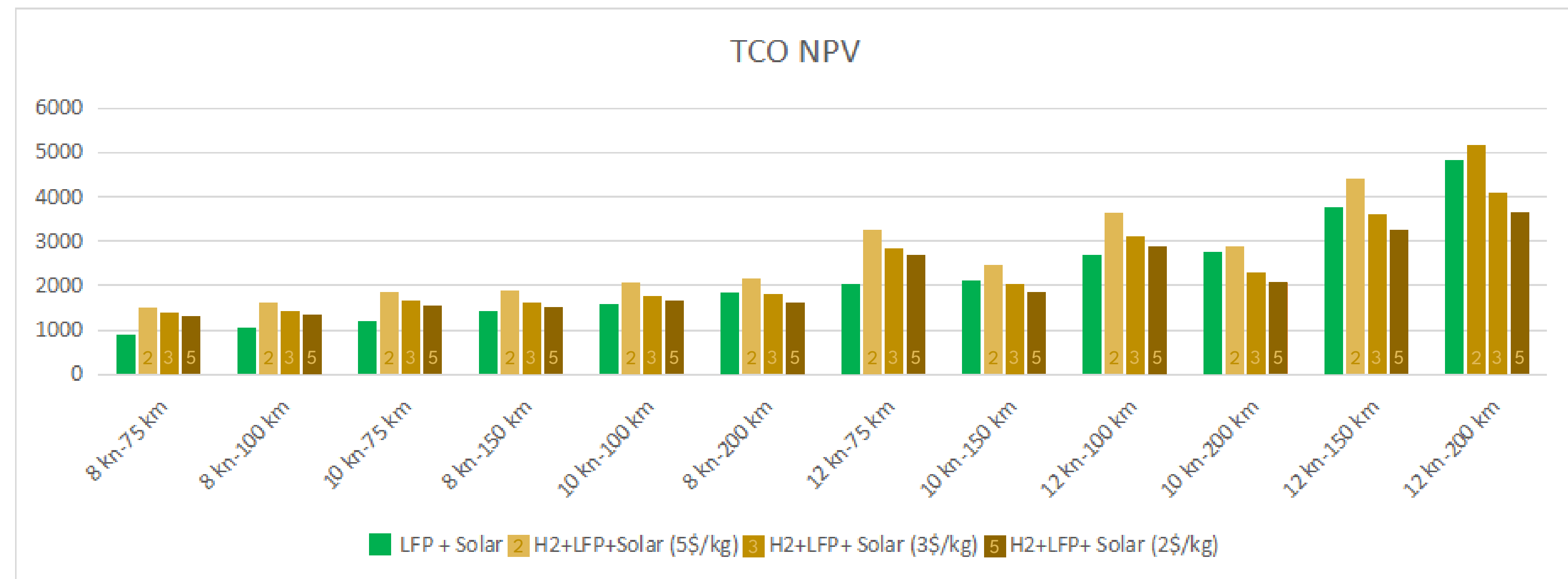


When is Hydrogen effective?

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

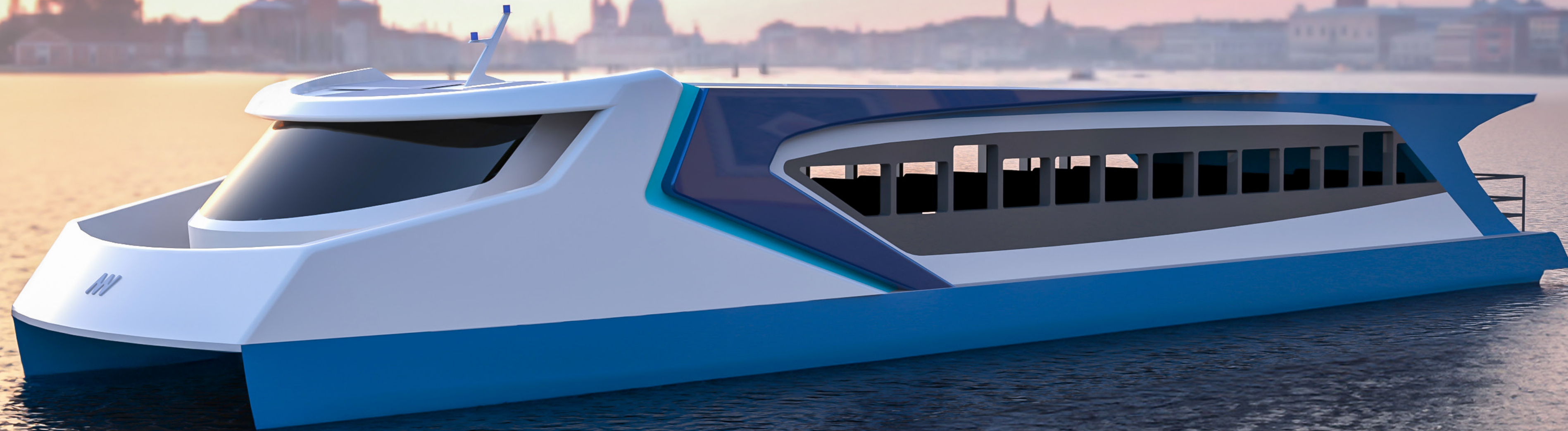
10 kn-75 km	1202	1541
10 kn-100 km	1581	1636
10 kn-150 km	2121	1852
10 kn-200 km	2770	2067

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

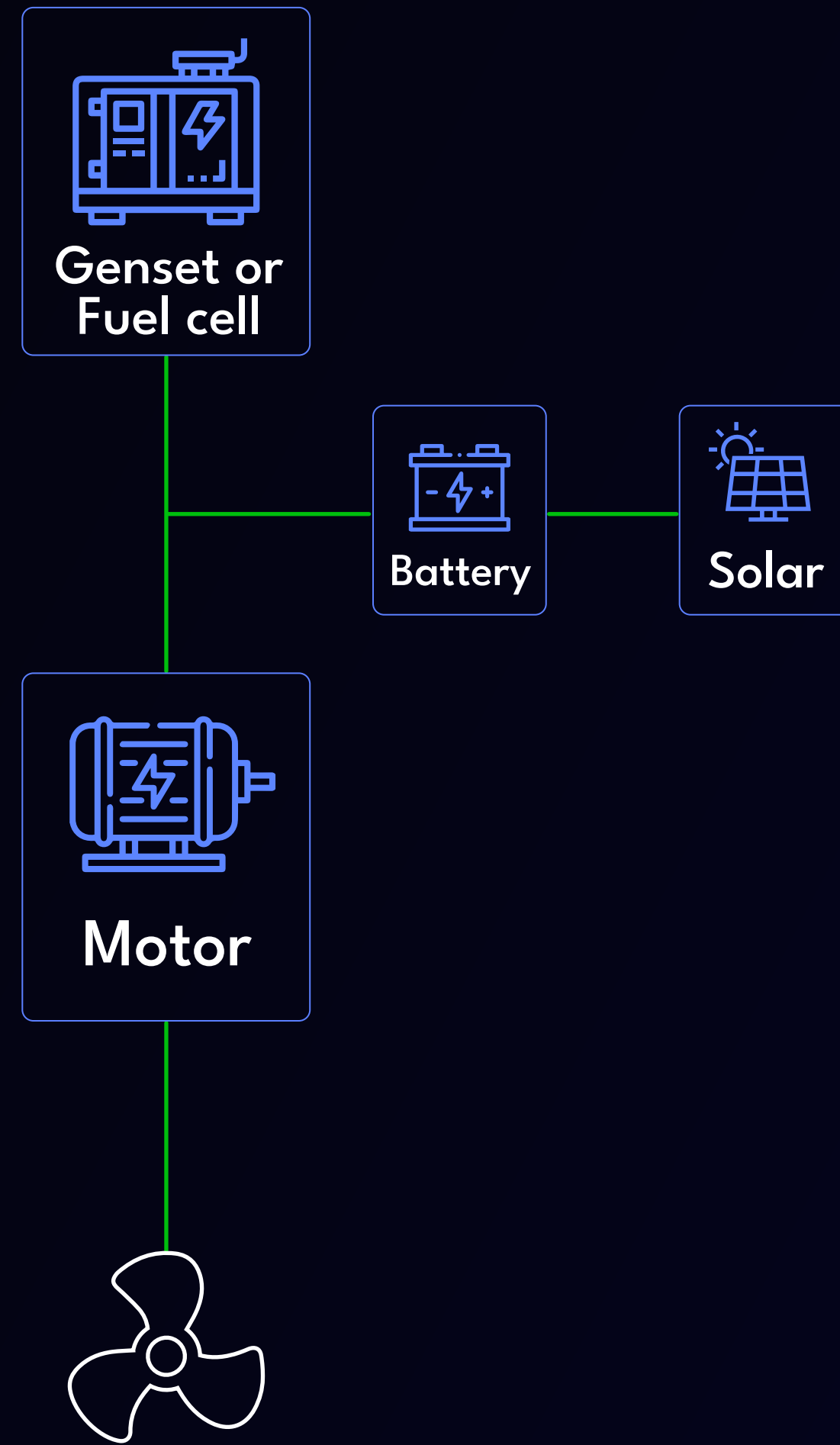
100 PAX FERRY



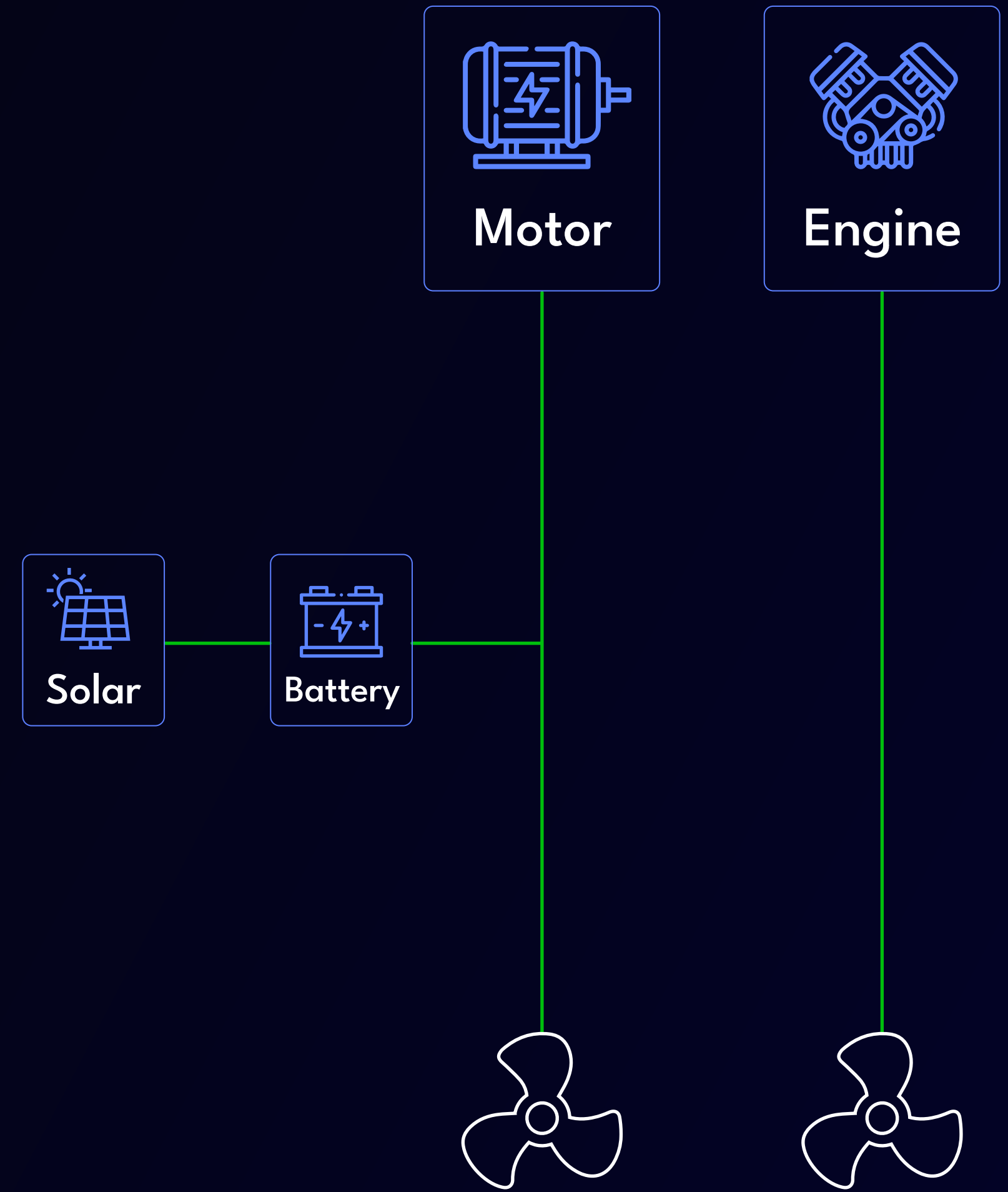
Speed 12 knots

Range 200 km/day

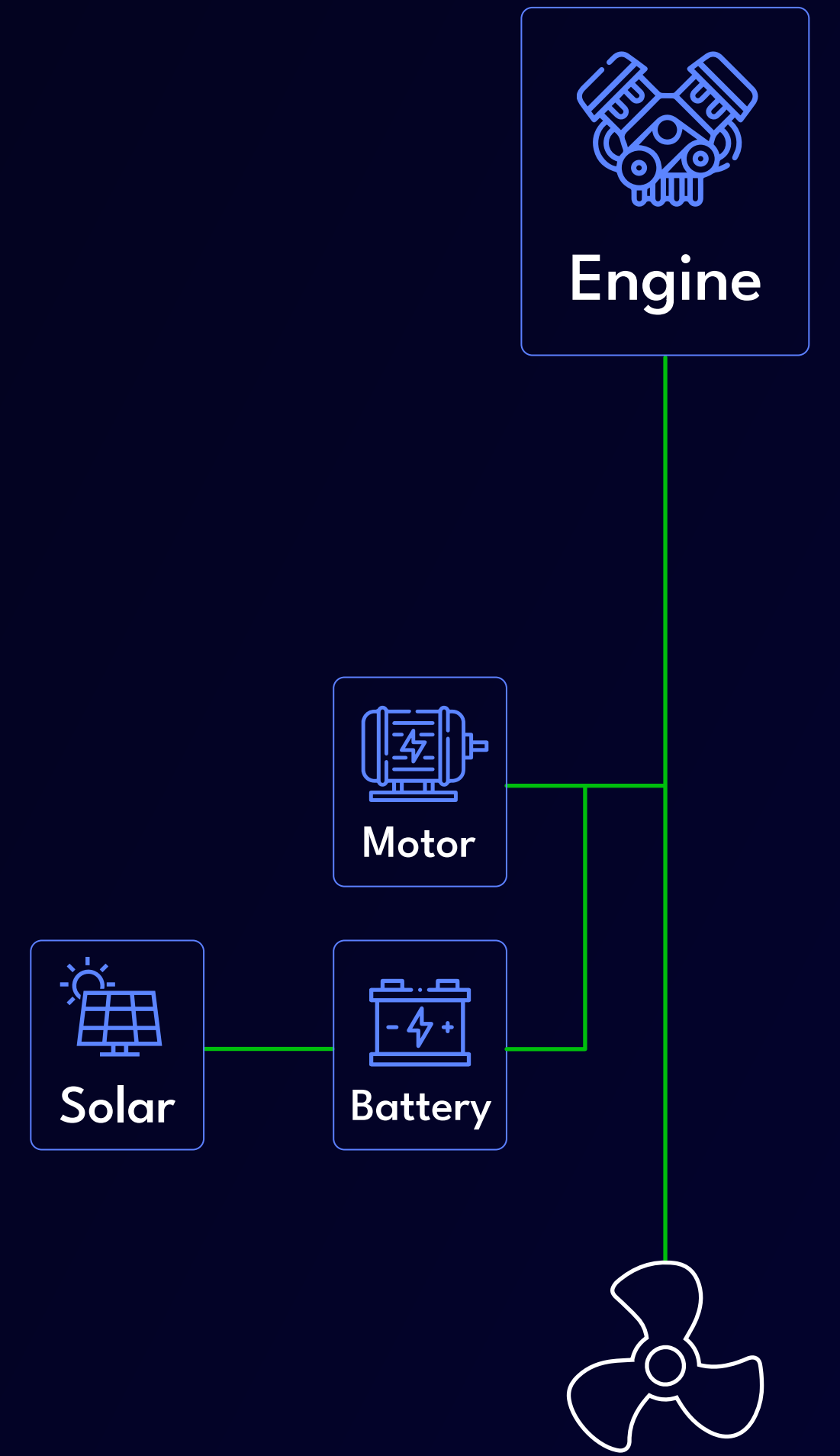
Trip range 100 km



Series



Independent shaft

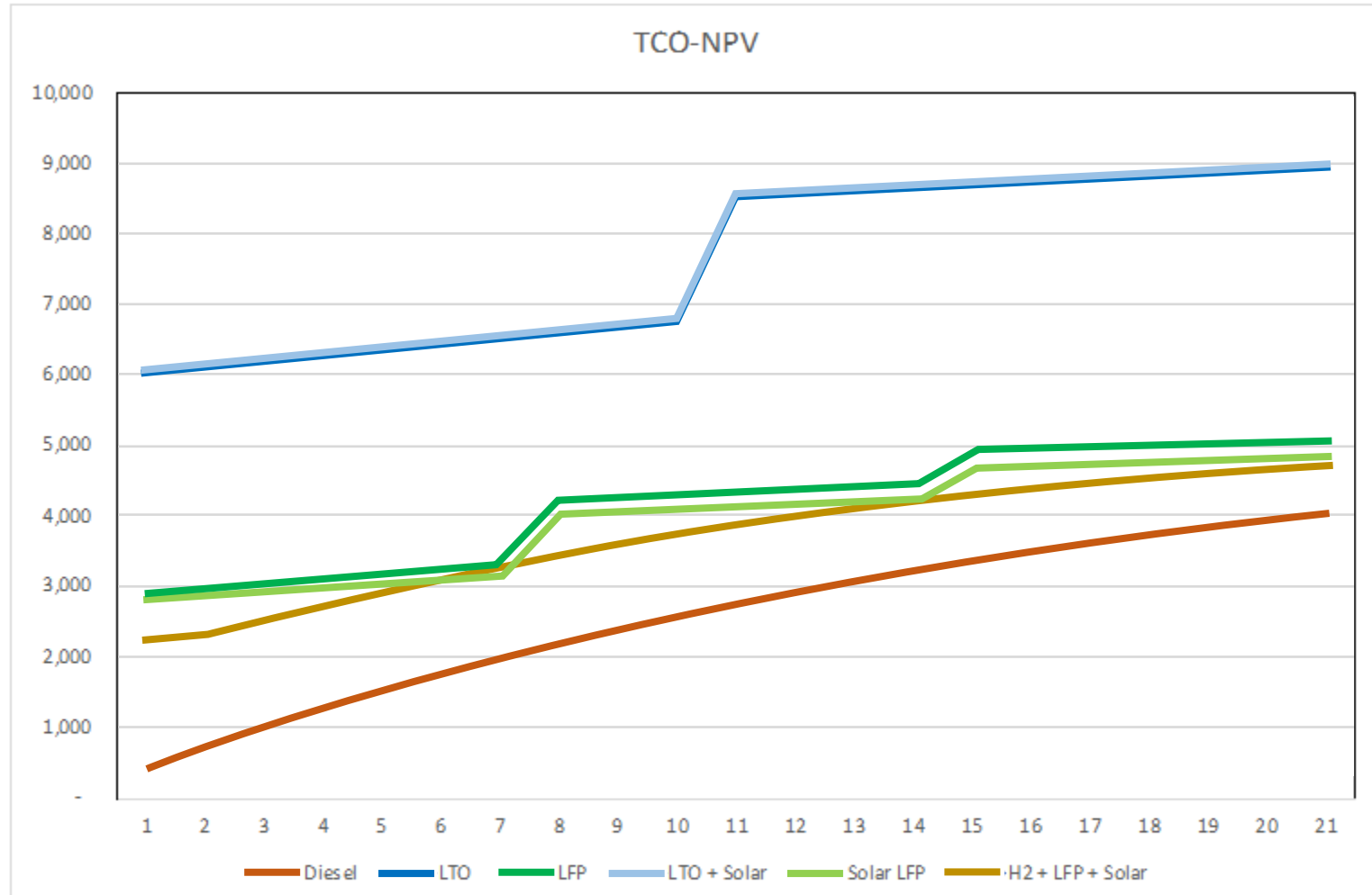


Same shaft

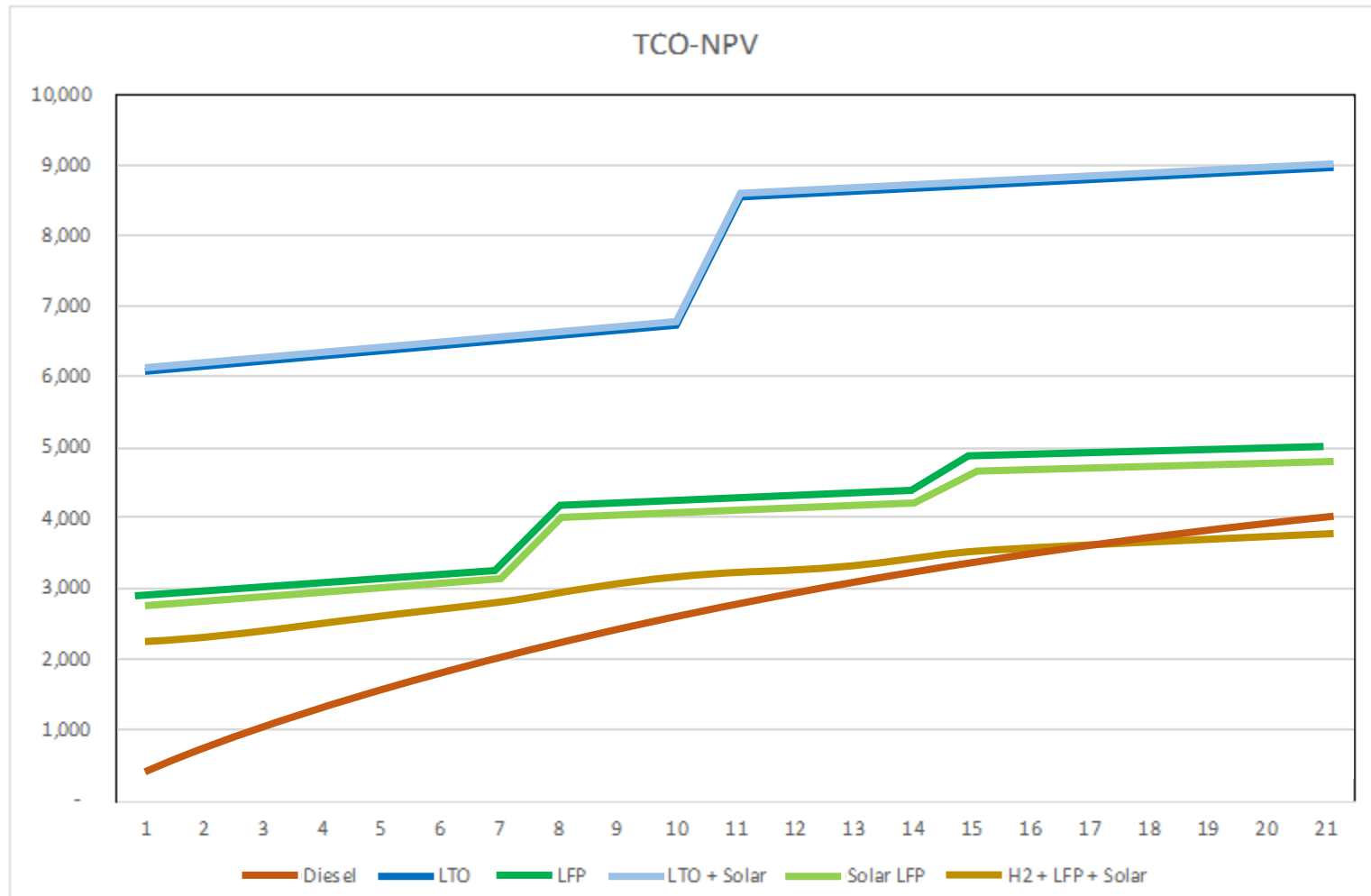
Parallel

What changes with high speed and high trip range?

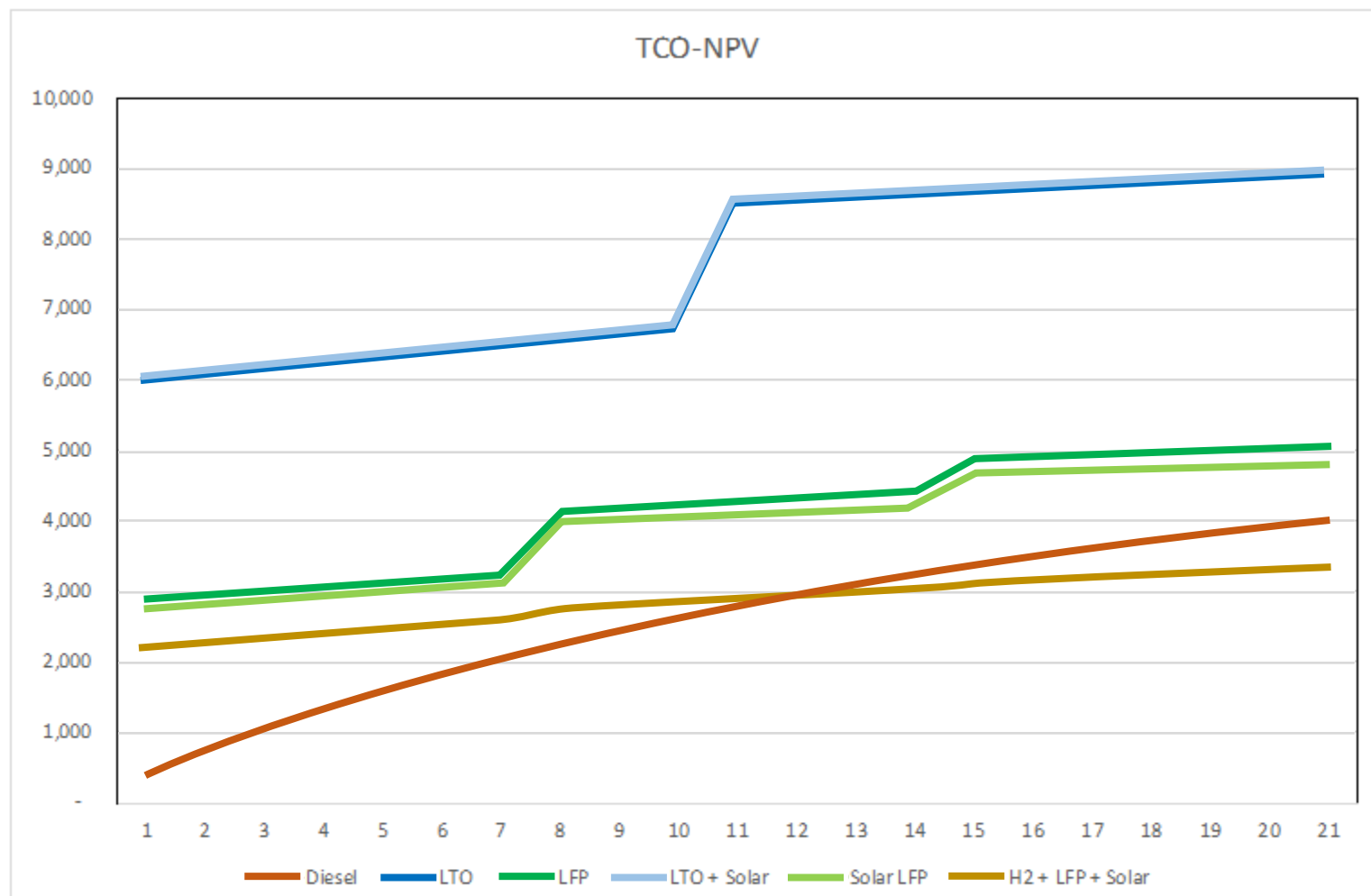
For long range - 12 knots, 200 km (with 100 km as recharge time)
for H2 FC and LTO 100 km is the recharge distance



H2 @ 5 USD/kg



H2 @ 3 USD/kg

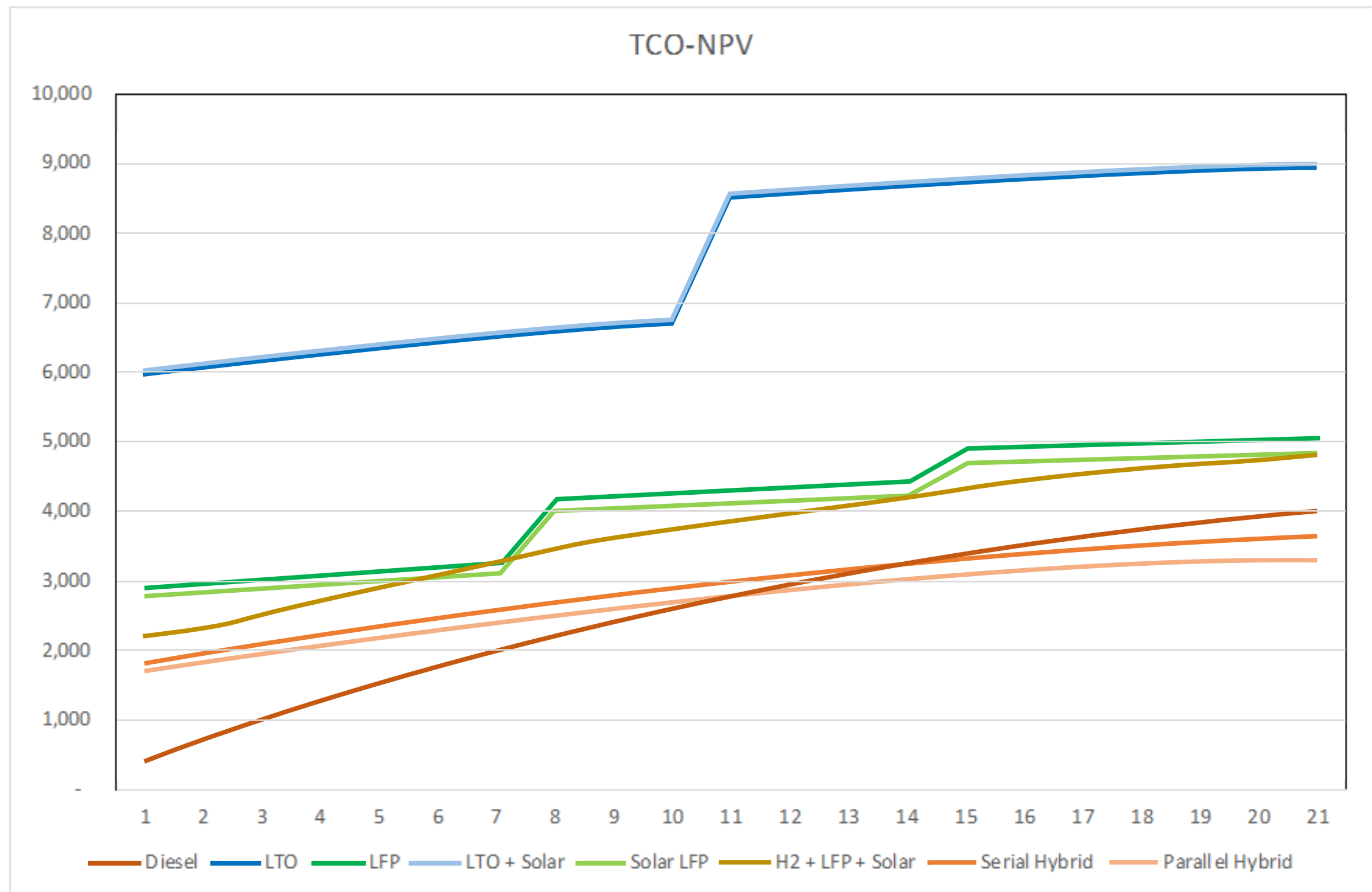


H2 @ 2 USD/kg

	Diesel	LTO	LFP	LTO + Solar	LFP + Solar	5 USD/kg H2 + LFP + Solar	3 USD/kg H2 + LFP + Solar	2 USD/kg H2 + LFP + 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 + Solar	LFP + Solar	H2 + LFP + Solar 5 USD/kg	H2 + LFP + Solar 3 USD/kg	H2 + LFP + Solar 2 USD/kg	Serial Hybrid	Parallel Hybrid	in 1000 USD
12 kn-200 km	1898	4009	8985	5049	9004	4822	4,798	3,783	3,336	3623	3350	

**Thank
You.**