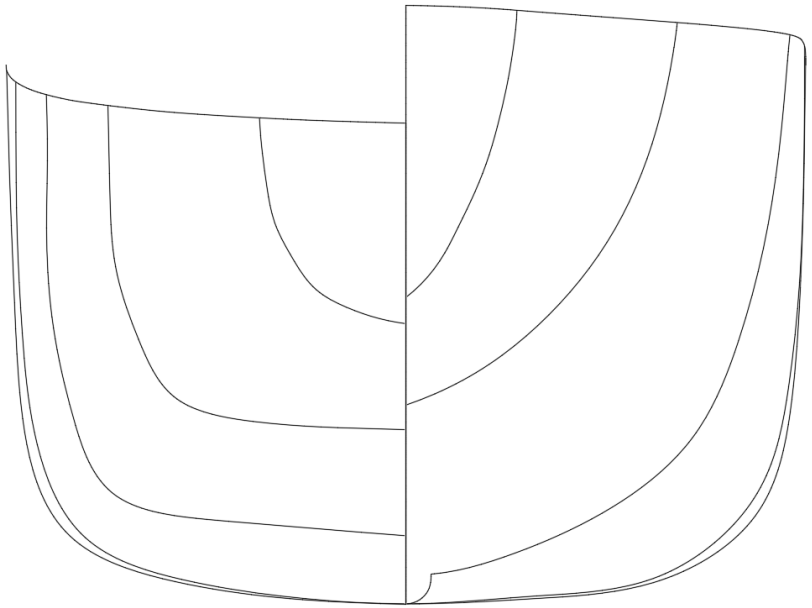
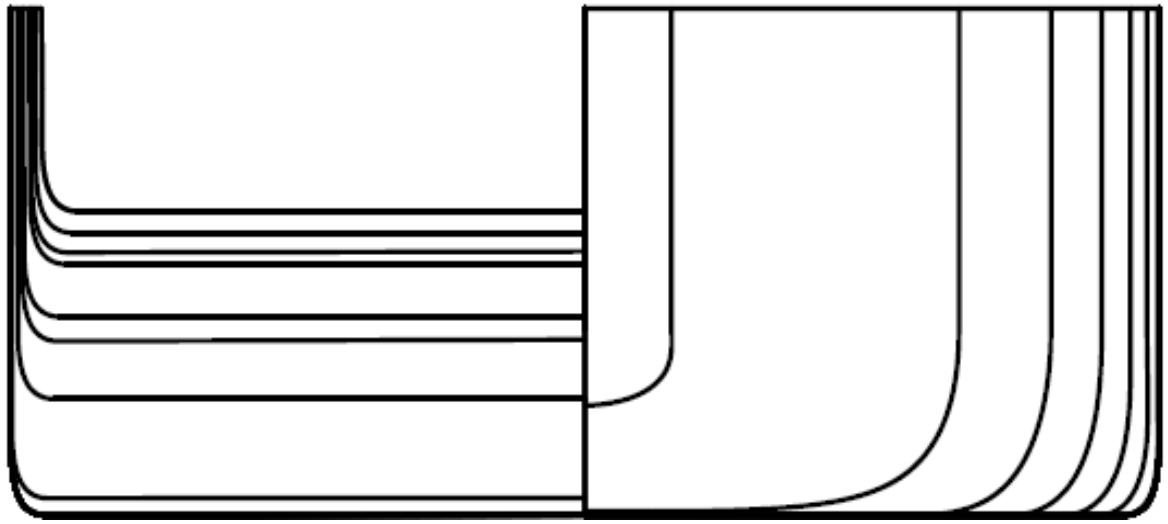
Proposal for Microreactor Usage for Widespread Application in the Maritime Industry





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Background - SISDO

- Topics of coverage
  - Financing and economics of sustainable shipping
  - Fleetwide optimizations
  - Alternative energy and power technology
- Domains
  - Government and military vessels
  - Bulk shipping

SISDO 2025

Abstract

- IMO Regulations set to implement net-zero emissions for maritime industry by 2050
  - Most practical solution for largescale power consumption while remaining green presently is nuclear
  - Icebreaker testbed used to develop maritime based modular microreactor by US government
  - Once proven and developed by US government, microreactors could be sourced out to commercial industry

Owners Requirements Icebreaker

- With global warming there's less multiyear ice in shipping lanes
- Icebreaker that can break ice 6 meters thick
- Smaller powerplant to implement use of multiple modular microreactors
- Modular microreactor which will be used in the commercial sector



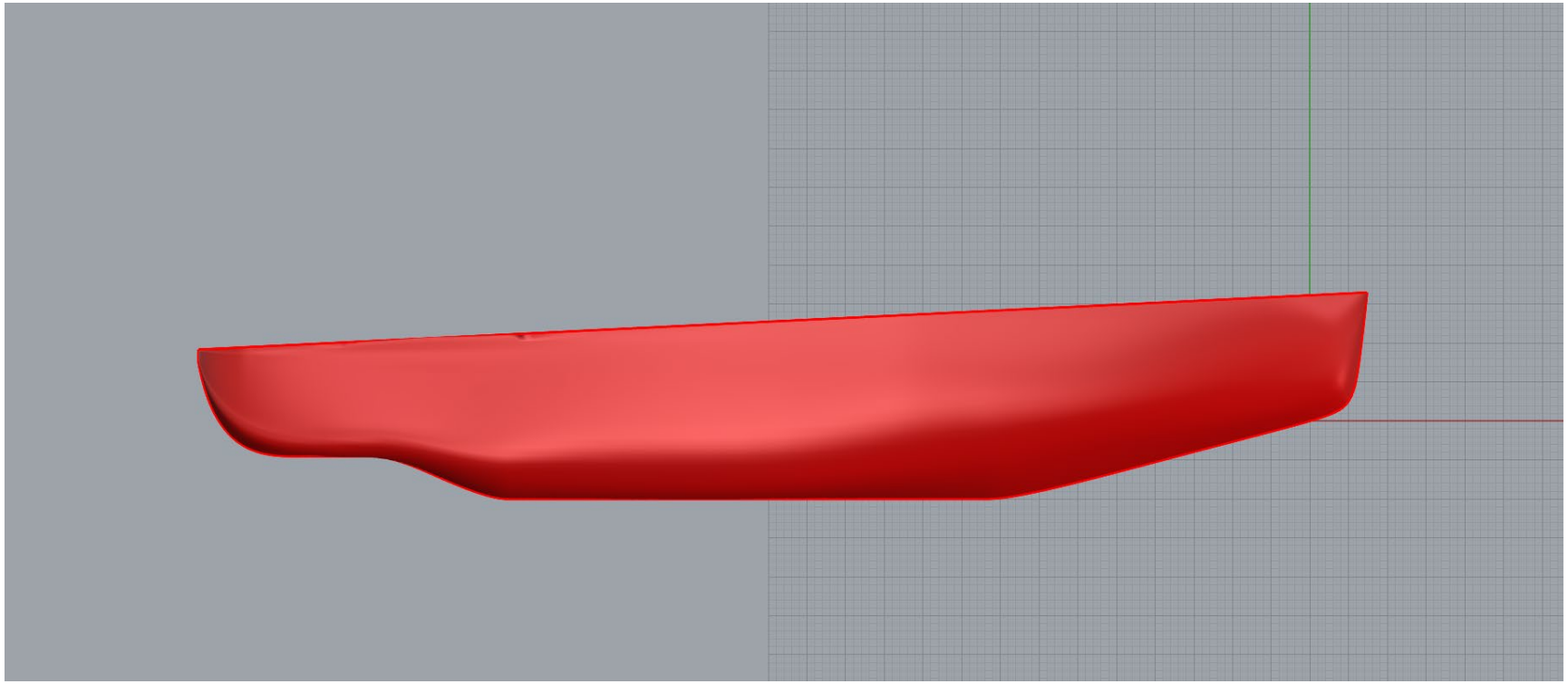


Parametrization Icebreaker

Vessel	Year Built	LOA (m)	Beam (m)	Draft (m)	GT	Engine Type
Arktika	2020	168.2	34	10.5	33500	Nuclear
Sovetskiy Soyuz	1989	150.02	30	11	20646	Nuclear
Sibir	2022	168.2	34	10.5	28484	Nuclear
Ural	2022	168.8	34	10.5	28494	Nuclear
Rossiya	1985	150.02	28.01	11	20680	Nuclear
50 let pobedy	2007	159.6	30	11.08	23439	Nuclear
Yamal	192	150	30	11	20646	Nuclear
Yakutiya	2025	168.2	34	10.5	28464	Nuclear
Our Vessel		158	31	10.8	~25000	Nuclear

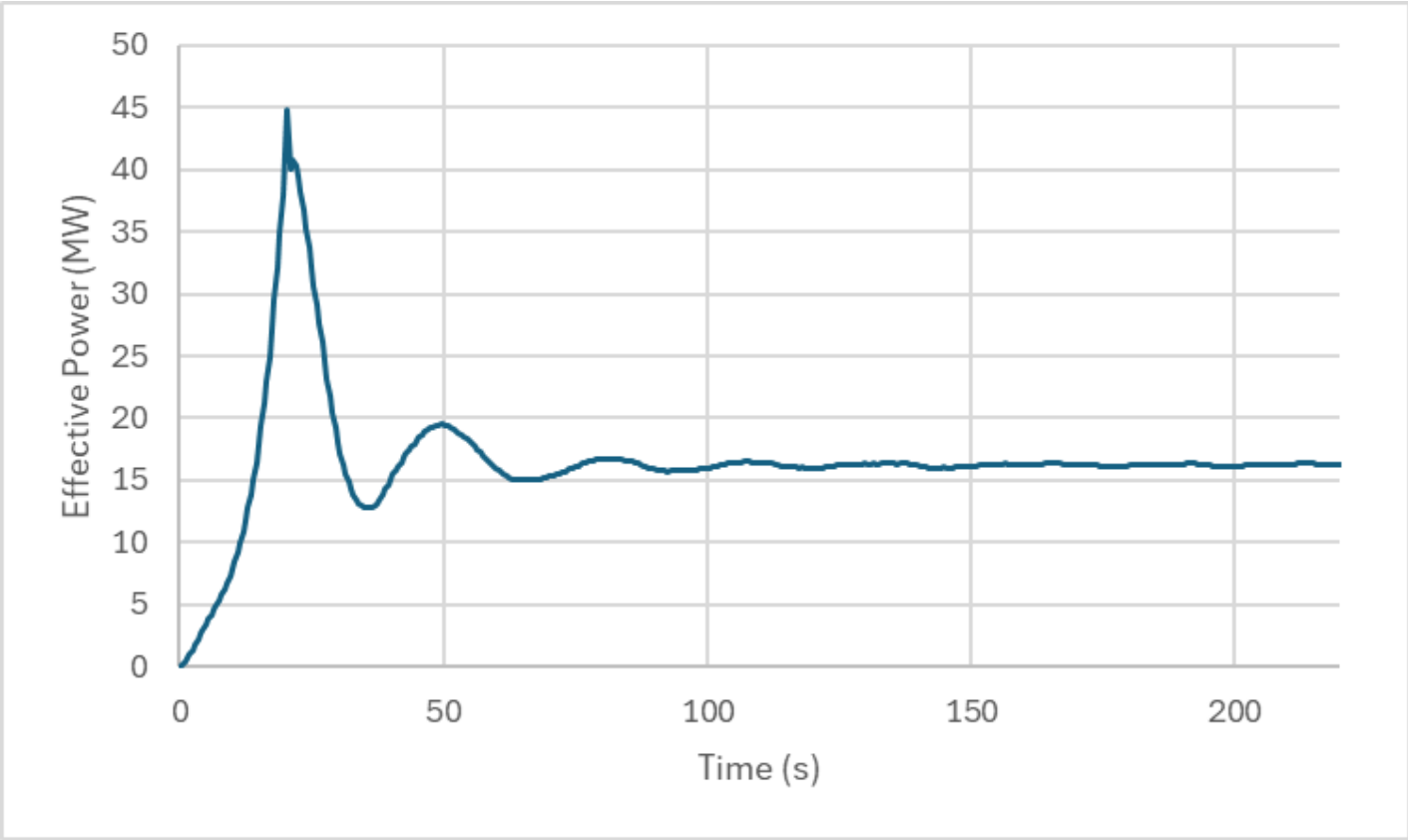


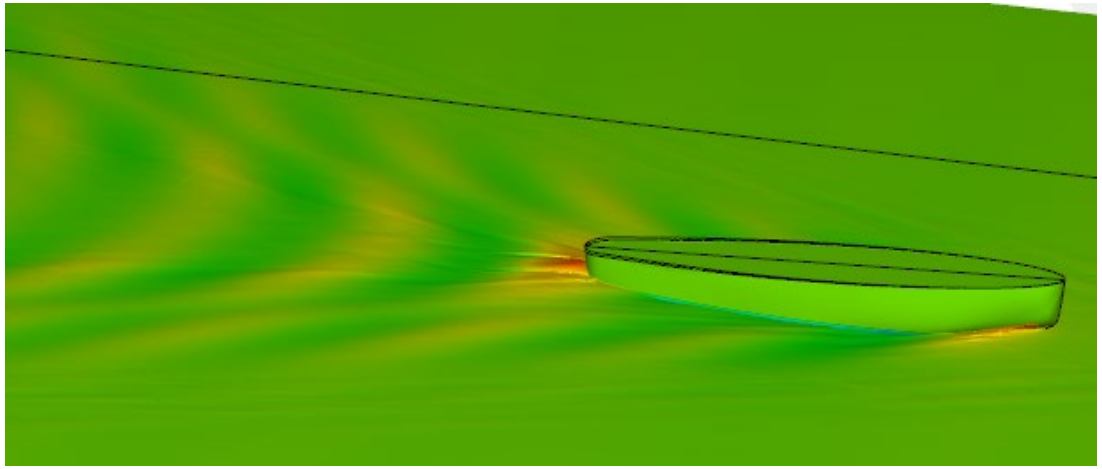
Parametrization Icebreaker Hull 1



LOA: 150m; Beam: 33.4m; Depth: 26.6m; Draft: 10.1m

CFD Icebreaker Hull 1





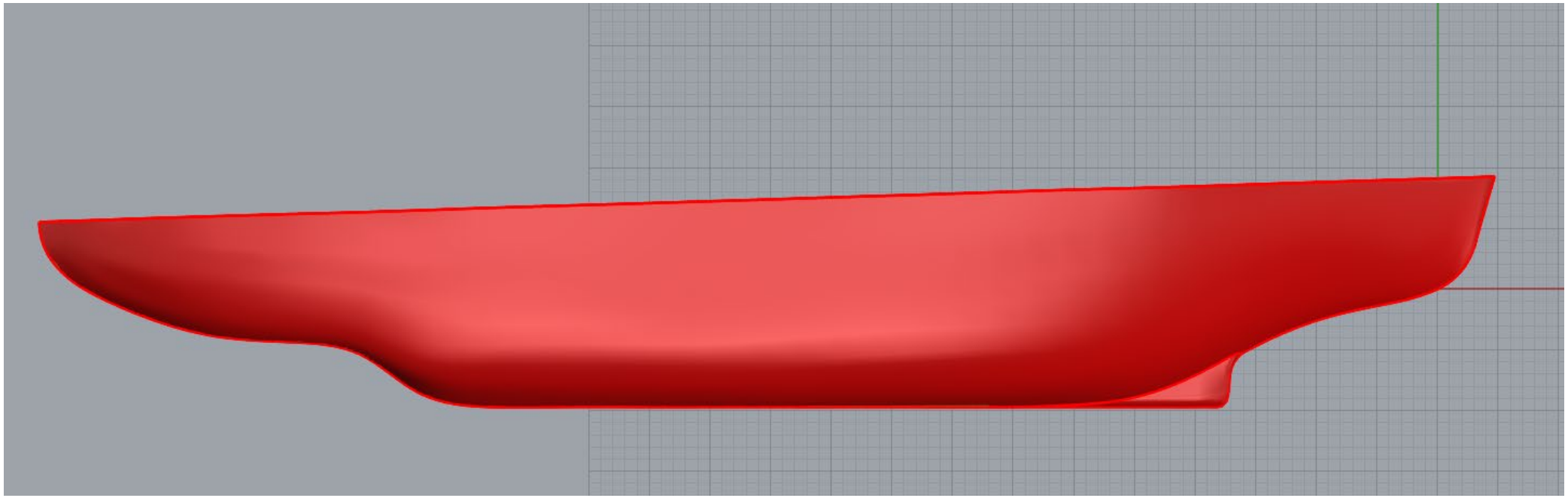
Max Effective Power: 45 Megawatts

Parametrization Icebreaker Hull 2

Vessel	Year Built	LOA (m)	Beam (m)	Draft (m)	GT	Engine Type
Alexander Sannikov	2018	121.7	26	8	11295	Diesel Electric
Andrey Vilkitskiy	2018	121.7	26	8	11295	Diesel Electric
Moskva	2008	116	29	8.5	9491	Diesel Electric
St. Petersburg	2009	116	29	8.5	9491	Diesel Electric
Novorossiysk	2016	119.76	27.5	8.5	11720	Diesel Electric
Polar Star	1973	122	25.6	10.4	13500	Diesel Electric/Gas Turbine
Polar Sea	1973	122	25.6	10.4	13500	Diesel Electric/Gas Turbine
Our Vessel		120	25.5	9.5	~12000	Nuclear



Parametrization Icebreaker Hull 2



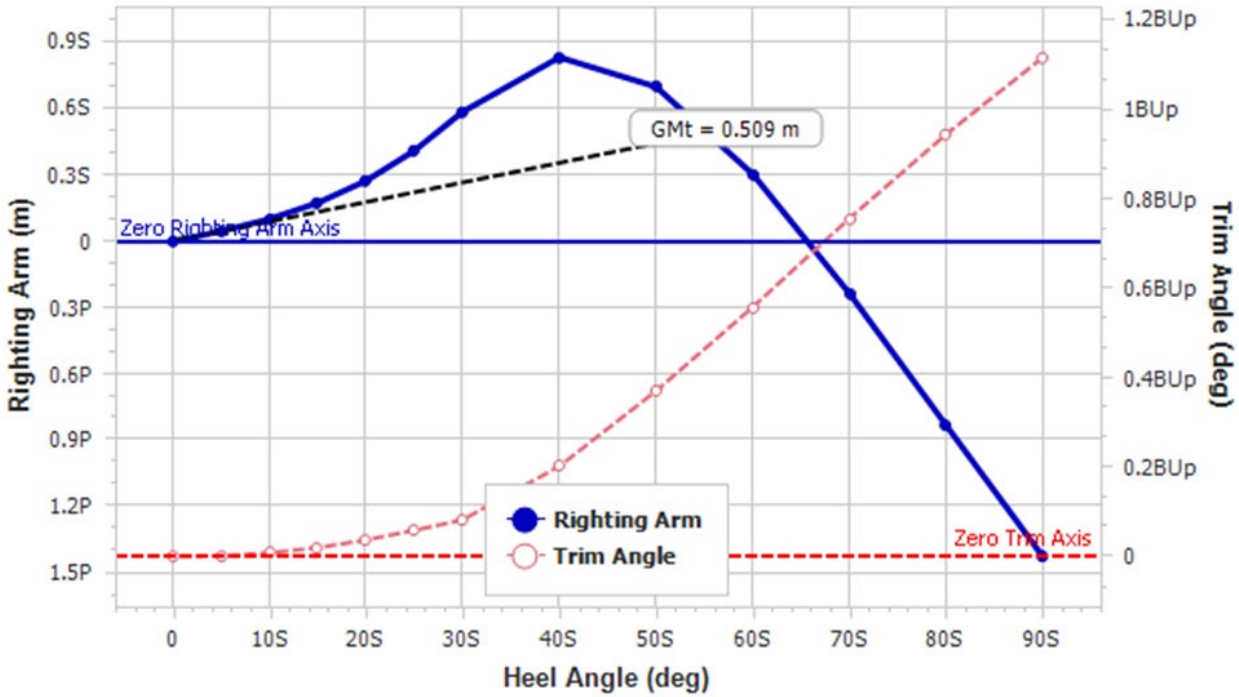
LOA: 120m; Beam: 25.4m; Depth: 19m; Draft: 9.7m

Results of Hull Design

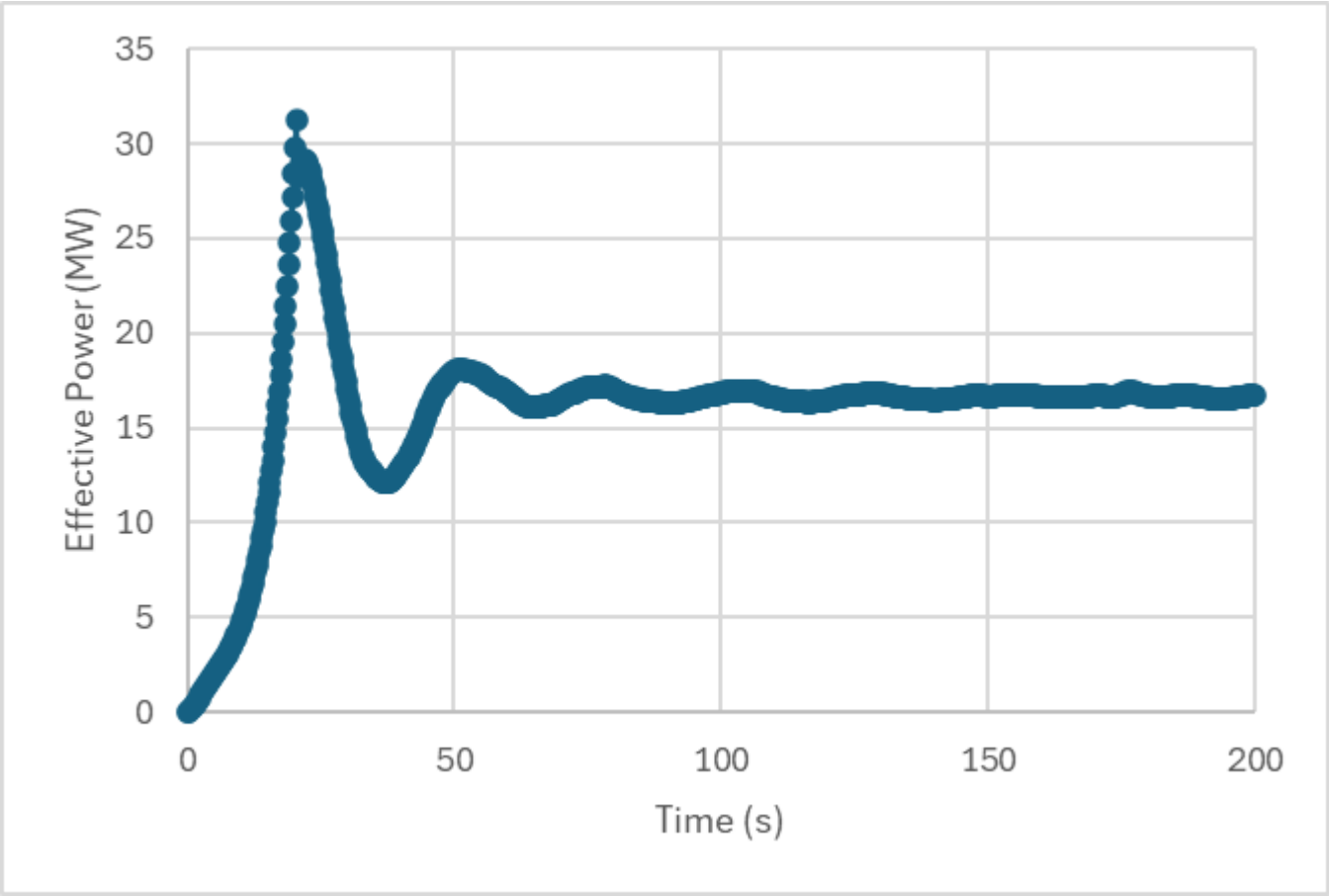
Parameters:	
Length (m)	120
Beam (m)	25.4
Draft (m)	9.7
Side Depth (m)	19
Displacement (tonnes)	15487
L/B	4.731
B/D	1.335
D/T	1.95
C_b	0.553

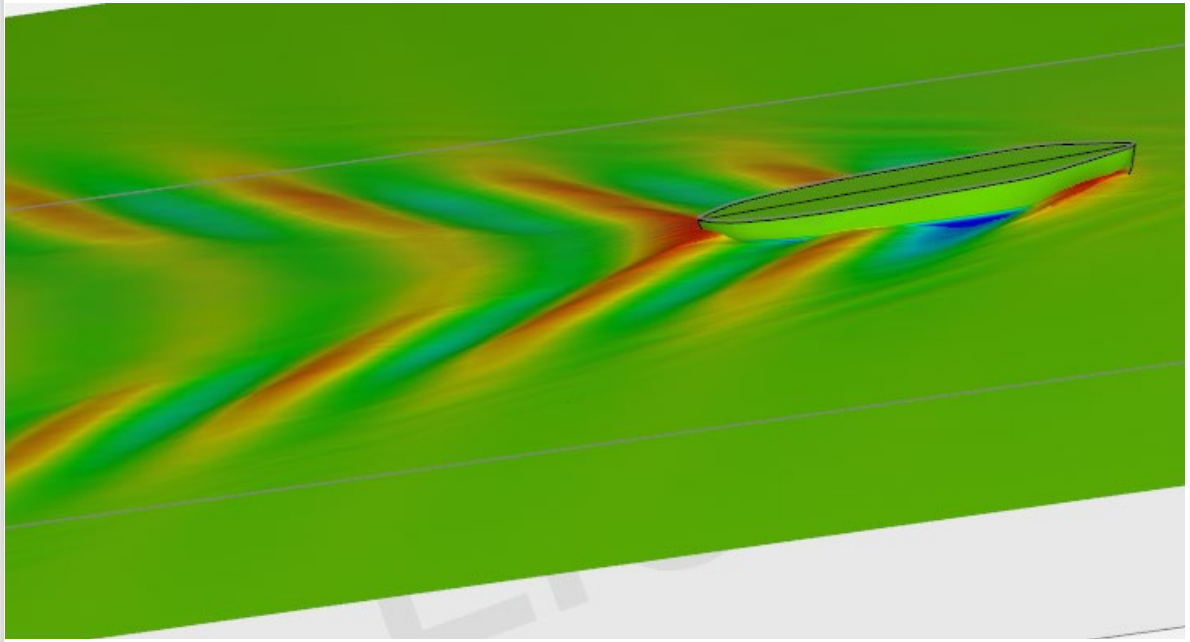
Icebreaker Stability

Regulation	Minimum	Actual
Metacentric Height, GM (m)	0.35	0.509
Righting Arm at 30° (m)	0.2	0.586
Maximum Righting Arm (°)	25	40
Area Under Righting Arm Curve at <40° (meter-radians)	0.090	0.237
Area Under Righting Arm Curve <30° (meter-radians)	0.055	0.113
Area Under Righting Arm Curve between 30° and 40° (meter-radians)	0.030	0.124
Positive Righting arm through 60°	60	65



CFD Icebreaker Hull 2





Max Effective Power: 31 Megawatts

Propulsion

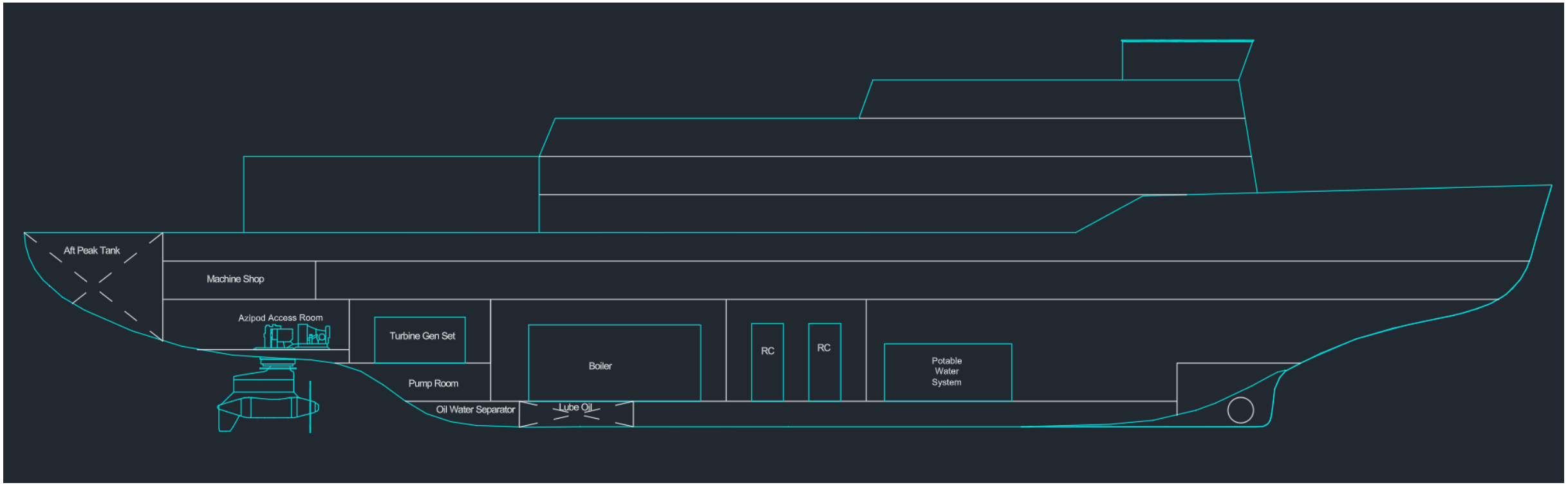
- Main machinery mover systems:
  - Nuclear-electric – Turbine Generator
- Propulsion:
  - Podded propulsion (AziPod) ~21Mw total



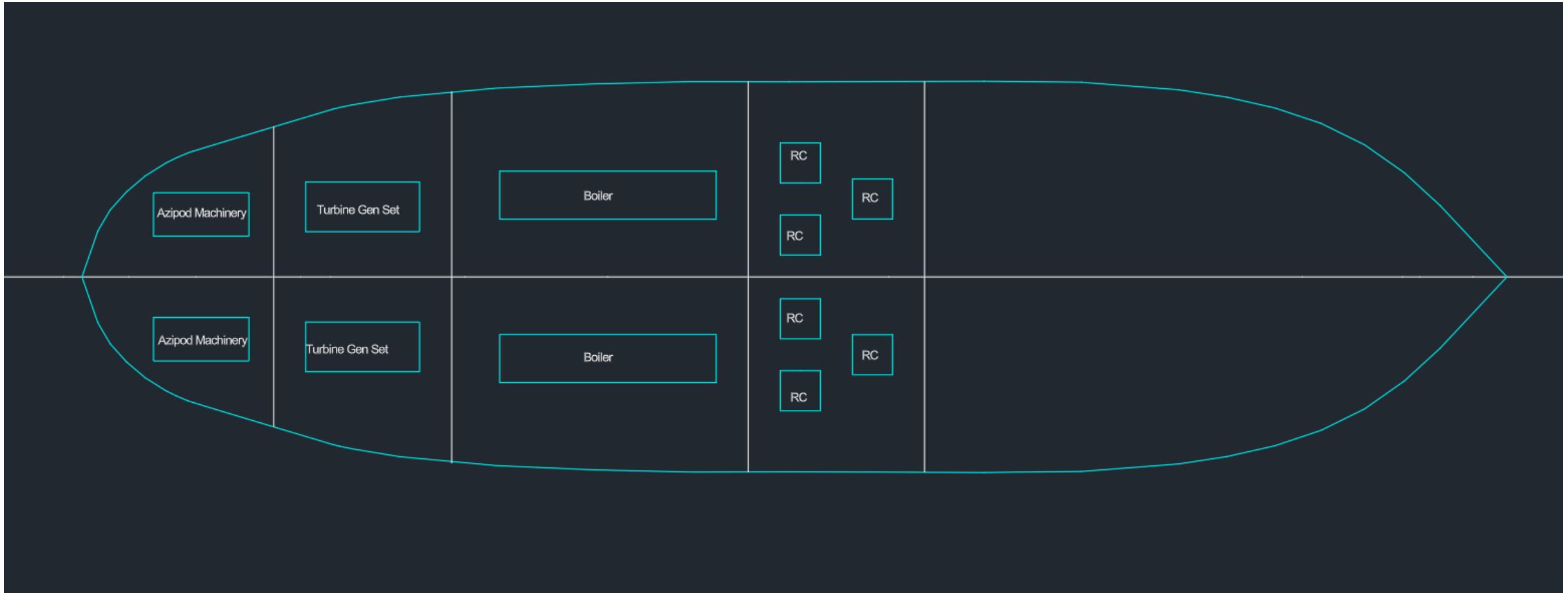




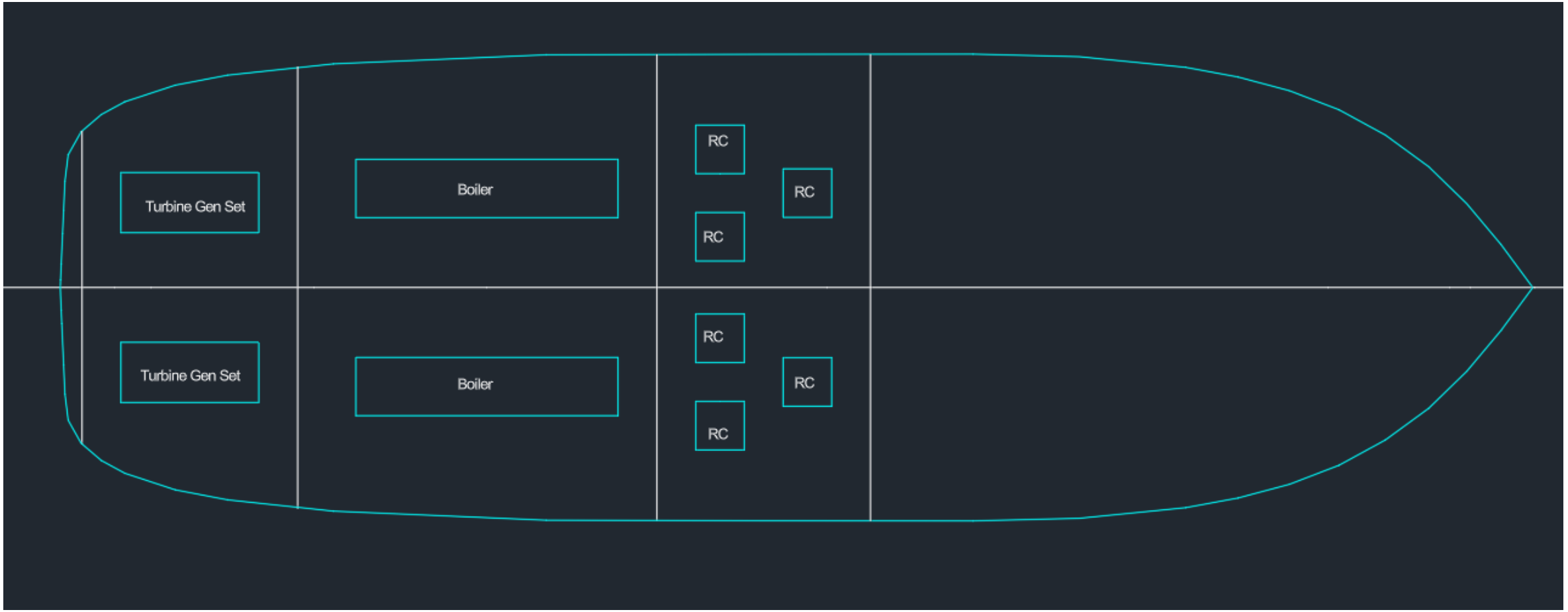
General Arrangement Icebreaker



General Arrangement Icebreaker

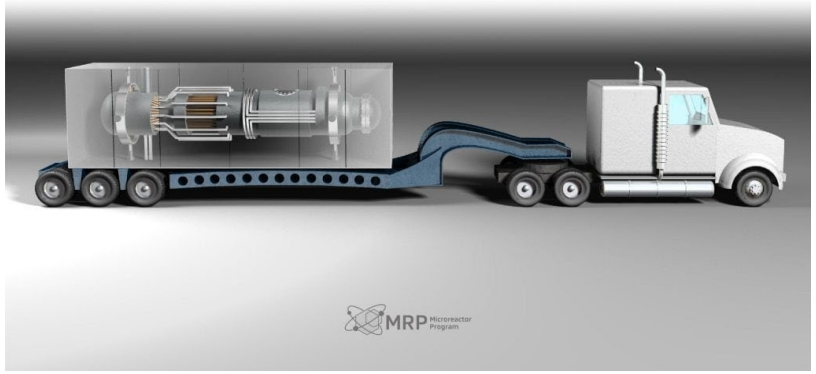


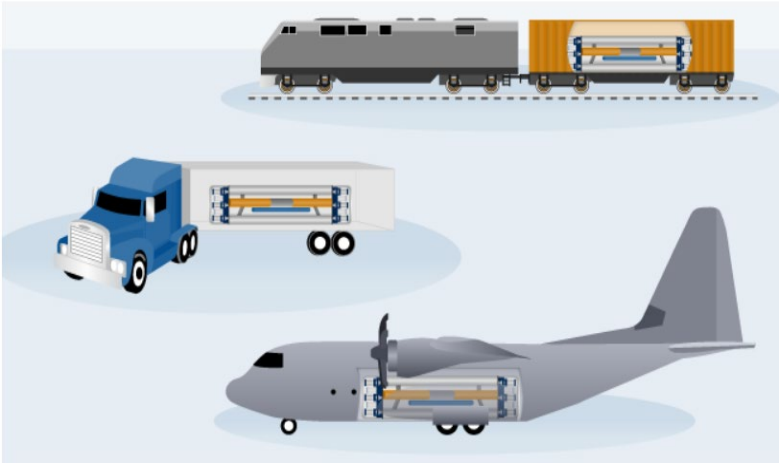
General Arrangement Icebreaker



Modular Microreactors

- Microreactors are on the cutting edge of development.
  - 2024 Tennessee State Energy Policy Council report compiles a high to low end of production cost ranging $4,300 – $2,900 kWe.
  - Nuclear Energy Institute Study estimates largescale microreactor production estimates electrical generation prices to fall between $0.33 - $0.09 /Kwh.
- Microreactors in development will be rapidly deployable.





CapEx Icebreaker

Structure	$	42,768,954
Outfit	$	19,062,734
Machinery	$	76,250,935
Reactor	$	201,034,053
Propulsion	$	21,794,327
Total Cost	$	360,911,003

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OpEx Icebreaker

Calulated cost in use:		
Duration:	213	[Days]
Operating Costs Per Day:	16,400	[$]
Reactor Daily Operation Cost:	180,000	[$]
Sum Daily Cost:	196,400	[$]
Year Cost	41,833,200	[$]

Calulated cost not in use:		
Duration:	147	[Days]
Operating Costs Per Day:	8,200	[$]
Reactor Daily Operation Cost:	180,000	[$]
Sum Cost:	188,200	[$]
Cost	27,665,400	[$]

SISDO 2025

Results Icebreaker

- While initial reactor capital expenditure & operational cost is high, with mass production, this would lower costs.
- Adaptable power presents most clear way forward for widespread use in maritime industry.



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Integration of Wider fleet Application

- With the US gov having "produced" multiple microreactors, mid-lower estimate ranges for these reactors will be used
- For this study, we will be applying these modular microreactors to bulk carriers on the great lakes



Owners Requirements

- Maximize Vessel Dimensions
  - Pass through Soo-Locks, not Saint Lawrance Seaway
- Modernization of Fleet
  - Look at implementation of modular microreactors to fit power requirements while maintaining net-zero carbon emissions
- Operational Standards
  - ~60 trips taken back and forth on the great lakes

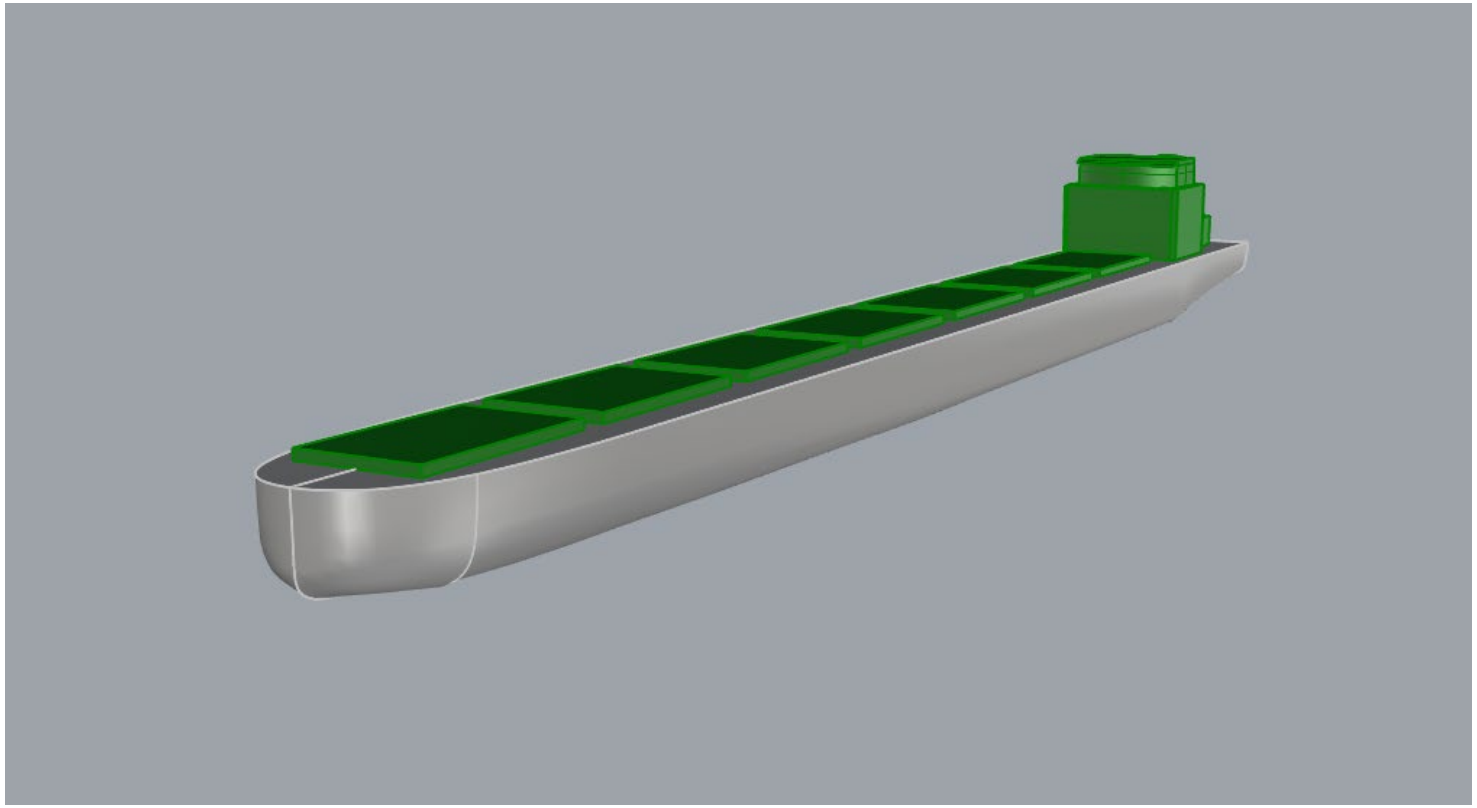
Parameterization Data Base Via Clarkson's

Vessel:	LOA (m)	Beam (m)	Daft (m)	LBP (m)	DWT (tonnes)	Power (kw)	Speed (kn)
Paul R. Tregurtha	308.93	32	9.16	304.82	69152	12000	11.6
American Spirit	304.8	32	7.93	303.1	61563	11768	10.7
American Century	304.27	32	10.38	301.77	91901	10474	10.9
Stewart J. Cort	304.8	31.88	8.52	303.29	60079	10591	10.9
Edwin H. Gott	304.8	32	10.38	301.8	79011	14400	12.4
Mesabi Miner	304.8	32	8.56	301.93	61563	5884	11.5
Edgar B. Speer	306.02	32.09	9.77	301.75	75188	14166	11.8
American Integrity	304.81	32	10.38	301.75	93641	10297	10.8
Walter J. McCarthy Jr.	304.8	32	10.38	301.75	92076	10591	11.1
Our Vessel		32	9.1	302	~70000		~10.4

Results of Hull Form Design

Initial Parameters:	
Length (m)	302
Beam (m)	32
Draft (m)	9.1
Side Depth (m)	14
Displacement (tonnes)	77,170
DWT w/ azipods (tonnes)	60,216
L/B	9.440
B/D	0.905
D/T	3.738
C_b	0.827

Hull Form



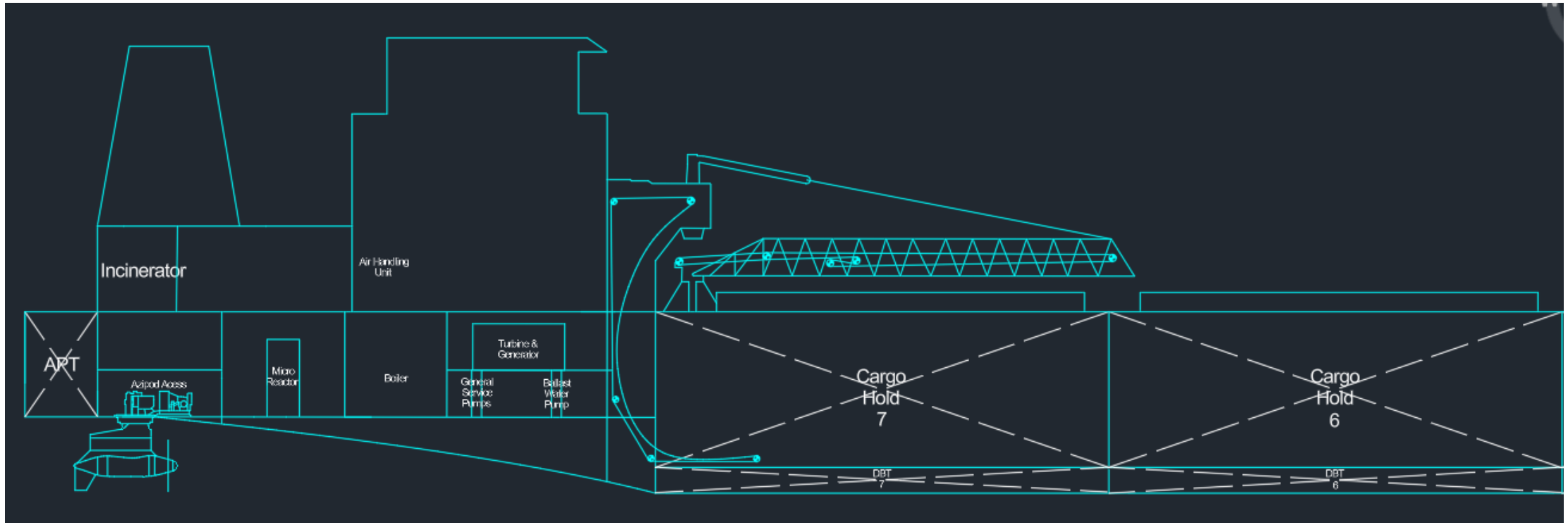
Lbp: 302 m; Beam: 32 m; Depth: 14 m; Draught: 9.1 m

Weights - Watson

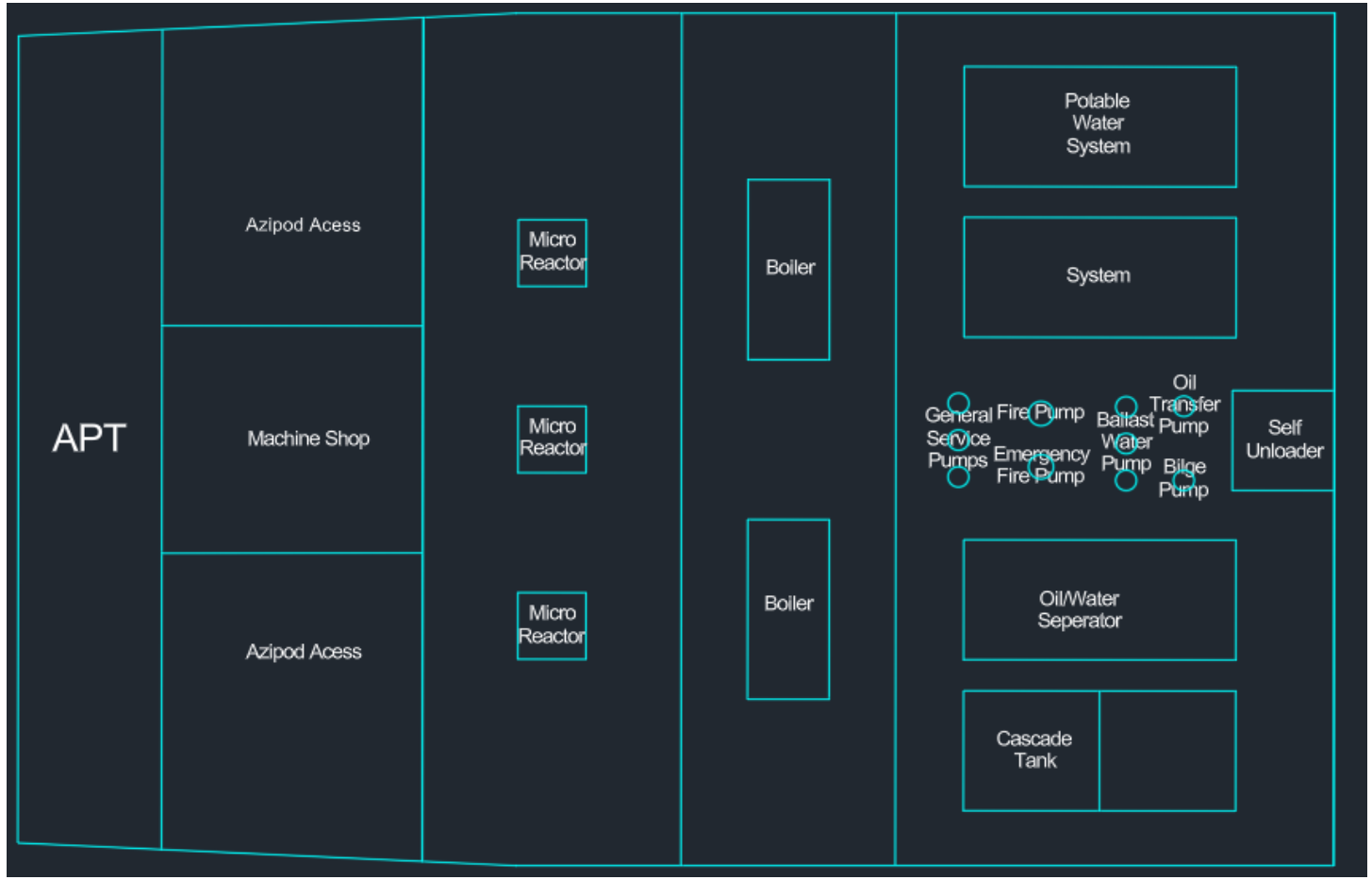
Structure	11,879	[Tons]
Outfit	1,933	[Tons]
Propulsion	132	[Tons]
Other Machinary	146	[Tons]
Reactor	600	[Tons]
Total	14,690	[Tons]
DWT	60,216	[Tons]

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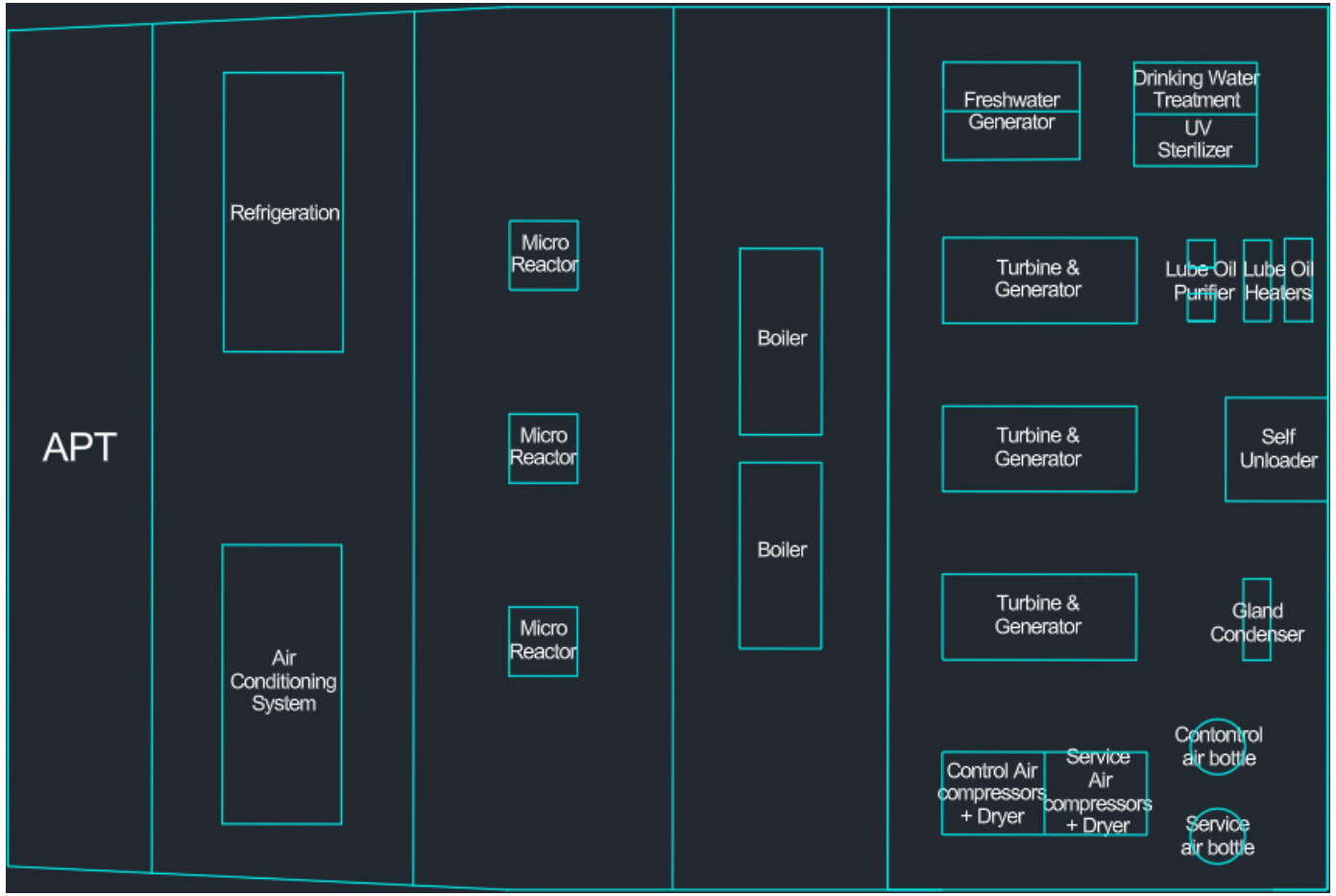
General Arrangement Bulk Carrier



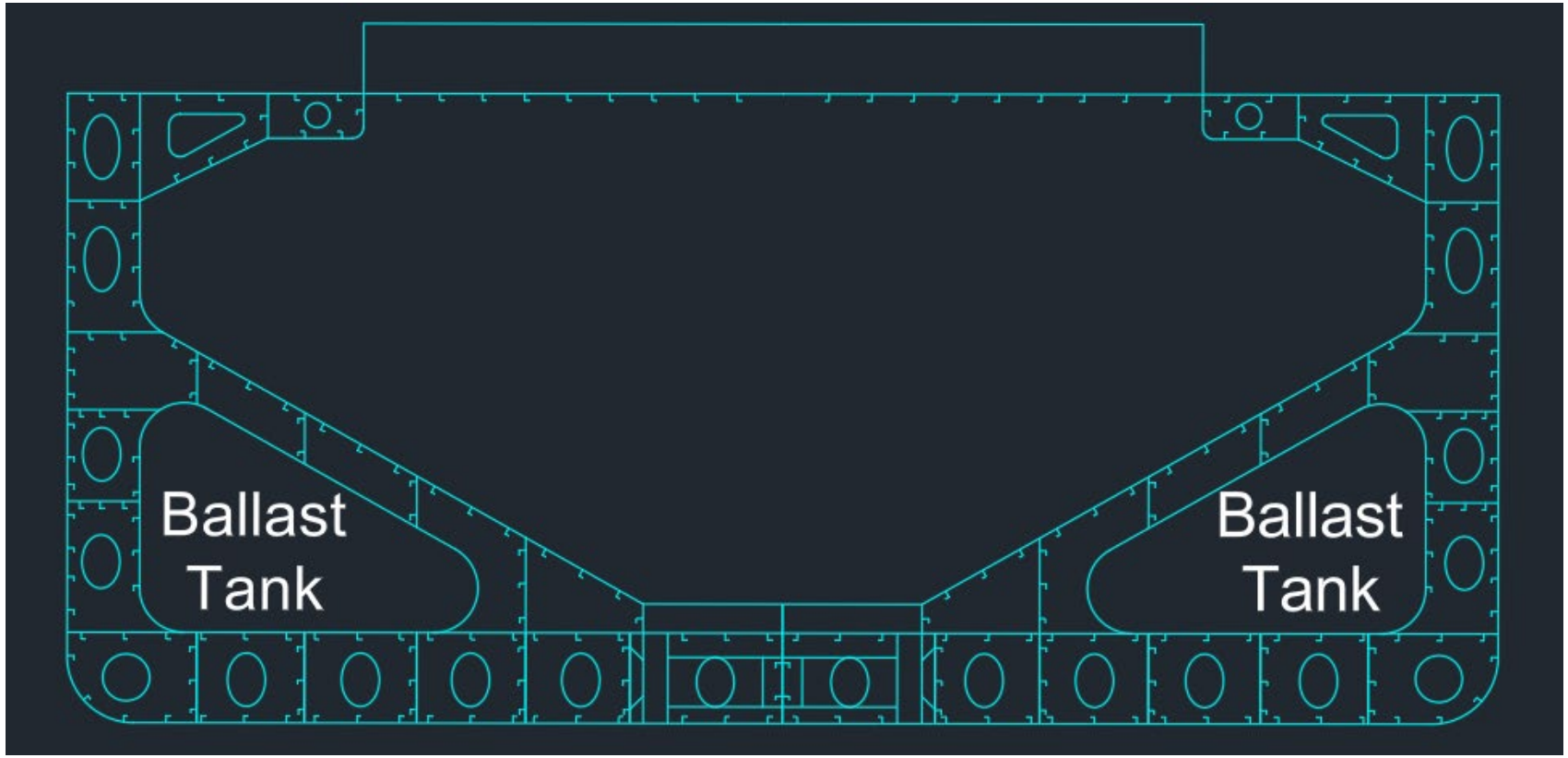
General Arrangement Bulk Carrier



General Arrangement Bulk Carrier



General Arrangement Bulk Carrier



Propulsion

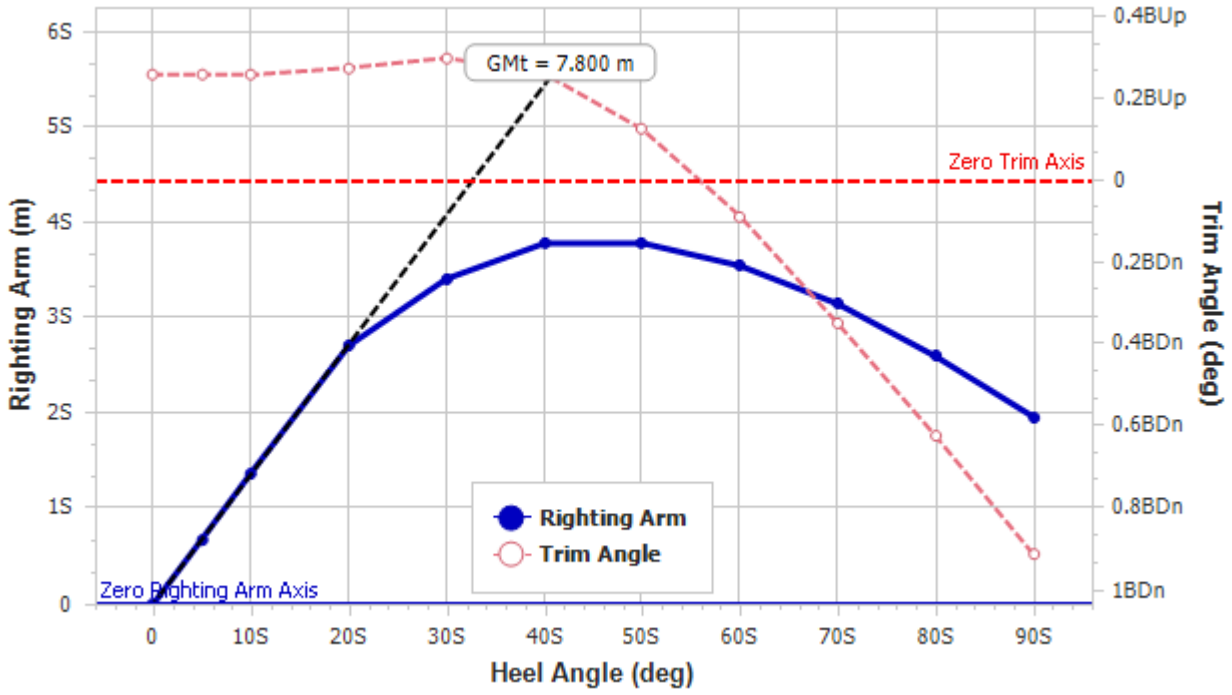
- Main machinery mover systems:
  - Nuclear-electric – Turbine Generator
- Propulsion:
  - Podded propulsion (AziPod) ~ 10.5Mw
  - Savings on reduction of tugs amounts to ~$1,010,000 dollars over 1 year in savings







Stability



Heel Angle [Deg]	Required Area [m*deg]	Actual Area [m*deg]
0-30	≥3.15	5.75
0-40	≥5.16	9.44
30-40	≥1.72	3.62

CapEx

Shipbuilding Cost	Max Pay	Min Pay
Structure	$ 34,643,967	$ 26,952,472
Outfit	$ 37,851,400	$ 19,746,737
Propulsion	$ 8,333,643	$ 8,177,187
Other Machinery	$ 1,471,280	$ 1,580,422
Reactor	$ 57,095,573	$ 56,469,195
Total	$ 139,395,864	$112,926,013

OpEx/Annual Profit

OSU:		
DWT Income (High):	905,028.18	[$]
DWT Income (Low):	717,392.76	[$]

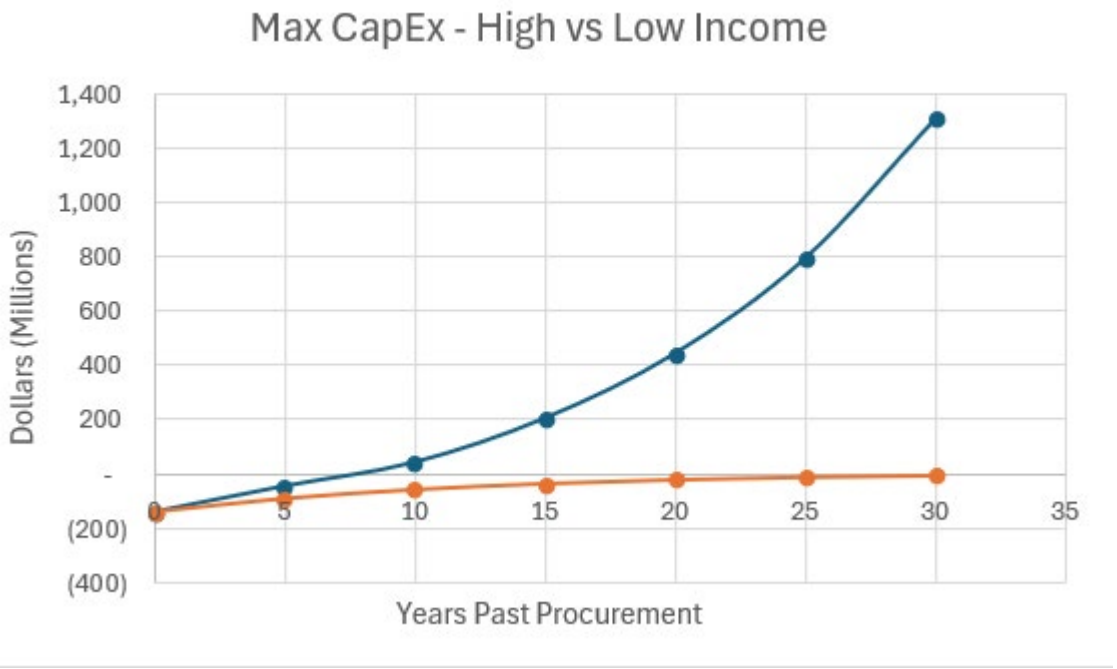
Calulated Cost Per Trip:		
Trip Duration:	3.21	[Days]
Operating Cost Per Trip:	52,564.10	[$]
Reactor Cost:	230,769.23	[$]
Port Cost:	8,849.40	[$]
Tug Cost:	1600	[$]
Sum Cost:	293,782.73	[$]

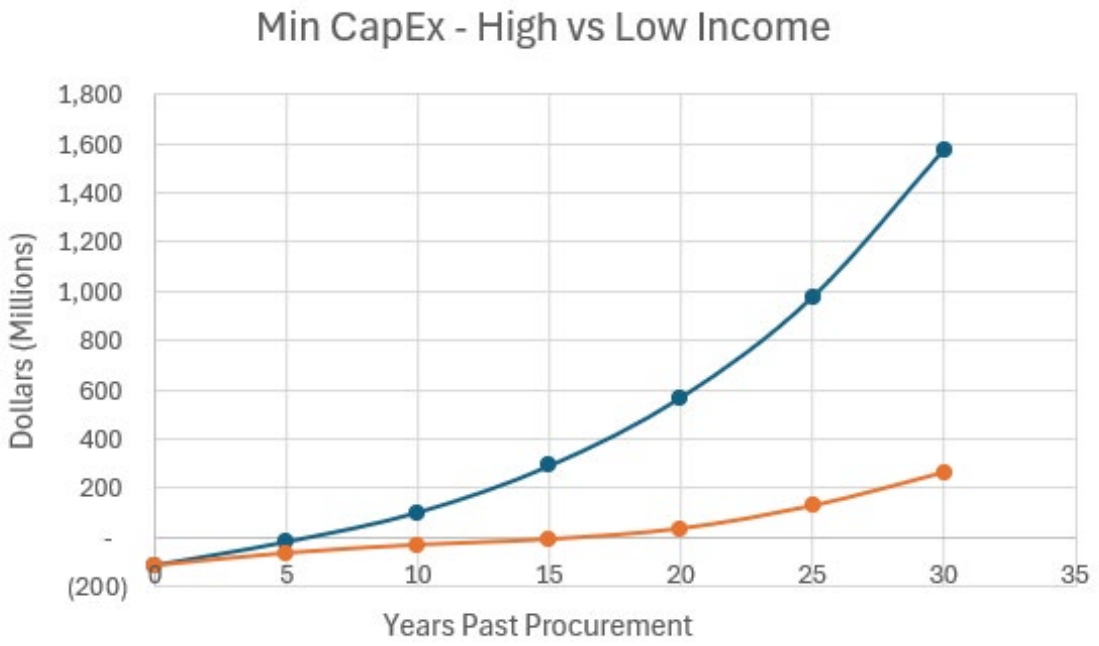
Yearly Profit:		
Year Income High:	54,466,858.73	[$]
Year Income Low:	43,174,489.96	[$]
Running Costs:	17,680,579.35	[$]
Laid up Costs:	12,673,874.00	[$]
Calulated Year Cost:	30,354,453.35	[$]
Proft High-Calc	24,112,405.38	[$]
Profit Low-Calc	12,820,036.60	[$]

Long Term Economics

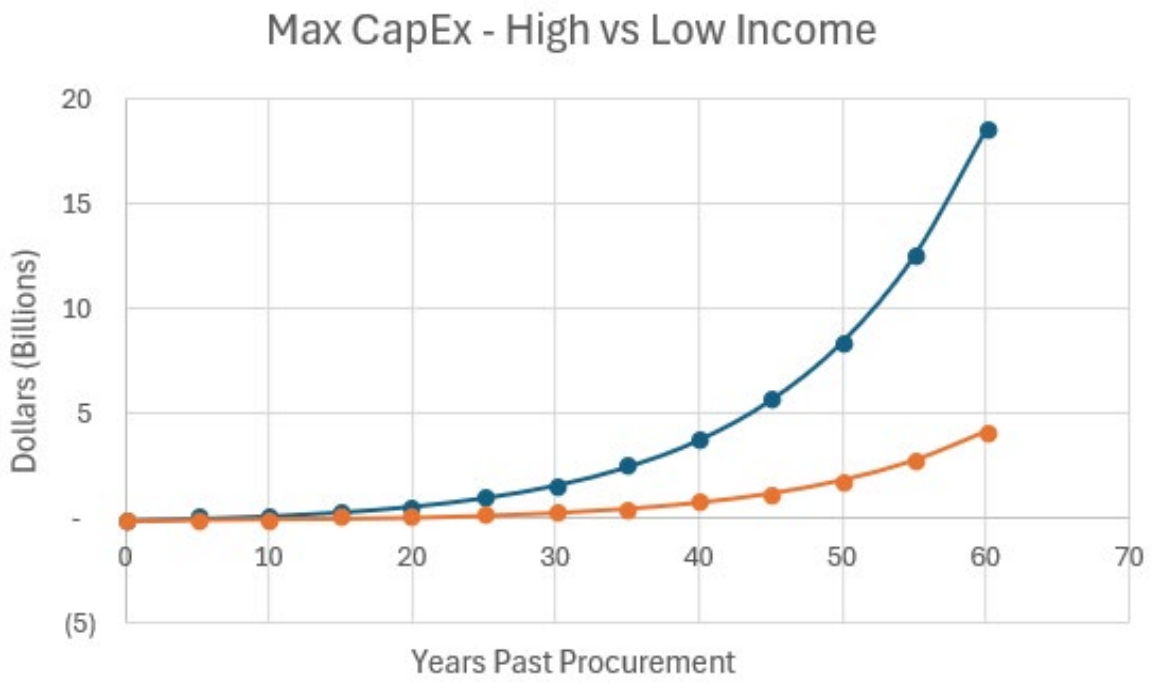
Given Intrest Rate: 8%	Time for Payoff:	Worth After 60 Years:
High-Calc Proft - Max CapEx:	8.3	15,848,181,947
High-Calc Proft - Min CapEx:	6.2	18,593,550,805
Low Calc Profit - Max CapEx:	36.0	859,059,719
Low Calc Profit - Min CapEx:	17.4	4,102,147,300

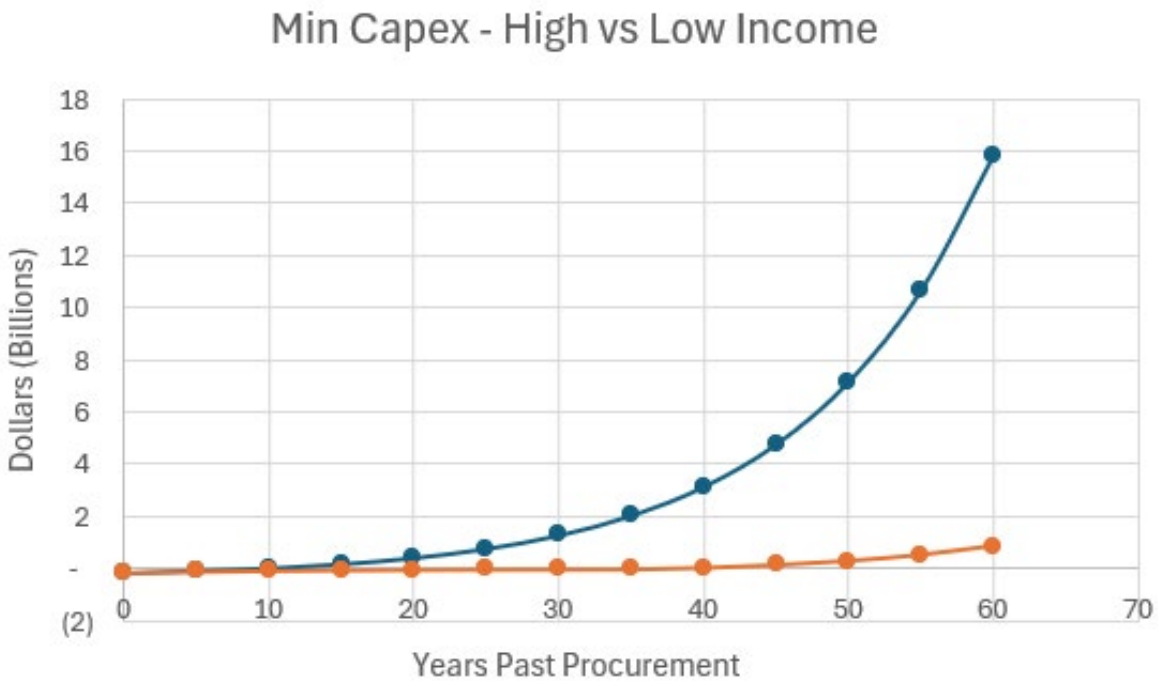
Long Term Economics





Long Term Economics





Conclusion

- Once several rectors are produced by the gov, the reactors become more affordable.
  - The modularity of the reactors can be implemented to install match power requirements on a wider swath of vessels
- Future work to be done
  - Greater detail on the engine room layout/powerplant footprint and systems present
  - Maneuvering analysis
  - Damage stability analysis

Thank You, Questions?





Propeller & Rudder Weight Estimation

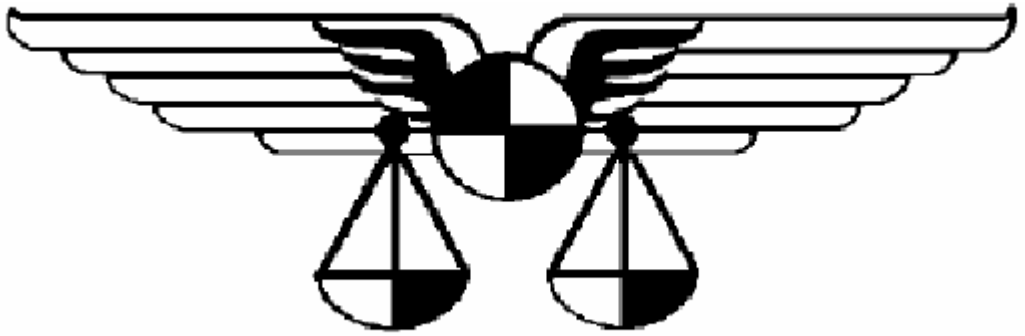
Ship type	$C = L \cdot T/A_B$
Cargo ships	65–75
Bulk carrier	70–75
Tankers	60–80
Short sea cargo ships	30–50
Reefers	45–60
Past ocean liner passenger ships	up to 85
Large passenger ships	55–70
Car ferries/RoPax	35–50
Trawlers	33–40
Open sea tugs	30–40

$$d_{rudder} = 0.13 \cdot (A_r)^{\frac{3}{2}}$$

$$d_{propeller} = 0.01 \cdot (P_{\emptyset})^3$$

Propeller (tonnes)	8.11
Rudder (tonnes)	120

Weights - SAWE



Steel Weight (tonnes)	15910.28
Outfit Weight (tonnes)	1691.04

Weights - SAWE

$$W_o = \times \left(0.69 \times \frac{CN}{12850} + 0.19 \times \left(\frac{CN}{12850} \times \frac{COMP}{177} \right) + 0.06 \times \left(\frac{L}{365.3} + \frac{D}{15488.72} \right) \right)$$

$$W_s = 0.40275 \times CN$$

$$CN = \frac{L \times B \times D}{100}$$

Steel weight (tonnes)	6385.5
Outfit weight (tonnes)	908