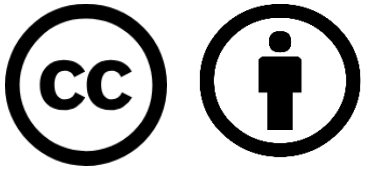
Annual energy usage and annual energy cost calculations

Electric Power Load Analysis (EPLA)

Revision of 8 August 2026

Dr. Norbert Doerry

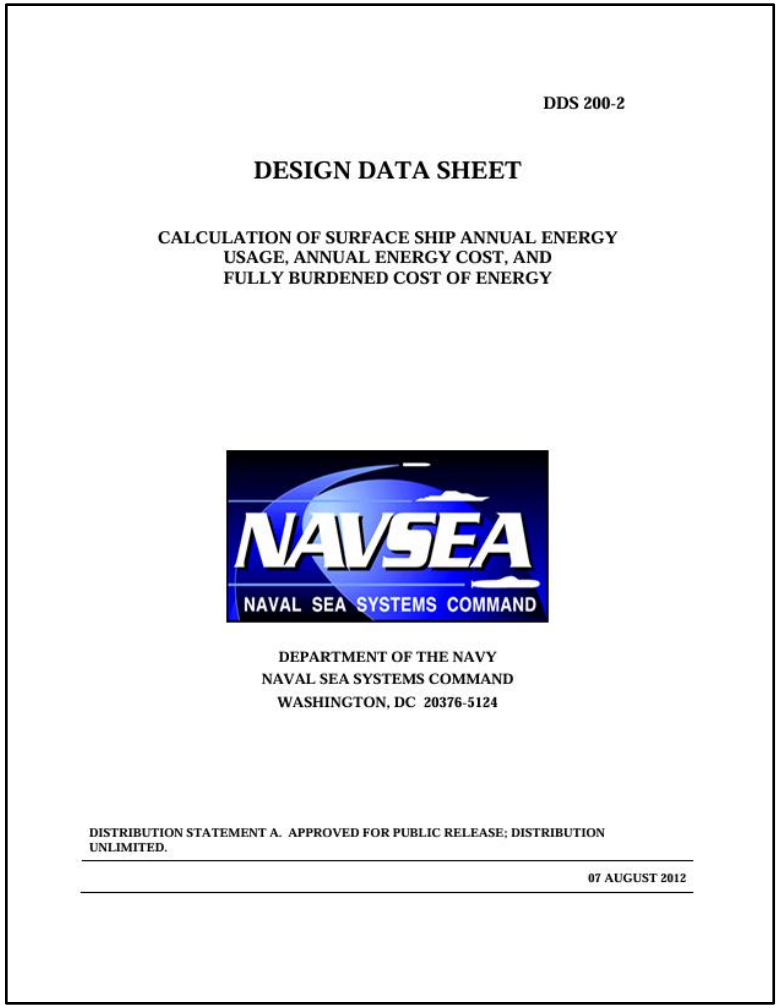


Essential Questions

What information is needed to perform an Annual Energy Usage and Annual Energy Cost Calculation?	Understand
How does one obtain the information needed to perform an Annual Energy Usage and Annual Energy Cost Calculation?	Understand
What are the results of an Annual Energy Usage and Annual Energy Cost Calculation used for?	Understand
How is an Annual Energy Usage and Annual Energy Cost Calculation performed?	Apply

Introduction

- Annual energy consumption estimates used to
  - Calculate Total Ownership Cost
    - Used to trade off different design options
    - Used in return on investment (ROI) calculations
  - Develop budgets for fuel
  - Derive requirements for underway replenishment ships
- Lifecycle cost of energy is a function of:
  - Operational profile development
  - Annual energy usage calculation
  - Fully Burdened Cost of Energy calculation
- DPC 200-2 focused on naval ships, but may be adapted to commercial ships



DDS 200-2

DESIGN DATA SHEET

CALCULATION OF SURFACE SHIP ANNUAL ENERGY USAGE, ANNUAL ENERGY COST, AND FULLY BURDENED COST OF ENERGY

NAVSEA
NAVAL SEA SYSTEMS COMMAND

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20376-5124

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Operational Profile

- Operational profile describes the number of hours a ship operates
  - For each year of the ship's design life
  - In each of its operational modes and associated speed-percent time profiles
- In early stages of design, the operational profile may be assumed to be the same for each year.
- As the design progresses, the operational profile may not be the same year to year based on
  - Expected employment of the ship
  - Maintenance and modernization strategy


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Operational Profile products

- Table of “ship states”
  - Ship states reflect a level of capability for the ship
  - Normally includes the operational conditions used for the EPLA
  - More ship states may be defined if required
- Operational modes list
  - Operational modes describe the capability sets a ship must support for a given period of time (generally at least a month)
  - Capture full range of ship activities over its service life in a relatively few number of categories
- Ship state participation Table
  - Fraction of time (participation factor) spent in each ship state for each operational mode
- Ship deployment and employment profiles
  - For each year in the ship’s service life, records the fraction of time (or number of hours) the ship is estimated to be in each of the operational modes
  - Multiple ship deployment and employment profiles may be created to span the range of possible alternate futures
    - Can be used as the basis for real options analysis

Operational Profile Example (DPC 200-2)

Ship states

Ship state participation Table

	Inport – shore	Underway – Economic al Transit	Underway – Surge to Theater	Underway – Mission
Maintenance and Modernization	0.9	0.05	0.0	0.05
Predeployment Training	0.6	0.2	0.0	0.2
Deployment	0.1	0.2	0.0	0.7
MCO	0.05	0.15	0.05	0.75

Operational Modes

Participation Factors

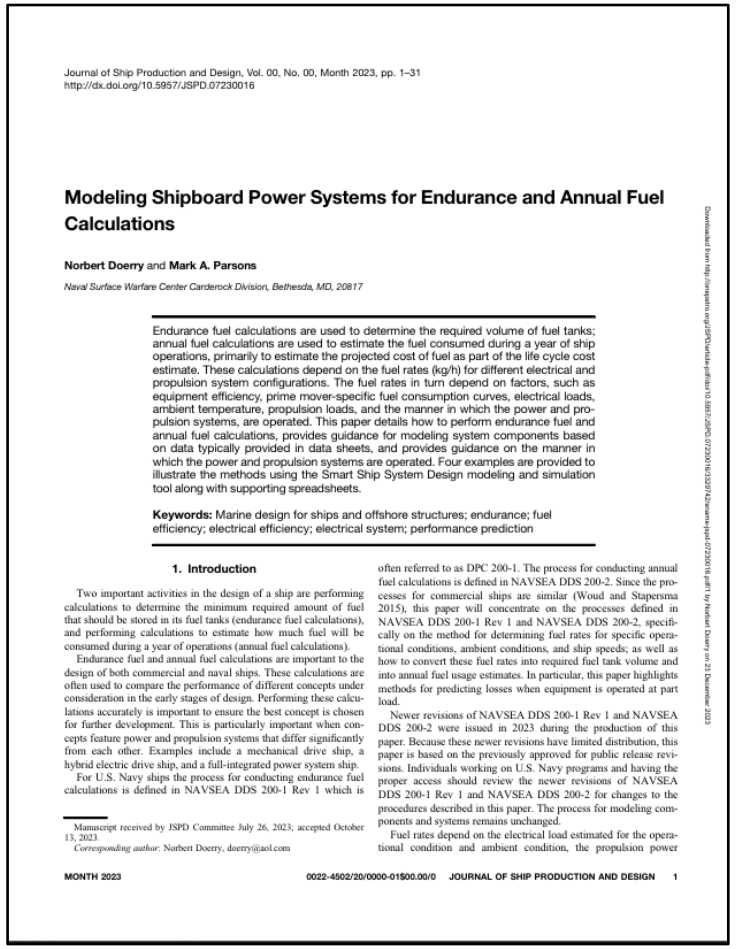
Ship deployment and employment profiles

	Low OPTEMPO (fraction of time)				High OPTEMPO (fraction of time)			
Year	**Maintenance and Modernization**	**Predeployment Training**	**Deployment**	**MCO**	**Maintenance and Modernization**	**Predeployment Training**	**Deployment**	**MCO**
1	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
2	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
3	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
4	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
5	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
6	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
7	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
8	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
9	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
10	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
11	0.25	0.25	0.5	0.0	0.16	0.17	0.0	0.67
12	0.25	0.25	0.5	0.0	0.16	0.17	0.0	0.67
13	0.25	0.25	0.5	0.0	0.16	0.17	0.0	0.67
14	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0
15	0.25	0.25	0.5	0.0	0.25	0.25	0.5	0.0

MCO = Major Combat Operations

Annual Energy Usage

- Calculates energy usage table for each ship deployment and employment profile:
  - Fuel consumed in kg
  - Shore power in kW-h
- Fuel consumed by ship
  - Use methods detailed in DPC 200-1 and Doerry & Parsons (2023) to calculate fuel rate (kg/h) for each ship state.
  - Use Ship State Participation Table to calculate the fuel rate (kg/h) for each operational mode
  - Use Ship Deployment and Employment Profile to calculate the fuel (kg) consumed each year and over the ship's service life.
- Shore power in kW-h
  - Estimate shore power for each ship state (kW)
  - Use ship state participation table to calculate average shore power for each operational mode (kW)
  - Use Ship Deployment and Employment Profile to calculate the Shore Power (kW-h) energy consumption consumed each year and over the ship's service life.



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Modeling Shipboard Power Systems for Endurance and Annual Fuel Calculations

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Endurance fuel calculations are used to determine the required volume of fuel tanks; annual fuel calculations are used to estimate the fuel consumed during a year of ship operations, primarily to estimate the projected cost of fuel as part of the life cycle cost estimate. These calculations depend on the fuel rates (kg/h) for different electrical and propulsion system configurations. The fuel rates in turn depend on factors, such as equipment efficiency, prime mover-specific fuel consumption curves, electrical loads, ambient temperature, propulsion loads, and the manner in which the power and propulsion systems, are operated. This paper details how to perform endurance fuel and annual fuel calculations, provides guidance for modeling system components based on data typically provided in data sheets, and provides guidance on the manner in which the power and propulsion systems are operated. Four examples are provided to illustrate the methods using the Smart Ship System Design modeling and simulation tool along with supporting spreadsheets.

Keywords: Marine design for ships and offshore structures; endurance; fuel efficiency; electrical efficiency; electrical system; performance prediction

1. Introduction

Two important activities in the design of a ship are performing calculations to determine the minimum required amount of fuel that should be stored in its fuel tanks (endurance fuel calculations), and performing calculations to estimate how much fuel will be consumed during a year of operations (annual fuel calculations).

Endurance fuel and annual fuel calculations are important to the design of both commercial and naval ships. These calculations are often used to compare the performance of different concepts under consideration in the early stages of design. Performing these calculations accurately is important to ensure the best concept is chosen for further development. This is particularly important when concepts feature power and propulsion systems that differ significantly from each other. Examples include a mechanical drive ship, a hybrid electric drive ship, and a full-integrated power system ship.

For U.S. Navy ships the process for conducting endurance fuel calculations is defined in NAVSEA DDS 200-1 Rev 1 which is often referred to as DPC 200-1. The process for conducting annual fuel calculations is defined in NAVSEA DDS 200-2. Since the processes for commercial ships are similar (Woud and Stapersma 2015), this paper will concentrate on the processes defined in NAVSEA DDS 200-1 Rev 1 and NAVSEA DDS 200-2, specifically on the method for determining fuel rates for specific operational conditions, ambient conditions, and ship speeds; as well as how to convert these fuel rates into required fuel tank volume and into annual fuel usage estimates. In particular, this paper highlights methods for predicting losses when equipment is operated at part load.

Newer revisions of NAVSEA DDS 200-1 Rev 1 and NAVSEA DDS 200-2 were issued in 2023 during the production of this paper. Because these newer revisions have limited distribution, this paper is based on the previously approved for public release revisions. Individuals working on U.S. Navy programs and having the proper access should review the newer revisions of NAVSEA DDS 200-1 Rev 1 and NAVSEA DDS 200-2 for changes to the procedures described in this paper. The process for modeling components and systems remains unchanged.

Fuel rates depend on the electrical load estimated for the operational condition and ambient condition, the propulsion power

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Annual Energy Use (fuel) example (DPC 200-2)

Ship states

	Inport - Shore	Underway - Economical Transit	Underway - Surge to Theater	Underway - Mission	Calculated Operational Mode Fuel Rate (kg/h)
Fuel Rate(kg/h)	0	3070	12028	3150	
Maintenance and Modernization	90%	5%	0%	5%	311
Predeployment Training	60%	20%	0%	20%	1244
Deployment	10%	20%	0%	70%	2819
MCO	5%	15%	5%	75%	3424

Operational Modes

Multiply operational mode fuel rate by hours in operational mode each year

Annual Energy Use (fuel) for Hi OPTEMPO

Year	Maintenance and Modernization (1000 kg)	Predeployment Training (1000 kg)	Deployment (1000 kg)	MCO (1000 kg)	Total Fuel (1000 kg)
1	682	2,726	12,356	0	15,763
2	682	2,726	12,356	0	15,763
3	682	2,726	12,356	0	15,763
4	682	2,726	12,356	0	15,763
5	682	2,726	12,356	0	15,763
6	682	2,726	12,356	0	15,763
7	682	2,726	12,356	0	15,763
8	2,726	0	0	0	2,726
9	682	2,726	12,356	0	15,763
10	682	2,726	12,356	0	15,763
11	682	2,726	0	20,112	22,402
12	682	2,726	0	20,112	22,402
13	682	2,726	0	20,112	22,402
14	682	2,726	12,356	0	15,763
15	682	2,726	12,356	0	15,763
				Lifetime Fuel (1000 kg)	243,331

Annual Energy Use (Shore Power) example (DDS 200-2)

	Inport - Shore	Underway - Economical Transit	Underway - Surge to Theater	Underway - Mission	Average Shore Power (kW)
Shore Power(Kw)	725	0	0	0	
Maintenance and Modernization	90%	5%	0%	5%	653
Predeployment Training	60%	20%	0%	20%	435
Deployment	10%	20%	0%	70%	73
MCO	5%	15%	5%	75%	36

Annual Energy Use (shore power) for Hi OPTEMPO

Year	Maintenance and Modernization (1000 kW-h)	Predeployment Training (1000 kW-h)	Deployment (1000 kW-h)	MCO (1000 kW-h)	Total Shore Power (1000 kW-h)
1	1,430	953	318	0	2,701
2	1,430	953	318	0	2,701
3	1,430	953	318	0	2,701
4	1,430	953	318	0	2,701
5	1,430	953	318	0	2,701
6	1,430	953	318	0	2,701
7	1,430	953	318	0	2,701
8	5,720	0	0	0	5,720
9	1,430	953	318	0	2,701
10	1,430	953	318	0	2,701
11	915	648	0	213	1,776
12	915	648	0	213	1,776
13	915	648	0	213	1,776
14	1,430	953	318	0	2,701
15	1,430	953	318	0	2,701
				Lifetime Shore Power (1000 kW-h)	40,760

Fully Burdened Cost of Energy

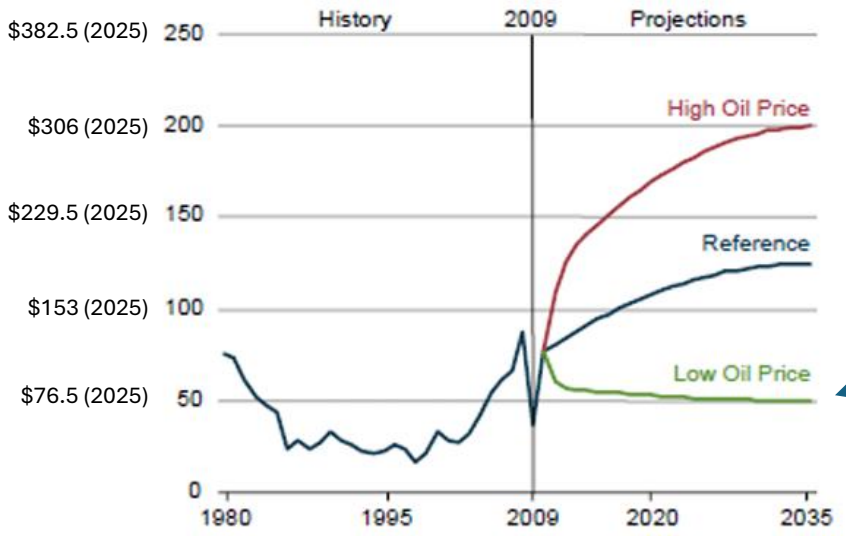
- The cost of fuel includes
  - Acquisition cost
  - Storage and handling cost
  - Delivery cost
  - Other cost
- All cost elements have uncertainty
- Costs can vary substantially year to year
  - Hard to predict
  - Should examine ranges of costs to understand design robustness
    - Low – Mid – High
    - For each year

Cost structure of Navy Fuel

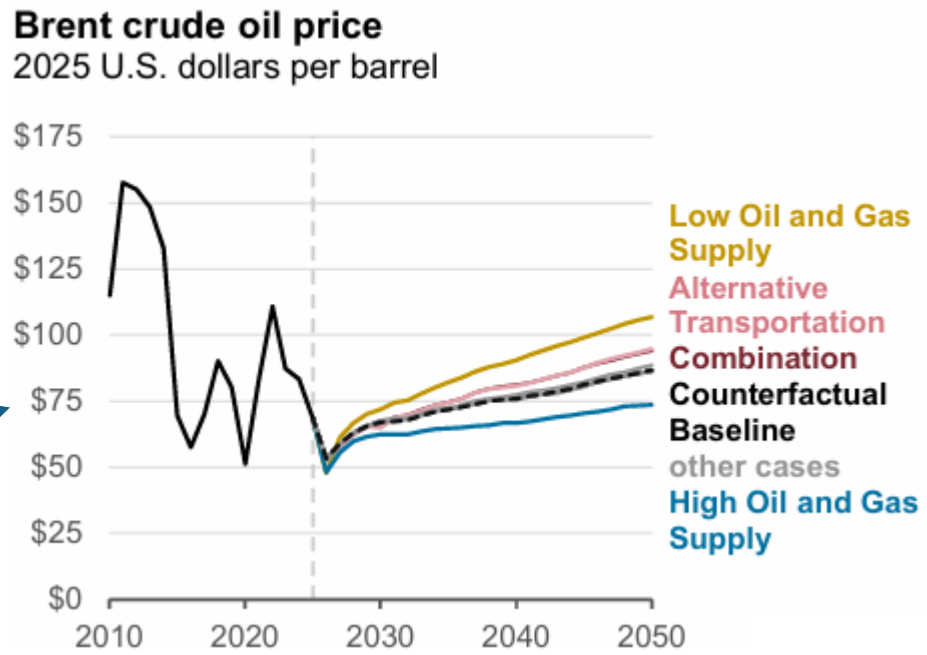
	Category	Element	Description
	Acquisition	Commodity Cost of Fuel	DLA Energy DoD standard price for the appropriate type or types of fuel.
BURDENED ELEMENTS	Storage & Handling	Direct Fuel Infrastructure O&S and Recapitalization Cost	Cost of fuel infrastructure that is not operated by DLA Energy and directly tied to energy delivery.
		Indirect Fuel Infrastructure O&S Cost	Cost of base infrastructure that is shared proportionally among all base tenants.
	Delivery	Depreciation Cost of Primary Fuel Delivery Assets	Measures the decline in value of fuel delivery assets with finite service lives using straight-line depreciation over total service life.
		Primary Fuel Delivery Asset O&S Cost	Cost of operating service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel delivery mission.
	Other	Environmental Cost	Cost representing carbon trading credit prices, hazardous waste control, and related subjects.
		Other Service & Platform Delivery Specific Costs	Includes potential costs associated with delivering fuel such as convoy escort, force protection, regulatory compliance, contracting, and other costs as appropriate.

Predicting crude oil price is difficult

Annual Energy Outlook 2011



Annual Energy Outlook 2025

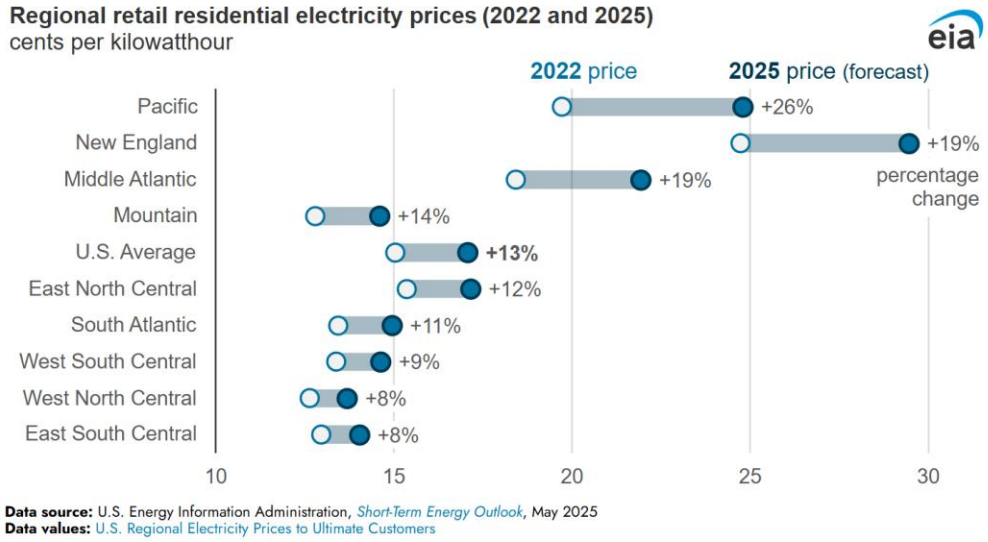


$1.00 in 2009 = $1.53 in 2025

Annual Energy Outlook is produced by the U.S. Energy Information Administration https://www.eia.gov/

Cost of Shore Power

- U.S. Energy Information Agency (https://www.eia.gov) provides rate information for electrical power
- Varies significantly by geographic region.
- Price of electricity is anticipated to grow about 4% per year for near future.
  - Slightly higher than the forecast growth in CPI
- Should estimate a low, mid, and high cost of shore power ($ per kW-h) for each year based on projections.



Annual Energy Cost Calculations

- Apply the range of energy costs to the energy usage predictions of each ship deployment and employment profile

Year	DLA Energy Estimate ($/bbl)	Storage and Handling ($/bbl)	Depreciation ($/bbl)	Fuel Delivery ($/bbl)	Environmental ($/bbl)	Other ($/bbl)	Fully Burdened Price ($/bbl)	Fully Burdened Price ($/kg)
2015	$137.55	$0.05	$11.67	$30.34	$4.20	$0.00	$183.81	$1.37
2016	$141.07	$0.05	$11.67	$30.34	$4.20	$0.00	$187.33	$1.40
2017	$144.58	$0.05	$11.67	$30.34	$4.20	$0.00	$190.84	$1.42
2018	$148.10	$0.05	$11.67	$30.34	$4.20	$0.00	$194.36	$1.45
2019	$151.61	$0.05	$11.67	$30.34	$4.20	$0.00	$197.87	$1.48
2020	$155.13	$0.05	$11.67	$30.34	$4.20	$0.00	$201.39	$1.50
2021	$157.58	$0.05	$11.67	$30.34	$4.20	$0.00	$203.84	$1.52
2022	$160.04	$0.05	$11.67	$30.34	$4.20	$0.00	$206.30	$1.54
2023	$162.49	$0.05	$11.67	$30.34	$4.20	$0.00	$208.75	$1.56
2024	$164.95	$0.05	$11.67	$30.34	$4.20	$0.00	$211.21	$1.58
2025	$167.40	$0.05	$11.67	$30.34	$4.20	$0.00	$213.66	$1.59
2026	$168.85	$0.05	$11.67	$30.34	$4.20	$0.00	$215.11	$1.61
2027	$170.29	$0.05	$11.67	$30.34	$4.20	$0.00	$216.55	$1.62
2028	$171.73	$0.05	$11.67	$30.34	$4.20	$0.00	$217.99	$1.63
2029	$173.17	$0.05	$11.67	$30.34	$4.20	$0.00	$219.43	$1.64

Note: Assume 134 kg/bbl.

High OPTEMPO annual cost of energy table:

Year	Price Per kg	1000 kg Fuel	Fuel Cost	Price Per kW-h	Shore Power (1000 kW-h)	Electricity Cost	Total Energy Cost
2015	$1.37	15,763	$21,623,467	$0.095	2,701	$256,597	$21,880,064
2016	$1.40	15,763	$22,036,987	$0.095	2,701	$256,597	$22,293,584
2017	$1.42	15,763	$22,450,507	$0.095	2,701	$256,597	$22,707,104
2018	$1.45	15,763	$22,864,027	$0.095	2,701	$256,597	$23,120,625
2019	$1.48	15,763	$23,277,548	$0.095	2,701	$256,597	$23,534,145
2020	$1.50	15,763	$23,691,068	$0.095	2,701	$256,597	$23,947,665
2021	$1.52	15,763	$23,979,798	$0.095	2,701	$256,597	$24,236,395
2022	$1.54	2,726	$4,197,143	$0.095	5,720	$543,382	$4,740,525
2023	$1.56	15,763	$24,557,258	$0.095	2,701	$256,597	$24,813,856
2024	$1.58	15,763	$24,845,988	$0.095	2,701	$256,597	$25,102,586
2025	$1.59	22,402	$35,720,275	$0.095	1,776	$168,750	$35,889,026
2026	$1.61	22,402	$35,961,518	$0.095	1,776	$168,750	$36,130,268
2027	$1.62	22,402	$36,202,760	$0.095	1,776	$168,750	$36,371,511
2028	$1.63	15,763	$25,643,972	$0.095	2,701	$256,597	$25,900,570
2029	$1.64	15,763	$25,813,724	$0.095	2,701	$256,597	$26,070,321
Lifetime		243,331	$372,866,041		40,760	$3,872,204	**$376,738,245**