CRUISE LINE ONSHORE POWER ANALYSIS

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Abstract

Emissions from energy, vehicles, and agriculture often get the most attention, but there is another significant source of emissions that affects daily life in various ways, such as energy prices, the cost of goods, and even the food in grocery stores, however, this sector often goes unnoticed. Greenhouse gases, the carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that emit from burning fossil fuels, has risen 9.6% in the shipping industry, which includes international, domestic, and fishing, from 2012 to 2018, now accounting for anthropogenic emissions of nearly 3% worldwide (IMOa, 2021). This research study aims to analyze and address potential avenues for immediate emission reduction behaviors in the shipping industry to curb the ever-growing rate the industry emits. Ships typically have predictable itineraries, consistent routes, and regular idle time at ports. While at port, while the ship is not moving, it must continue to power the necessary equipment and facilities onboard, meaning it will either continue to run one of the engines or plug in to the onshore power grid to provide the necessary power to the network.

This study researched and compared two scenarios: business-as-usual, running engines while at port, or building out solar and battery energy storage systems, allowing the engines to turn off and plug into renewably sourced energy. Many variables contribute to both scenarios, resulting in various worst-case and best-case outcomes. Applying the variables across their lowest, middle, and highest impacts allowed for a comparison of the two scenarios across nine potential outcomes. Across a 30-year horizon, 7 of the 9 outcomes favored renewable onshore power (savings ranging from 10% to 238%), however, when considering a 10-year horizon, only 3 of the outcomes favored renewable onshore power (savings ranging from 1% to 27%). While renewable onshore power was found to be cheaper in the long run across most scenarios, should innovation in the shipping sector occur sooner than expected, it may make the costly investment less attractive.

Primary Reader and Advisor: Sharon S.

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Finally, I want to thank my parents, Ken and Jody, and my wife, Taylor, for their support and time in allowing me to complete this program over the last three years. I could not have done it without their help, support, and encouragement along the way.

Dedication

This thesis is dedicated to my amazing wife, Taylor, and three wonderful children, Arya, Cooper, and Finan, who each inspire me to leave the world in a better place, every single day.

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Executive Summary

The Intergovernmental Panel on Climate Change's (IPCC) special report on the impacts of global warming at 1.5°C above pre-industrial levels was clear in both the dangers of going above this target, as well as the pathways necessary to have a chance at hitting the target. The world has already endured a 1.0°C (likely range of 0.8°C -1.2°C) increase in global warming, and at the current emissions pace it is expected that 1.5°C will be reached between 2030 and 2052 (IPCC, 2018). While exceeding the 1.5°C target would not make the earth inhabitable, it does drastically get worse as it increases, even at small amounts. Every climate variable rises in predicted occurrence even when comparing a small overshoot from 1.5°C to a 2°C increase: temperature extremes, heavy precipitation, droughts, sea level rise, ocean acidification; causing species loss and extinction, decreased biodiversity, wildfires, floods, etc. The list of harmful impacts from going above 1.5°C is endless, impacts the globe, and will negatively impact every aspect of human life. Hundreds of millions will be driven towards poverty just from going a half-degree higher, straining adaptation and adaptive capacity even more, and these all continue to get worse with every slight increase in global temperature.

IPCC's model pathways predict a necessary decline in global net anthropogenic carbon dioxide emissions by 45% from 2010 levels by 2030 and reaching net zero around 2050. To put that in perspective, this target would require an annual reduction at 7.5% continuously for decades to hit net zero by 2050. In addition, the IPCC pathways all assume the use of wide-scale deployment of negative emissions technologies, such as afforestation and reforestation, soil carbon sequestration, bioenergy with carbon capture and storage (BECCS), direct air carbon capture and storage, and many others. These technologies have not been scaled or sustained to-date and require a significant increase in research and development to determine feasibility. The goal of these carbon dioxide removal technologies would be offsetting some of the lingering emissions still occurring, such as air travel or shipping, and to ultimately achieve net negative emissions to maintain the 1.5°C target.

Any decarbonized energy plan will require all manners of renewable energy and innovation, across all sectors, including the shipping industry. The challenges only increase as you consider current shipping transport demands will also grow over the coming decades; and while carbon intensity has improved for international shipping, there is no guarantee greenhouse gas emissions will decrease (Brown, Englert, Lee & Salgmann, 2022). Many will argue that future innovation in renewable shipping is the only solution, such as green methanol, power-to-gas, hydrogen, ammonia, or advances in small modular nuclear reactors, however, every ton of emissions saved is a ton that does not require removal in the future. Plugging into renewable onshore power may present an opportunity to invest and innovate in the present, taking advantage of reliable and affordable clean energy right where it is needed, increasing efficiency, and reducing emissions, and buying necessary time for longer term innovation.

Introduction

The purpose of this research is to conduct a budget impact analysis on the economic and financial consequences of adopting a new intervention for a cruise line while at berth at one of their regularly planned destinations, for example, Disney Cruise Lines at their existing island, Castaway Cay, or Royal Caribbean at their private destination in Labadee, Haiti. When cruise ships are at berth, there are two options for generating the necessary power supply: running engines on the ship or connecting to onshore power. Traditionally cruise ships run engines to power the ships at port, but onshore power allows electrical power to be provided to the docked ship from the shore. This research aims to conduct a budget impact analysis comparing business-as-usual (engine support) versus the development of solar and battery infrastructure to allow the ship to utilize carbon-free energy at berth.

Developing and communicating corporate social responsibility (CSR) in the environment will be a key component to any companies future bottom-line, especially for companies that rely on a strong public image for success. Walt Disney Co. has become a leader in embracing CSR and making a strong commitment to the environment. This commitment starts by understanding and knowing your full impact as a company. This includes, but is not limited to, direct and indirect emissions, energy requirements, waste, and water consumption. From there, goals and targets can be developed to reduce each segment's environmental impact, followed by regular reporting and updates to the goals and targets. Another tool companies, including Walt Disney Co., are beginning to use is creating an internal carbon price. Establishing a monetary value for each ton of greenhouse gas emissions and incorporating it into the business strategy creates a financial incentive for companies to reduce their impact.

Corporate carbon pricing can follow a multitude of approaches, such as a carbon fee, a shadow price, an implicit carbon price, or a hybrid approach that combines multiple methods. Walt Disney Co., for example, follows a hybrid approach. They use an internal carbon fee ranging from $10-$20 per metric ton to help meet its target of reducing emissions, whereas they use a shadow price for new projects to guide its capital planning (Ahluwalia, 2017). This allows the company to make informed decisions and prepare for a carbon-constrained future. In addition, increasing pressure from financial investors and shareholders will make this a top concern, and by developing a strong CSR combined with internal carbon pricing a company can communicate its current carbon footprint and future projections in a meaningful way.

To mitigate risk of the political unknowns, global energy disruptions, both in supply and pricing, and the eventual transition from high-carbon to low-carbon activities, it is in the best interest for any company to invest in renewable energy and sustainability immediately. This will result in lowered emissions, cost-savings, a positive public image, increased brand loyalty with consumers, and thus increased profits. This research hopes to highlight an opportunity within a cruise line company's existing and future cruise operations to decrease costs, risks, and emissions.

Of the various carbon emitters that are being re-evaluated for reductions in carbon emissions, the shipping industry has been slower and more resilient to change. The main challenges have been the inability to attribute emissions from shipping to any specific nation, the massive pre-existing fleet of heavy fuel oil (HFO) ships, and the lack of international enforcement and regulation as the emissions do not fall under the Paris Agreement.

The shipping industry accounts for 90% of transportation for world trade and currently generates about 3% of total global GHG emissions per year, however, the future of that figure is subject to debate. Some estimates range from an increase of 50% to 250% by 2050 and could account for one-fifth of global emissions (Green, 2018). While the ship engines themselves are very efficient, the HFO used by more than 80% of the world's shipping fleet is more carbon-intensive than other fuels and emits sulfur dioxide into the atmosphere (EIA, 2019).

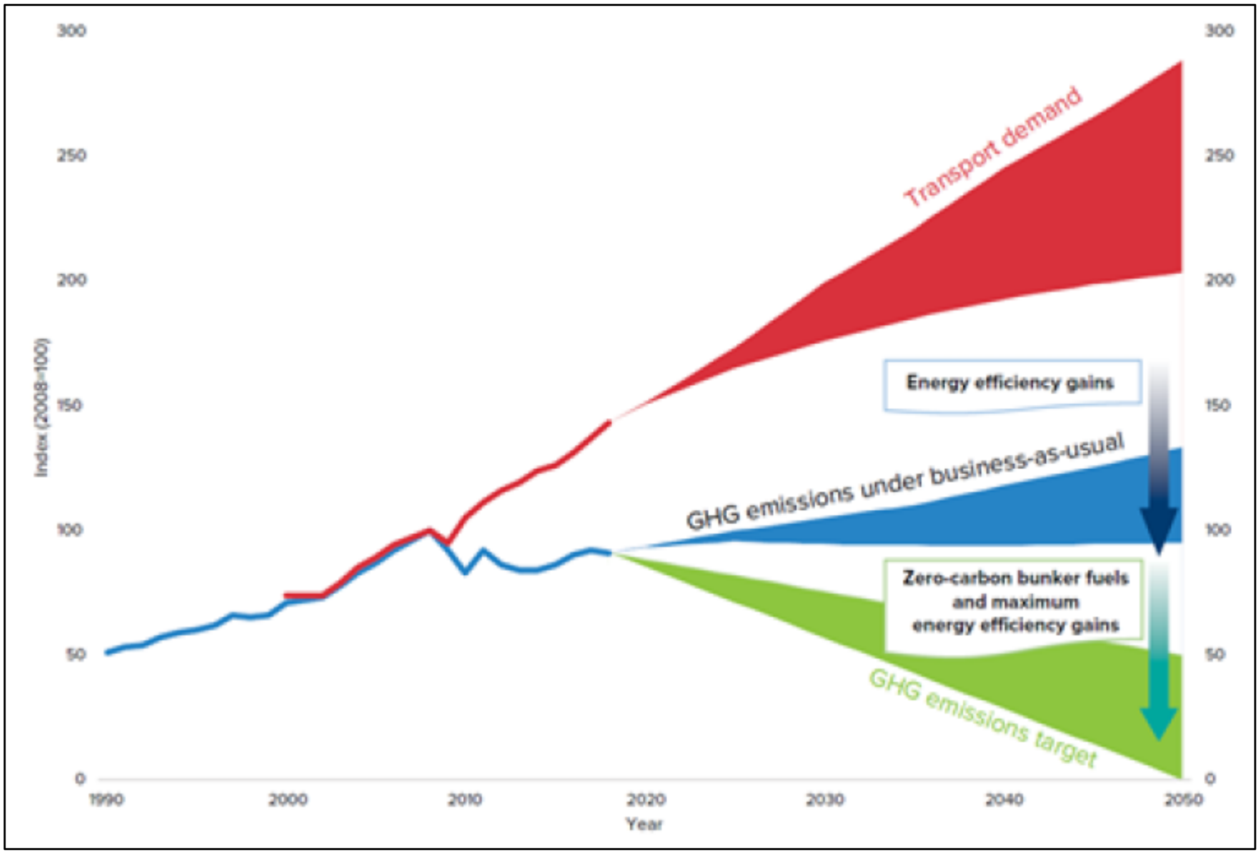

Figure 1: Historical and projected transport demand & GHG emissions from international Shipping
Source: UNEP, World Bank (Brown, Englert, Lee & Salgmann, 2022)

The International Maritime Organization (IMO), created in 1948, is an agency of the United Nations and is responsible for regulating the shipping industry. One of the many areas of focus for the IMO is around the shipping industry's role in carbon emissions, falling under the Marine Environment Protection Committee (MEPC) (IMOb, 2022). The MEPC addresses all environment issues related to shipping, including air pollutants and greenhouse gas emissions. The most significant initiative in addressing maritime emissions is the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978, or MARPOL, short for MARitime POLlution.

Within MARPOL, there are six annexes, each with their own pollutant. Of significance are Annexes I and VI; Annex I was entered into force in 1983 for the prevention of pollution by oil and Annex VI entered into force in 2005 for the prevention of air pollution from ships (IMOc, 2022). Most recently, separate from the six annexes, is the IMO 2020 rule, which will ban ships from using high sulfur fuel. Previously, marine fuel was allowed up to a 4.5% sulfur limit, which decreased to 3.5% in 2012, and now down to 0.5% in 2020 (EIA, 2019). This rule requires ships to either use low sulfur fuel, at 0.5% or lower, be fit with a scrubber when using high sulfur fuel, or switch to alternative fuels, such as liquefied natural gas (LNG) (Reuters Staff, 2020). In addition, in the European Union and in coastal cities in the United States, there are locally regulated Emission Control Areas (ECA) that restrict the maximum output of sulfur to 0.1% (Bergqvist, R., Turesson, M., & Weddmark, 2015).

In 2011, MARPOL adopted the Energy Efficiency Design Index (EEDI) to set efficiency standards for ships to reduce fuel use and pollution (Caughlan & Reynolds, 2016). This will require new ships to be 10% more efficient than the average efficiency from 2000 to 2010. The target will increase every 5 years and has been established up to 2025 when a 30% reduction is mandated for applicable ship types. The applicable ships account for approximately 85% of the carbon emissions in international shipping, however, this only applies to new non-passenger ships, and with only 1000 to 2000 new ships built annually against a fleet of 40,000 to 45,000 ships, this will take decades to see significant emission reductions (Timperley, 2017).

In 2018, the IMO MEPC adopted resolution MEPC.304(72) on Initial IMO Strategy on reduction of GHG emissions from ships. Within this climate deal are three levels of ambition, including an absolute emissions reduction target: carbon intensity of the ship to decline through implementation of future phases of EEDI, carbon intensity of international shipping to decline by reducing carbon emissions per transport work by at least 40% by 2030 and towards 70% by 2050, compared to 2008 levels, and for GHG emissions from international shipping to peak as soon as possible and decline, with a goal of at least by 50% by 2050 compared to 2008 (UNFCCC Talanoa Dialogue, 2018).

Between the MARPOL Annex VI, the EEDI, and MEPC.304(72), the current and future direction of the shipping industry and their emissions is clear. This may have weighed in the decision to power Disney's newest ships with LNG. The Disney Wish is the fifth in its fleet and first to use LNG, setting sail on its maiden voyage in the summer of 2022 with two more LNG powered ships currently in construction (Hunter, 2022). Beyond these ships, Disney Cruise Line announced a next generation ship that will be among the first to utilize green methanol, as did Maersk, ordering 12 cargo vessels able to run on methanol and subsequently securing the green methanol to power them (Cade, Yolanda, 2022, & De La Garza, 2022). Green methanol has the potential to reduce greenhouse gas emissions significantly, by utilization of renewable energy in the production process (see Figure 2) (thyssenkrupp, 2022). However, while the IMO moves the industry in the right direction, many critics feel it is not enough due to its inability to meet the goals set forth from the Paris Agreement. In addition, because of the long lifetime of the ships, 20 to 30 years, those newer vessels that are being built now will be in service by 2050 and will require costly retrofitting to maintain updated efficiency targets or be replaced years ahead of schedule.

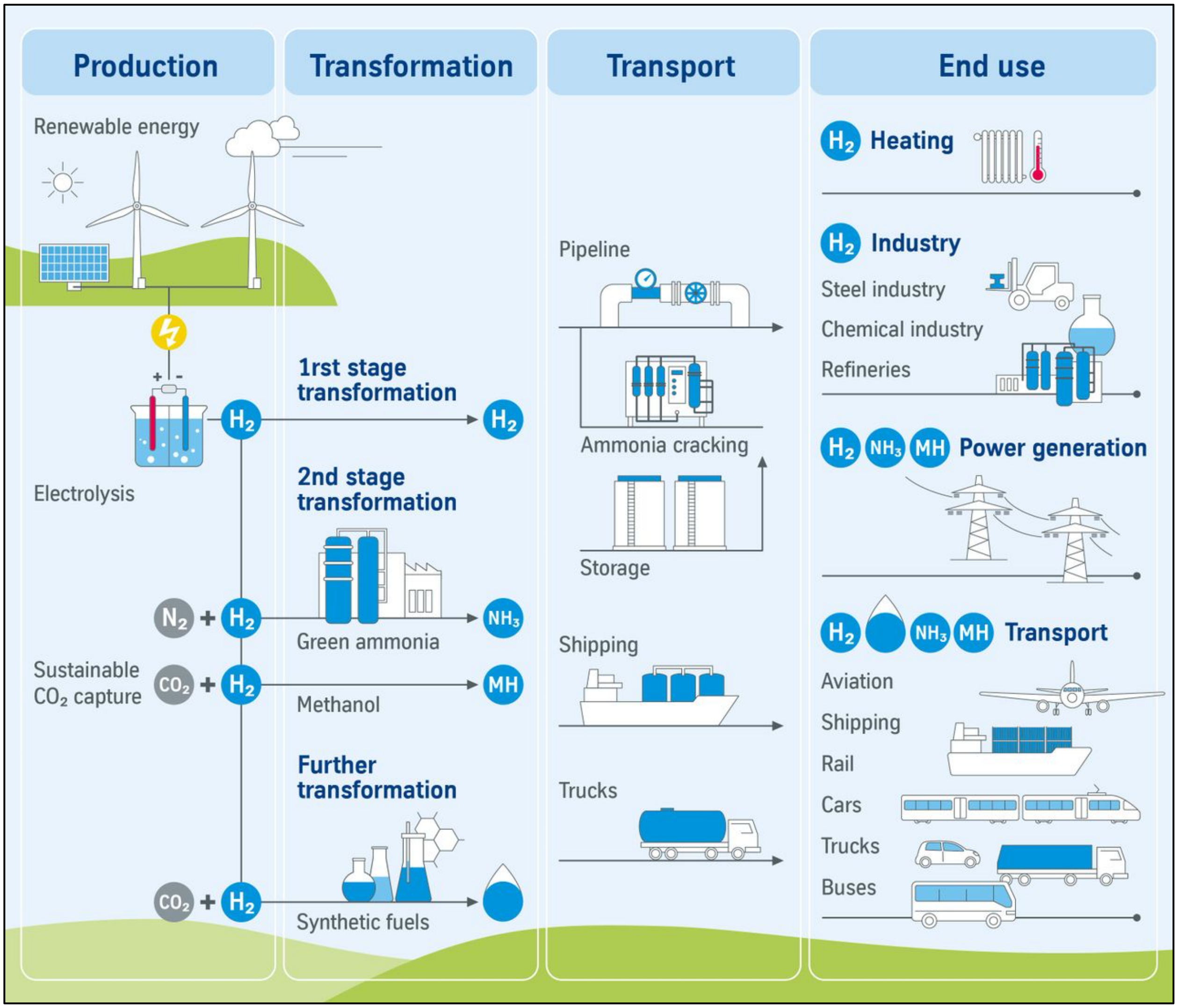

Figure 2: The value chain of green methanol – from production to application in various industries
Source: thyssenkrupp AG (thyssenkrupp, 2022)

Ships are found to emit as much as 60% of their emissions within 20 nautical miles of shore, and one study found this attributed to 14,500-37,500 premature deaths in East Asia (Jacewicz, 2016). Switching from HFO to liquified natural gas has seen increasing adoption, as it reduces shipping emissions by 25% while also reducing NOx, SO2, and particulate emissions

(Winnes, Styhre, & Fridell, 2015). However, there can be a few percent of methane that leaks during the combustion process. While methane breaks down in the atmosphere quicker than carbon dioxide, it is far more potent as a greenhouse gas; up to 72 times more powerful across a 20-year timeline and 25 times across a 100-year timeline. This means the total carbon emission impact is only minorly decreased across a 100-year horizon and has a higher emission impact across the 20-year horizon (Winnes, Styhre, & Fridell, 2015). This same study found that shipping operations had the largest impact on emissions reductions compared to business as usual, specifically by reductions in speed and lay time at berth. The ability for onshore power supply for vessels at berth can have a large impact, depending on how the onshore power supply was powered. For example, if powered by a coal plant, onshore power supply might have higher emissions compared to generating the power on-board the ship. But if onshore power supply is powered by renewables, such as wind, hydro, nuclear, or solar, the emissions reductions can be substantial when compared to on-board powering (Winnes, Styhre, & Fridell, 2015).

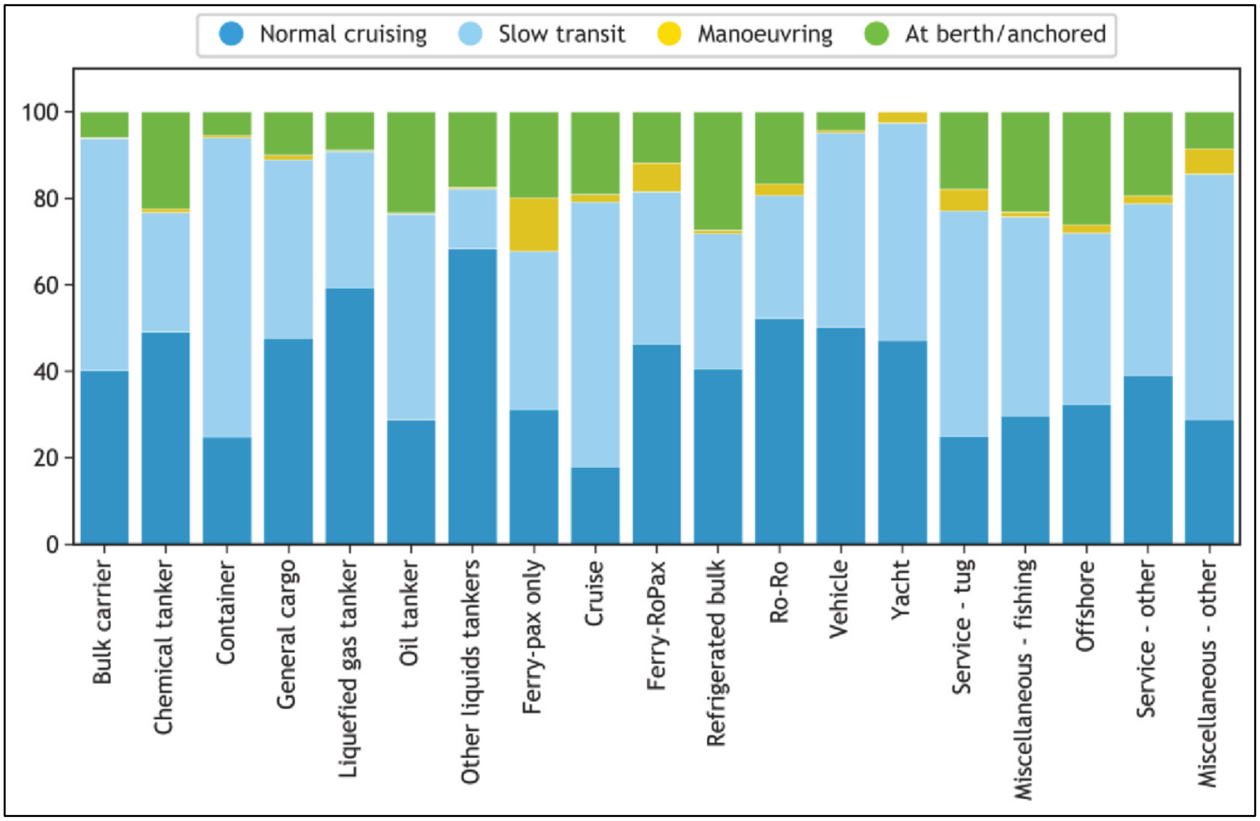

Figure 3 – Proportion of international GHG emissions (in CO2e) by operational phase in 2018, according to the voyage-based allocation of emissions. Operational phases are assigned based on the vessel's speed over ground, distance from coast/port and main engine load
Source: Fourth IMO GHG Study 2020 (IMOa, 2021)

What is abundantly clear is the solution to maritime emission reductions on the scale of IPCC and Paris goals will require a multitude of angles and approaches, there is no 'one size fits all' solution. As an example, even Maersk, the largest container shipping company, won't consider scrubbers as a viable solution to the IMO 2020 rule, stating the cost to meet the rule will be around $2 billion. When factoring in the cost of specialized personnel for the scrubbers, the math simply doesn't work out (Szakonyi, Mark, 2017). In the meantime, Maersk has self-imposed their own ambitious goals of transporting goods at 60% of 2008 emission levels and with zero carbon emissions by 2050 (Domonoske, 2019). They know that if emissions continue, a viable shipping industry likely ceases to exist. Additionally, while scrubbers reduce air emissions, they require scrubber wash water discharge, negatively impacting the nearby aquatic ecosystems with acidic and hazardous waste (Teuchies, Cox, Van Itterbeeck, et al, 2020).

Of course, if new alternative fuels, such as green hydrogen, methanol, or ammonia, or synthetic natural gas sourced by renewables, were to be proven effective and scaled up, it's possible that the cost of building a new ship or retrofitting old ships with clean power would be cheaper than business as usual with HFO, solving all these problems. Like coal becoming cheaper in some areas to simply shut down and replace with natural gas or renewables, it’s possible that a new alternative forces early ship retirement or retrofitting due to the inexpensive price when compared to dirtier fuels. Currently, there’s a lot of focus around hydrogen fuel cells, with hydrogen-powered vessels under construction in Norway, France, and California (Hersher, 2019), as well as green methanol, with Disney and Maersk investing in the biofuel, and even green ammonia, with shipbuilder Samsung Heavy Industries and engine manufacturer Wartsila investing in research and development (Irfan, 2022). While these technologies show vast promise of eliminating shipping emissions, it doesn’t reduce the emissions today. This research hopes to provide a blueprint and consideration for reducing a portion of emissions today, by utilizing renewably powered onshore power supply.

Methods

The methods used for this research required multiple inputs and estimates to accurately inform the modeling of the budget impact analysis to effectively compare business-as-usual with engine support versus the development of solar and battery infrastructure to allow a ship to utilize carbon-free energy at berth. Inputs and pricing estimates researched and required include the following:

Table 1:

Engine Inputs	Findings	*Notes*
Fuel type used at port	Marine Diesel Oil	
Annual Call Days	250 days/year	
Daily average of hours at port (hours/day)	8 hours	
Average fuel consumption	2 tons/hour	
Marine diesel oil cost	$800/ton	*Price has ranged historically from $600 to $1000/ton*

Table 2:

Renewable Energy Inputs	Findings	*Notes*
Ship hotel electrical load required	10 megawatts	
Acreage necessary for solar/battery infrastructure	18 acres	
Onshore power supply infrastructure **Festooning system** **Onshore transformer** **Meters** **Cable connectors** **Excavation** **Installation**	$10,000,000	*Assumes no IRA Investment Tax Credit due to infrastructure being located offshore on non-United States land*
Solar PV and Battery Energy Storage System	$24,000,000	*Assumes no IRA Investment Tax Credit due to infrastructure being located offshore on non-United States land*

Annual Operations Expenditures to support renewable energy infrastructure	1.15% to 4.5% of Total Capital Expenditures	*Based on Lazard Estimates (World Bank Group, 2020 & Lazard, 2020)*
Financing Terms	0 to 15 to 30 years Interest of 5% to 8%	*Financing options and attractiveness can vary*

These inputs were then placed into a model using Microsoft Excel to extrapolate and analyze budgetary impacts across a 30-year horizon for both the business-as-usual scenario of utilizing engine support and building a solar and battery energy storage system. An inflation factor of 2% annually was applied to the methodology.

Analysis

Three calculations were completed based on the findings of the required inputs, noted as Lowest, Most Likely, and Highest, across both scenarios. This allowed the findings calculated to provide a range of potential outcomes for both engine support and solar and battery energy storage system support, allowing assessment of potential risks and variability over a 30-year horizon with peak and trough calculations across both.

Inflation factors, 15-year financing amortization, and 30-year financing amortization inputs can be found in the Supplemental Index. Of note, in some situations it would be appropriate to consider additional variables that were not included in this analysis. These variables and considerations include, but are not limited to, depreciation of assets, debt flows, debt interest, non-taxable incentives, and other benefits, such as excess energy sales.

Results

Table 3 includes the inputs for lowest, most likely, and highest scenarios for solar and battery energy storage system support, with the inputs provided from table 2 in the methods section informing the subsequent calculations across a 30-year horizon. Likewise, table 4 follows the same pattern, utilizing inputs provided from table 1 in the methods section to calculate engine support.

Using the results of tables 3 and 4, figure 4 displays the total capital expenditure over time and figure 5 displays the total 30-year capital expenditure. Lastly, table 5 and table 6 make nine comparisons across the two scenarios (solar and battery energy storage system and engine support) across three potential outcomes (lowest, most likely, highest), with table 5 displaying 10-year expenditure comparisons and table 6 displaying 30-year expenditure comparisons.

Table 3:

Solar and Battery Energy Storage System Support			
Inputs	**Lowest**	**Most Likely**	**Highest**
Shore Power Infrastructure	$10,000,000		
BESS CAPEX	$24,000,000		
Finance Term	0	15	30
Financing Rate	0	5%	8%
BESS OPEX % (annually)	1.15%	2.83%	4.50%
BESS OPEX (annually)	$391,000.00	$962,200.00	$1,530,000.00
Year			
0	$34,000,000	$2,844,289	$3,276,360
1	$398,820	$4,207,882	$4,554,359
2	$406,796	$4,227,511	$4,585,571
3	$414,932	$4,247,532	$4,617,408
4	$423,231	$4,267,954	$4,649,881
5	$431,696	$4,288,785	$4,683,003
6	$440,330	$4,310,031	$4,716,788
7	$449,136	$4,331,703	$4,751,249
8	$458,119	$4,353,809	$4,786,398

9	$467,281	$4,376,356	$4,822,251
10	$476,627	$4,399,354	$4,858,821
11	$486,159	$4,422,813	$4,896,122
12	$495,883	$4,446,740	$4,934,169
13	$505,800	$4,471,146	$4,972,978
14	$515,916	$4,496,040	$5,012,562
15	$526,235	$2,639,374	$5,052,938
16	$536,759	$1,320,894	$5,094,122
17	$547,494	$1,347,312	$5,136,129
18	$558,444	$1,374,259	$5,178,976
19	$569,613	$1,401,744	$5,222,681
20	$581,005	$1,429,779	$5,267,259
21	$592,626	$1,458,374	$5,312,729
22	$604,478	$1,487,542	$5,359,108
23	$616,568	$1,517,292	$5,406,415
24	$628,899	$1,547,638	$5,454,638
25	$641,477	$1,578,591	$5,503,887
26	$654,306	$1,610,163	$5,554,089
27	$667,393	$1,642,366	$5,605,296
28	$680,740	$1,675,213	$5,657,526
29	$694,355	$1,708,718	$5,710,802
30	$708,242	$1,742,892	$4,018,783
Total:	**$50,179,361**	**$89,174,098**	**$154,653,298**

Table 4:

Engine Support			
Inputs	**Lowest**	**Most Likely**	**Highest**
Annual Call Days (days/year)	250		
Daily Average of Hours at Port (hours/day)	8		
Average Fuel Consumption (tons/hour)	2		
Annual Fuel Consumption (tons/year)	4000		
Marine Diesel Oil ($/ton)	$600.00	$800.00	$1,000.00
Year			
0	$2,400,000	$3,200,000	$4,000,000
1	$2,448,000	$3,264,000	$4,080,000
2	$2,496,960	$3,329,280	$4,161,600
3	$2,546,899	$3,395,866	$4,244,832
4	$2,597,837	$3,463,783	$4,329,729
5	$2,649,794	$3,533,059	$4,416,323
6	$2,702,790	$3,603,720	$4,504,650

7	$2,756,846	$3,675,794	$4,594,743
8	$2,811,983	$3,749,310	$4,686,638
9	$2,868,222	$3,824,296	$4,780,370
10	$2,925,587	$3,900,782	$4,875,978
11	$2,984,098	$3,978,798	$4,973,497
12	$3,043,780	$4,058,374	$5,072,967
13	$3,104,656	$4,139,541	$5,174,427
14	$3,166,749	$4,222,332	$5,277,915
15	$3,230,084	$4,306,779	$5,383,473
16	$3,294,686	$4,392,914	$5,491,143
17	$3,360,579	$4,480,773	$5,600,966
18	$3,427,791	$4,570,388	$5,712,985
19	$3,496,347	$4,661,796	$5,827,245
20	$3,566,274	$4,755,032	$5,943,790
21	$3,637,599	$4,850,132	$6,062,665
22	$3,710,351	$4,947,135	$6,183,919
23	$3,784,558	$5,046,078	$6,307,597
24	$3,860,249	$5,146,999	$6,433,749
25	$3,937,454	$5,249,939	$6,562,424
26	$4,016,203	$5,354,938	$6,693,672
27	$4,096,528	$5,462,037	$6,827,546
28	$4,178,458	$5,571,277	$6,964,097
29	$4,262,027	$5,682,703	$7,103,379
30	$4,347,268	$5,796,357	$7,245,446
Total:	**$101,710,658**	**$135,614,211**	**$169,517,763**

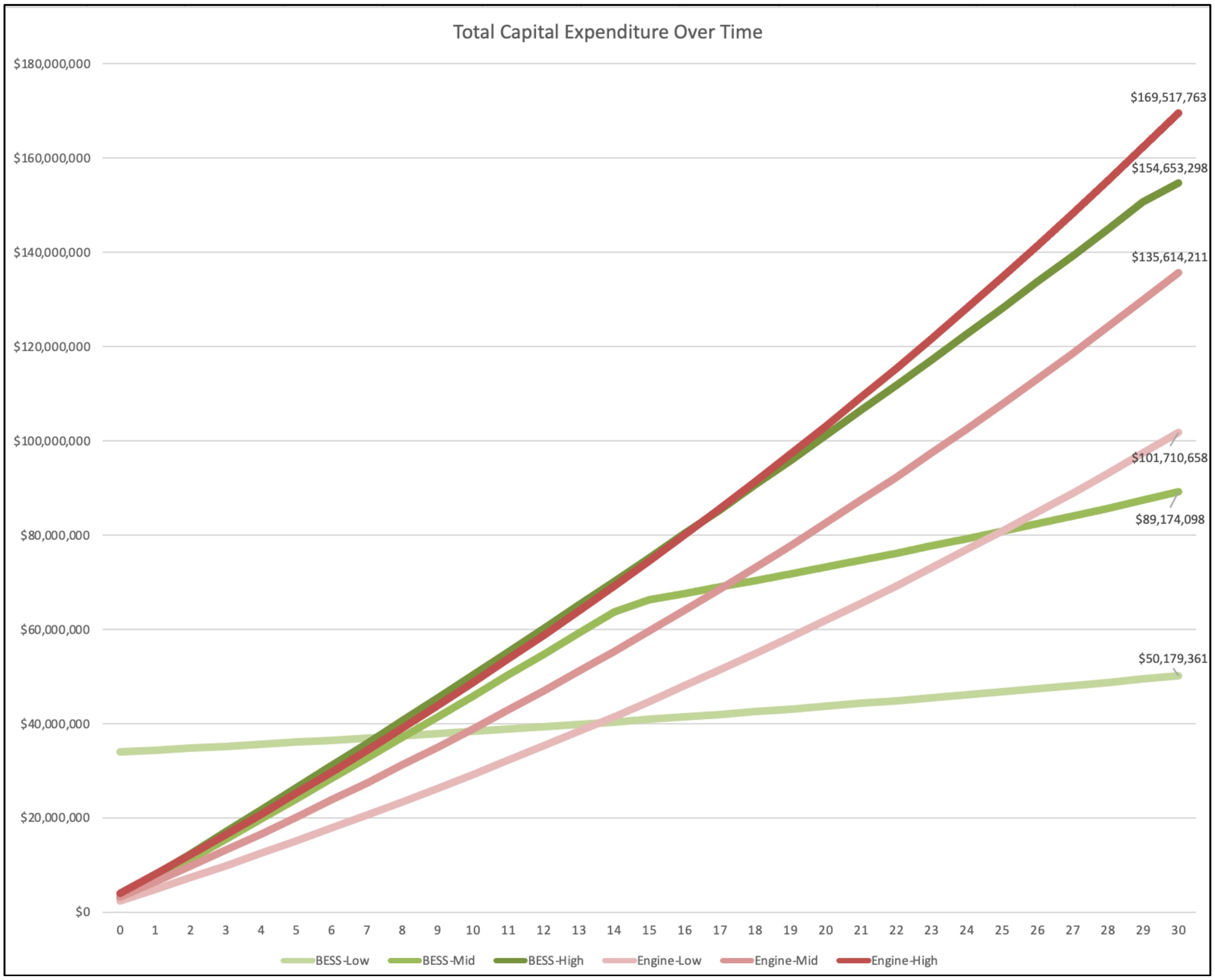

Figure 4: Total Capital Expenditure Over Time

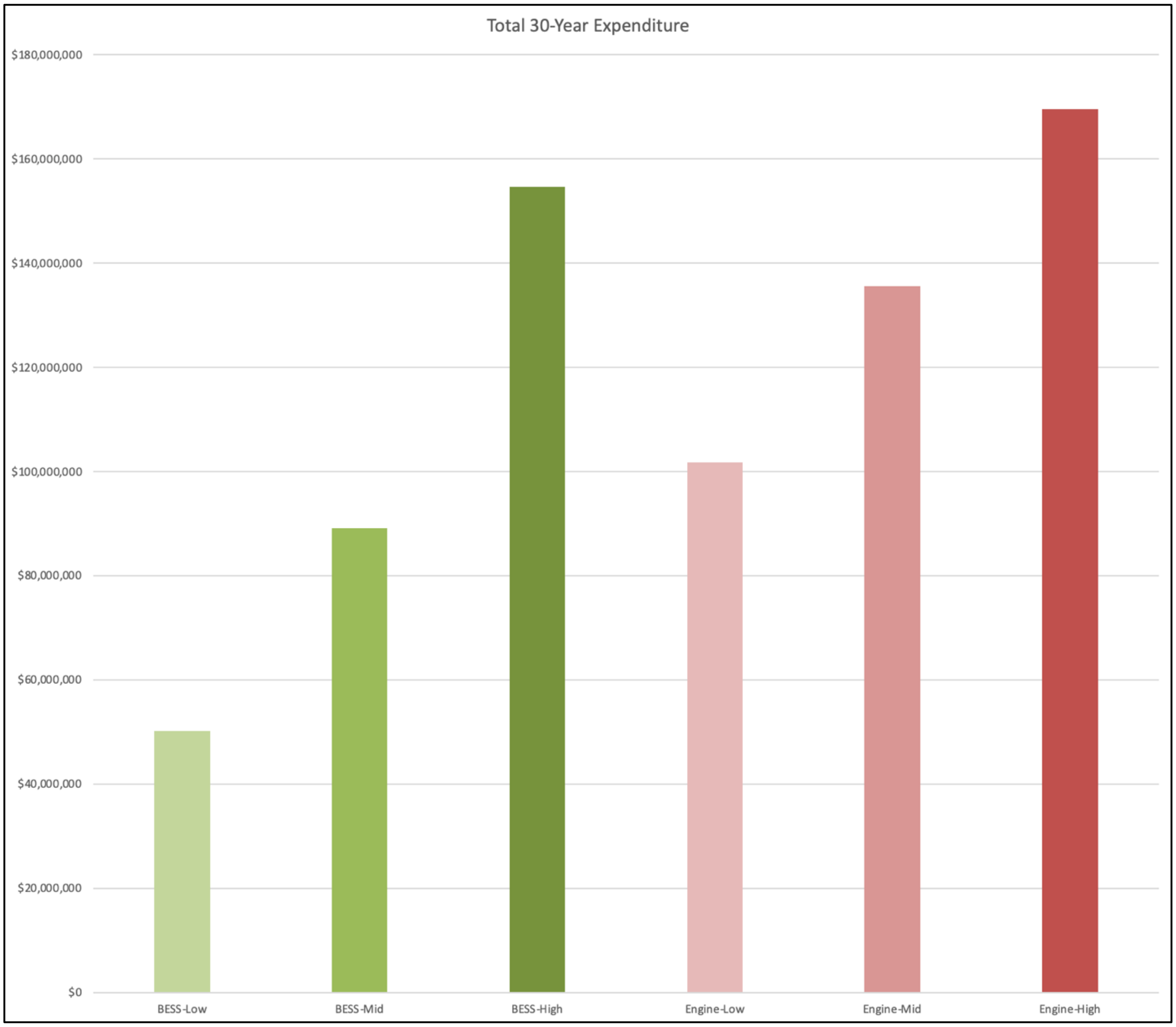

Figure 5: Total 30-Year Expenditure

Table 5:

10-Year Comparisons Across Low, Mid, & High		Difference ($)	Difference (%)
BESS-Low	**Engine-Low**		
$38,366,968	$29,204,917	$9,162,051	-24%
BESS-Low	**Engine-Mid**		
$38,366,968	$38,939,889	-$572,922	1%
BESS-Low	**Engine-High**		
$38,366,968	$48,674,862	-$10,307,894	27%
BESS-Mid	**Engine-Low**		
$45,855,207	$29,204,917	$16,650,290	-36%
BESS-Mid	**Engine-Mid**		
$45,855,207	$38,939,889	$6,915,317	-15%
BESS-Mid	**Engine-High**		
$45,855,207	$48,674,862	-$2,819,655	6%
BESS-High	**Engine-Low**		
$50,302,089	$29,204,917	$21,097,172	-42%
BESS-High	**Engine-Mid**		
$50,302,089	$38,939,889	$11,362,200	-23%
BESS-High	**Engine-High**		
$50,302,089	$48,674,862	$1,627,227	-3%

Table 6:

30-Year Comparisons Across Low, Mid, & High		Difference ($)	Difference (%)
BESS-Low	**Engine-Low**		
$50,179,361	$101,710,658	-$51,531,297	103%
BESS-Low	**Engine-Mid**		
$50,179,361	$135,614,211	-$85,434,849	170%
BESS-Low	**Engine-High**		
$50,179,361	$169,517,763	-$119,338,402	238%
BESS-Mid	**Engine-Low**		
$89,174,098	$101,710,658	-$12,536,560	14%
BESS-Mid	**Engine-Mid**		
$89,174,098	$135,614,211	-$46,440,113	52%
BESS-Mid	**Engine-High**		
$89,174,098	$169,517,763	-$80,343,665	90%
BESS-High	**Engine-Low**		
$154,653,298	$101,710,658	$52,942,640	-34%
BESS-High	**Engine-Mid**		
$154,653,298	$135,614,211	$19,039,088	-12.3%
BESS-High	**Engine-High**		
$154,653,298	$169,517,763	-$14,864,465	10%

Discussion

This research anticipated finding business-as-usual as financially favorable in the short-term (5-10 years), however, becoming unfavorable over longer timeframes (10 years and beyond) when compared to renewable onshore power development. It was expected the results would present a clear, viable, and financially convincing path to emission-free onshore power while at port, reducing costs, reducing emissions, and reducing future macroeconomic and geopolitical risks.

In comparing the two options, with three potential outcomes depending on variables like future fuel costs, financing and interest rates, and potential operational expenditures, there becomes nine potential comparisons. If considering the long-term horizon of 30 years, 7 of the 9 scenarios support renewable onshore power development. When thinking about 30 years, the differences and percentages can appear larger, but provide less impact when considering differences annually. For example, if comparing the middle scenarios to each other, the renewable onshore power saves 52% compared to business-as-usual, with $46,440,113 in savings. Across 30 years, that calculates to only $1,548,003 in savings per year. The decision would have to weigh all options and consider where best to invest and reduce risk as much as possible. This could additionally provide the purchaser leverage in fuel price negotiations. Would the producer rather sell no fuel or agree to bring down the cost to a price point that allows the cruise line to break-even, when compared to the alternate option of renewable onshore power development. Should operational expenditures trend higher and the fuel be secured cheaper than expected, that ~$1.5 million would quickly evaporate. Sticking with this example, should the operational expenditures shift higher than expected, from 2.83% to 4.0%, and the fuel be secured at a lower price, from $800 to $625 per ton, the savings across a 30-year horizon are eliminated entirely.

Realistically, a 30-year fuel purchasing agreement is unlikely, but a 10-year contract could be reasonably secured. Comparing the nine scenarios across the first 10-years closes the gap significantly, only 3 of the scenarios support renewable onshore power, at 1%, 6%, and 27% savings. The 1% and 6% savings scenarios would likely not outweigh the risks, effectively leaving 1 scenario (BESS-Low versus Engine-High) in support of renewable onshore development. Ten years is worth considering, not just because of the potential to secure a long-term fuel commitment that provides predictable and reliable outcomes with far less risk, which is highly sought after in for-profit ventures, but because the fossil fuel sectors are all undergoing rapid innovation to find low or emission-free sources. Research and development are increasing swiftly in finding new decarbonized options in transportation, including shipping. These include advances in green biofuels, like methanol and ammonia, renewable power-to-gas, green hydrogen, or advances in small modular nuclear reactors.

Should any one of these innovative technologies move from concept to reality, any appeal to renewable onshore power development becomes reduced, if not outright unattractive. Of course, not all would be lost, as the infrastructure could be repurposed to provide renewable energy to the local grid should the need for onshore power become diminished. If the shipping industry is fortunate enough to have this problem, it would likely pave the way for other industries, such as long-distance trucking and aviation, ushering in a clean, decarbonized future.

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Supplemental Index

Table 7:

Inflation	
Year	Inflation factor
0	1.00
1	1.02
2	1.04
3	1.06
4	1.08
5	1.10
6	1.13
7	1.15
8	1.17
9	1.20
10	1.22
11	1.24
12	1.27
13	1.29
14	1.32
15	1.35
16	1.37
17	1.40
18	1.43
19	1.46
20	1.49
21	1.52
22	1.55
23	1.58
24	1.61
25	1.64
26	1.67
27	1.71
28	1.74
29	1.78
30	1.81

Table 8:

15-year Term at 5% Interest			
Year	**Principal**	**Interest**	**Balance**
0	$901,630.06	$980,458.77	$33,098,369.94
1	$1,608,038.40	$1,618,399.59	$31,490,331.54
2	$1,690,308.70	$1,536,129.30	$29,800,022.84
3	$1,776,788.10	$1,449,649.90	$28,023,234.74
4	$1,867,691.95	$1,358,746.04	$26,155,542.79
5	$1,963,246.62	$1,263,191.38	$24,192,296.17
6	$2,063,690.04	$1,162,747.96	$22,128,606.13
7	$2,169,272.34	$1,057,165.66	$19,959,333.79
8	$2,280,256.43	$946,181.57	$17,679,077.36
9	$2,396,918.68	$829,519.32	$15,282,158.68
10	$2,519,549.58	$706,888.41	$12,762,609.10
11	$2,648,454.52	$577,983.47	$10,114,154.58
12	$2,783,954.48	$442,483.51	$7,330,200.10
13	$2,926,386.88	$300,051.12	$4,403,813.22
14	$3,076,106.38	$150,331.61	$1,327,706.84
15	$1,327,706.84	$16,672.35	$0.00
Total	$34,000,000.00	$14,396,599.96	

Table 9:

30-year Term at 8% Interest			
Year	**Principal**	**Interest**	**Balance**
0	$162,922.60	$1,583,437.08	$33,837,077.40
1	$297,546.25	$2,696,213.21	$33,539,531.15
2	$322,242.44	$2,671,517.02	$33,217,288.71
3	$348,988.40	$2,644,771.06	$32,868,300.31
4	$377,954.27	$2,615,805.19	$32,490,346.04
5	$409,324.29	$2,584,435.17	$32,081,021.75
6	$443,298.00	$2,550,461.46	$31,637,723.75
7	$480,091.52	$2,513,667.94	$31,157,632.23
8	$519,938.88	$2,473,820.58	$30,637,693.35
9	$563,093.55	$2,430,665.91	$30,074,599.80
10	$609,830.03	$2,383,929.43	$29,464,769.77
11	$660,445.63	$2,333,313.83	$28,804,324.14
12	$715,262.29	$2,278,497.17	$28,089,061.85
13	$774,628.71	$2,219,130.76	$27,314,433.14
14	$838,922.51	$2,154,836.96	$26,475,510.63

15	$908,552.66	$2,085,206.80	$25,566,957.97
16	$983,962.08	$2,009,797.38	$24,582,995.89
17	$1,065,630.45	$1,928,129.01	$23,517,365.44
18	$1,154,077.25	$1,839,682.21	$22,363,288.19
19	$1,249,865.09	$1,743,894.37	$21,113,423.10
20	$1,353,603.28	$1,640,156.18	$19,759,819.82
21	$1,465,951.69	$1,527,807.78	$18,293,868.13
22	$1,587,624.95	$1,406,134.51	$16,706,243.18
23	$1,719,397.04	$1,274,362.42	$14,986,846.14
24	$1,862,106.15	$1,131,623.31	$13,124,739.99
25	$2,016,660.04	$977,099.42	$11,108,079.95
26	$2,184,041.83	$809,717.63	$8,924,038.12
27	$2,365,316.22	$628,443.24	$6,558,721.90
28	$2,561,636.30	$432,123.16	$3,997,085.60
29	$2,774,250.85	$219,508.61	$1,222,834.75
30	$1,222,834.75	$24,565.04	$0.00
Total	$34,000,000.00	$55,812,753.84	