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The Feasibility and Current Estimated Capital Costs of Producing Jet Fuel at Sea Using Carbon Dioxide and Hydrogen

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14. ABSTRACT
A cost/benefit and energy balance analysis has been done to address the critical scientific and technical challenges that impact the economic feasibility of producing jet fuel at sea using carbon dioxide and hydrogen. The report also evaluates the capital cost, operation maintenance, and electrical generation costs for synthesizing jet fuel at sea.

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THE FEASIBLITY AND CURRENT ESTIMATED CAPITAL COSTS OF PRODUCING JET FUEL AT SEA USING CARBON DIOXIDE AND HYDROGEN

1.0 BACKGROUND

Producing jet fuel that meets MIL-DTL-5624 JP5 specification at sea utilizing carbon and hydrogen sources available in seawater is envisioned. In-theater, fuel synthesis is a "game changing" proposition that would offer the Navy significant logistical and operational advantages by reducing dependence on increasingly expensive fossil fuels and by reducing fuel logistic tails and their vulnerabilities.

Technologies currently exist to synthesize hydrocarbon fuel on land, given sufficient primary energy resources such as coal and natural gas [1,2]. Most of these technologies are not CO_2 neutral, and they are not practical for a sea-based operation.

The principal carbon source for hydrocarbon production at sea would be carbon dioxide from the ocean. The world's oceans contain approximately 100 mg of CO_2 per liter of seawater. Approximately 2 to 3% of the CO_2 is in the form of a dissolved gas and the remaining 97 to 98% is in the chemically bound state as bicarbonate and carbonate [3,4]. The concentration of CO_2 in the atmosphere is approximately 370 ppm (v/v) which is 0.7 mg/L (w/v). Comparing this value on a w/v basis to that found in the ocean (100 mg/L), it is readily apparent the concentration of bound and dissolved CO_2 in the ocean is about 140 times greater than that found in air [1]. Thus if processes are developed to take advantage of the higher concentration of CO_2 in seawater coupled with more efficient catalysts for the heterogeneous catalysis of CO_2 and hydrogen, a viable jet fuel production process at sea may be possible. In addition from an environmental perspective, such a combination of integrated processes would have tremendous benefit in reducing the impact CO_2 has on climate change. In effect the process is CO_2 neutral and also eliminates the emission of sulfur and nitrogen compounds that are produced from the combustion of petroleum derived fossil fuel.

2.0 INTRODUCTION

A cost/benefit and energy balance analysis that addresses the critical scientific and technical challenges that impact the economic feasibility of producing jet fuel at sea using CO_2 and hydrogen has been proposed. Figure 1 is a schematic diagram showing the basic process variables involved in producing jet fuel at sea. This report summarizes the theoretical amounts of carbon and hydrogen feedstock needed to synthesize 100,000 gallons of jet fuel a day, and the energy requirements associated with acquiring hydrogen for the process based on current technologies as a first step in an initial engineering analysis of all the process variables [5]. In addition this report will evaluate the capital cost, operation and maintenance, and electrical generation costs based on current technologies for two different scenarios of producing jet fuel at sea [6]. The two scenarios for producing electrical power for the jet fuel process at sea are the Ocean Thermal Energy Conversion (OTEC) process and nuclear power. The results provide insight into the economic benefits of a shipboard based fuel synthesis for the Navy.

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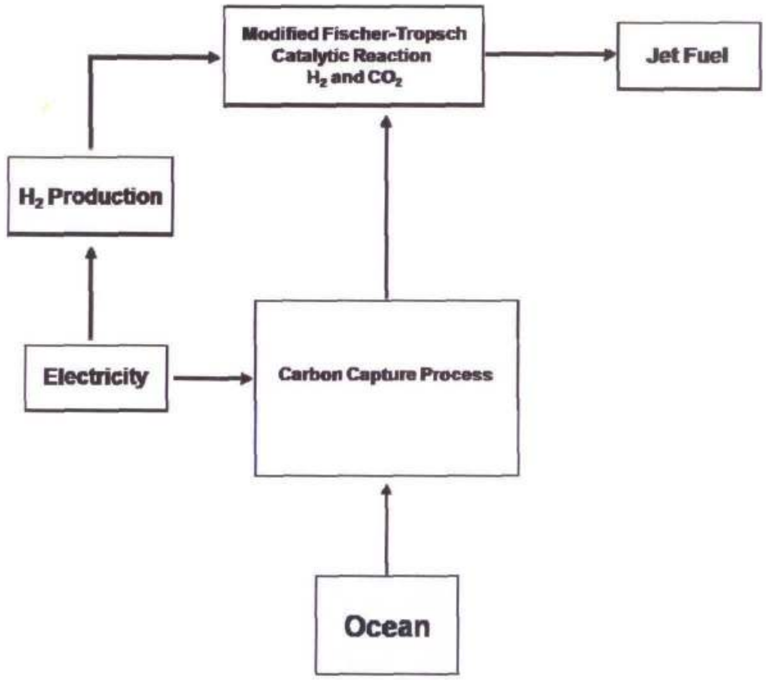

Figure 1: Basic Process Variables For Producing Jet Fuel At Sea

3.0 RESULTS AND DISCUSSION

3.1 Theoretical Determination of Carbon and Hydrogen Needed to Synthesize 100,000 gal/day Jet Fuel

Table 1 provides a summary of all values utilized to make the initial theoretical determinations reported within.

Table 1. Conversion Table

Density of hydrogen	0.0899 kg/m^3
Density of carbon dioxide	1.98 kg/m^3
Density of jet fuel	750 kg/ m^3
Density of seawater	1027 kg/m^3
Concentration of CO_2 in seawater	100 mg/L seawater (0.1 kg/m^3)
Energy content of jet fuel	118,000 BTU/gallon
1 kilowatt hour	3 412.14 BTU
1 gram	1 x 10^{-6} metric ton

In the initial volumetric analysis for production of 100,000 gal/day of jet fuel, there are two principle reactions that take place. In equation 1 below, CO_2 is reduced to CO by the reverse water gas shift reaction. Then CO is converted to a minimum hydrocarbon chain length of eleven by the Fischer-Tropsch reaction shown in equation 2 [7]. The sum of equations 1 and 2 results in equation 3.

$11CO_2 + 11H_2 \rightarrow 11CO + 11H_2O$ (1) Reverse water gas shift

$11CO + 23H_2 \rightarrow C_{11}H_{24} + 11H_2O$ (2) Fischer Tropsch

$11CO_2 + 34H_2 \rightarrow C_{11}H_{24} + 22H_2O$ (3) Sum of equations 1 and 2

Thus to produce 100,000 gal/day of $C_{11}H_{24}$ 1,815,986 moles/day of $C_{11}H_{24}$ is needed. To produce 1,815,986 moles/day of $C_{11}H_{24}$ the reaction in equation 3 suggests we need the following amounts of CO_2 and H_2:

11 x (1,815,986 moles/day) CO_2 = 19,975,846 x 44 grams/mol = 878,937,224 grams/day
34 x (1,815,986 moles/day) H_2 = 6,1743,524 x 2 grams/mol = 123,487,048 grams/day

Using the densities for carbon dioxide and hydrogen from Table 1, a flow rate of 18,496 m^3/hour or 443,904 m^3/day of carbon dioxide and a flow rate of 57,233 m^3/hour or 1,373,604 m^3/day of hydrogen is needed to make 100,000 gallons per day of jet fuel.

The world's oceans contain approximately 100 mg/L of CO_2. Assuming 100% carbon capture efficiency from seawater, the minimum amount of seawater that must be processed is 8,900,000 m^3/day. This is equivalent to a cube of seawater that is about 200 meters on each side.

3.2 Theoretical Determination of Power Requirements For Hydrogen Needed To Synthesize 100,000 gal/day Jet Fuel

For this analysis, hydrogen will be produced from commercial off the shelf conventional electrolysis equipment like the unit shown in Figure 2 [8].

Figure 2: Commercial Electrolysis Equipment From Hydrogen Technologies

Using proton exchange membrane electrolysis or alkaline equipment will result in sufficient hydrogen production for this process. Since 1,373,604 m^3/day of hydrogen is needed to make

100,000 gallons per day of jet fuel, it is estimated by the following calculations that the minimum amount of seawater that must be processed for electrolysis is:

Electrolysis Reaction $2H_2O \rightarrow 2H_2 + O_2$ (4)

From the electrolysis reaction, 1,111 metric tons of H_2O seawater/day or 1,082 m^3/day H_2O seawater must be processed.

Typical large scale electrolyzers (4m x 4m x 13m) like the one shown in Figure 2 produce 485 m^3/hr of hydrogen at standard temperature and pressure (STP) and require 4.3 kWhr/m^3 (STP) at maximum output. This is based on sales values from Hydrogen Technologies [8]. Thus if 4.3 kWhr/m^3 is the electrical consumption rate for conversion of water to its components of hydrogen and oxygen and 57,233 m^3/hour of hydrogen is needed for synthesis of 100,000 gallons/day of jet fuel, then we would need 246,102 kWhr/hr or simply 246 MWhr/hr.

In terms of BTU, a 100,000 gallons/day of jet fuel contains approximately 1.2 x 10^{10} BTU/day of energy. The parasitic load for producing hydrogen is 246,102 kWhr/hr or 5,906,448 kWhr/day. This is equivalent to 2.0 x 10^{10} BTU/day. As a result there is no surplus of energy out and in fact it takes more energy to make the fuel as shown below:

1.2 x10^{10} BTU/day for 100,000 gallons per day process – 2.0 x 10^{10} BTU/day for hydrogen generation.

= - 8,353,637,106 BTU/day

The overall energy balance would be unfavorable with the produced liquid hydrocarbon fuel being a little over half the energy of the entire process needed to produce the fuel. It should be noted that the actual hydrogen and carbon monoxide/dioxide gas phase reactions are catalytic and highly exothermic, so this would tend to improve overall energy balances [7]. Though the energy balance is unfavorable, electricity can't and never will be able to fuel jet turbines, so this unfavorable energy balance should not be a deciding factor against this proposed energy conversion scheme.

3.3 Key Technical Parameters for Jet Fuel Synthesis at Sea

Table 2 summarizes the theoretical amounts of carbon dioxide and hydrogen needed to synthesize a given amount of $C_{11}H_{24}$ (jet fuel) along with the minimum amount of seawater that must be processed to acquire the carbon dioxide and hydrogen. In addition the Table provides the minimum power requirements to obtain enough hydrogen for the production of $C_{11}C_{24}$ (jet fuel). The energy in jet fuel has been converted into BTU's, along with the energy to produce the hydrogen to make the jet fuel, to provide a clearer picture of the energy balance of the process. To put Table 2 values into context, the smallest operating crude oil refinery produces 400,000 gal/day at an energy cost of 1.0 x 10^{10} BTU, and Canadian tar sands upgrading processes produce 70,000 m^3/day of hydrogen [9]. The mass and energy required for each of these processes are not considered to be atypical.

Table 2. Theoretical Amounts of H_2 and CO_2 from Seawater for Jet Fuel Process at Sea.

Jet vol Produced gal/day	Jet Energy BTU/day	CO_2 Needed m^3/day	Seawater Processed for CO_2 m^3/day	H_2 required m^3/day	H_2O Processed for H_2 m^3/day	MW required	BTU for H_2 required
1,000	1.2×10^8	4,439	8.9×10^4	13,736	11	2.5	2.0×10^8
10,000	1.2×10^9	44,390	8.9×10^5	137,360	108	25	2.0×10^9
41,000	4.8×10^9	182,002	3.6×10^6	563,178	444	100	8.3×10^9
50,000	5.9×10^9	221,950	4.4×10^6	686,800	541	123	1.0×10^{10}
100,000	1.2×10^{10}	443,900	8.9×10^6	1,373,600	1082	246	2.0×10^{10}

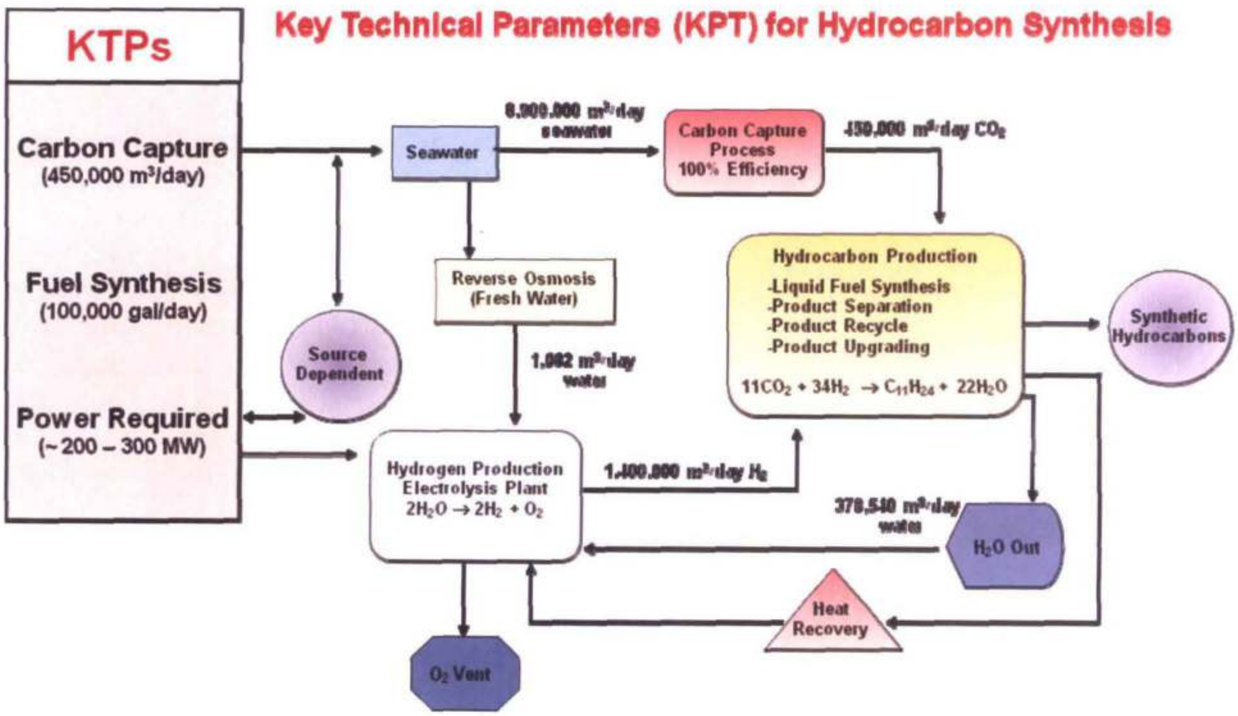

Figure 3: Parameters for Jet Fuel Synthesis of 100,000 gallons/day

The schematic in Figure 3 uses the values in Table 2 to begin to illustrate and summarize the key technical variables involved in liquid hydrocarbon synthesis. This initial analysis is the first step towards deriving a cost benefit model that can be adjusted to reflect breakthroughs in research and variability in price and availability of petroleum derived fuels. The future power requirements for the process may be derived from nuclear power or OTEC sources. The US Navy has committed to building OTEC as a source of electricity for bases located in Diego Garcia, Guam, and Hawaii [10,11]. The derivation of the values will be used below as the premises for the initial cost/benefit analysis of producing liquid hydrocarbon fuel at sea using OTEC or nuclear power as the electrical source.

3.4 Jet Fuel Synthesis By Ocean Thermal Energy Conversion (OTEC)

The OTEC process converts solar thermal radiation absorbed by the ocean into electrical power [12,13]. Some of the biggest challenges facing this technology are its initial capital cost and ability to create a large scale power plant (100 to 200 megawatts (MW)) capable of withstanding the ocean environment. Lockheed Martin (LM) has estimated that such a facility would cost $1.5 billion and Sea Solar Power Inc. (SSP) estimates $0.9 billion (Table 2) [11]. Since there is renewed interest in this technology, an additional Naval application can be envisioned. The creation of a novel ocean based paradigm which combines the energy produced from solar OTEC with CO_2 captured from seawater for production of liquid hydrocarbon fuel at sea for Naval use.

During the OTEC process dissolved carbon dioxide (CO_2) in ocean water is liberated as a gas. There is potential to harvest the CO_2 generated from the process and use it as a carbon source for the production of synthetic liquid hydrocarbon fuel (Jet Fuel).

The CO_2 content liberated from ocean water by the OTEC process is actually only 2 to 3% of the total CO_2 available from ocean water. The remainder of this CO_2 is bound as dissolved bicarbonate. The concentration of bound and dissolved CO_2 in the ocean is about 140 times greater than that found in air [1]. Thus if processes are developed to take advantage of the higher concentration of CO_2 in ocean water coupled with the OTEC process, the overall efficiency of recovery would be significantly improved. This would greatly increase jet fuel production.

It is estimated that a large platform producing 100 MW from OTEC must remove the heat energy content of 1.12 billion gallons of seawater per day [12,13]. Thus it can be envisioned that 20 to 30 tons of carbon from CO_2 is available from the OTEC process itself and we propose additional processes to remove the remaining 97% bound as bicarbonate. This process would take advantage of the ocean water already being pumped for the OTEC heat removal, thus for each gallon of water pumped the heat energy content **and** the total carbon content will be removed at the same time. This would result in 500 tons of additional CO_2 per day for producing jet fuel.

If CO_2 is used as a carbon feedstock for the production of jet fuel, a source of hydrogen is required [5]. A 100 MW OTEC plant would be capable of supplying enough electricity to generate 563,000 m^3/day if hydrogen through commercial off the shelf conventional electrolysis equipment. The hydrogen produced by this conventional process would then be utilized in a gas to liquids catalytic process capable of producing approximately 41,000 gallons of liquid hydrocarbon per day as previously reported [5]. Table 2 suggests that a 200 MW OTEC plant is theoretically capable of producing enough electricity to generate 82,000 gallons of liquid hydrocarbon fuel per day.

The generation of electricity is by far the greatest capital cost for a jet fuel process at sea that uses hydrogen and carbon dioxide. For a 200 MW OTEC plant, it would require 47,000 m^3/hour of hydrogen (Table 2). Based on sales values from Hydrogen Technologies, an estimated 97 units would be needed for hydrogen production at $2 million per unit for an overall electrolysis capital cost of $194 million (Table 3) [8].

Table 3. Estimated Cost of Various Major Components of the OTEC/Jet Fuel Process.

Plant	Cost ($)
Capital Cost OTEC Plant (LM)	1,500,000,000
Capital Cost OTEC Plant (SSP)	900,000,000
Capital Cost Hydrogen Units (Jet Fuel)	194,000,000
Capital Cost Carbon Capture (Jet Fuel)	16,000,000
Capital Cost of Gas to Liquid Reactors (GTL) (Jet Fuel reactor)	140,000,000
Capital Cost LM OTEC + Jet Fuel	1,850,000,000
Capital Cost SSP OTEC + Jet Fuel	1,250,000,000

In addition to the electrolysis units, commercial reactors and carbon capture materials must also be accounted for in the overall cost of a jet fuel process. There are several commercial gas to liquid (GTL) reactors units that may be retrofitted to accommodate any catalysis process used for liquid hydrocarbon fuel production. Recent cost estimates for jet fuel production of 791,000 gallons per day suggest that a GTL unit would cost $356 million [14]. Since a 200 MW OTEC plant can produce an estimated 82,000 gallons per day of fuel from carbon dioxide and hydrogen, then $140 million was the total estimated capital cost for the GTL system (Table 3). An additional $16 million in capital costs was estimated for a carbon capture system (Table 3).

Table 4 is a cost summary that estimates the price of electricity and fuel produced by OTEC and current commercial jet fuel technologies by both LM and SSP. Table 4 has been divided into two parts reflecting the major difference in capital cost estimates of LM and SSP. Sea Solar Power Inc is a privately funded company that is developing and testing critical components of a Rankine cycle OTEC plant. The Rankine cycle is a thermodynamic cycle that converts heat into work and it is this cycle that produces 80% of all electrical power throughout the world [15]. The values in Table 4 do not take into account advances in cost savings that would be made by critical advances in carbon capture technologies, hydrogen production, and reactor design.

Table 4. Estimated Cost ($) of Electricity and Fuel Produced by OTEC Process.

Cost and Energy Requirements for OTEC and OTEC/Jet Fuel process	**OTEC Plant (LM)**	**OTEC + 82,000 gpd Jet Fuel Process (LM)**		**OTEC Plant (SSP)**	**OTEC + 82,000 gpd Jet Fuel Process (SSP)**
Capital Costs	1,500,000,000	1,850,000,000		900,000,000	1,250,000,000
Capital Cost Amortize 30 years @ 8% per year	132,000,000	168,000,000		73,000,000	110,000,000
Operation and Maintenance @ 5% per year	75,000,000	92,000,000		45,000,000	63,000,000
Capital Costs + OPM per year	207,000,000	260,000,000		118,000,000	173,000,000
Output	200 MW	200 MW		200 MW	200 MW
MWhr @ 1day	4,800			4,800	
MWhr @365	1,752,000			1,752,000	
Operational days per year	365	365		365	365
Total Cost MWhr	118.00			67.00	
Hydrogen Unit Energy kWhr/m3		4.3			4.3
Hydrogen Production m3/day		46,931			46,931
Gallons of Synthetic Fuel per day		82,000			82,000
Gallons of Synthetic Fuel per year		29,930,000			29,930,000
Total Cost	12 cents/kwhr	8.70 dollars/gallon		7 cents/kwhr	5.78 dollars/gallon

Table 4 estimates that an OTEC plant constructed by LM would be capable of producing electricity for $0.12/kwhr. The additional capital costs associated with producing fuel by the LM OTEC process increased the capital cost from $1.5 billion (OTEC only) to $1.85 billion (LM OTEC + Jet Fuel). The result is a fuel that could be produced at an estimated cost of $8.70/gallon. When the capital cost of LM's process is compared to SSP's process, the estimated electricity that can be supplied to the grid is reduced from 0.12/kwhr to 0.07 /kwhr. The cost per gallon of jet fuel using the SSP OTEC was reduced from $8.70/gallon to $5.80/gallon. It is clear by comparing the capital cost of both OTEC processes, that advances in GTL reactor technology and hydrogen production will have an impact on the overall feasibility of producing fuel from an OTEC process by lowering the overall capital costs. However such a great difference in capital cost estimates for a 200 MW OTEC plant between the two companies suggests that technological advances in heat exchangers and materials for processing water 3,000 feet below the sea surface will make energy generation through this method at a comparable price range to nuclear, coal, natural gas, and synthetic fuel.

3.5 Jet Fuel Synthesis By Nuclear Power

The U.S. Navy's Nimitz class aircraft carriers are powered by two nuclear fission pressurized water reactors (PWRs) capable of producing a total minimum of 275 MW of power [16]. The estimated capital cost of these light water reactors (LWR) is 1,200 dollars per kilowatt of electricity (Table 5) [14]. Table 6 is a summary of the capital costs for producing electricity or jet fuel at sea aboard a Navy littoral platform using 200 MW nuclear reactor for the purpose of comparison to an equivalent 200 MW OTEC process.

Table 5. Estimated Cost of Naval Shipboard/Jet Fuel Process.

Plant	**Cost ($)**
Capital Cost Floating Platform	650,000,000
Capital Cost Nuclear Reactor	240,000,000
Capital Cost Hydrogen Units (Jet Fuel)	194,000,000
Capital Cost Carbon Capture (Jet Fuel)	16,000,000
Capital Cost of Reactors (Jet Fuel)	140,000,000
Capital Cost Platform + Nuclear Reactor	890,000,000
Capital Cost Platform + Nuclear Reactor + Jet Fuel	1,240,000,000

Table 6. Estimated Cost ($) of Electricity and Fuel Produced by Nuclear Process.

Cost and Energy Requirements for Platform and Nuclear Reactor/Jet Fuel process	Nuclear Electric Process	Nuclear + 82,000 gpd Jet Fuel Process
Capital Costs	890,000,000	1,240,000,000
Capital Cost Amortize 30 years @ 8% per year	78,000,000	110,000,000
Operation and Maintenance @ 5% per year	45,000,000	62,000,000
Capital Costs + OPM per year	123,000,000	172,000,000
Output	200 MW	200 MW
MWhr @ 1day	4,800	
MWhr @365	1,752,000	
Operational days per year	365	365
Total Cost MWhr	70.00	
Hydrogen Unit Energy kWhr/m3		4.3
Hydrogen Production m3/day		46,931
Gallons of Synthetic Fuel per day		82,000
Gallons of Synthetic Fuel per year		29,930,000
Total Cost	7 cents/kwhr	5.74 dollars/gallon

Tables 4 and 6 show that production of electricity ($0.07/kwhr) or jet fuel ($5.74/gallon) by current Navy nuclear reactor technology is less expensive to produce than the electricity ($0.12 kwhr) or jet fuel ($8.70/gallon) produced by the LM OTEC process. SSP's capital cost estimates (Tables 4 and 6) suggest that either electricity production or jet fuel production is comparable to that generated by current Navy nuclear power (Tables 4 and 6).

Size and mobility of the littoral platform for a nuclear reactor process could significantly either increase or lower the capital cost of such a process (Table 5). In addition, the advances in nuclear reactor technology suggest that increases in hydrogen production for a jet fuel process may be achievable for the same megawatt electric power rating [17]. More hydrogen availability translates into more jet fuel production in a carbon rich environment such as the ocean. Thus the overall capital costs of producing the jet fuel at sea by nuclear power is reduced.

High-temperature reactors (HTR) such as gas turbine-modular helium reactors (GT-MHR) are helium-cooled and operate at higher temperatures (850 °C) than traditional LWR (315 °C) [17]. The energy conversion factor for HTR reaches 47% due to better thermodynamic matching of the GT and the HTR requirements. This thermodynamic match is not as favorable for the LWR whose design and operation is based on steam plant principles. This results in only a 32% conversion efficiency. The higher operating temperatures of HTR may be used to assist other technological processes such as hydrogen production through thermochemical cycles.

3.6 Cost Analysis of Jet Fuel Synthesis at Sea

3.6.1 Electricity

The average retail price of electricity across all sectors (residential, commercial, industrial, and transportation) in the US in 2009 was $0.095/kwhr [18]. In more remote areas of the country like Hawaii, the average price in 2009 was $0.23/kwhr [18]. These prices indicate that present OTEC technology (LM $0.12/kwhr and SSP 0.07/kwhr) could be quite competitive with commercial methods of producing electricity by nuclear power plants and coal fired power plants. This is particularly true in Hawaii where the Navy has proposed OTEC as a solution to Hawaii's future energy needs. The demand and availability of energy from fossil fuels will continue to result in large swings in price [19]. Thus any substantial breakthroughs made in the OTEC process to reduce its initial capital cost will make this technology far more competitive for other areas in the US and around the world.

Table 7. U.S. Energy Information Administration Average Retail Price of Electricity in 2009 (cents per kilowatt hour) [18].

US Location	**Residential**	**Commercial**	**Industrial**	**Transportation**	**Average**
New England	16.32	15.76	11.43	7.65	14.99
Mid Atlantic	14.52	13.11	7.95	12.97	12.76
East North Central	10.32	8.71	6.41	7.64	8.63
West North Central	8.27	6.85	5.27	6.28	7.00
South Atlantic	10.69	9.37	6.54	10.62	9.51
East South Central	8.84	8.8	5.61	9.39	7.63
West South Central	10.4	8.75	6.16	9.86	8.65
Mountain	9.7	8.14	5.58	8.41	7.99
Pacific Contiguous	11.97	10.29	7.29	8.34	10.39
Pacific Noncontiguous	21.63	19.37	18.39	----	19.83
US Average	**10.93**	**9.73**	**6.52**	**11.01**	**9.44**

3.6.2 Jet Fuel Production

The Defense Energy Support Center reports the average cost of JP-5 and F76 diesel in April of 2010 to be $2.82/gallon JP-5 and $2.79/gallon F76 (Table 8) [20]. This price doesn't include logistical storage and delivery of the fuel, which in many cases is 2 to 3 times the initial price of the fuel. While the price of fuel at $2.80/gallon doesn't appear to be alarming, Figure 3 shows that the price of fuel (jet and diesel) to the Navy has steadily increased since FY2000. It has gone up from an average of $0.60/gallon in FY2000 to $2.80/gallon in FY2010. If this 4.7 fold increase in fuel prices over 10 years continues to occur, by 2020 fuel will cost over 13 dollars a gallon. Table 8 and Figure 4 also show a spike in fuel cost in FY2008. By the end of FY2008 the Navy was purchasing fuel for over $4/gallon. Though the cost was significantly reduced to an average $1.94/gallon in FY2009, this significant swing in price will only become more exacerbated and uncertain as global demand for fossil fuel increases and its availability decreases [19].

This cost analysis suggests that jet fuel production by current OTEC and Navy nuclear power will produce a fuel that costs approximately $6/gallon (Table 4 and 6). Though this price is over 2 times the cost of the fuel the Navy is purchasing currently (Table 8), in ten years this fuel could be well over 2 times less expensive based on historical trends in fuel price increases. In addition, strategic placements of Navy jet fuel processes would allow for production of fuel at or near the point of use. Any production of fuel at or near the point of use would significantly reduce costs associated with logistical storage and delivery of the fuel. Presently in many instances fuel that costs $6 /gallon produced at the point of use is less expensive than fuel that costs $2.80/gallon that must be delivered to a battle group (over $8.0/gallon).

Table 8. Defense Energy Support Center Standard Price FY 2000-2010 [2]. White spaces indicate interim price changes in FY.

Fiscal Year	**Cost JP5 ($)**	**Cost F76 ($)**
FY 2000	0.63	0.60
FY 2001	1.03	0.98
FY 2002	1.02	0.96
FY 2003	0.86	0.81
FY 2004	0.93	0.84
FY2005	1.36	1.33
FY2005	1.76	1.73
Average FY2005	1.56	1.53
FY2006	2.16	2.13
FY2006	2.02	1.99
FY2006	2.55	2.52
Average FY006	2.24	2.21
FY2007	2.32	2.29
FY2007	2.16	2.13
Average FY2007	2.24	2.21
FY2008	2.33	2.31
FY2008	3.06	3.03
FY2008	4.09	4.06
Average FY2008	3.16	3.13
FY2009	2.51	2.48
FY2009	1.68	1.65
FY2009	1.46	1.43
FY2009	2.15	2.12
Average FY2009	1.95	1.92
FY2010	2.80	2.77
FY2010	2.84	2.81
Average FY2010	2.82	2.79

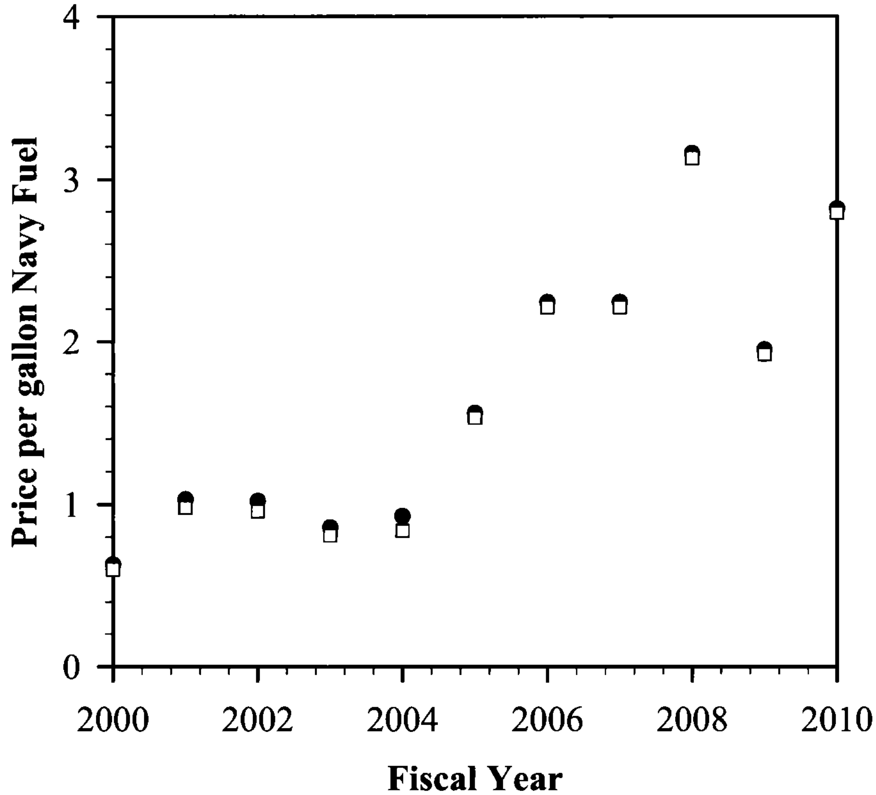

Figure 4: Graph of Defense Energy Support Center Standard Prices FY 2000-2010 for JP-5 (●) and F76 (□)

4.0 CONCLUSIONS

The theoretical amount of carbon dioxide and hydrogen needed to synthesize 100,000 gallons of fuel a day for the Navy along with the minimum process requirements for seawater to obtain these materials as a feedstock has been determined. Concurrently these values have been used to illustrate the economic feasibility of producing jet fuel at sea using electrical power from current OTEC and or Navy nuclear power technology.

The initial calculations indicate that the production of hydrogen requires a significant amount of energy to synthesize the fuel and that this energy is almost twice the amount of energy that would be stored in the liquid hydrocarbon fuel that has been synthesized. The chemical reaction to synthesize the fuel is catalytic in nature and is highly exothermic which will contribute to improving this energy balance.

The cost analysis of producing jet fuel at sea using CO_2 and hydrogen by current OTEC or Navy nuclear power technology is presented in efforts to build on previous theoretical results and process requirements for determining the economic feasibility of producing jet fuel at sea using

CO_2 and hydrogen [5]. The analysis for both processes indicates that jet fuel can be produced for as little as $6/gallon. This is significant as historical data suggests that in 10 years the price of fuel for the Navy could be over $13/gallon excluding the costs associated with logistical storage and delivery. The analysis also serves to illustrate that the estimated initial capital costs associated with jet fuel production (reactor, electrolysis equipment, carbon capture) are far less than the capital costs of developing the OTEC or nuclear platforms (Tables 3 and 5) at sea in which to produce the jet fuel. While hydrogen production is the largest capital cost in jet fuel production, advances in nuclear power technology could lead to increases in hydrogen production with no additional energy penalties. This translates into more jet fuel for the same capital costs. In addition there have been recent advances in carbon capture technologies in which a portion of the hydrogen needed for the jet fuel process is produced with no additional energy penalties [21,22]. This technological breakthrough could result in the need for less hydrogen electrolysis equipment, and therefore a reduction in overall capital costs and footprint needed for the process.

The analysis further suggests the OTEC processes proposed (LM or SSP) could be competitive with commercially available electricity generation. This is particularly true for the remote areas of the world in which NAVFAC and ONR have expressed interest in OTEC as a solution to future electrical energy needs. These places include the naval installations at Guam, Diego Garcia, and Hawaii.

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