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FULLY BURDENED COST OF FUEL USING INPUT-OUTPUT ANALYSIS

by

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The Duncan Hunter National Defense Authorization Act for Fiscal Year 2009 mandates that the Fully Burdened Cost of Fuel, including the total cost of procuring and transporting fuel, infrastructure operating costs, and the cost of force protection for the logistics tail, be applied in trade-off analyses for all Department of Defense systems that create a demand for energy.

Using data from the Defense Logistics Agency Energy, this thesis builds a model of its worldwide supply chain for bulk fuels, and uses the principles of input-output analysis to calculate the total cost to deliver three fuel types to each destination in the supply chain. Although the Defense Logistics Agency Energy charges a standard price to each service for bulk fuels, these results show that they incur very different costs, ranging from less than a penny per gallon to over 70 cents per gallon, to deliver to different locations. Given the appropriate data on services' fuel distribution networks, a Department of Defense-wide extension of the Bulk Fuels Distribution Model could be used to replace the current seven-step Fully Burdened Cost of Fuel process with a single step, allowing for less complex and more accurate Fully Burdened Cost of Fuel calculations.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEM	Atlantic, Europe, and the Mediterranean
AOAs	Analysis of Alternatives
DAG	Defense Acquisition Guidebook
DAU	Defense Acquisition University
DDG	Guided Missile Destroyer
DDR&E	Director of Defense Research and Engineering
DESC	Defense Energy Support Center
DFSP	Defense Fuel Support Point
DLA	Defense Logistics Agency
DoD	Department of Defense
DoDI	Department of Defense Instruction
DoN	Department of the Navy
DoDAAC	Department of Defense Activity Address Code
DSB	Defense Science Board
EIO	Enterprise Input-Output Analysis
FBCE	Fully Burdened Cost of Delivered Energy
FBCF	Fully Burdened Cost of Fuel
FY	Fiscal Year
IEGC	Inland East and Gulf Coast
IO	Input-Output Analysis
JASON	JASON Group
KPPs	Key Performance Parameters
LMI	Logistics Management Institute Government Consulting
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Programs
MILSPECS	Military Specifications
MOH	Motor Oil Hellas
MORS	Military Operations Research Society
NATO	North Atlantic Treaty Oranization
NDAA	National Defense Authorization Act

NPS	Naval Postgraduate School
OASN	Office of the Assistant Secretary of the Navy for Research, Development and Acquisition
OSD	Office of the Secretary of Defense
OUSD (AT&L)	Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics
OSD(EPP)	Office of the Assistant Secretary of Defense for Operational Energy, Plans & Programs
QDR	Quadrennial Defense Review
Q West	Qayyarah Airfield West
RMWC	Rocky Mountain and West Coast, United States
SECDEF	Secretary of Defense
TF	Task Force
TNPS	Turkey NATO Pipeline Sytems
USG	United States Gallon
USN	United States Navy
USMC	United States Marine Corps
WESTPAC	Western Pacific

EXECUTIVE SUMMARY

The U.S. armed forces consumed five billion gallons of bulk fuel in Fiscal Year (FY) 2011 at operating locations around the world. A decrease in energy demand in the battle space would reduce the logistics tail required to support operational missions and would create tactical, operational, and strategic benefits in terms of cost, force protection, and overall effectiveness of the fighting force. Saving a gallon of fuel in energy-demanding systems results in more than a gallon of fuel saved, because there are additional savings in operating and transportation costs throughout the distribution system.

By congressional mandate and Department of Defense (DoD) policy, the Fully Burdened Cost of Fuel (FBCF) must be used in cost estimates for energy-demanding systems in many acquisition analyses and decisions. The FBCF is an estimate of the total cost of procuring and transporting fuel, fuel-related infrastructure operating costs, and the cost of force protection for the logistics tail. The purpose of the FBCF is to provide DoD acquisition decision makers with more accurate information on the effects of energy-demanding systems in order to support more informed decisions.

This thesis uses the principles of Input-Output analysis (IO) to calculate the FBCF. IO models show how production levels in one component in an economy generate successive rounds of demand for products of further components. The Bulk Fuels Distribution Model was created using Defense Logistics Agency (DLA) Energy data and information to track the cost to transport fuel along the DLA Energy bulk fuels supply chain and estimate delivery costs.

Based on the Bulk Fuels Distribution Model, delivery costs were calculated for 473 DoD components receiving fuel in 2011. This model calculates the total cost to deliver JP-5, JP-8, and F-76 to each destination component in the DLA Energy supply chain. These calculations track all costs along the supply chain from point of procurement, through all stages of the supply chain, to the final destination. The resulting delivery costs are compared across locations, regions, and fuel types to provide insights on the actual cost for delivering fuel worldwide. In addition, the use of the delivery cost results to conduct an Analysis of Alternatives (AOAs) is demonstrated, and the feasibility

of using the IO approach to estimate the FBCF for other portions of the DoD fuel supply chain is evaluated. The Bulk Fuels Distribution Model provides a basis for quantitative analysis of the impact of a change in fuel demand on total DoD costs, which supports better-informed decisions for AOAs.

Using the IO approach could improve estimates of the FBCF in the DoD. The DLA Energy charges a standard price to each service, yet incurs different costs to deliver to different locations. The current Office of the Secretary of Defense (OSD) seven-step FBCF process only takes into account the DLA Energy standard price. The Bulk Fuels Distribution Model can use a much better estimate of the DLA Energy's actual costs for delivery to each location to gain a more accurate representation of the actual FBCF.

The seven-step calculation could be condensed to a single step using a model of the same structure as the Bulk Fuels Distribution Model if the services maintained data analogous to the DLA Energy data. A single-step process would allow for less complex and more accurate FBCF calculations. Additionally, the OSD seven-step process allows for variation in FBCF calculations by service, but this approach provides a relatively simple methodology that could be used by all services to minimize inter-service differences in calculations.

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I. INTRODUCTION

Energy security is a part of our national security. The United States armed forces consumed five billion gallons of bulk fuel in FY11 and “as long as U.S. forces rely on large volumes of energy, the vulnerability and volatility of supplies will continue to raise risks and costs for the armed forces” (Office of the Assistant Secretary of Defense for Operational Energy, Plans & Programs (OSD [EPP]), 2011, p. 1). As a matter of national security, the U.S. armed forces must reduce the amount of fuel required to conduct global military operations.

The missions of the U.S. military require large amounts of fuel based on long travel distances, rapid deployments, and a sustained global presence. In support of these missions, a large volume of fuel is transported through a robust supply chain. This supply chain creates long logistics tails, which generates tactical challenges and risks. By increasing energy efficiency and decreasing the demand for energy, the logistics tail can be reduced, while improving military capability, range, and endurance. A report by OSD (EPP) in 2011 stated, “Lightening the load for logistics forces is particularly relevant today. Current counterinsurgency operations and asymmetric conflicts have increased the threats to logistics forces, even as rising demand for energy is increasing the size of the logistics footprint” (OSD [EPP], 2011, p. 4). A decrease in energy demand in the battle space would reduce the logistics tail required to support operational missions and would create tactical, operational, and strategic benefits in terms of cost, force protection required, and overall effectiveness of the fighting force.

Decisions concerning U.S. force structure, posture, and strategy have a major impact on future energy demands. In a 2011 document, *Energy for the Warfighter*, the OSD (EPP) stated, “energy consumption and the associated costs and logistics challenges must be taken into account in all decisions about strategic planning, structuring, equipping, and posturing the force” (p. 10). The DoD must take energy demands into consideration when making trade-off decisions for equipping and employing future forces. In order to ensure energy is delivered to the correct place at the correct time, the DoD maintains a robust logistics infrastructure, greatly contributing to considerable overhead costs. The operating costs associated with force protection, infrastructure, transportation, and equipment greatly increase the cost of energy for the end user.

The purpose of this thesis is to calculate the FBCF using the principles of IO analysis. FBCF estimates the total cost of procuring and transporting fuel, infrastructure operating costs, and the cost of force protection for the logistics tail. Saving a gallon of fuel in energy-demanding systems results in more than a gallon of fuel saved. It also provides additional savings in operating and transportation costs throughout the distribution system. The purpose of FBCF is to provide DoD acquisition decision makers with more accurate information on the effects of energy-demanding systems in order to make more informed decisions. FBCF captures the effects of a change in the demand for energy by the end user, while taking into account the effect of the change on the operating costs involved in the complex DoD supply chain. The OSD and Congress require the DoD to use FBCF in many acquisition decision processes.

A. DEPARTMENT OF DEFENSE (DOD) POLICY

The Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) (OUSD[AT&L]) sponsored the Defense Science Board (DSB) to “identify technologies that improve fuel efficiency of the full range of weapons platforms and assess their operational, logistics, cost and environmental impacts for a range of practical implementation scenarios” (OUSD[AT&L], 1999, p. 1). The DSB is a committee of 45 civilian experts appointed by the Secretary of Defense (SECDEF) to advise DoD on scientific and technical matters. This was the DoD’s first step in investigating the impact of improved fuel efficiency, and led to further studies that identified large operating costs associated with the complex DoD fuel supply chain.

1. Energy-Related Studies and Reports

In the 2001 study, the DSB Task Force (TF) emphasized a need for the DoD to base investment decisions for energy-demanding systems on the true cost of delivered fuel and to include fuel efficiency in requirements and acquisition processes. According to the study, these processes provide the greatest potential impact for improving warfighting capability by means of reduced fuel burden.

In 2006, the Director of Defense Research and Engineering (DDR&E) contracted the JASON Group (JASON) to assess ways for the DoD to reduce its dependence on fossil fuels, based on the United States' increased dependence on foreign oil as well as increasing fuel prices. JASON is a group of scientists that advises the government on matters of science and technology. The Group's study estimated that fuel costs accounted for only 2.5%–3% of the FY05 DoD budget, but provided several reasons to minimize fuel usage across the DoD. The study reported that "fuel use is characterized by large multipliers and co-factors: at the simplest level, it takes fuel to deliver fuel" (JASON, 2006, p. iv). The study also found that the cost for the Army to deliver fuel to the front lines varies from $100 to $600 per gallon (FY05$), and the cost of air-to-air fuel delivery is in the range of $20 to $25 per gallon (FY05$). The smallest component of the cost for air-to-air fuel delivery is the standard price of the fuel. Another compelling reason for minimizing DoD fuel usage was "fuel use imposes large logistical burdens, operational constraints and liabilities, and vulnerabilities" (JASON, 2006, p. iv). Vulnerable supply chains are weaknesses that an enemy can exploit to counter capable offensive forces. JASON (2006) concluded that fuel consumed by the logistics component during fuel delivery is the most significant driver for reducing DoD fuel usage. The study advised the DoD to reduce its dependence on fossil fuels in order to decrease its logistics requirements and increase its military capabilities.

The Office of Force Transformation and Resources contracted Logistics Management Institute Government Consulting (LMI) to develop an approach to establish a DoD Energy Strategy. LMI (2007) identified "three areas of disconnect between DoD's current DoD energy consumption practices and the capability requirements of its strategic goals: Strategic, Operational, Fiscal" (LMI, 2007, p. iii). Disconnects are misalignments among the DoD's strategic objectives and current energy policies.

The strategic disconnect stems from the United States' current and future reliance on foreign oil, as well as the need to ensure sustained availability. Reliance on foreign oil will have an increasing impact on the DoD, potentially influencing future conflicts if changes are not made.

The U.S. policy of a constant global presence and operational mobility results in significant energy usage and an increasing rate of consumption, which creates the operational disconnect. Long logistics tails create vulnerabilities for combat forces, which amplify the need to reduce reliance on fuel on the battlefield. Long supply chains not only have high overhead costs, they also place service members in danger. According to United States Marine Corps (USMC) Major General Richard Zilmer, "Reducing energy use at outlying bases reduces the frequency of logistics convoys required to provided their energy needs thereby reducing danger to the Marines, soldiers, and sailors" (LMI, 2007, p. E-25).

Increased fiscal pressure and mounting costs to support and operate the military led to the fiscal disconnect. LMI (2007) recommends examining the delivered cost of fuel, which would give a greater understanding of the total fuel cost. Additionally, LMI recommends incorporating "energy considerations in all future concept developments, capability developments, and acquisition actions" (LMI, 2007, p. iv). Taking energy considerations into account when making DoD acquisition decisions will allow for more informed decisions.

The OUSD (AT&L) again sponsored a DSB TF in March 2006, with four primary purposes.

- Identify opportunities to reduce fuel demand and assess the effects on cost, operations, and force structure.
- Identify opportunities to deploy renewable and alternative energy sources for facilities and deployed forces.
- Identify institutional barriers to making the transitions recommended by the TF.
- Identify the potential national benefits from the DoD deployment of new energy technologies.

The DSB noted that two recommendations from the 2001 DSB TF had not been implemented: the development and implementation of energy Key Performance Parameters (KPPs) and the development and implementation of the true cost of delivered fuel to guide acquisition investments (DSB, 2007).

The Military Operations Research Society (MORS) sponsored the first MORS Special Meeting on Energy and Energy Assurance in December 2009. The purpose of the meeting was to evaluate how best to implement "requirements development and potentially acquisition trade-space decision-making to new DoD guidance and identify current analysis gaps" (MORS, 2009, p. 1). The meeting focused on the development and implementation of KPPs as well as methods for calculating the FBCF. The participants in the meeting established that there is not an agreed on methodology for calculating FBCF. Various methodologies for calculating FBCF were proposed and explored during the Special Meeting, but the participants did not agree on a single FBCF methodology.

Recent theses published by the Naval Postgraduate School (NPS) have focused on the FBCF. Corley (2009) reviewed and provided analysis for recent Department of the Navy (DoN) Major Defense Acquisition Programs (MDAP) impacted by FBCF estimates. His thesis calculated the FBCF for a fleet of destroyers (DDG-51) under different scenarios and conducted analysis using the OSD (AT&L) FBCF calculator. Corley found that in a maritime scenario, the DLA Energy standard price of delivered fuel is approximately 30%–50% of the FBCF, and recommended using FBCF to account for total fuel costs during acquisition analyses.

Truckenbrod (2010) investigated the FBCF for Naval aviation by calculating the FBCF for the F/A-18 E/F aircraft using the OSD (AT&L) calculator. When compared to Corley (2009), the results demonstrate that the FBCF for the F/A-18 E/F is approximately double the FBCF for a fleet of destroyers. The FBCF calculations for the different scenarios and platforms did differ in many areas and required many assumptions to make the comparison. Truckenbrod concluded that the most substantial portion of logistics support costs is in-flight refueling. The DoD has an opportunity for strategic advantage through fuel conservation technology and platform endurance (Truckenbrod, 2010).

Roscoe (2010) described the various methodologies used by the U.S. armed services to calculate the FBCF. Based on the analysis, he made three recommendations:

- FBCF definitions and units should be consistent across all services within the DoD.
- Scenarios should remain as one of the steps when calculating the FBCF.

- A stochastic mechanism to address the uncertainty associated with all estimates should be included (Roscoe, 2010, p. xvi).

2. DoD Guidance

It is the responsibility of the OUSD (AT&L) to implement policy and oversee the DoD acquisition process. The OUSD (AT&L) Deputy Secretary concurred with two main points discussed in previous government-sponsored studies: specifically, (1) that a force less dependent on a long supply chain is a more capable force, and (2) the acquisition process does not emphasize energy efficient technology. On April 10, 2007, the OUSD (AT&L) directed,

> Effective immediately, it is DoD policy to include fully burdened cost of delivered energy in trade-off analysis conducted for all tactical systems with end items that create a demand for energy and to improve the energy efficiency of those systems, consistent with mission requirements and cost effectiveness. (OUSD[AT&L], 2007, p. 1)

On January 24, 2007, President George W. Bush signed Executive Order 13423, Strengthening Federal Environmental, Energy, and Transportation Management. It announced goals in the areas of acquisition, energy efficiency, and renewable energy and outlined objectives intended to maximize the economic efficiency of energy use, applied to the DoD as a federal agency (The White House, 2007).

In March 2008, the Deputy Director of OUSD (AT&L), Mr. Chris DiPetto, testified before the House Committee on Armed Services Readiness Subcommittee on behalf of the Deputy USD (AT&L). He highlighted two reasons for using FBCF. The first is for decision makers to gain insight on the risks generated by the enormous fuel demand of the DoD. The second reason is “to open up science, technology, and acquisition with the properly valued financial costs of delivering fuel to the operator” (DiPetto, 2008, p. 8).

In October 2008, Congress enacted the 2009 Duncan Hunter National Defense Authorization Act (NDAA), setting conditions that must be considered for the logistics costs of delivering energy during the acquisition process. This Congressional Act directs the SECDEF to “require life-cycle cost analysis for new capabilities include the fully burdened cost of fuel during analysis of alternatives and evaluation of alternatives and acquisition program design trades" (110th Congress, 2008, p. 66). Section 332 of the Duncan Hunter NDAA outlines dates and milestones for FBCF implementation. The Act gave the SECDEF six months to develop an implementation plan, mandated a progress report after two years, and provided guidance to implement 2009 NDAA requirements by the 3-year point (110th U.S. Congress, 2008).

On December 8, 2008, the DoD updated Department of Defense Instruction (DoDI) 5000.2, Operation of the Defense Acquisition System, to include FBCF guidance. The instruction directed that "the fully burdened cost of delivered energy (FBCE) shall be used in trade-off analysis for all DoD tactical systems with end items that create a demand for energy" (OUSD[AT&L], 2008, p. 59). The addition of fully burdened cost of delivered energy into the acquisition process created a specific requirement in the AoAs phase, which is a prerequisite for milestone decision points. The Milestone Decision Authority (MDA) has to assess whether programs took into consideration improvements in energy efficient improvements for tactical systems (OUSD[AT&L], 2008).

In February 2010, the DoD published the 2010 Quadrennial Defense Review (QDR). The QDR is a mandated 4-year plan by Congress that outlines top priorities within the DoD. Energy considerations in the acquisition process are addressed in the section, "Crafting a Strategic Approach to Climate and Energy," and states that "DoD must incorporate geostrategic and operational energy considerations into force planning, requirements development, and acquisition processes" (DoD, 2010, p. xv). Additionally, the QDR lists the DoD's focus on implementing Congressionally-mandated requirements. The DoD "will fully implement the statutory requirement for the energy efficiency KPPs and FBCF set forth in the 2009 NDAA" (DoD, 2010, p. 87). The DoD's priorities are outlined in the QDR and are in line with the guidance provided for the DoD by Congress for implementing FBCF in acquisition decisions.

On June 20, 2011, the DoN published their Energy Evaluation Factors in the Acquisition Process Memorandum (Office of the Assistant Secretary of the Navy for Research, Development and Acquisition (OASN), 2011). This memorandum provided DoN guidance relating to the use of energy-related factors and energy performance for acquisition planning, trade-off analysis, development of technology, and selection among competing platforms and weapons systems. This memorandum specified that for all DoN platforms and weapons systems that consume energy, FBCE calculations must be included in the AOA phase by October 2011, in order to inform trade-off decisions and to differentiate between competing systems (OASN, 2011).

In May 2011, the DoD published its first operational energy strategy—*Energy for the Warfighter: Operational Energy Strategy*—whose goal is to guide the DoD in how to become more energy efficient in support of strategic and energy security goals, and ensure that the U.S. military will have the required energy resources to meet future challenges. As a matter of national security, the U.S. armed forces must reduce the amount of fuel required to conduct global military operations.

B. FULLY BURDENED COST OF FUEL (FBCF)

The Defense Acquisition Guidebook (DAG) defines the FBCF as "the cost of fuel itself plus the apportioned cost of all fuel delivery logistics and related force protection required beyond the Defense Energy Support Center (DESC) point of sale to ensure refueling of the system" (Defense Acqusition University [DAU], 2009, p. 1). The NDAA defines FBCF as the "commodity price for fuel plus the total cost of all personnel and assets required to move and, when necessary, protect the fuel from the point at which the fuel is received from the commercial supplier to the point of use" (110th U.S. Congress, 2008, p. 66). FBCF estimates the total cost of procuring and transporting fuel, infrastructure operating costs, and the cost of force protection for the logistics tail. Although the definition of FBCF is not consistent across the DoD, the underlying principles are agreed on and understood among each branch of service.

There are seven steps outlined in the DAG for calculating the FBCF and they are reproduced in Sections 1–7. Each step is calculated individually and then all seven cost elements are summed to find the FBCF estimate. This is the accepted and current methodology for calculating FBCF throughout the DoD.

1. Commodity Cost of Fuel

This is the only step that is consistent among all services. DLA Energy provides all energy-related products to the DoD. The DLA Energy standard price is the cost of the fuel plus a surcharge for operating costs. The services pay the standard price and then DLA Energy reimburses the money into the Defense Working Capital Fund. DLA Energy operates as a reimbursable fund, so its standard price is based on a trailing 18-month cycle to protect the military from the instability of the global petroleum market. Thus, the DLA Energy standard price is not the current marketplace price.

2. Primary Fuel Delivery Assets Operating and Support (O&S) Cost

This step calculates the cost of operating service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel mission (DAU, 2009). Historical O&S costs for the service-specific fuel delivery systems are available in databases such as the Air Force Total Ownership Cost, the Navy's Visibility and Management of Operating and Support Costs, and the Army's Force and Organization Cost Estimating System and Cost Factors Handbook.

3. Depreciation Cost of Primary Fuel Delivery Assets

Step three measures the decline in value of fuel delivery assets, with finite service lives using straight-line depreciation over total service life (DAU, 2009).

4. Direct Fuel Infrastructure O&S and Recapitalization Cost

Step four calculates the cost of fuel infrastructure that is not operated by DLA Energy and is directly tied to energy delivery (DAU, 2009). The direct fuel infrastructure costs are restricted to fuel bladders, pumping hoses, and storage sites. The DLA Energy standard price includes the direct costs of fuel infrastructure operated by DLA Energy, which must not be included in step four. The Office of the Deputy Under Secretary of Defense for Installations and Environment provides direct fuel infrastructure costs for the military at http://www.acq.osd.mil/ie/ (Corley, 2009).

5. Indirect Fuel Infrastructure

This step calculates the cost of base infrastructure that is shared proportionally among all base tenants (DAU, 2009). To calculate indirect fuel infrastructure costs, OSD (AT&L) recommends determining the Operating and Support costs of a base and dividing that figure by the total work force of that base. Finally, multiply that total by the work-force number for fuel-related activity.

6. Environmental Cost

Step six calculates the cost representing carbon trading credit prices, hazardous waste control, and related costs (DAU, 2009). Although the environmental fuel-related costs are challenging to quantify, the Office of the Secretary of Defense (Program, Analysis, and Evaluation) developed an estimate derived from costs associated with DoD environmental clean-up and hazardous material control, as well as the potential costs of carbon emission offsets (Corley, 2009).

7. Other Service and Platform Delivery Specific Costs

These costs include potential expenses associated with delivering fuel such as convoy escort, force protection, regulatory compliance, contracting, and other costs as appropriate (DAU, 2009). This final step attempts to capture any applicable costs that have not been included elsewhere in the FBCF calculations.

C. INPUT-OUTPUT (IO) ANALYSIS

Professor Wassily Leontief was a twentieth century economist recognized for his research on how changes in one sector of an economy may influence other sectors. Leontief developed the IO analytical framework in the late 1930s and, in 1973, he received the Nobel Prize in Economic Science for this work. IO is a general equilibrium model in which the impact of marginal changes in one sector can be propagated and measured through the rest of the economy. The general equilibrium nature of IO makes it is useful for analyzing and forecasting economic impacts (Wu & Chen, 1990).

IO demonstrates how production levels in one sector generate successive rounds of demand for products of further sectors (Wu & Chen, 1990). IO models industries that both produce goods for, and consume goods from, other industries. The goods that an industry produces are its outputs and the goods that the industry consumes are its inputs.

The outputs of each industry become inputs to other industries and may be consumed by the ultimate consumers, usually taken to be households. An IO model can complete three separate tasks (Lin & Polenske, 1998):

- Provide a way to construct a consistent account of the flows from suppliers to end user.
- Identify the impact of production (technology) changes over time.
- Convert accounting data into an enterprise IO model to be used for a variety of analytical tasks.

IO is commonly applied by the U.S. Department of Commerce for national economic analysis, and in regional economic planning and analysis by states, industry, and the research community (Miller & Blair, 2009).

In an IO model, the system consists of a set of n linear equations with n unknowns, each describing the distribution of an industry's product throughout the economy. The information in an IO model is displayed in matrix form, called an interindustry table. The rows in the table describe the distribution of a producer's output and the columns describe the composition of inputs required by a particular industry to produce its output (Miller & Blair, 2009). The basic balance equations of the IO model are (Wu & Chen, 1990):

$$x_i = \sum_j x_{ij} + F_i = \sum_j a_{ij} x_j + F_i \tag{1}$$

where

x_i = total domestic gross output in sector i

x_{ij} = purchases by sector j as an input from sector i

F_i = final demand for sector i's product

a_{ij} = the direct input or technical coefficients.

The total domestic production of any sector of an economy is equal "to the sector's products used by all sectors in the economy as an input to produce their output plus the amount demanded for final use by consumer, exports, investments and government" (Wu & Chen, 1990, p. 72). IO determines the level of output that each of the n industries in an economy must produce, in order to sufficiently satisfy the total demand for that product

(Chiang, 1984). The output of the cotton industry is needed as in input for other industries within an economy, as well as itself. The correct level of output depends on the input requirements of all the industries in the economy requiring cotton. Additionally, other industries' outputs enter the industry as inputs. The correct levels of the other products will, in turn, depend partly on the input requirements of the cotton industry.

IO models normally encompass large, complex economies with many industries. Assumptions are made in order to simplify the problem. IO model assumptions are (Chaing, 1984):

- Each industry produces only one homogeneous output.
- For each sector, there is proportional consumption of multiple inputs. This means that production in every industry is subject to constant returns to scale.
- It is a static model: given one set of input-output relationships, the model implies a given output level for each sector. This means that each industry uses a fixed input ratio for the production of its output.

D. INPUT-OUTPUT (IO) FOR A SUPPLY CHAIN

Wu and Chen (1990) developed a fixed IO framework, the energy IO model, used for analyzing short-run energy issues to model the relationships among industry inputs and outputs with a demand for energy commodities. The energy IO model has three primary areas for application:

- As a forecasting tool.
- Projecting final demand for an economy. The energy IO model can predict future energy requirements for each component in an economy.
- For impact analysis to estimate the overall effects of changes in the price of energy.

Albino, Izzo, and Kühtz (2002) used an IO approach to develop specific models that investigate flows among production processes for both a global supply chain and a localized supply chain. Their models serve as accounting and design tools for a supply chain. As accounting tools, they help explore supply chain materials and energy. As design tools, the developed IO models help consider the impact of changes in process technology, process location, or final product output or demand on a supply chain.

Supply chains are complex systems of processes that procure, transform, and deliver a product to a consumer through distribution systems. If all interrelated processes, required raw materials, and IO flows of intermediate goods needed to produce the end product are identified, the supply chain of a final product can be described and modeled using IO analysis. Albino, Izzo, and Kühtz (2002) consider specific tools that capture economic, energy, and environmental interactions in order to conduct analysis on materials, including pollution and energy flows within the supply chain production processes.

Albino, Dietzenbacher, and Kühtz (2003) developed an enterprise IO (EIO) model that uses the IO methodology for an industrial district to analyze material and energy flows. An industrial district is comprised of multiple of businesses, supply chains, and production processes. One business may contribute to numerous production processes, which include multiple supply chains. In the EIO model, each production process transforms inputs into outputs. The main output of a process is the input of the next process. The final product is the output, which is consumed outside the supply chain. Each process requires a given quantity and type of energy as input.

There are many difficult factors associated with modeling a very large system. The IO model divides the economy into sectors. The level of disaggregation may not be sufficient if the system being analyzed on a micro scale. In an IO model, it is very important to conduct analysis on the proper level of aggregation. The scale of the model must consider the level of resources, materials, forms of energy, and production processes. The higher the level of disaggregation, the more accurate representation of actual material and energy flows (Albino, Dietzenbacher, & Kühtz, 2003). A disadvantage of working on a micro scale is the lack of consistency in the direct input coefficients. A change in technology for a single process can change the coefficients (Albino, Dietzenbacher, & Kühtz, 2003).

Lu and Rencheng (2007) developed an Enterprise IO (EIO) model of an international supply chain to expand the understanding of the complex process of flows within a multilocation enterprise's production network. Their EIO model accounts for consumption during production activities, as well as the consumption resulting from a supply chain with plants dispersed in various locations.

> From a physical point of view, a supply chain can also be considered as an IO system that describes the product flows existing among production processes. The supply chain can be considered as an IO system that produces a specific good, and the IO system can involve many production units characterized by a specific work division. (Lu & Rencheng, 2007, p. 5)

The supply chain concept is useful for making investment decisions and regulatory planning (Lu & Rencheng, 2007). Their EIO model is based on an international manufacturing enterprise with a multilocation supply chain characterized by dispersed plants, vendors, and markets. The base model captures strategic issues like how to plan production, procurement, and distribution decisions (Lu & Rencheng, 2007).

E. THESIS OBJECTIVES

This thesis develops an EIO model of the bulk fuel flow through the DoD supply chain. All bulk fuel used by the DoD is procured by DLA Energy from contractors and flows through a robust supply chain until it reaches the end user. The DoD bulk fuel supply chain can be modeled as an EIO to account for all fuel flows and costs associated with the supply chain.

The objective of this thesis is to create a model of the DLA Energy bulk fuels supply chain to evaluate the feasibility of using IO analysis to calculate the FBCF within the DoD, as well as demonstrate the value. An IO supply chain model can be applied to evaluate the impact of changes in either fuel demand or technology. The goal of FBCF is to provide more information to acquisition decision makers and an IO model can capture the complexities associated with a supply chain.

II. METHODOLOGY

A model based on IO principles was created using DLA Energy data and information to track the cost to transport fuel along the DLA Energy bulk fuels supply chain and estimate delivery costs. The model, called the Bulk Fuels Distribution Model, is used to calculate the total cost to deliver JP-5, JP-8, and F-76 to each component in the DLA Energy supply chain by solving a set of linear equations. These calculations track all costs along the supply chain from point of procurement, through all stages of the supply chain, to the final destination. The final destination, however, is not always the place of consumption for the fuel. Delivered bulk fuel may be consumed at the final location in the DLA Energy supply chain, or the bulk fuel may be transported through a service specific supply chain to follow-on locations for consumption in remote sites.

A. DEFENSE LOGISTICS AGENCY (DLA) ENERGY FUEL SUPPLY CHAIN

The DLA Energy, formerly known as DESC, is responsible for procuring, storing, transporting, and delivering all energy resources throughout the DoD. It facilitates the cycle of storage and deployment of fuels and other energy sources (DLA Energy, 2011a). Although DLA Energy provides all energy resources to the DoD, only bulk petroleum—fuels that are required to meet military specifications (MILSPECS)—requires a robust supply chain. The end user procures other fuels.

The DLA Energy Bulk Petroleum Division provides contract support for the entire bulk petroleum supply chain including worldwide bulk fuels requirements, additives, alternative fuels, and lube oils. Additionally, it oversees the global acquisition of fuel-related services such as contract-operated defense fuel support points; alongside-aircraft fuel delivery; lab testing; and environmental compliance, assessment, and remediation. The DLA Energy Bulk Petroleum Division is also the single source for drafting, negotiating, concluding, and amending international fuel agreements with foreign governments supporting worldwide DoD operations (DLA Energy, 2010).

The three primary bulk fuels used by the DoD are JP-5, JP-8, and F-76. U.S. Navy (USN) and USMC sea-based aircraft use JP-5. Land-based aircraft and equipment use JP-8 fuel. Conventionally-powered ships use a distillate fuel for propulsion, F-76 (Chairman of the Joint Chiefs of Staff, 2003). These three bulk fuels have to meet particular MILSPECS, which creates the demand for a robust supply chain to ensure that the right fuel is delivered at the right time to support operational readiness. According to 2010 data provided by DLA Energy, the bulk fuels program transported 852 million United States Gallon (USG) of F-76, 1.2 trillion USG of JP-5, and 4.8 trillion USG of JP-8. The DoD supply chain for each of the three bulk fuel products is different, although there is overlap on many transportation lines, storage locations and facilities, and end-user locations. These supply chains are described below.

DLA Energy divides the world into four regions:

- Atlantic, Europe, and the Mediterranean (AEM)
- Inland East and Gulf Coast, United States (IEGC)
- Western Pacific (WESTPAC)
- Rocky Mountain and West Coast, United States (RMWC)

Within each region, DLA Energy tracks where and to whom the fuel is delivered, as well as who consumed how much. Each region tracks exactly how much JP-5, JP-8, and F-76 was delivered to and sent from each component in the supply chain. DLA Energy tracks final destinations as the location where the fuel was delivered and consumed in order to perform a military function. Each component that consumes fuel is a final destination, even if that component also sends fuel further down the supply chain. The Defense Fuel Support Point (DFSP) in Akasaki, Japan, the U.S. Naval Station Guam, and the Marine Corps Air Station in Iwakuni, Japan are all final destinations for fuel in the WESTPAC region, despite their differences in size, mission, fuel type, and amount of fuel consumed.

The robust DoD supply chain includes many underlying costs required to ensure fuel flow to the end user. In addition to the bulk fuel delivered to the final destinations, there are additional costs associated with transporting the fuel as well as with the overhead cost of terminals and storage facilities. Transportation costs includes the cost of fuel expended during delivery as well as the additional cost added for contractor delivery to a government fuel depot. Terminal operating cost consists of the total overhead cost required to operate the fuel terminals.

B. DATA

In the DLA Energy supply chain, each component or supplier is a node. An arc consists of the link between nodes on which fuel travels. The bulk fuel travels from its original shipping point to each following node until it reaches the final destination for consumption. Figure 1 represents the Kanto Plain Product Flow for Hakozaki. Each box represents a node and each arrow connecting nodes represents an arc. Bulk fuel is delivered to Hakozaki by an ocean tanker from suppliers and then transported to various locations by either barge or tanker truck. Both nodes and arcs have associated costs as described in Figure 1.

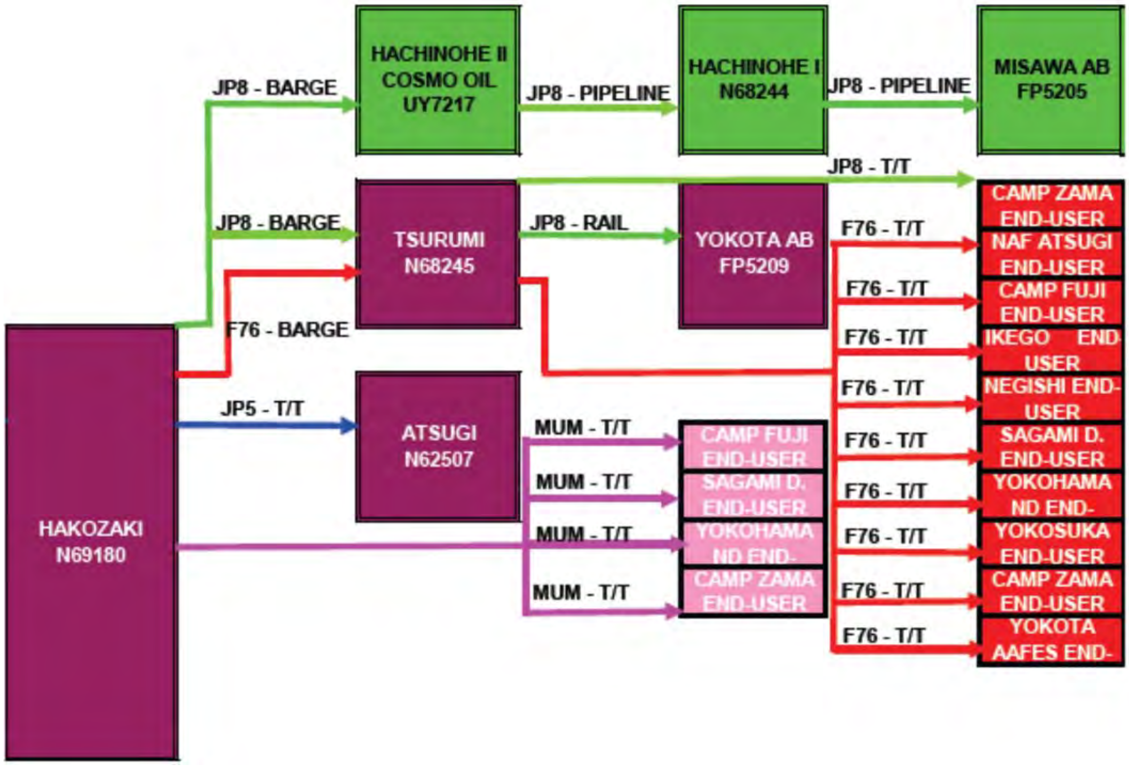

Figure 1. Representation of the bulk fuel flow through Hakozaki, Japan (From DLA Energy, 2011b, World Wide Distribution Maps).

We worked with Patrick J. Dulin, the Deputy Commander, DLA Energy, and Linda Barnett, DLA Energy Chief, Inventory & Distribution Management, who provided data on transportation costs after the fuel is acquired by DLA Energy, and terminal operating costs within the DLA Energy bulk fuels supply chain.

Ms. Barnett provided the 2011 terminal operating costs, transportation rates, and distribution plan for the four regions. The transportation rate data set consists of all the bids from suppliers to deliver a specific bulk fuel from a component in the supply chain to another component. These rates incorporate the specific mode of transportation and are in dollars per USG. Using the transportation rate bids, DLA Energy determines how many USG of each variety of bulk fuel will travel on each arc. The DLA Energy distribution plan is the result of this decision, and indicates how much fuel is expected to travel on each arc in a given year.

Terminal operating costs consists of the total overhead cost (in dollars per year) required to operate the fuel terminals. These costs do not capture all overhead costs associated with the logistics infrastructure required to support the bulk fuels supply chain in all cases; however, they are the best available estimate and provide a lower bound on the cost of facilities operation in the bulk fuel logistics tail.

Figure 2 represents how JP-8 is delivered to Iraq, based on the transportation rates and distribution plan provided by DLA Energy. The source node on the left of the graph is the supplying oil company, Motor Oil Hellas (MOH). MOH delivers 214 million USG of JP-8 is through a pipeline to DFSP Greece, which has no additional delivery cost charged to DLA Energy. At a rate of $0.07 per USG, 111 million USG of the 214 million USG is transported by ocean tanker from DFSP Greece to the Turkey North Atlantic Treaty Oranization (NATO) Pipeline System (TNPS) East, in Mersin, Turkey. From the 111 million USG, 27 million USG are transported by pipeline to DFSP Adana, Turkey for no additional cost. As the JP-8 arrives in DFSP Adana, tanker trucks transport 10.5 million USG to Kirkuk, Iraq at a cost of $0.46 per USG, 6.5 million to Qayyarah Airfield West, Iraq (Q West), at a cost of $0.49 per USG, 3.5 million USG to Camp Diamondback, Iraq at a cost of $0.47 per USG, and 6.5 million USG to Tikrit, Iraq at a cost of $0.58 per USG.

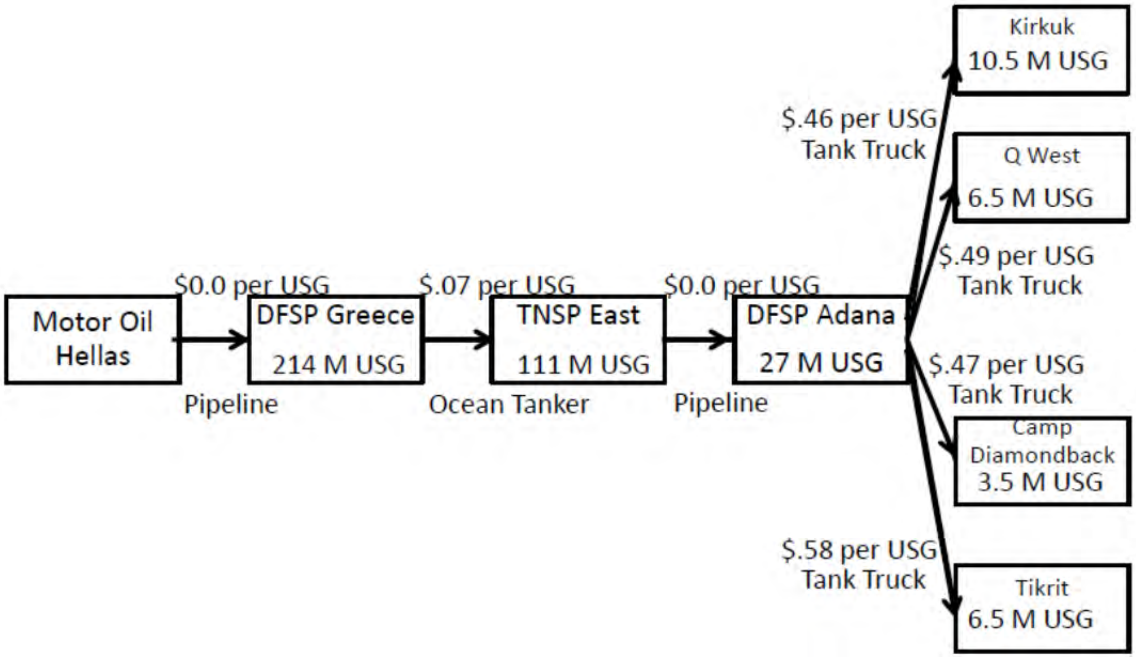

Figure 2. Iraq JP-8 fuel distribution plan.

The transportation rates provided by DLA Energy capture the actual direct delivery cost charged to DLA Energy for transportation of fuel from a single node to another single node. The transportation rates provided do not include the cost of operating terminals or the cost of the infrastructure needed to support fuel delivery. For the portion of the supply chain shown in Figure 2, no terminal operating cost data were available.

C. INPUT-OUTPUT (IO) MODEL FORMULATION

The IO model is used to calculate the total cost of delivery for a specific fuel type to each component in the supply chain. DoD facilities are designated a DoD Activity Address Code (DoDAAC), which is a code for identifying specific military installations. Each component is a node.

In order to track the mode of fuel transportation, fuel type being delivered, supplying component that fuel is departing from, and location where fuel is arriving to for each node and arc in the supply chain, the following indices were used:

Indices

$j =$ DoDAAC receiving fuel, $j \in D$

$D =$ DLA Energy facility components

$i =$ DoDAAC or supplier that fuel is departing from, $i \in \{D, X\}$

$X =$ External supplier components

$m =$ Mode of fuel transportation, $m \in M = \{T, P, K, B, C\}$

$m = T$ for fuel that is delivered by a tanker truck, P for fuel that is delivered by pipeline, K for fuel delivered by an ocean tanker, B for fuel delivered by a barge, C for fuel delivered by a rail car.

$f =$ Fuel Type, $f \in F = \{JP8, JP5, F76\}$

The following data were provided by DLA Energy:

$q_{ijfm} =$ Gallons of fuel type f transported from i to j by mode m in 2011 (from bulk fuels distribution plan)

$c_{ijfm} =$ Cost (\$) to transport one gallon of fuel type f from i to j by mode m (from transportation rates bids, where c_{ijfm} is the accepted bid for the given arc and fuel type)

$T_j =$ Terminal operating cost (\$) at j in 2011

The price DLA Energy pays to purchase fuel varies with the commercial market. According to LCDR Bruce Begley, the Deputy Chief, Inventory & Distribution Management at DLA Energy,

> Suppliers bid on what [DLA Energy] refers to as a base reference date and the price noted in our solicitation for that base reference date comes from the Platt’s Oilgram Price Report for the selected date and the applicable index. As the market moves throughout the contract performance period the actual price paid will go up or down with the market, however, the margin will remain. (B. Begley, personal communication, August 2, 2011)

The market price of the reference commodity for fuel type f at location was not accounted for in the IO model. However, the IO model includes a reference variable as a placeholder in the event future uses of this model include market price of fuel.

$r_{jfm} =$ Market price of reference commodity for fuel type f at location j delivered by mode m.

Based on DLA Energy's data, the following were calculated for all j and f:

$$Q_{jf} = \sum_{m\in M} \sum_{i\in\{X,D\}} q_{ijfm} \tag{2}$$

= Total amount of fuel of type f that component j receives (USG)

$$Q'_{jf} = \sum_{m\in M} \sum_{i\in D} q_{jifm} \tag{3}$$

=Total amount of fuel of type f that component j delivers (USG)

$$t_j = \frac{T_j}{\sum_{f\in F} Q'_{jf}} \tag{4}$$

=Terminal operating cost of j per unit of fuel delivered from j (\$/USG)

The delivered unit cost of fuel type f at component $j \in D$ is calculated by summing delivered costs over all the immediate prior components that are external suppliers, and the immediate prior components that are DoD facilities, then dividing by the total amount of fuel of type f that component j receives, as shown in Equation 5.

$$C_{jf} = \frac{\sum_{m\in M}\sum_{i\in X}(c_{ijfm} + r_{jfm})q_{ijfm} + \sum_{m\in M}\sum_{i\in D}(t_i + C_{if} + c_{ijfm})q_{ijfm}}{Q_{jf}} \tag{5}$$

= Delivered unit cost of fuel type f at component j (\$/USG)

The C_{jf} s are thus the solution to a set of linear equations, as C_{if} appear on the right-hand side. This calculation exploits the network formulation of the supply chain to track all costs along the supply chain from external suppliers, through multiple arcs of the supply chain, to each component j. The market price of reference commodity varies over the course of the year and was not included in this analysis. In this thesis, r_{jfm} is treated as zero. Therefore, C_{jf} is just the delivery cost.

The formulation was implemented using two spreadsheets for each of the four regions. The first set of spreadsheets (one for each region) organized the data provided by DLA Energy using the bulk fuel distribution plan and transportation rates. The second set of spreadsheets used the first set of spreadsheets, as well as the terminal operating costs, to simultaneously solve the set of linear equations shown in Equation 5 to calculate the delivered unit cost for each fuel type at each location. This solution exploited the fact that the supply chain network in each region is hierarchical.

III. ANALYSIS

Based on the data provided by DLA Energy and the Bulk Fuels Distribution Model, delivery costs were calculated for all 473 DoD components receiving fuel in the model. This analysis compares the costs across locations, regions, and fuel types to provide insights on the actual cost for delivering fuel worldwide. In addition, the delivery cost results are applied to an AOA demonstration, and the feasibility of using the IO approach to estimate FBCF for other portions of the DoD fuel supply chain is evaluated.

A. DELIVERY COSTS BY REGION AND FUEL TYPE

Figure 3 is the average, over all DoD components $j \in D$ within a region, of the delivery cost, C_{jf}, for all three bulk fuel types. Delivery of JP-8 in the WESTPAC region costs an average of $0.35 per USG, in addition to the commodity cost of fuel. The average delivery cost of JP-8 in the WESTPAC region and AEM region are over twice as high as the delivery cost of JP-8 in the RMWC region and the IEGC region. The high average cost for JP-8 in the AEM is caused by the high costs associated with driving tanker trucks from Mersin, Turkey to various locations in Iraq. The high average cost for delivered JP-8 in the WESTPAC region is a result of pipeline charges throughout South Korea that average $0.60 per USG to transport JP-8 to its final destination.

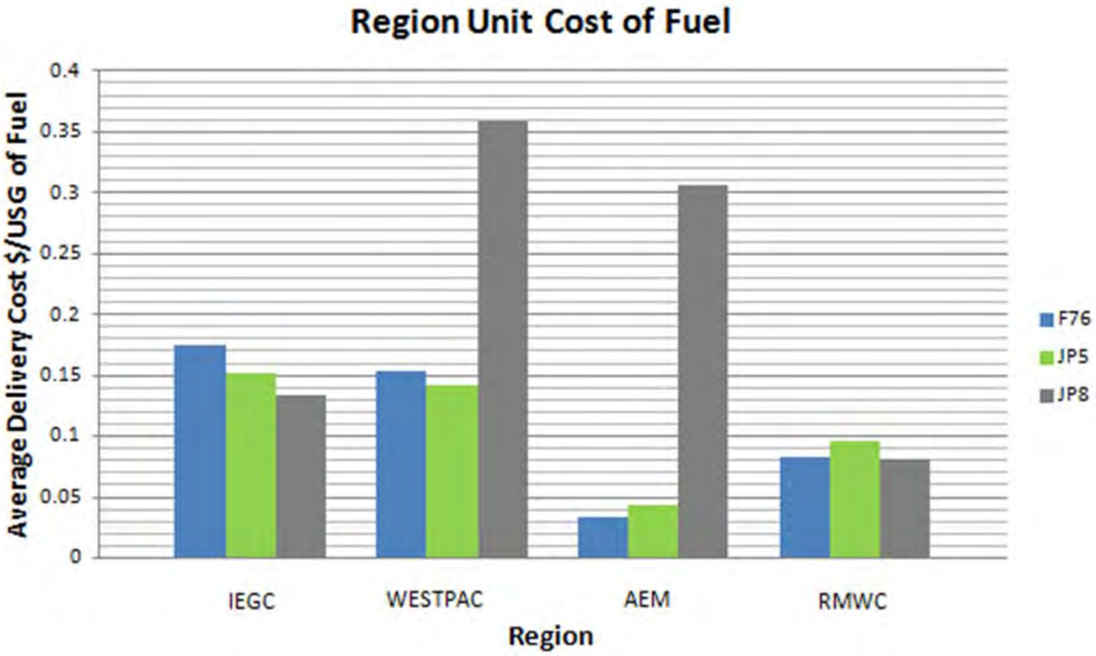

Figure 3. Average delivery cost, C_{jf}, for all three bulk fuel types over DoD facilities receiving fuel, by region.

Figure 4 is a box plot of delivery cost, C_{jf}, for all three fuel types and DoD facilities receiving fuel in the model. The whiskers in Figure 4 represent the maximum and minimum delivery cost ($ per USG). For JP-5, JP-8, and F-76 in each of the four regions, there are locations where pipelines transfer fuel directly from a supplier to the final destination and the delivery cost is only a small fraction of a cent.

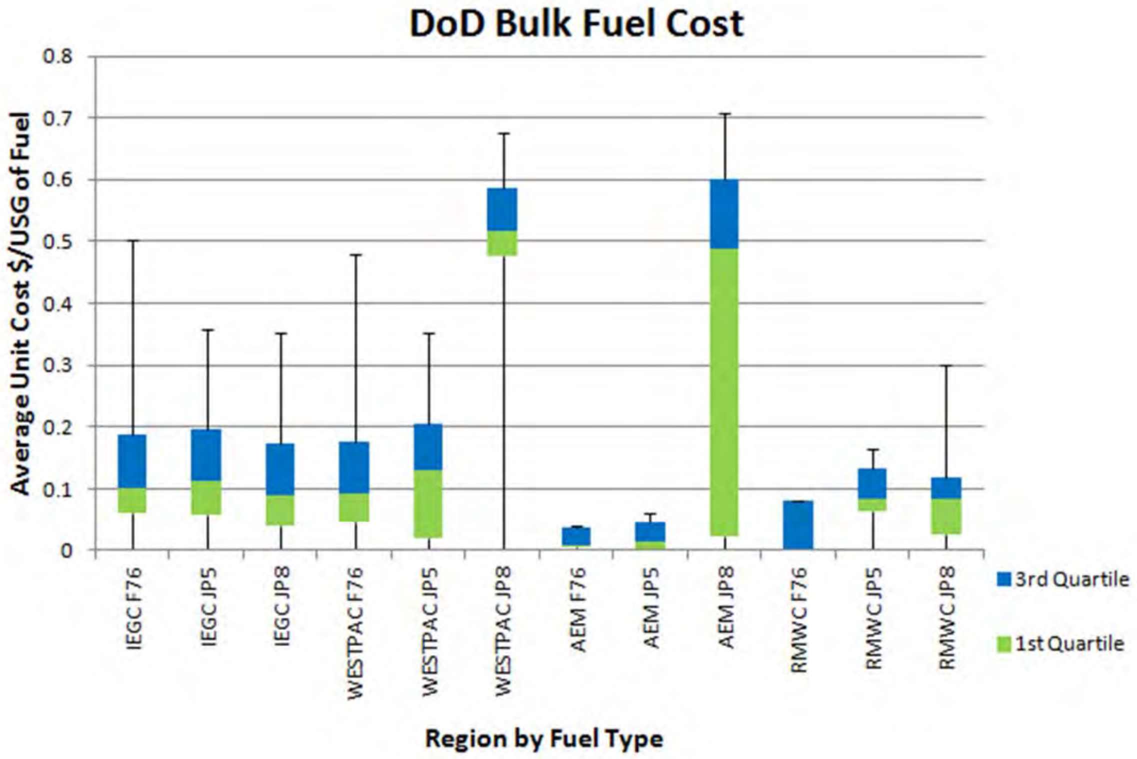

Figure 4. Box plot of delivery cost, C_{jf}, for all three fuel types and DoD facilities receiving fuel in the model.

The box plot shows the large variability for JP-8 in the AEM region, which is a result of the high cost of transporting JP-8 by trucks into Iraq; most facilities in the AEM region have much lower delivery costs. The small variability for JP-8 in the WESTPAC region is because the majority of the locations consuming JP-8 there receive fuel that travels through the South Korean pipeline system.

The bars in Figure 5 show the quantity of fuel being delivered for each fuel type within each region, in millions of USG in 2011.

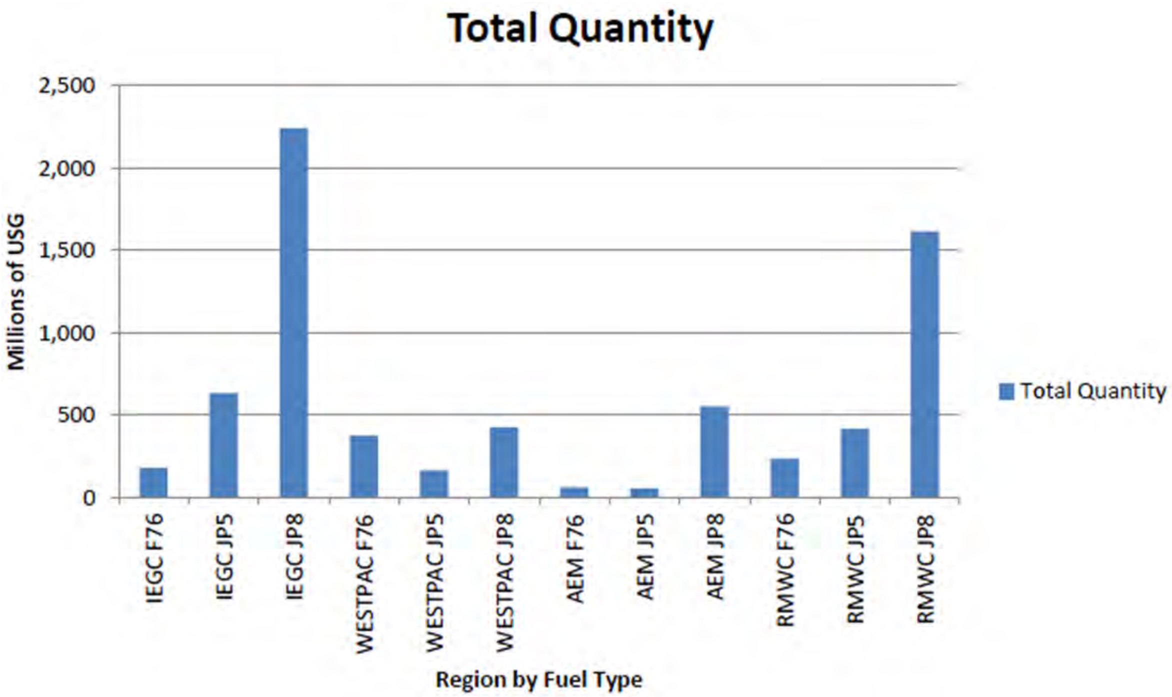

Figure 5. The quantity of fuel being delivered for each fuel type within each region, in millions of USG in 2011.

The two U.S. regions consume the highest quantity of JP-8. Both the IEGC and RMWC regions consume more than three times as much JP-8 as any other region.

B. LOCATION-SPECIFIC FUEL DELIVERY COSTS IN AOAS

The purpose of calculating FBCF is to provide more information to decision makers during AOAs. This section illustrates how the location-specific fuel delivery costs could be used in an AOA.

A Naval Surface Warfare Center report (2008) found that hybrid Guided Missile Destroyers (DDGs) have an 8.9% overall fuel savings over traditional DDGs. According to the Bulk Fuels Distribution Model, the cost to deliver F-76 to DFSP Guam is $0.22 per USG. Assuming that 60% of the F-76 used at DFSP Guam is consumed by DDGs, annual savings of replacing all DDGs at Guam with hybrids can be estimated. The total F-76 consumed annually, multiplied by the percentage consumed by DDGs, gives the amount consumed by DDGs.

48.40 million USG × 60% = 29.04 million USG

The total amount of F-76 saved by converting to a fleet of all hybrid DDGs is calculated by multiplying the amount consumed by DDGs by the hybrid fuel savings.

29.04 million USG × 8.9% = 2.58 million USG

The annual savings is calculated by multiplying the fuel savings by the delivery cost, subtracting the new total cost from the original cost.

2.58 million USG × $0.22 per USG = $567,600

This value is just the savings in delivery cost. The savings in actual commodity purchase price of fuel would be additional. This methodology can be used for every location where DDGs consume F-76 to analyze the impact of a fleet with only hybrid DDGs during AOAs. The methodology shown in the hybrid DDG example can be used for any system that creates a demand for JP-5, JP-8, or F-76 for each of the services.

C. BULK FUELS DISTRIBUTION MODEL COULD REDUCE OSD SEVEN STEPS

The first step in the OSD seven-step process (described in Section I.B) is to calculate the DLA Energy standard price, which is the cost of the fuel plus a surcharge for operating costs. The Services pay a standard price based on a trailing 18-month cycle to protect the military from the instability of the global petroleum market; thus, the DLA Energy standard price is not the current marketplace price. In addition, the standard price charged to the Services is the same regardless of the location where the fuel is transferred to the service. Therefore, the actual cost to DoD is not accurately reflected in the standard price. The Bulk Fuels Distribution Model can be used to easily calculate location-specific delivery costs, providing a more accurate representation of the actual cost of fuel to the DoD.

For the DLA Energy bulk fuels supply chain, steps two through five can be consolidated to one step using the Bulk Fuels Distribution Model. Steps two and three in the OSD seven-step process are to calculate the operating and support costs and the decline in value of fuel delivery assets. For the DLA Energy portion of the supply chain, these costs are captured in the IO model with no additional calculations required. Steps four and five are to calculate direct and indirect infrastructure costs, which are incorporated in the Bulk Fuels Distribution Model using terminal operating costs.

Although fuel is delivered to many DoD facilities by the DLA Energy, fuel is then sent to forward operating points at an additional expense. For fuels delivered using organic service assets, the delivery costs could be readily calculated using the same structure as the Bulk Fuels Distribution Model if the Services were able to provide the data analogous to the DLA Energy data, or data that supported the calculation of costs associated with each node (facility) and arc (transport between facilities) in the supply chain. Dubbs (2011) built a model of a small portion of the USMC supply chain in Afghanistan to demonstrate the feasibility of a service-specific model.

The sixth step in the OSD process is to calculate the environmental costs. These costs are proportional to the total amount of fuel consumed per gallon consumed by the end user, and should include the fuel consumed by transportation assets and facilities in the supply chain. This total fuel consumption per gallon consumed by the end user is greater than one (Dubbs, 2011), and can be calculated using the IO approach if DLA Energy were able to provide data on fuel consumption on each arc and for each node. This would require modeling a second output for each component, measured in USG, delivered to each follow up node in the supply chain. A second set of balance equations, like those in Equation 5, would also be required.

The final step in the OSD process is to calculate other service and specific platform delivery costs such as force protection. These costs may be captured within a service-specific model, as in Dubbs (2011).

D. BULK FUELS DISTRIBUTION MODEL ADVANTAGES

The Bulk Fuels Distribution Model provides new insight to DLA Energy and a methodology that the DoD may adapt to capture a more accurate estimate of the total cost of delivered fuel.

1. Scenarios

The current OSD seven-step FBCF process requires the Services to identify appropriate scenarios based on approved joint Defense Planning Scenarios. The scenarios are used to identify required logistics resupply of energy to support the energy-demanding system. Scenario-driven analysis is necessary when calculating FBCF for a new energy-demanding system without a current comparable system, but is not required when using the Bulk Fuels Distribution Model in conducting AOAs on a change in technology or a comparable replacement for a current system. For example, scenarios do not have to be included in an FBCF calculation when analyzing the FBCF of adding armor to an AH-64 Apache helicopter, therefore increasing fuel consumed. Scenarios are also not required when conducting an FBCF comparison between the F/A-18E Super Hornet and the F-35C Joint Strike Fighter because their fuel burn rate can be used to estimate the impact of a change in fuel demanded using the Bulk Fuels Distribution Model. On the other hand, scenarios would be required when conducting FBCF calculations for the logistics impact and total cost of the acquisition of an unmanned aerial vehicle that consumes biofuel with no supporting infrastructure in place; costs associated with the existing supply chain would not be directly applicable.

2. Complex Supply Chain Interactions

In the IO approach, the output of one node in a supply chain is the input to other nodes, which allows for modeling complex interactions such as networks with cycles. Although the DLA Energy bulk fuels supply chain does not have such complexities, the model can capture these interactions in a supply chain using a set of simultaneous linear equations. A change in demand propagates throughout the supply chain and the effect of these intricacies on system-wide costs are captured.

3. Query for Multiple Components

The Bulk Fuels Distribution Model enables less work and immediate results for FBCF calculations for multiple components. The FBCF for a change in demand for a single or multiple locations in the supply chain, or a change in demand for energy demanding systems, can immediately be calculated and the impact identified.

4. Bulk Fuel Supply Chain

The Bulk Fuels Distribution Model is an accurate representation of the DoD bulk fuel supply chain. The model’s inputs are based on DLA Energy data from the approved bulk fuels distribution plan. For every location in the supply chain, the model calculated the delivery cost.

E. DATA CHALLENGES

There were many challenges in obtaining data to accurately model the DLA Energy bulk fuels supply chain. DLA Energy does not maintain datasets in the format required to be used as inputs into the model. DLA Energy uses the transportation rates for each arc based on winning bids from suppliers. These rates are maintained in a separate dataset from the distribution plan, which identifies how many USG will be transported over each arc. When combining the two datasets, 80% of the data matched up, leaving 20% of the arcs missing data for transportation rates. To minimize the impact of incomplete data, “nearest match” data was used for transportation rates that were missing based on similar bids from a supplier (e.g., for another fuel type with the same origin and destination).

Another area in which data limited the model’s ability to more accurately represent the supply chain data on fuel consumption at terminals, as well as fuel consumed in the transportation of fuel. Fuel consumption within the supply chain, whether of bulk fuel or other fuel, impacts the total delivery cost. When Humvees are driven along pipelines to conduct corrective and routine maintenance, fuel is consumed at a cost to the DoD. Data at this granularity was not available, yet this fuel consumption increases the actual delivery cost of fuel. Additionally, although the transportation rates from the suppliers include the cost of fuel, data on the amount of fuel is not available. The amount of fuel consumed is necessary to calculate the environmental cost for emissions.

The terminal operating costs available from DLA Energy were incomplete; the values used in this model were based on future budgets. Terminal operating costs were for only 16% of the components in the model. Every terminal in the DLA Energy supply chain has a cost to the DoD and more accurate terminal cost data is required to provide better estimates of the actual delivery cost of bulk fuel.

Lastly, the price DLA Energy pays to purchase fuel varies with the commercial market. Data on the market price of the reference commodity for each bulk fuel was not provided by DLA Energy. The Bulk Fuels Distribution Model includes a reference variable to include the market price of fuel, which would enable the model to provide a more accurate estimate of the total cost of purchase plus delivery.

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IV. CONCLUSIONS AND FOLLOW-ON STUDIES

The Bulk Fuels Distribution Model can provide quantitative analysis of the impact of a change in fuel demand on total DoD costs, which supports better informed decisions for AOAs.

The OSD seven-step FBCF process could be condensed to a single step, using a model of the same structure as the Bulk Fuels Distribution Model, if the Services maintained data analogous to the DLA Energy data provided. A single-step process would allow for less complex and more accurate FBCF calculations. Additionally, the OSD seven-step process allows for variation in FBCF calculations by service, but the Bulk Fuels Distribution Model allows each service to use the same methodology to minimize inter-service differences in calculations.

DLA Energy charges a standard price to each service, yet incurs different costs to deliver to different locations. The OSD seven-step FBCF process only takes into account the DLA Energy standard price. The Bulk Fuels Distribution Model can use a much better estimate of the DLA Energy's actual costs for delivery to each location to gain a more accurate representation of the actual FBCF.

Fuel is sent every day to the front lines and forward operating points in Afghanistan and Iraq and, in order to accurately calculate the FBCF, data must be maintained on the complete supply chain. With additional data collection, a DoD-wide extension of the Bulk Fuels Distribution Model could be used to more accurately calculate the FBCF.

Dubbs (2011) modeled fuel distribution in Afghanistan and estimated the fuel multiplier effect (but not the expenses) associated with delivering fuel to the front lines of a war zone. A follow-on study could combine the Bulk Fuels Distribution Model with the Dubbs model to calculate the FBCF to deliver fuel to all operating posts in Afghanistan. This study would provide additional insight to the FBCF for energy-demanding systems in a time of war.

The Bulk Fuels Distribution Model could be used to estimate the FBCF for supporting F/A-18E Super Hornet and the F-35C Joint Strike Fighter. The fuel burn rates and regions in which the F/A-18E Super Hornet consumed fuel can be used to readily determine the FBCF for these systems.

The delivery costs calculated using Bulk Fuels Distribution Model could be used to compare the distances fuel travels in the supply chain against the cost to deliver the fuel, thus enabling the DoD to identify infrastructure deficiencies that could reduce the delivered cost of fuel.

The Bulk Fuels Distribution Model has limitations. When conducting AOAs, the model can be useful for a system with a close analogy, but for a new system such as a UAV with no current fuel supply chain in DoD, the Bulk Fuels Distribution Model cannot provide accurate estimates. Another limitation is a result of the lack of data. The model is only as good as its inputs and unless DLA Energy, as well as each service, maintains specific databases to use as the model's inputs, the model cannot accurately capture the total cost of delivering bulk fuel.

Although the cost of delivered fuel using the Bulk Fuels Distribution Model does not include environmental costs, neither do other FBCF estimates. The Bulk Fuels Distribution Model provides better estimates and greater insight into the relative cost of fuel for a given location in the DLA Energy supply chain for future planning and analysis.

LIST OF REFERENCES

110th Congress of the United States. (2008). *Duncan Hunter national defense authorization act for fiscal year 2009.* Washington, D.C.: Government Printing Office.

Albino, V., Dietzenbacher, E., & Kühtz, S. (2003). Analyzing material and energy flows in an industrial district using an enterprise input-output model. *Economic Systems Research*, *15*(4), 457–480.

Albino, V., Izzo, C., & Kühtz S. (2002). Input-output models for the analysis of a local/global supply chain. *International Journal of Production Economics*, *78*(2), 119–131.

Chairman of the Joint Chiefs of Staff (CJCS). (2003). *Joint publication 4–03: Joint bulk petroleum and water doctrine.* Retrieved from http://www.bits.de/NRANEU/others/jp-doctrine/jp4_03(03).pdf

Chiang, A. C. (1984). *Fundamental methods of mathematical economics.* New York: McGraw-Hill.

Corley, R. M. (2009). *Evaluating the impact of the fully burdened cost of fuel* (Master's thesis). Monterey, CA: Naval Postgraduate School.

Defense Acquisition University. (2009). *Fully burdened cost of delivered energy – Methodological guidance for analyses of alternatives and acquisition tradespace analysis.* Retrieved 2 August 2011 from https://acc.dau.mil/fbcfmethod

Defense Logistics Agency Energy. (2010). *The Defense Logistics Agency Energy fact book fiscal year 2010* [ebrary version]. Retrieved from http://www.desc.dla.mil/dcm/files/Fact%20Book%20FY10%20Final%20Web.pdf

Defense Logistics Agency Energy. (2011a). Products and services. Retrieved from http://www.desc.dla.mil/

Defense Logistics Agency Energy. (2011b). *World wide distribution maps.* [PowerPoint presentation, slide 28]. Fort Belvoir, VA: Author.

Defense Science Board. (2001). *More capable warfighting through reduced fuel burden.* Report of the Defense Science Board Task Force on Improving Fuel Efficiency of Weapon Platforms. Retrieved from http://www.acq.osd.mil/dsb/reports/ ADA392666.pdf

Defense Science Board. (2007). *More fight-Less fuel*. Report of the Defense Science Board (DSB) Task Force on DoD Energy Strategy. Retrieved from http://www.acq.osd.mil/dsb/reports/ADA477619.pdf

Department of Defense. (2010). Quadrennial defense review. Retrieved from http://www.defense.gov/qdr/qdr%20as%20of%2029jan10%201600.PDF

DiPetto, C. (2008). *Testimony of Chris DiPetto, Office of the Under Secretary of Defense (Acquisition, Technology & Logistics).* Proceedings before the United States House Committee on Armed Services Readiness Subcommittee. Washington, D.C.: Government Printing Office.

Dubbs, S. R. (2011). *Estimating the fully burdened cost of fuel using an input-output model—A micro-level analysis* (Master's thesis). Monterey, CA: Naval Postgraduate School.

The JASON Group. (2006). *Reducing DoD fossil-fuel dependence*. McLean, VA: Author.

Lin, X., & Polenske, K. R. (1998). Input-output modeling of production processes for business management. *Structural Change and Economic Dynamics, 9,* 205–226.

LMI Government Consulting. (2007). *Transforming the way DoD looks at energy: An approach to establish an energy strategy*. McLean, VA: LMI.

Lu, W., & Rencheng, T. (2007). *Input-output analysis for multi-location supply chain management control: A theoretical model.* Retrieved from http://www.iioa.org/pdf/16th%20Conf/Papers/Wang-274.pdf

Military Operations Research Society (MORS) Special Meeting. (2009). *Power and energy special meeting in November 30 – December 3, 2009.* Reston, VA: MORS.

Miller, R., & E., Blair, P. (2009) *Input–output analysis: Foundations and extensions.* Cambridge, U.K.: Cambridge University Press.

Naval Surface Warfare Center. (2008). *Flight IIA hybrid drive viability study.*West Bethesda, MD: Carderock Division.

Office of the Assistant Secretary of Defense for Operational Energy, Plans & Programs. (2011). *Energy for the warfighter: Operational strategy, May 2011.* Washington, D.C.: U.S. Government Printing Office.

Office of the Assistant Secretary of the Navy (Research, Development and Acquisition). (2011). *Energy evaluation factors in the acquisition process, 20 June 2011.* Washington, D.C.: U.S. Government Printing Office.

Office of the Under Secretary of Defense (Acquisition, Technology & Logistics). (1999). *Memorandum for the Chairman, Defense Science Board, 18 June 1999.* Washington, D.C.: U.S. Government Printing Office.

Office of the Under Secretary of Defense (Acquisition, Technology & Logistics). (2007). *Memorandum for the Deputy Under Secretary of Defense, Acquisition & Technology, 10 April, 2007.* Washington, D.C.: U.S. Government Printing Office.

Office of the Under Secretary of Defense (Acquisition, Technology & Logistics). (2008). *Operation of the defense acquisition system* (DoD Instruction 5000.02). Washington, D.C.: U.S. Government Printing Office.

Roscoe, S. A. (2010). *A comparison of the fully burdened cost of fuel methodologies employed across the Department of Defense* (Master's thesis). Monterey, CA: Naval Postgraduate School.

Truckenbrod, D. R. (2010). *Estimating the fully burdened cost of fuel for Naval aviation fixed wing platform* (Master's thesis). Monterey, CA: Naval Postgraduate School.

The White House. (2007). *Executive order 13423 – Strengthening federal environmental, energy, and transportation management.* Washington, D.C.: National Archives and Records Administration.

Wu, R., & Chen, C. (1990). On the application of input-output analysis to energy issues. *Energy Economics, 12*(1), 71–76.

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