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Economic and environmental assessment of liquefied natural gas as a supplemental aircraft fuel

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ABSTRACT

In 2013, natural gas is 70–80% cheaper than jet fuel on an energy basis. As an alternative aviation fuel, natural gas may reduce operating costs. In this paper, we assess the use of liquefied natural gas (LNG) as a supplemental aircraft fuel in a military context, with detailed assessments of the Lockheed Martin C-130H and C-130J transport aircraft. We estimate the cost of retrofitting these aircraft to use LNG and the savings from reduced fuel expenses. We evaluate the societal impacts of LNG within a cost–benefit framework, taking into account resource consumption, human health impacts related to air quality, and climate damage. In order to compare alternative uses of natural gas in aviation, we include in our analysis Fischer–Tropsch (FT) jet fuel from natural gas as a drop-in alternative. Uncertainty analysis is performed with Monte Carlo simulations. We find that aircraft operators can save up to 14% on fuel expenses (retrofit costs included) by employing LNG retrofits, with a 95% confidence interval of 2–23%. Society can also benefit by 12% (3–20%) from LNG use as a result of improved surface air quality, lower resource consumption, and net climate neutrality. These results are highly dependent on fuel prices, the quantity and cost of the LNG retrofits, and the frequency and length of missions. FT jet fuel is not cost-competitive with conventional fuel and results in increased fuel expenses by 17%. FT fuel provides marginal societal benefits relative to jet fuel.

Contents

Abbreviations: CRF, concentration–response function; DAPCA, development and procurement costs of aircraft; DCFROR, discounted cash flow rate of return; FAU, fleet aircraft utilization; FEU, forty-foot equivalent unit; FOB, freight-on-board; FT, Fischer–Tropsch; GHG, greenhouse gas; GTL, gas-to-liquid; GWP, global warming potential; HEFA, hydro-processed esters and fatty acids; IRR, internal rate of return; JFE, jet fuel equivalent; LH_2, liquefied hydrogen gas; LNG, liquefied natural gas; LTO, landing and takeoff; PM, particulate matter; $PM_{2.5}$, particulate matter with diameter below 2.5 μm; PPI, producer price index; R&D, research and development; RDT&E, research, development, testing and evaluation; RF, radiative forcing; UAG, unaccounted gas; UAV, unmanned aerial vehicle; VSL, value of a statistical life

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1. Introduction

Alternative transportation fuels have received considerable attention as a means for diversifying energy supplies and mitigating transportation's impact on climate and air quality. Apart from demonstration flights using synthetic fuels, jet fuel currently comes exclusively from petroleum. Jet fuel demand in the United States is projected to increase by 48.7% by 2033 compared to 2012 [1], while worldwide demand is forecasted to increase by 86.0–105.9% [2], which would lead to increased dependence on petroleum reserves, if no alternative fuels are introduced.

The current contribution of aviation to total anthropogenic radiative forcing is estimated at ~5% although significant uncertainties remain [3,4]. It has also been estimated that aviation emissions result in ~10,000 premature mortalities per year globally due to degradation of air quality [5]. Given the expected increase in air traffic, greenhouse gas emissions and health impacts are expected to increase in the absence of significant mitigation measures.

There are many alternative energy sources for aviation, each with varying degrees of required modifications to the aircraft. Drop-in alternatives need no aircraft modifications and can be used with the current aviation system, including existing distribution and refueling infrastructure. Conversely, electric propulsion (with batteries or fuel cells) requires a complete redesign of the propulsion system and generally the airframe itself. Cryogenic fuels, such as liquid hydrogen (LH_2) and liquefied natural gas (LNG), can in some cases be used with minimal changes to the aircraft, depending on the application [6].

1.1. Drop-in fuels

Synthetic jet fuels (biomass-derived or otherwise) are typically intended to be "drop-in" fuels, i.e. fuels that are sufficiently chemically similar to conventional (petroleum-derived) jet fuel that existing infrastructure and aircraft can be used [7]. Nevertheless, there are important technical issues that must be addressed. For example, conventional jet fuel is known to soften and swell the nitrile elastomers found in O-ring seals within the engine [8], a chemical property that depends heavily on the presence of aromatic components in the fuel. Because synthetic jet fuel usually contains few or no aromatics, there is concern that it may cause O-rings to shrink and fail [9]. As a result of this limitation, alternative jet fuel blends are currently certified to a maximum of 50% synthetic fuel by volume [10]. Synthetic jet fuel containing aromatics can also be produced (synthetic kerosene with aromatics, or SKA) to maintain seal swelling behavior, though these fuels have yet to be certified [11].

A number of different feedstock-to-fuel pathways have been assessed in terms of life cycle greenhouse gas emissions using the metric CO_2 equivalent (CO_2e) where non-CO_2 emissions are converted to a CO_2 basis using their global warming potentials [12]. For example, life cycle emissions associated with the production and use of hydro-processed esters and fatty acid (HEFA) jet fuel from soybean oil have been estimated at 27.3–59.2 gCO_2e/MJ, which is 69–31% lower than the conventional jet fuel baseline of 87.5 gCO_2e/MJ [21]. In addition, measurements of emissions associated with biomass-derived jet fuels show reductions in pollutants of concern to air quality and human health. For example, a 40% blend of biomass-derived fuel was found to reduce overall particulate matter (PM) number-based emissions by 35% over the full landing and take-off cycle compared to conventional jet fuel [13].

Notwithstanding potential benefits of biomass-derived jet fuels, such fuels face a number of challenges including high production costs [14], scalability limits due to feedstock availability [15], environmental and other implications of large-scale land use change [16,17], water use associated with biomass cultivation [18,19], and the time required to scale-up biomass cultivation and conversion facilities [20]. In addition to biomass as a jet fuel feedstock, non-conventional fossil feedstocks for drop-in jet fuel have also been investigated. These alternatives—specifically shale oil-derived jet fuel and Fischer–Tropsch (FT) conversion of coal or natural gas into liquid fuels—have been shown to result in increased life cycle greenhouse gas emissions [21].

1.2. Electric propulsion

Fully electric propulsion for manned aircraft is still in its infancy, and large-scale commercial and military applications have been regarded as being 20 years away [22]. Nevertheless, several advancements have recently been made with unmanned aerial vehicles (UAVs) and light sport aircraft, which have lower specific energy and specific power requirements [23–25]. Current battery and fuel cell technologies are characterized by low energy and power densities, making them well suited for applications with low speeds and payloads.