Peak oil, fuel costs and the future of aviation

Richard Klophaus
Centre for Aviation Law and Business
Trier University of Applied Sciences
Trier, Germany
klophaus@umwelt-campus.de

***Abstract*—This research investigates the impact of global oil production peak transmitted via soaring fuel prices on future air traffic. The paper analyzes the short-term impact of higher fuel prices on airline operating costs, passenger fares and demand for short-haul and long-haul services. Results indicate that the rate of air traffic growth constrained by scarcity of kerosene is much lower - and may even be negative - than unconstrained air traffic growth. Services offered by low-cost carriers and long-haul services are most adversely affected. It is also contended that a strong increase in fuel prices outweighs the potential impact of proposed emission trading systems for the aviation industry. Looking beyond the peak in oil production the paper provides a brief discussion of potential substitutes for petroleum kerosene as jet fuel.**

Keywords-environment; peak oil; airline operating costs; air fares; traffic growth

I. INTRODUCTION

The aviation industry is probably the economic sector most depending on fossil fuels besides the petrochemical industry itself. Today, commercial aviation is characterized by growing passenger numbers and cargo volumes as well as expanding airport and airline capacities. According to a recent Airports Council International (ACI) forecast the current number of 4.5 billion passengers worldwide is expected to reach 9 billion by 2025[1]. Similar forecasts of air traffic growth are issued by manufacturers of commercial jetliners like Airbus and Boeing and proliferated by other sources including public agencies and academia. Based on these forecasts of air traffic growth the demand for kerosene is bound to grow.

The prospering world economy leads to a soaring demand for crude oil aside from aviation. OPEC projects a growth of oil demand from 84 million barrels per day (mb/d) in 2005 to 118 mb/d in 2030 [2]. In 2007 crude oil prices have been boosted by growing worldwide demand. By the time peak oil is reached and half of the global oil resources are exploited, costs for oil extraction will rise and keeping up the production level will become increasingly difficult. The depletion of the world's oil reserves results in an upward price trend for crude oil and also for its refinery products such as kerosene. To our knowledge the potential impact of peak oil on commercial aviation has only recently been addressed [3]. This paper investigates the short-term economic impact of higher crude oil prices on fuel costs, air fares and air passenger demand. The analysis uses the methodology developed for quantifying the impact of emission trading on aircraft operators [4]. With regard to the relationship between kerosene prices and airlines' fuel costs different fuel hedging scenarios are considered. The paper indicates that the rate of air traffic growth constrained by scarcity of kerosene is much lower - and may even be negative - than unconstrained air traffic growth, especially leading to a strong reduction of demand for leisure traffic and long-haul services.

The paper is structured as follows: Section 2 contains considerations on peak oil including an overview of predictions on the time of global oil production peak and forecasts for the future price of crude oil. Section 3 examines the short-term economic impact, i.e. assuming one-year horizon, of higher fuel prices on airline costs, ticket prices and passenger demand for short-haul and long-haul services. Short-haul is further differentiated into routes operated by full service network carriers (FSNCs) and low-cost carriers (LCCs). In the long run the aviation industry has to look beyond the fuel-efficient '3 liter aircraft' and search for new groundbreaking ways to become less dependent on fossil fuels. Hence, Section 4 gives an overview of current research directions in the fields of future aircraft technology and evaluates potential alternative fuels to kerosene. The closing Section 5 summarizes the paper's results and concludes that peak oil has the potential to stop and even reverse long-term air traffic growth.

II. PEAK OIL AND FUTURE FUEL PRICES

End of Oct. 2007 the spot price of Brent-Europe crude oil reached for the first time $90 a barrel. This reflects that world oil demand has continued to grow much faster than oil supply but also ongoing geopolitical risks, OECD inventory tightness, worldwide refining bottlenecks and speculative trading. $90 a barrel is about 50 percent more than Oct. 2006. In real terms, adjusted for inflation, oil is at its highest price since the early 1980s when it hit its peak following the Iranian Revolution and the beginning of the Iran-Iraq war (Fig. 1).

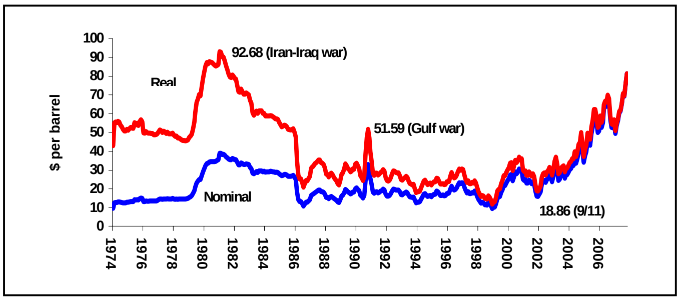

Figure 1. Real and nominal crude oil prices, 1974-2007 (real prices in 2007 dollars).

ISBN: 978-0-615-20720-9

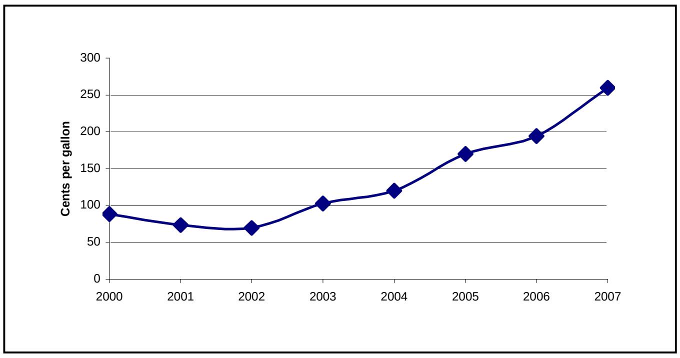

Figure 2. Kerosene-type jet fuel prices in Rotterdam, 2000-2007 (2000-2006: annual average price, 2007: spot price in Oct.).

Kerosene is produced by distilling crude oil. Hence, the product price of kerosene is closely linked to crude oil prices. End of Oct. 2007 the spot price for kerosene-type jet fuel in Rotterdam was about 260 cents per gallon (Fig. 2). This translates into close to $110 per barrel. This spread of approx. $20 on the spot price of Brent-Europe crude oil reflects the gross refining margin. According to the International Air Transport Association (IATA) fuel outranked labor as largest single cost item in the global airline industry in 2006 [5]. Fuel accounted for 25.5% of total operating costs in 2006 compared to 13.6% in 2001. The rise in fuel costs reflects a sharp increase in the price of crude oil but also a widening in the refining margin.

Counteracting soaring fuel costs airlines intensified their efforts to improve fuel efficiency and to obtain cost savings in non-fuel cost items. In particular, labor productivity has improved resulting in a falling labor share of airline operating costs to 23.3% in 2006. The 25.5% fuel share of total operating costs calculated by IATA rests upon an average price of jet fuel of approx. $82 per barrel. With a kerosene price of $110 per barrel at the end of Oct. 2007 the share of fuel costs further increases in the airline industry even if fuel hedging contracts lock a percentage of the fuel purchases at lower prices. Airlines react by increasing average prices for passenger tickets and rates for air cargo. For example, European airlines like Air France-KLM (AF-KLM) or Lufthansa raised their fuel surcharges for passenger tickets several times in 2007 (see Section 3).

Crude oil prices react to the balance of demand and supply. Hence, the current spiking of fuel prices creates concerns about a global shortage of future oil supplies. If actors in the oil market expect a shortage of oil supplies, oil prices increase before a shortage actually occurs. This is reflected in contracts for future deliveries of crude oil, called futures. In Oct. 2007 the prices of crude oil futures soared to all-time highs after Energy Information Administration (EIA) indicated a drop in commercial US crude inventories to the lowest level in two years. EIA providing the official energy statistics from the US government publishes an International Energy Outlook [6]. In the so-called reference case of its most recent outlook, EIA projects a growth of world consumption of petroleum products by more than 40% from 84 mb/d in 2005 to 118 mb/d in 2030, an average annual growth rate of 1.4%. The demand of China grows much stronger with a forecasted rate of 3.5%. Strong growth is also projected for the other non-OECD economies with the exception of Russia. In addition to the reference case EIA also analyzes high and low oil price cases. Despite considerable differences between oil prices the demand projections for 2030 do not vary substantially indicating that long-term demand is relatively inelastic to oil price changes. It is a question whether the suggested lack of demand elasticity remains a valid proposition once production of crude oil falls short of demand due to finite oil reserves. If global crude oil production cannot be increased even with mounting oil prices there has to be a demand adjustment.

The US Government Accountability Office (GAO) examined more than twenty studies on the timing of the peak in oil production conducted by government authorities, oil companies and oil experts (Fig. 3) [7]. According to this meta-analysis most studies estimate peak oil sometime between now and 2040. The range of estimates on the timing of peak oil is wide due to multiple and uncertain factors including (1) the amount of oil still in the ground, (2) technological, cost and environmental challenges to produce that oil, (3) political and investment conditions in countries where oil is located and (4) the future global demand for oil. Some of the studies cited by GAO consider only the peak in conventional oil, while other studies include non-conventional sources of oil – oil sands, heavy and extra-heavy oil deposits and oil shale. The production process of oil from non-conventional sources is more costly, uses larger amounts of energy and presents environmental challenges.

According to the recently published energy outlook by the International Energy Agency (IEA) the oil production in most countries outside the Middle East has already peaked or will do in the near future. Approximately 70% of the estimated remaining global oil reserves are located in politically insecure regions respectively are kept under OPEC control [8]. OPEC statements concerning strategic oil reserves may be questioned. Oil production represents a major sector of economy in OPEC countries, and the admission of declining oil reserves harms their financial standing and political importance. The number of discovered oil fields decreases year by year. About 42,000 oil fields have been discovered until today, the 400 largest represent about 75% of global oil reserves. The annual worldwide crude oil consumption exceeds the amount of discovered reserves since 1981. The predominant part of extracted crude oil nowadays derives from oil fields discovered in the 1970s [9].

 ISBN: 978-0-615-20720-9

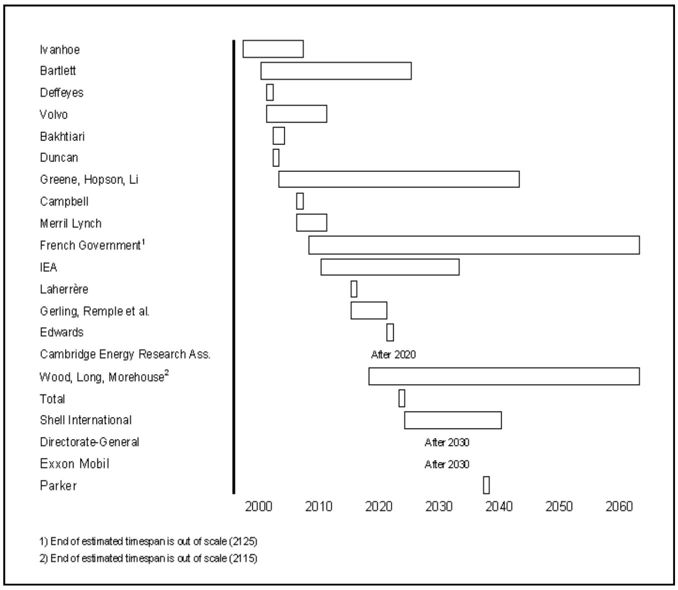

Figure 3. Estimates of the timing of peak oil (Source: GAO [7])

Finite oil resources and global economic growth lead to an upward trend for crude oil prices. However, due to multiple and uncertain factors concerning near-term and long-term oil production and the future development of global oil demand it is not surprising that forecasts on future prices show a wide range. EIA differentiates three world oil price cases [6]. In the high world oil price case, world oil prices climb from $43/barrel to $100/barrel in 2030 (all values in 2005 real dollars). In the low price case, oil prices moderate fairly quickly to $49/barrel in 2010 and then further to $34/barrel in 2015 and remain at that level through 2030. The reference case oil prices rise steadily after 2015 to $59/barrel in 2030.

For the purpose of this paper the 50% increase of world oil prices in the one-year period Oct. 2006 – Oct. 2007 from around $60/barrel to $90/barrel is simply prolonged for another year. This results in $135/barrel in Oct. 2008. This figure is not to be considered as another oil price forecast but only as starting point for the analysis of the possible short-term impact of higher kerosene prices on commercial aviation. $135/barrel is beyond the oil price ranges of most recently published short-term forecasts. In November 2007, EIA expects the average West Texas Intermediate (WTI) crude oil price in 2008 at nearly $80/barrel [10]. However, most short-term oil price forecasts published in recent years underestimated the actual oil price development. For example, in January 2007 EIA also projected a WTI crude oil spot price of $65 for the 3rd and 4th quarter of 2007.

III. ECONOMIC IMPACT OF SOARING KEROSENE PRICES

This section considers the short-term response of passenger demand for air travel resulting from the cause-and-effect chain depicted in Fig. 4. This cause-and-effect chain is referred to as direct impact of higher fuel prices. In addition, there are potential indirect impacts of soaring fuel prices, for example, a reduction in air travel demand resulting from lower disposable income of households or an increase in airlines' operating costs for other cost items than fuel due to inflation.

Figure 4. Direct economic impact of higher fuel prices

The paper assumes no disruptions in normal economic activity and that the overall political and economic setting for commercial aviation remains intact. The time horizon is only one year allowing to differentiate a scenario with high level of airline fuel hedging and a scenario with no fuel hedging a year ahead. This short-term approach justifies not to account for fuel efficiency measures and also to use current operational and cost data.

The volatility of kerosene prices is an important issue for the airline industry. In 2006, the fuel consumption of Lufthansa (LH) amounted to 6,940,587 tons equivalent to 54,564,363 barrels (1 barrel = 159 liter, 1 liter kerosene = 0.8 kg) [9]. Without fuel hedging a fuel price rise by $1 a barrel increases LH's operating costs by more than $50 millions. Fuel hedging is often touted as the solution to this problem.

Fuel hedging means stabilizing fuel costs by locking in the costs of future fuel purchases to protect against sudden cost increases from rising fuel prices. However, fuel hedging also prevents savings from decreasing fuel prices and might even lack a theoretical justification [11]. In practice, fuel hedging strategies vary significantly between airlines, some opting to hedge their entire fuel needs, while others leave themselves exposed to fluctuations in fuel costs. The lack of fuel hedging might not be strategy-driven but simply the result of insufficient cash or credit. According to Morrell and Swan, most airlines typically hedge between one- and two-thirds of fuel costs and look forward six months in their hedging, with few hedges more than a year ahead. Hence, the fuel hedging policy of AF-KLM with regard to the time period covered seems to be rather exceptional (Table I).

TABLE I. AF-KLM FUEL HEDGING POLICY

Year	2007-08	2008-09	2009-10	2010-11
Forecasted spot price (Brent, $/barrel)	79	83	79	78
Hedged consumption (%)	77	67	51	31
Average hedged price (Brent, $/barrel)	62	61	68	69
Final average price (Brent, $/barrel)	66	68	73	75

Source: www.airfranceklm-finance.com, visited 26th October 2007.

ISBN: 978-0-615-20720-9

AF-KLM forecasts a spot price of $79/barrel in 2007-08. The average fuel price for AF-KLM is locked with fuel-hedging contracts that secure 77% of the airline's fuel requirements in 2007-08. Even for 2010-11 31% of the fuel needs are hedged. The average hedged price in 2007-08 with $62/barrel is only two thirds the spot price of crude oil at end of October 2007 of more than $90/barrel. By using the futures markets AF-KLM managed to soften the affect of higher fuel prices but still increased its fuel surcharges on air fares several times in 2007.

From the information publicly available, AF-KLM hedges only the crude oil price. This leaves the price difference between crude oil and kerosene uncovered. The kerosene price is driven by crude oil price developments but is also influenced by other specifics, especially refinery capacities and price switches between diverse oil products. End of October, the spot price for kerosene-type jet fuel in Rotterdam was about $110/barrel, i.e. approx. $20 higher than the spot price of Brent-Europe crude oil.

For the purpose of this paper the 50% increase of world oil prices in the one-year period Oct. 2006 – Oct. 2007 from a level of $60/barrel to $90/barrel is simply prolonged for another year. This results in $135/barrel in Oct. 2008. As already stated in Section 2 this figure is not another oil price forecast but only serves as starting point for the analysis of the short-term impact of higher kerosene prices on commercial aviation. Additionally, a constant refining margin of $20/barrel is assumed. Hence, all further calculations are based on a spot price for kerosene-type jet fuel of $155/barrel.

All airlines are confronted with volatility of fuel prices. Besides the structure of fleet and network different fuel hedging policies lead to a varying effect on fuel costs among airlines. In Europe, network carriers like AF-KLM and LH pass along higher fuel costs to passengers through higher ticket prices with changing fuel surcharges added to air fares. Ryanair (FR) and other European LCCs do not add fuel surcharges but increase the average fare level. The following calculations estimate the increase in ticket prices and the resulting changes in passenger demand due to rising fuel prices. As reference value to measure fuel price increases the final average price of $68/barrel forecasted by AF-KLM for 2008-09 by end of Oct. 2007 is used (Table I). This fuel price is further on referred to as AF-KLM base. As no similar information about spot price forecasts, hedged and average fuel prices for LH and FR has been available to the authors, it is assume that the AF-KLM base is also valid for LH and FR.

The airline’s fuel costs ($/liter kerosene) at a given future time (e.g. Oct. 2008) based on the future spot crude oil price, the airline’s hedged consumption, the average hedged price and the refiner margin can be calculated as follows:

$$C = ([\alpha \cdot p_h + (1-\alpha) \cdot p_s] + c_r) / 159 \qquad (1)$$

with

- C Future fuel costs ($/liter kerosene),
- α Share of fuel consumption hedged (%),
- p_h Average hedged crude oil price ($/barrel),
- p_s Future spot crude oil price ($/barrel),
- c_r Gross refining margin ($/barrel).

Assuming a spot price p_h= $135 for crude oil in Oct. 2008, the AF-KLM fuel hedging policy (α=0.67; p_h=$61) and a refiner margin c_r=$20, the fuels costs ($/liter kerosene) for AF-KLM in Oct. 2008 resulting from (1) amount to C= 0.66. In comparison, the AF-KLM forecast of a spot price p_h= $83 for crude oil in Oct. 2008 (see Table I) leads to C=0.56 other things being equal. Hence, with a high level of fuel hedging fuel costs would be 18% higher than forecasted. In a scenario with fuel hedging contracts running out or no airline fuel hedging a year ahead (α =0) future fuel costs even rise to C=0,97. To account for soaring fuel costs, airlines like AF-KLM increase fuel surcharges on passenger tickets.

The economic impact of higher fuel costs passed on to passengers via higher ticket prices is investigated for exemplary routes (Table II). Based on the operational data provided by [12] following routes are analyzed:

- Frankfurt (FRA) – London-Heathrow (LHR) served by LH.
- Hahn (HHN) – London-Stansted (STN) served by FR.
- LH-operated intercontinental route FRA – Singapore (SIN).

For each route the analysis differentiates the impact of fuel price increases with fuel hedging (α=0.67) and without fuel hedging (α=0). Results are compared with AF-KLM base of $68/barrel. Lacking airline-specific information it is assumed that any increase in fuel costs in excess of the AF-KLM base is fully passed on to passengers via higher ticket prices, i.e. fuel cost increase equals ticket price increase. FR has a no fuel surcharge policy and accommodates higher fuel prices by increasing average ticket prices. LH increases its fuel surcharge on air fares. In Oct. 2007 LH’s fuel surcharge on long-haul tickets amounted to €67 per sector and for short-haul tickets €14 per sector [13]. This fuel surcharge has been increased several times by LH and other European carriers in 2007. Table II shows fuel consumption and average passenger number per flight for the three selected exemplary routes. Based on this data, the route-specific future fuel costs per passenger can be calculated for AF-KLM base as reference value (C=0.56) and two fuel hedging scenarios (C=0.66 and C=0.97) as follows:

$$c_{pax} = C \cdot \frac{k}{n} \qquad (2)$$

with

- c_{pax} Future fuel costs per passenger ($/PAX),
- C Future fuel costs ($/liter kerosene),
- k Fuel consumption per flight (liter kerosene),
- n Average passenger number per flight (PAX).

ISBN: 978-0-615-20720-9

TABLE II. INCREASES IN FUEL COSTS AND TICKET PRICES DUE TO HIGHER KEROSENE PRICES

Route (carrier)		**HHN-STN (FR)**	**FRA-LHR (LH)**	**FRA-SIN (LH)**
Operational data	Distance flown	572	695	10,603
	Aircraft type	B 737-800	A 321-100	A 340-300
	No. of seats	189	182	247
	Avg. seat load factor	76.1%	66.9%	80.5%
	Avg. no. of passengers	144	122	199
	Fuel consumption (liter kerosene)	3,250	4,125	107,500
Fuel costs (c_{pax})	AF-KLM base	12.6	18.9	302.6
	$\alpha = 0.67$	14.9	22.3	356.5
	$\alpha = 0$	21.9	32.8	524.0
Fuel costs (€/PAX)	AF-KLM base	8.7	13.0	208.7
	$\alpha = 0.67$	10.3	15.4	245.9
	$\alpha = 0$	15.1	22.6	361.4
Avg. ticket price (per sector, €/PAX)		44	136	602
Abs. price increase (€/PAX)	$\alpha = 0.67$	1.6	2.4	37.2
	$\alpha = 0$	6.4	9.6	152.7
Rel. price increase	$\alpha = 0.67$	3.6%	1.8%	6.2%
	$\alpha = 0$	14.5%	7.1%	25.4%

As FR and LH denominate their ticket prices in Euro, fuel costs need to be converted into Euro as well. Table II uses the Dollar/Euro exchange rate €1 = $1.45 valid end of Oct. 2007.

The short-term impact of soaring kerosene prices on fuel costs and ticket prices depicted in Table II remains relatively moderate as long as fuel hedging by airlines mitigates fuel price increases. In absolute terms the price increase for the two short-haul routes is €1.6 (HHN-STN) and €2.4 (FRA-LHR) corresponding to a relative price increase per passenger and sector of 3.6% and 1.8% respectively. The higher price increase in per cent for FR results from its significantly lower average ticket price per sector and passenger compared to LH which cannot be compensated by FR's shorter flight distance and the higher average number of passengers per flight. For the long-haul route FRA-SIN the impact is already more pronounced, with an absolute price increase of €37.2 corresponding to 6.2% in relative terms. It should be noted that even in a scenario with fuel hedging (α=0.67) the impact of increasing fuel prices is higher than the financial burden due to the introduction of the emission trading scheme as proposed by the European Commission [12].

For the scenario with fuel hedging contracts running out or no airline fuel hedging (α=0) the impact is much stronger. In relative terms, LH's short-haul operation is less affected than the operation of FR. The average ticket price sold by LH on FRA-LHR rises by 7.1% (€9.6) and FR's price on HHN-STN by 14.5% (€6.4). The impact on surcharges on long-haul traffic largely exceeds the impact on short-haul traffic. For FRA-SIN operated by LH an additional fuel surcharge of €152.7 would occur. Based on an average fare per passenger and sector of €602, the additional fuel surcharge represents a relative fare increase of 25.4%.

€152.7 is the additional fuel surcharge calculated for LH resulting from assuming spot prices for crude oil to rise by 50% compared to current 90$/barrel and no softening of spot prices by fuel hedging. In principle, this paper equates short-term with a one-year horizon. In its hedging practice, LH hedges up to 90% of its planned fuel requirement on a revolving basis over a period of 24 months. In April 2007 even 70% is hedged one year ahead [13]. LH reduces its hedging ratio from this share each month by 5% leading to a growing exposure to fluctuations in fuel prices after one year. Hence, our results seem to overestimate the short-term impact of rising fuel costs on LH's fuel surcharge. However, FR has recently complained to EU over abusive increases in fuel surcharges based on spot prices on the global crude oil markets rather than hedged prices. According to FR, carriers like LH do not only increase ticket prices for passengers in lockstep with their higher fuel costs but even beyond their additional fuel costs.

As a result of shifting costs to passengers via higher ticket prices, demand for flights is expected to decrease. Table III shows how passenger demand reacts to higher ticket prices. The average price elasticity for short-haul leisure and business demand as well as for long-haul leisure and business demand is taken from a synoptic study [14], the shares of business travelers are adopted from [12] and the relative increases in ticket prices from Table II.

In the fuel hedging scenario (α=0.67), the estimated change in passenger demand for HHN-STN - a typical short-haul flight operated by FR - is -4.7%, while for LH's short-haul FRA-LHR and long-haul FRA-SIN it amounts to -2.0% and -4.0% respectively. Passenger demand for LCCs like FR will be more negatively affected by soaring fuel prices than demand for full service network carriers like LH. The higher demand reduction for FR results from a higher relative fare increase compared to LH as well as a higher share of more price-sensitive leisure travelers. Compared to short-haul routes like FRA-LHR demand for long-haul routes such as FRA-SIN will be more affected due to the relative strong increase in ticket prices and despite lower price elasticities for long-haul travel.

Without fuel hedging (α=0), the short-term impact on passenger demand is even stronger. The estimated change in passenger demand due to higher ticket prices for HHN-STN is -19,1%, -7.9% for FRA-LHR and -16,6 % for FRA-SIN.

TABLE III. DEMAND REDUCTION DUE TO HIGHER TICKET PRICES

Route (carrier)		**HHN-STN (FR)**	**FRA-LHR (LH)**	**FRA-SIN (LH)**
Avg. price elasticity	Business	-0.7	-0.7	-0.265
	Leisure	-1.52	-1.52	-1.04
Share of business travelers		25%	50%	50%
Rel.price increase	$\alpha = 0.67$	3.6%	1.8%	6.2%
	$\alpha = 0$	14.5%	7.1%	25.4%
Change in demand	$\alpha = 0.67$	-4.7%	-2.0%	-4.0%
	$\alpha = 0$	-19.1%	-7.9%	-16.6%

 ISBN: 978-0-615-20720-9

Table III does not differentiate the relative price increases with regard to leisure and business market segments. As the average ticket price per passenger is higher for business travelers compared to leisure travelers, the reduction in leisure demand is even stronger and the reduction in business demand lower than shown in Table III.

This section only estimated the isolated effect of soaring fuel prices transmitted via higher ticket prices on passenger demand. This cause-and-effect chain corresponds to the direct impact of higher fuel prices. There will be indirect impacts of soaring fuel prices, for example, a reduction in air travel demand resulting from lower disposable incomes. Looking at the calculated short-term reduction in passenger demand of more than 15% for typical short-haul services operated by LCC as well as for long-haul services in the no fuel hedging scenario, higher ticket prices due to soaring fuel prices strongly influence commercial aviation. However, this direct impact may be compensated by other factors influencing travel demand. Fuel surcharges levied by airlines in recent years did not keep aviation from growing more than 5% annually [12]. In addition, the estimated changes in passenger demand for services offered by FR and LH have to be set in due proportion to the future growth trend in commercial aviation, especially the currently expected growth rates for European LCCs that go well beyond 5% p.a. The reduction in air travel demand caused by soaring fuel prices may only confine the overall demand increase.

IV. ALTERNATIVES TO KEROSENE AS JET FUEL

The previous results show that the rate of air traffic growth constrained by scarcity of kerosene will be much lower - and may even be negative - than unconstrained air traffic growth, especially leading to a strong reduction of demand for leisure traffic and long-haul services. Hence, the entire aviation industry has to look beyond the fuel-efficient ‘3 liter aircraft’ and search for new groundbreaking ways to become less dependent on fossil fuels. This section provides a brief overview how to save fuel or even replace kerosene as jet fuel.

At present, aircraft and engine manufacturers improve aircraft design (e.g. blended wing aircraft) and fuel-efficiency of engines in order to reduce fuel consumption. Fuel saving strategies by airlines include shorter air routes, carrying less minimum fuel, increased fuel blending, shorter sector lengths, modern fleet, increased load factors and more efficient ground operations (e.g. reduction of ground delays). All these efforts contribute to fuel conservation by commercial aviation but do not provide a substitute to conventional petroleum kerosene.

Kerosene is considered the ideal jet fuel. First reason is its high energy content. The energy content of fuel is measured as specific energy which is the energy content per unit mass (joules/kg) and as energy density which is the energy per volume (joules/liter). The high energy content of kerosene positively affects the total size and weight of the aircraft. Operationally, the heavier the aircraft is at takeoff, the more fuel is required to lift it into the air. With regard to safety criteria, the Jet A-1 kerosene used in commercial aviation has a high flash point of not lower than 40° Celsius reducing explosion hazards and a low freezing point Kerosene also does not contain or absorb water which means that in cold temperatures no ice crystals form that block fuel filters and ultimately lead to fuel starvation. These safety over a wide temperature range is an important selection criterion for jet fuels.

Below alternative fuels (synthetic kerosene, bio-fuels and liquid hydrogen) and a new aircraft propulsion technology (fuel cells) are presented and briefly evaluated with reference to [15], [16], [17] and [19] along following criteria: high energy content, safety, environmental impact, availability and price. Ethanol and methanol are not considered because of their unfavorable properties at jet fuel.

A. Synthetic kerosene

This is a carbon-based fuel synthesized by using a Fischer-Tropsch conversion process. According to the raw material used three types of synthetic kerosene are differentiated:

- Biomass to liquid (BTL).
- Gas to liquid (GTL).
- Coal to liquid (CTL).

Today, synthetic kerosene is only approved in commercial aviation as a blend with petroleum kerosene despite of having basically the same energy content and safety qualities. Semi-synthetic fuels (50 percent normal fuel and 50 percent synthetic fuel) for the aviation industry have been produced in South Africa since 1999 [16].

BTL is more environmentally clean than GTL and CTL as the combustion process of BTL releases carbon dioxide (CO_2) in the same quantity as the plants have absorbed from the atmosphere during their growth process. However, the CO_2 benefits of BTL must be assessed by life cycle analyses considering emissions generated by cultivation, processing and transport. BTL can be produced from almost any type of plants and offers new perspectives for farmers but implies the risk of competition with food production.

B. Bio-fuels

Bio-fuels refer to fuels derived from feedstock such as rapeseed, soybeans or algae without a Fischer-Tropsch synthesis as in the case of BTL. Bio-fuels have a somewhat lower energy content than kerosene [16]. The primary concern with the use of bio-fuels are their low temperature properties with freezing points near 0° Celsius, much higher than the maximum freezing point of petroleum kerosene (-40° Celsius). With additives the low temperature operability at cruising altitudes of bio-fuels can be improved. There are doubts that bio-fuels can be mass-produced affordably because of limited farmland [17]. For these reasons, bio-fuels are currently not considered as alternative jet fuels on their own but more suitable for blending with kerosene.

C. Hydrogen

Liquid hydrogen is the liquid state of the element hydrogen. It is probably the most commonly discussed long-term alternative to kerosene. Hydrogen provides 2.5 times the

ISBN: 978-0-615-20720-9

energy per kg than kerosene but is also about four times more voluminous. Liquid hydrogen is non-corrosive. A major potential advantage of hydrogen compared to kerosene is the significant reduction of harmful emissions. The primary combustion product of hydrogen is water. A negative byproduct of its combustion is water vapor as greenhouse gas. Depending on how hydrogen is produced there are significant CO_2 emissions generated during its life cycle.

Today, hydrogen is expensive to produce and difficult to store. Due to the large volume and the requirement to cool down hydrogen to the liquid state (-253° Celsius), the cryogenic storage of hydrogen constitutes a major challenge for aircraft manufacturers. A hydrogen powered aircraft will look very different from today's kerosene aircraft. Hydrogen will not be stored in conventional wings because of pressurization and insulation requirements. The positioning of fuel tanks in the fuselage results in an enlarged fuselage or less passenger capacity. Ensuring explosion safety of cryogenic aircraft is a challenge. Hydrogen will also require a radical change in engine design. Yet the Russian aircraft manufacturer Tupolev managed these technical challenges with the cryogenic fuel aircraft TU-155 performing its maiden flight already in 1988 [18].

Hydrogen aircraft also pose a major challenge for airport infrastructure which at present is only designed for kerosene aircraft. A prerequisite for a change from kerosene to hydrogen already in the transition stage is the global availability of two parallel fueling systems at airports. Hence, a transition to hydrogen-powered aviation may take decades, especially considering the long life-span of aircrafts currently in operation.

D. Fuel cells

Fuel cells have been used in spacecrafts since the 1960's to power auxiliary engines. Experimental aircraft powered only by a fuel cell supported by lightweight batteries during takeoff and climb is on its way. A fuel cell is an electrochemical device that converts hydrogen directly into electricity and heat without combustion. Fuel cells are emission-free and quieter than hydrocarbon fuel-powered engines. The main challenge is to develop compact and lightweight electric propulsion systems with more power. Today, using fuel cell technology as primary power for a passenger airplane leads to a propulsion system several times heavier than conventional aircraft engines and still far from their efficiency. However, chilled superconducting magnets carrying electricity without resistance have been proposed that may allow for lightweight and powerful electric jet engines in the long run [19].

Table IV summarizes the pros and cons of jet fuel alternatives relative to petroleum kerosene along selected criteria. "+'' indicates that the potential substitute performs better with regard to the respective criterion, "o" suggests equal and "-" worse properties compared to conventional kerosene.

TABLE IV. ASSESSMENT OF ALTERNATIVE JET FUELS AND FUEL CELLS RELATIVE TO PETROLEUM KEROSENE

Criterion		Energy Content	Safety	Environ-mental impact	Avail-ability and price
Synthetic kerosene	BTL	o	o	+	-
	CTL	o	o	-	-
	GTL	o	o	-	-
Bio-fuels		-	-	+	?
Hydrogen		+	?	+	-
Fuel Cells		-	?	+	-

The assessment does not account for ground-breaking technology developments and, hence, has to be regarded as preliminary. Evaluating alternatives to petroleum kerosene in the near future, synthetic kerosene holds the greatest promise as it basically can be used in existing aircraft either alone or blended with petroleum kerosene. The main problem for synthetic kerosene with the exception of BTL is the large amount of CO_2 generated during production. In the long run, hydrogen seems to be a promising candidate to replace kerosene if safety standards of civil aviation can be secured but asks for a fundamental change in aircraft design and new ground infrastructure at airports.

V. CONCLUSIONS

Conventional wisdom in commercial aviation is that global air traffic will continue to grow in the coming decades. This implicitly assumes no constraint in traffic growth due to finite oil resources. This is in stark contrast to studies that estimate peak oil sometime between now and 2040.

This paper analyzed the short-term economic impact of soaring fuel prices on commercial aviation. The time horizon was only one year from now allowing fuel hedging by airlines to balance increasing spot prices. The analysis was restricted to the direct effect of higher kerosene prices on operating costs, fare levels and passenger demand. Indirect effects on passenger demand resulting from a reduction of purchasing power, an increase in unemployment and higher costs for other input factors besides kerosene were not considered. The analysis also ignored possible political crisis and economic shocks for oil importing countries forced to spend significantly more on their energy purchases. Hence, the scope of this paper has been somehow limited.

However, the limited approach already shows that the rate of air traffic growth constrained by scarcity of kerosene will be much lower - and may even be negative - than unconstrained air traffic growth, especially with regard to price-sensitive leisure demand. Services offered by low-cost carriers and long-haul services will be most adversely affected by higher fuel prices. Further, the impact of soaring fuel prices largely exceeds the impact of the proposed EU emission trading system (ETS) for the aviation industry. This leads to the question whether ETS is actually needed in view of finite

ISBN: 978-0-615-20720-9

supplies of fossil fuels that may restrict or even terminate air traffic growth. In addition, high fuel prices are a strong incentive to use more fuel-efficient engines, to optimize minimum fuel policies, to improve air routes and ground operations, etc., in the same direction as intended by ETS.

The fuel price development will also influence the typical air service pattern, for example, there may be a renaissance of technical stops for re-fueling on intercontinental routes or more point-to-point traffic in order to avoid fuel burning detours via hubs. To avoid high fuel costs, regional carriers have already replaced regional jets on some routes by turboprops. The in-depth analysis of the relative economic benefit of competing services patterns and the use of turboprops instead of regional jets in times of high fuel prices is an interesting issue for further research.

Peak oil will happen, the open question is when. It is a problem that may soon replace the global warming debate in commercial aviation as jets are not as fuel-flexible as ground vehicles. Aviation industry and politicians better face the long-term implications of finite oil resources. Airline and airport managers should no longer exculpate themselves by referring to future air frame designs to be developed by aircraft manufacturers or increased blending of other fuels with kerosene by the petrochemical industry. More research than today should be devoted to the economic evaluation of kerosene substitutes in combination with the associated future requirements for airline fleets and airport infrastructure.

REFERENCES

[1] Airports Council International (ACI), Global Traffic Forecast 2006 – 2025, Executive Summary, Geneva, 2007.

[2] Organization of the Petroleum Exporting Countries (OPEC), World Oil Outlook, Paris, 2007.

[3] A. Kuhlman, “Peak oil – impacts on commercial aviation,” Aerlines, e-zine edition, Issue 38, 2007, pp. 1-5.

[4] J. Scheelhaase and W. Grimme, “Emissions trading for international aviation - an estimation of the economic impact on selected European airlines,” Journal of Air Transport Management, vol. 13, 2007, pp. 253-263.

[5] International Air Transport Association (IATA), IATA Economic Briefing, Montreal, June 2007.

[6] Energy Information Association (EIA), International Energy Outlook, Washington, 2007.

[7] United States Government Accountability Office (GAO), “Uncertainty about future oil supply makes it important to develop a strategy for addressing a peak and decline in oil production,” report to congressional requesters, Washington, 2007.

[8] International Energy Agency (IEA), International Energy Outlook 2007 – Petroleum and Other Liquid Fuels, Paris, 2007.

[9] Deutsche Lufthansa AG, Balance 2007, Cologne, 2007

[10] Energy Information Association (EIA), Short-term Energy Outlook, November 6, 2007.

[11] P. Morrell and W. Swan, “Airline jet fuel hedging: theory and practice,” Transport Reviews, vol. 26, pp. 713-730, 2006.

[12] J. Scheelhaase, W. Grimme, W. and M. Schaefer, “European Commission plans emissions trading for aviation industry,” Aerlines, e-zine edition, Issue 36, 2007, pp. 1-5.

[13] www.lufthansa-financials.de/servlet/PB/menu/1023437_l2/index.html (visited Oct. 31, 2007)

[14] D. Gillen, W. Morrison and C. Stewart, “Air travel demand elasticities - concepts, issues and measurement,” study commissioned by the Canadian Department of Finance, Ottawa, 2004.

[15] C. Smith, “Aviation and oil depletion,” presentation at Energy Institute, London, November 2006.

[16] Chevron, “Alternative jet fuels,” supplement to Chevron’s Aviation Fuels Technical Review, Houston, 2006.

[17] Boeing, Alternate Fuels for use in Commercial Aircraft, Seattle, 2007.

[18] www.tupolev.ru/English/Show.asp?SectionID=82 (visited Nov. 20, 2007).

[19] P.J. Masson and C. A. Luongo, “High power density superconducting motor for all-electric aircraft propulsion,“ IEEE Transactions on Applied Superconductivity, vol. 15, 2005, pp. 2226-2229.

ISBN: 978-0-615-20720-9