

Published in Energy Policy

Volume 37, Issue 10, Pages 4003-4010

<http://dx.doi.org/10.1016/j.enpol.2009.04.048>

Aviation fuel and future oil production scenarios

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Abstract

Most aviation fuels are jet fuels originating from crude oil. Crude oil must be refined to be useful and jet fuel is only one of many products that can be derived from crude oil. Jet fuel is extracted from the middle distillates fraction and competes, for example, with the production of diesel.

Crude oil is a limited natural resource subject to depletion and several reports indicate that the world's crude oil production is close to the maximum level and that it will start to decrease after reaching this maximum. A post Kyoto political agenda to reduce oil consumption will have the same effect on aviation fuel production as a natural decline in the crude oil production. On the other hand, it is predicted by the aviation industry that aviation traffic will keep on increasing.

The industry has put ambitious goals on increases in fuel efficiency for the aviation fleet. Traffic is predicted to grow by 5% per year to 2026, fuel demand by about 3% per year. At the same time aviation fuel production is predicted to decrease by several per cent each year after the crude oil production peak is reached resulting in a substantial shortage of jet fuel by 2026. The aviation industry will have a hard time replacing this with fuel from other sources, even if air traffic remains at current levels.

Key words: aviation fuels, peak oil, future air traffic scenarios

1 Introduction

The basis for globalization is global transportation and a driving force has been the growth in global air traffic. Projections by the aviation industry predict a “Business as Usual” (BAU) future with a growth of 5% per year. Currently, aviation fuel is almost exclusively extracted from the kerosene fraction of crude oil.

When future energy scenarios are discussed a BAU scenario is also normally included. The most well known scenario for future oil production is the one delivered by the International Energy Agency (IEA) in its yearly publication World Energy Outlook (WEO). This scenario is based on a growing global economy and that growth needs more oil.

The nations of the world are now gathering to make decisions to reduce global emissions of carbon dioxide. On the agenda is a target for a reduction in oil use on the order of 20 percent by 2020 and even more in the future. The Peak Oil community also discusses such a decline, but the decline is not based on political decisions, rather it is based on the fact that oil production in the future will naturally decline. Peak Oil scenarios can be said to be consistent with the ambitions of politicians.

We will investigate whether the BAU scenario presented by the aviation industry is consistent with the BAU scenario given by the IEA. We will also examine how a peaking and decline of oil production – whether politically motivated or due to natural decline – will affect the production of aviation fuel.

2 Methodology

The air traffic data in the article originates from outlooks by Boeing (2007) and Airbus (2007), which are in good agreement compared to other forecasters, such as the International Air Transport Association (IATA). The effect air traffic forecasts could have on future aviation fuel demand, if fulfilled, is demonstrated as three aviation fuel demand scenarios. The scenarios are all based on air traffic forecasts, but differ in the projected fuel efficiency increase of the world aviation fleet.

Today global oil production is roughly 81.5 million barrels per day (Mb/d), which is equivalent to an annual output of 3905.9 Mt (BP, 2008). There are many different methodologies for predicting future crude oil production, all relying on different assumptions and ideas (Bentley and Boyle, 2007). Some are more optimistic when it comes to the amount that can be produced than others.

In this study, oil production forecasts from IEA (2008a), Aleklett and Campbell (2003) and Robelius (2007) are taken as representative scenarios for future oil production. The three different future crude oil production forecasts are converted into three scenarios of future aviation fuel production. The aviation fuel part of crude oil production is assumed to be a fixed percentage in each scenario.

These forecasts for future demand and supply of aviation fuel are finally compared to see how well the demand and supply forecasts match each other. This will illustrate how compatible the air traffic forecasts are with future supply of oil.

3 Historical air traffic trends and industry forecasts

Airbus and Boeing are leading manufacturers of aircraft with 100 seats or more. Both companies construct forecasts, built on market knowledge and trade data, to predict future air traffic demand and other parameters. What is most important for this study is their view of the air traffic development, and particularly their numbers for Revenue Passenger Kilometre (RPK), but to some extent also the forecast of goods traffic growth.

Figure 1 shows the historical RPK flown and the growth predicted by Boeing and Airbus out to 2026. The numbers of passengers carried have grown an average of 4.9% per year since 1970, and in 2006 more than 2 billion people travelled by air. Counted in RPK, the growth has been 6.1% per year.

The amount of goods transported by aviation has grown by 5.3% per year since 1970, from 6.1 to 37.7 Mt per year. Every tonne is transported an average of 3780 kilometres. If calculated in tonne-kilometres, the growth since the 1970s was 6.7% per year according to the Swedish Institute for Transport and Communication Analyses (SIKA, 2008).

Airbus has predicted a yearly growth of 4.9% and Boeing a yearly growth of 5.0% (Airbus, 2007; Boeing, 2007). Cargo traffic is predicted to grow by 5.8%, according to Airbus (2007), and 6.1%, according to Boeing (2007). Boeing also predicts that 80% of those aeroplanes flying today will be replaced by the year 2026 and that the new aeroplanes will be more fuel efficient and more comfortable (Boeing, 2007). In the Airbus forecast, the percentage of planes that are expected to be replaced or reconstructed is 95% (Airbus, 2007).

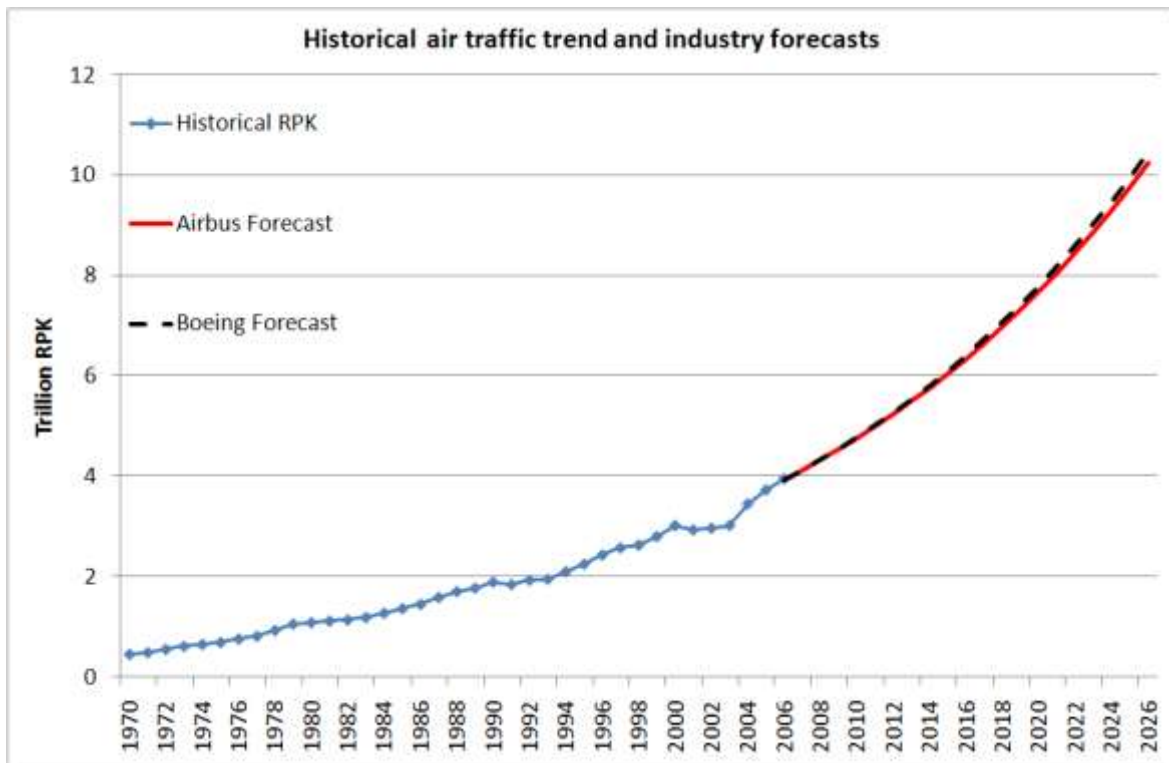


Figure 1: Historical data of RPK and by Airbus and Boeing forecasted growth. The two forecasts from the aviation industry are virtually identical. Source: Boeing (2007), Airbus (2007) and SIKA (2008)

Both companies believe in a strong Asia-Pacific market, but that a lot of new aeroplanes will also be sold to North America and Europe. The European and American markets will grow at a slower rate than the Asia-Pacific market and some of the new aeroplanes will replace those being retired, whereas in Asia-Pacific a lot of new capacity will be added.

4 Fuel consumption trends

Jet fuel demand and aviation traffic growth are not strictly correlated, since the efficiency of aircraft and air traffic management are improving. The aviation industry actually has gone through a huge development since the first commercial aircraft in service. Since the 1960s aircraft are 75% quieter and have reduced fuel consumption by 70% (Airbus, 2007). The Association of European Airlines (2008) declares that the current average fuel consumption is less than 5 litres/hundred RPK, and that the modern aircraft consume approximately 3.5 litres/hundred RPK. Figure 2 shows the historical trend for average fuel consumption of the global fleet of aircraft together with an exponential extrapolation to predict possible future fuel consumption.

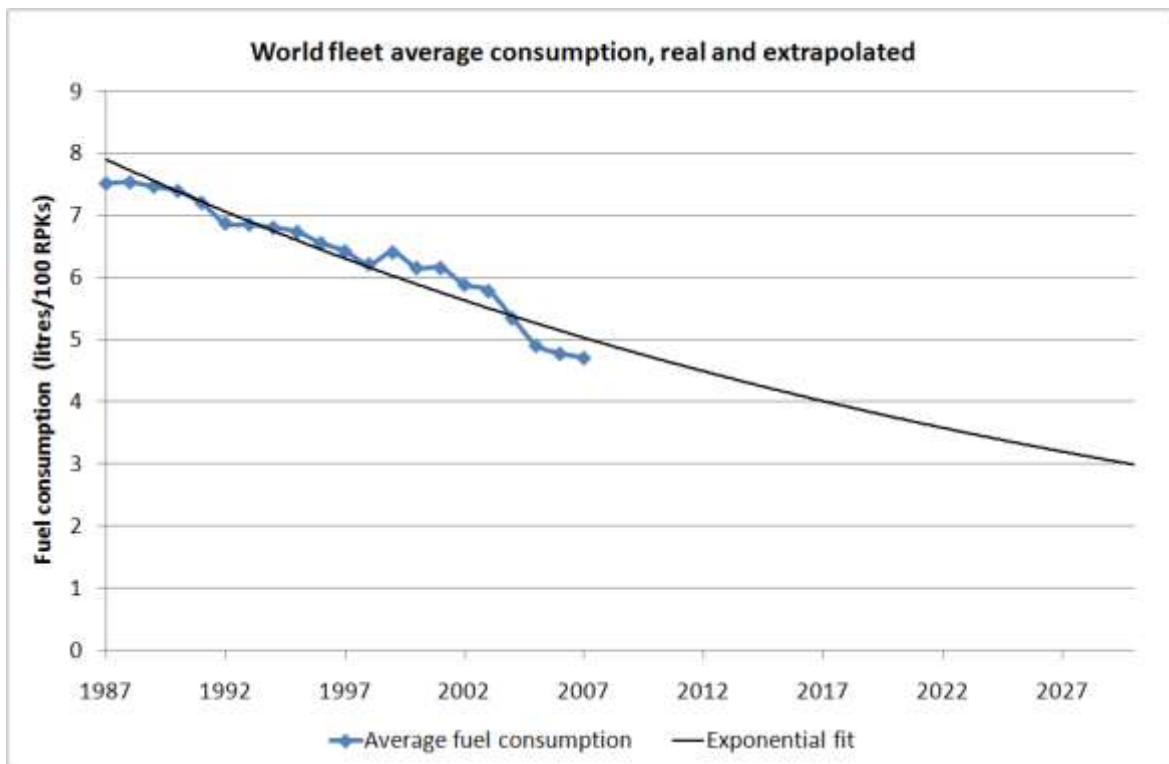


Figure 2: The historical world fleet of aircrafts average fuel consumption together with an exponential extrapolation to predict possible future fuel consumption. Source: Airbus (2007)

Industry and politicians in Europe have as a goal an improvement in fuel efficiency of 50% per RPK before the year 2020 according to the Advisory Council for Aeronautics Research in Europe (2001). The goal is supposed to be met through replacement of old aircraft with new, which are more fuel-efficient, combined with better air traffic management. The aim is to reduce carbon dioxide emissions but will at the same time decrease fuel consumption. Airframe manufacturers are supposed to contribute 20-25% of efficiency gains, engine manufacturers 15-20%, and improved operation 5-10% (Airbus, 2007).

Load factor is a measure of aircraft occupancy and it is easy to understand that a high load factor is crucial for efficient transportation. The load factor has improved over the years and was on average 76% in 2006 (SIKA, 2008).

5 Aviation Fuel

Aviation fuels include both jet fuel for turbine engines and aviation gasoline for piston engines. The dominant fuel is jet fuel originating from crude oil as it is used in all large aircraft. Jet fuel is almost exclusively extracted from the kerosene fraction of crude oil, which distills between the gasoline fraction and the diesel fraction.

The IEA has estimated that the world's total refinery production in 2006 at 3861 million tonnes (Mt). The aviation fuel part was 6.3%, implying an annual aviation fuel production of 243 Mt (corresponding to about 5 Mb/d), including both jet fuel and aviation gasoline (IEA, 2008b). Figure 3 shows how the world's refinery production is divided into different fractions.

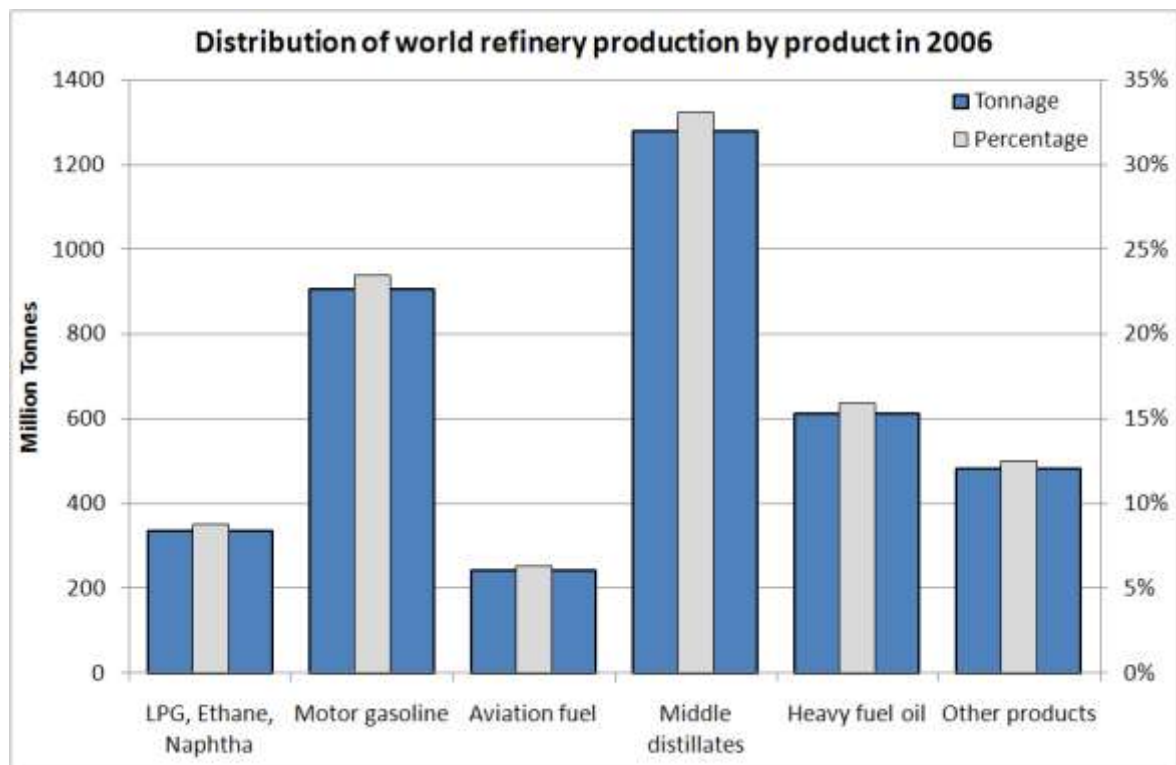


Figure 3: Distribution of world refinery production in 2006. The total production was 3861 Mt. Source: IEA (2008b)

The type of crude oil used in a refinery and the products manufactured are to some extent possible to vary: two Swedish refineries owned by Preem Petroleum AB are taken as examples of the effect this can have on jet fuel production.

The refinery Preemraff Gothenburg is situated on the west coast of Sweden. The atmospheric distillation process divides the crude oil into five different fractions. The second fraction of about 33% of the crude oil input contains the raw material for jet fuel production. This fraction is further processed in the Distillate Hydrotreater (DHT). About 14-15% of the feed to the DHT become kerosene (Åhman, 2008) and the kerosene fraction, of the initial crude oil used, can then be calculated to around 4-5%.

In 2007 crude oil input was 4.56 Mt, about 33 million barrels. Jet fuel production was about 12 000 cubic meters, corresponding to 75 500 barrels using conversion factors from BP (2008). A comparison, between the 33 million barrels crude oil input with 75 500 barrels jet fuel produced, gives jet fuel as only 0.2% of the crude input. That is considerably less than the original kerosene fraction of 4-5% and kerosene that is not sold as jet fuel is primarily mixed into to the diesel fraction.

The size of jet fuel production at the Preem Gothenburg refinery is dependent on various parameters.

- The market situation at any given moment.
- The grade/quality of the crude oil processed
- The logistic situation at the refinery

If the refinery would like to increase jet fuel production, diesel production must decrease. This also implies that jet fuel production could be increased without large investments or time delays. During the year the proportion between diesel and jet fuel production changes and the fuel most profitable at that moment is produced (Åhman, 2008).

The other Preem petroleum AB refinery is Preemraff Lysekil, which is a refinery more adapted to heavy crude oil. Swedish Environmental class-1, ultra-low sulphur, diesel is a prioritized product, which has the consequence that no jet fuel at all is manufactured. The kerosene fraction is blended directly into the diesel fraction to provide the correct viscosity properties. Having fewer products is a way to increase the efficiency of the refinery (Preem, 2008).

The conclusion to be drawn is that aviation fuel production is not a fixed percentage of refinery output. In 2006, aviation fuel was 6.3% of world refinery production (Figure 2), but in 1973 the aviation fuel part of refinery production was only 4.2%. Since 2001, production has varied between 6.0 and 6.3% (IEA, 2008b). The volume of aviation fuel has changed a lot, from 114 Mt in 1973 to 243 Mt by 2006 according to IEA (2008a; 2008b).

The kerosene fraction is an average of 8-10% of the crude oil, but all kerosene does not become jet fuel or diesel. Kerosene can also be used to decrease the viscosity of the heavy fractions of crude oil and is used as lamp oil in certain parts of the world.

Simple refinery process changes could increase jet fuel production and if the hydrocrackers were optimized to produce jet fuel the share could probably increase much more (Wernersson, 2008). To be able to produce even more jet fuel new hydrocrackers could be developed, but that would take time.

Production changes in the refinery can only change the yield of different products. If jet fuel production were to increase obviously the production of other products would decrease (such as gasoline and diesel).

The environmental parameters that define the operating envelope for aviation fuels such as pressure, temperature and humidity vary dramatically both geographically and with altitude. Consequently, aviation fuel specifications have developed primarily on the basis of simulated performance tests rather than defined compositional requirements. Given the dependence on a single source of fuel on an aircraft and the flight safety implications, aviation fuels are subject to stringent testing and quality assurance procedures.

The fuel is tested in a number of certified ways to be sure of obtaining the right properties following a specification of the international standards from, for example, *IATA guidance material*, *ASTM specifications* and *UK defence standards* (Air BP, 2000). Tests are done several times before the fuel is finally used in an aeroplane.

6 Crude oil production forecasts

Attempts to forecast crude oil reserves and future production have been made over a long time period using a variety of different methods and approaches. There are forecasts by scientists, organisations and others.

Overviews of different forecasting methods have been done previously (Bentley and Boyle, 2007; Brandt, 2007; Carlson, 2007), and all of the models have their strengths and weaknesses. Bentley and Boyle concluded that the group of models that predict the peak in crude oil production before 2020 are the most realistic.

An industry task force, including aviation companies in the Virgin Group, has ranked peak oil as a larger threat to the UK than terrorism and climate change (UK Industry Task Force on Peak Oil & Energy Security, 2008). Even the IEA chief economist, Fatih Birol, has recently spoken of the proximity of oil peaking (Birol, 2008). A growing awareness of peak oil and its imminence can be found.

In a discussion paper, prepared for OECD and International Transport Forum, the peak oil issue is summarized (Alekklett, 2007). The paper mostly concentrates on two oil production models, the depletion model and the giant field model.

The most well known scenario for future oil production is the one delivered by the International Energy Agency (IEA) in its yearly publication *World Energy Outlook* (WEO). This scenario is based on a growing global economy and that growth needs more oil. In WEO 2008 (IEA 2008a) the increase in oil use till 2030 is divided between 1.3 percent for 2009 to 2020 and then 1.0 percent to the end of the period. The next step is to find production to fulfill demand. In this article this “Business as Usual” (BAU) is called Alternative 1.

Alternative 2 is a depletion model, called the ‘Campbell depletion model’. The model and the results can be found in a peer-reviewed article (Alekklett and Campbell 2003). The results have been updated later, the latest from 2008 (Campbell, 2008).

As Alternative 3, crude oil production forecast from the ‘Uppsala giant field model’ (Robelius, 2007) was chosen. It is the result of a doctoral thesis, meaning it has been reviewed and approved by a person chosen at Uppsala University and a grading committee of 5 persons.

Future aviation fuel production scenarios presented in this article are based on these three forecasts. Future oil production scenarios used in this study should not

necessarily be seen as an example of how only supply constraints may influence future aviation. They can also be seen as a picture of how voluntary oil phase out and oil consumption reduction will impact the future. The cause of the decrease in oil supply is not important in this study, rather the size of future production flows.

The European Economic and Social Committee (2009) proclaimed that the oil demand for Europe must decrease by 50% by 2050, in order to meet the targets of the Climate Change and Energy package. This would correspond to an approximate 2% annual decrease in oil consumption, which is virtually exactly what Campbell (2008) projects. Robelius (2007) and other peak oil forecasts agree with the climate change mitigation proposals and emission reduction scenarios.

Peaking of oil production or an oil consumption and emission reduction policy may therefore be seen as opposite sides of the same coin. In both cases, the flow of oil to the aviation fuel sector would decrease.

In numbers the WEO 2008 forecasts an increase in world oil production (Alternative 1). The production is predicted to increase from 82.3 Mb/d in 2007 to 101.3 Mb/d in 2026 (IEA, 2008a). On the other hand in the Campbell forecast (Alternative 2) crude oil production is expected to decrease from 84.4 Mb/d in 2008 to 61.5 Mb/d in 2026. This is the equivalent to an approximate 2% annual decrease in global oil production.

The Uppsala giant field model is based on production from the giant oil fields, fields with ultimate recoverable resources of at least 500 million barrels. Giant oil fields are the dominating contributors to world oil production, accounting for more than 50% of present output. The conclusion is that production in the giant fields determines the world peak in oil production (Robelius, 2007). Four different scenarios for future production were built and a peak in crude oil production was calculated to occur in a time span between 2008 and 2013 or as late as 2018 if adjusted to the IEA prediction for future oil demand. Oil production, as in the Campbell depletion model, is forecast to decrease and will in the year 2026 be 66 Mb/d in the worst-case scenario and 72 Mb/d in the best-case scenario (Robelius, 2007). The prognosis includes new field developments, deep-water production, tar sand, heavy oil and natural gas liquids (NGL).

7 Future scenarios of aviation fuel supply and demand

In this chapter the scenarios of future aviation fuel demand and supply are presented, and the scenarios are the base for the calculations of the outlook on aviation fuel demand and supply. The time frame of the outlook was decided by the end date of the Boeing (2007) and Airbus (2007) forecasts. Consequently, the end date will be 2026 for this study.

Three scenarios have been constructed for future aviation fuel demand. The scenarios are based on industry forecasts, both when it comes to traffic growth and goals for fuel efficiency increase.

The forecast numbers for RPK growth is used as an indicator of the growth of jet fuel consumption. All the calculations of future aviation fuel demand have been calculated based on aviation fuel production in 2006 or normalized to that value, since that was the most recent aviation fuel production number published by the IEA. For closer discussion of the scenarios, see Nygren (2008).

Demand scenarios 2006-2026

- A: Traffic will continue to grow according to industry forecasts and average fuel consumption for the world aviation fleet will remain as it is today. Fuel consumption will increase at the same rate as the increase in traffic.
- B: Traffic will keep growing according to industry forecast but the average fuel consumption (litre/100 RPK) for the world aviation fleet will go down by 50 per cent compared to 2005 by the year 2020. A decrease of 1 per cent per year from 2020 to the year 2026 is assumed.
- C: Traffic will keep growing according to industry forecasts and average fuel consumption for the world aviation fleet will follow a curve (Figure 2) extrapolated from the average fuel consumption of the years 1987 to 2007.

Table 1: Summary of future aviation fuel Scenario A, B, and C

Scenario	A	B	C
RPK growth/year	5 %	5 %	5 %
Goods traffic growth/year	5 %	5 %	6.1 %
Starting value aviation fuel consumption (2006)	243 Mt	243 Mt	243 Mt
Fuel consumption increase/year	5 %	0.3 % to 2020 then 4 %	3%

For each of the three scenarios we use the three different crude oil production alternatives described in section 6.

Aviation fuel is estimated to be 6.3% of total forecast crude oil production according to the three different crude oil production alternatives described in section 6. The production is then normalized to the value of aviation fuel production in 2006, the real value for aviation fuel production in that year.

For the calculations in this article aviation fuel production is fixed at 6.3% of crude oil production. Varying this number would give different outcomes for the available amount of jet fuel in the future and this will be discussed in the discussion section.

8 Future outlook

The result of the forecast is presented as three figures, each representing a demand scenario together with the three supply scenarios.

With a scenario of 5% fuel demand growth, and aviation fuel production fixed at 6.3% of crude oil production it can be seen (Figure 4) that demand exceeds supply enormously in the three supply scenarios. The IEA production forecast would require aviation fuel to be about 13.7% of world crude oil production (i.e. refinery output) and the others an even bigger percentage.

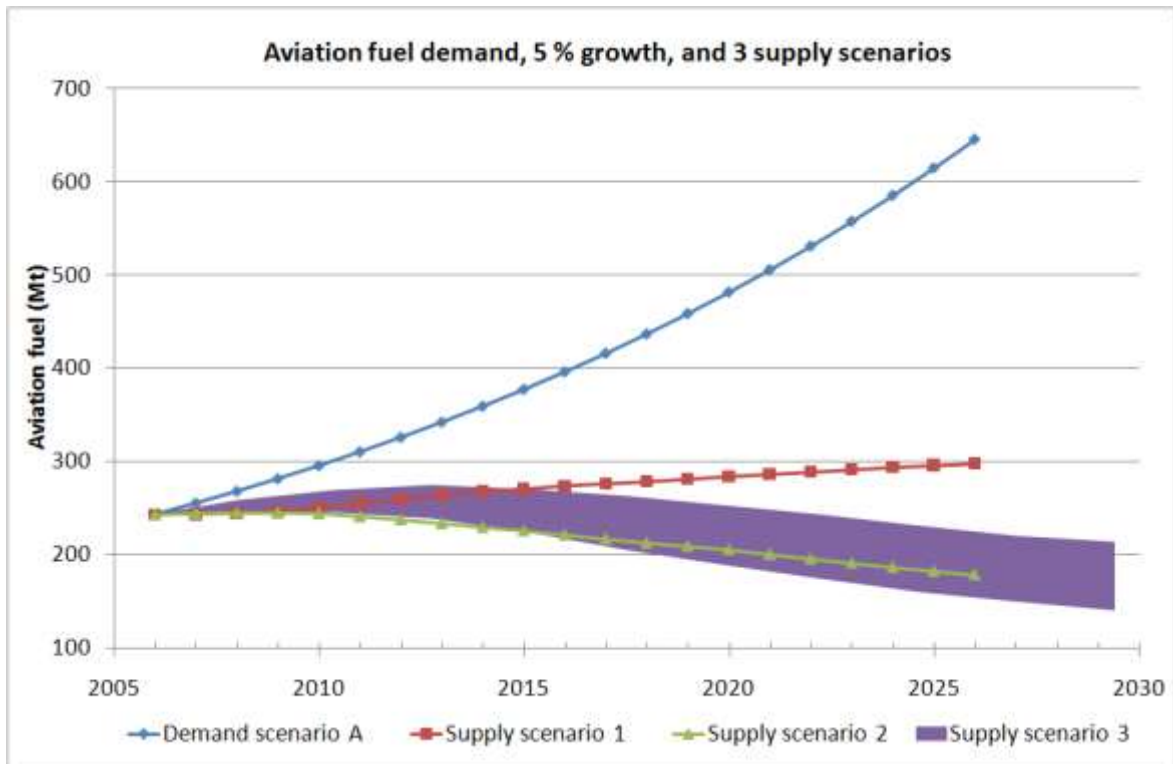


Figure 4: Demand scenario A is the scenario where aviation fuel demand grows the most, at the same rate as the forecasted RPK growth. Source: Boeing (2007), Robelius (2007), Campbell (2008) and IEA (2008a)

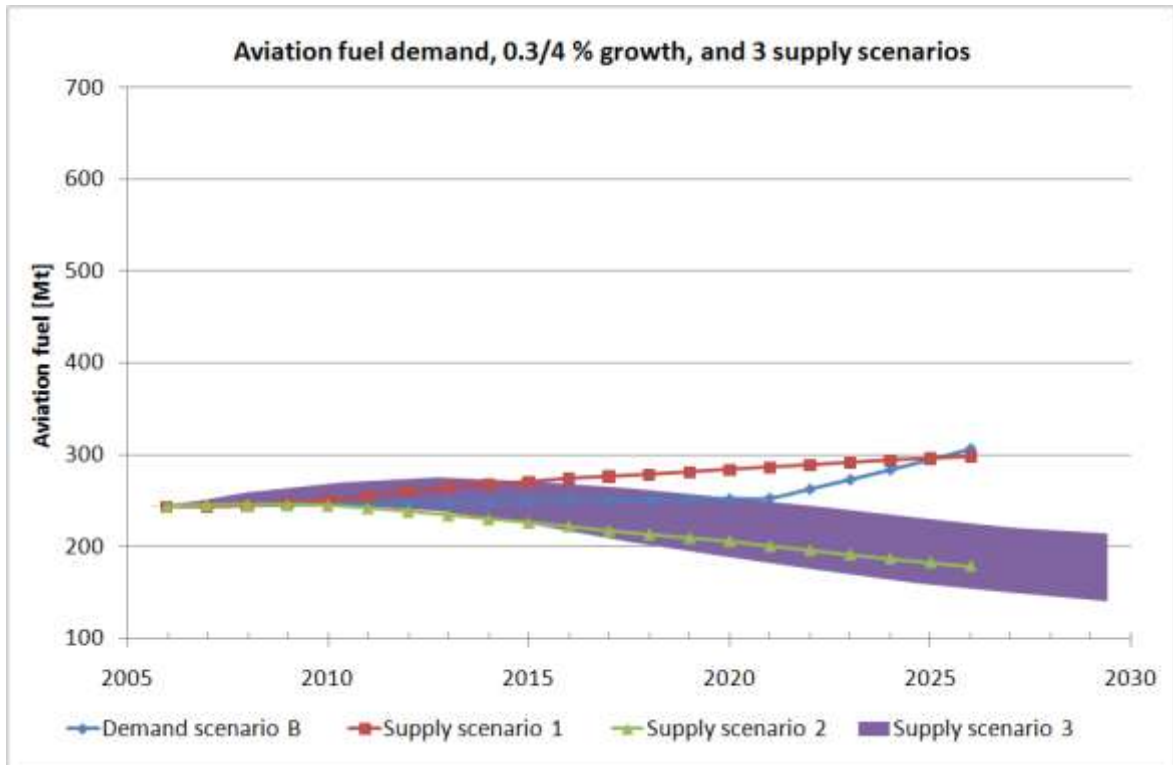


Figure 5: The demand scenario B is where the aviation fuel consumption increases the least, despite a 5% growth of traffic. After 2020, a 4% growth is assumed and that dramatically changes the shape of the curve and makes it cross the line of the IEA supply forecast. Source: Boeing (2007), Robelius (2007), Campbell (2008) and IEA (2008a)

In the case represented in Figure 5, aviation fuel demand is much reduced in comparison to Figure 4. It is a reduction by almost 5% a year to the year 2020, which almost reduces aviation fuel demand increase to zero compared to 2006.

The much steeper increase in fuel consumption 2020 to 2026 still keeps demand below the BAU supply scenario. The other three supply scenarios lead to a situation where demand exceeds supply. The lowest supply scenario, the worst case scenario of the giant field model, would require aviation fuel to be 13.8%, which is almost the same as in the previous figure for the IEA supply case and the 5% demand scenario.

Figure 6 represents a demand scenario that is an extrapolation of the current trend of efficiency improvements, and to some point may represent the most realistic development of aviation traffic. However, this trend does not look reasonable when compared to forecasts of future aviation fuel supply, since all supply scenarios end up below the demand scenario with the current division between refinery products.

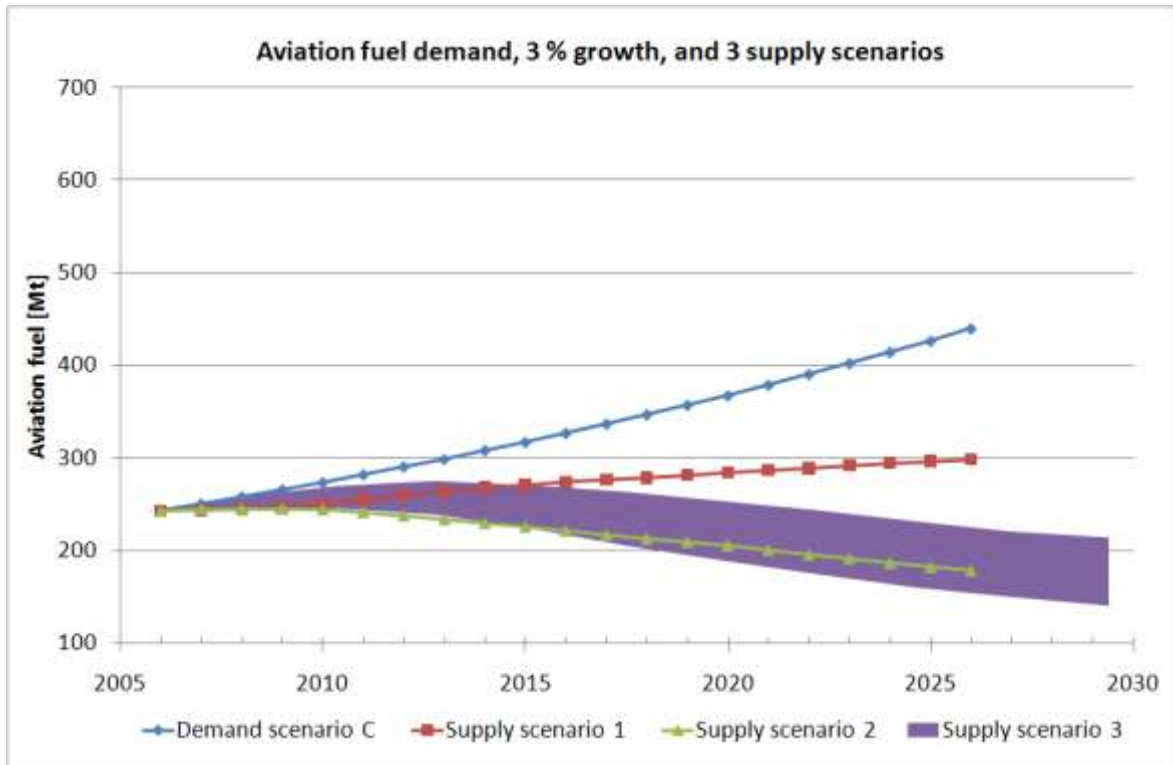


Figure 6: The demand scenario C is following the current trend of aviation fuel consumption. Source: Boeing (2007), Robelius (2007), Campbell (2008) and IEA (2008a)

9 Discussion

Maybe the most realistic scenario, of those proposed, is one where traffic grows by 5% and fuel consumption by 3% a year, following historic trends. That would require a growth for the aviation fuel part of refinery production from 6.3% of refinery output to about 9.3% in the BAU oil production scenario and 19.8% of refinery output if the production follows the worst production case in the studied scenarios.

9.1 Biofuels

The aviation industry is actively searching for replacements for conventional jet fuel through the use of biofuels. Air New Zealand and Continental Airlines have recently performed two successful test flights (Air New Zealand, 2008; ATW, 2009). Furthermore, Virgin Atlantic (2008) reports successful test flights using biofuel. For the moment biofuels is more of a problem for the aviation industry due to the issue with FAME. Production of bio-jet fuels has so far only been for research purposes and far from on an industrial scale.

What would the effect be on the outlook of this article if the IATA goal of 10% biofuels in 2017 were fulfilled? For example, if consumption followed historic trends (Figure 6), it can be seen that a 10% reduction of aviation fuel demand in 2017 would not take consumption down to the ‘business as usual’ production scenario.

Where should biofuels come from? If biofuels are to be 10% of aviation fuel by 2017, and consumption grows by 3% (Scenario C), 270 million barrels of bio-jet fuel will be required by 2017 (0.7 Mb/d). That is more biofuels than is currently produced in total,

when all transport biofuels counted for 0.6 Mb/d (219 million barrels in total for 2006), if adjusted for energy content (IEA, 2008b). Another thing to take into account is that about 83% of the biofuel produced was ethanol, which is not suitable for aviation traffic. The rest is biodiesel that theoretically could probably be further refined to jet fuel (Daggett et al., 2007). Aviation biofuel production is still in practice zero.

The IEA (2008a) believes a growth of biofuel consumption of 6.8% a year from 2006-2030, predicting a biofuel production of about 1.3 Mb/d in 2017. Around one fifth of that is forecast to be biodiesel, which corresponds to less than 0.3 Mb/d. This value must be compared to the 0.7 Mb/d of bio-jet fuels needed. All of these numbers make it hard to believe that the aviation industry could achieve 10% biofuel by 2017 starting from zero in 2008.

The second highest ranked renewable energy company, according to Biofuel Digest, Sapphire Energy, state that they can produce 300-350 b/d of aviation fuel from algae in three years (ATW, 2009). However, this capacity is negligible compared to the aim of 10% bio-jet fuel utilization and would require a crash course development program in order to achieve the necessary production volumes.

Today, the increasing addition of biofuels to diesel is a problem for the aviation industry (Gallaher, 2008). One of the more common biodiesels is FAME (Fatty Acid Methyl Ester). FAME is not a hydrocarbon and no non-hydrocarbons are allowed in jet fuel, except for approved additives as defined in the various international specifications such as DEF STAN 91-91 and ASTM D 1655. Consequently, biofuels-contaminated jet fuel cannot be utilized due to jet fuel standards (JIG, 2008a).

The problem with FAME is that it has the ability to be absorbed by metal surfaces (JIG, 2008a). Diesel and jet fuel are often transported in a joint transport system making it possible for FAME stuck in tanks, pipelines and pumps to desorb to the jet fuel. The limit for contamination of jet fuel with FAME is 5 ppm (JIG, 2008b). FAME can be picked up in any point of the supply chain, making 5 ppm a difficult limit and therefore the introduction of biofuels to the diesel fraction has had a negative impact upon jet fuel supply security (Gallaher, 2008).

Work is ongoing to be able to approve 100 ppm of FAME in jet fuel to ease the pressure on the oil product transport systems. Results from fuel analysis often arrive after delivery of fuel, meaning that airlines need to know how to act if the fuel is declared contaminated (Farmery, 2008). To help avoid FAME contamination there are several procedures that should be followed, for example there should always be a buffer transport between biodiesel and jet fuel in pipeline systems and road tankers should be cleansed (JIG, 2008a).

9.2 Crude oil production outlook

Can the 'business as usual' scenario be too positive regarding future oil production? After the publication of World Energy Outlook 2008 (IEA, 2008a), some remarkable statements from IEA chief economist, Fatih Birol, have been made. Petroleum newspaper Upstream (2008) writes that IEA predict oil prices to rebound to around 100\$ in 2010-2015. Furthermore, Birol (2008) has also stated that an oil peak could occur in 2020. The IEA (2008a) states that enough oil reserves are available for production, if the necessary investments are made. The recent statements may probably be seen as a sign that the needed investments are not being made fast enough.

The European Union (EU) recognises that aviation contributes to about 2% of man-made CO₂ emissions, and therefore, aviation cannot be considered a major contributor to climate change (EU, 2009). Still a reduction of aviation's impact on climate change is requested. The fuel consumption and consequently the CO₂ emissions are supposed to decrease by 50% by 2020 (demand scenario B in this article). The EU (2009) is discussing to include aviation in the EU emission trading scheme, as suggested by the International Civil Aviation Organization (2009). IATA (2009) would also like a scheme for reduction of emissions, but wishes it to be global so that country specific taxes could be avoided. Furthermore, IATA (2009) argues that aviation should be treated in proportion to its contribution to climate change and not unfairly punished economically.

9.3 Refinery production

Is there any room for a larger part of aviation fuel from crude oil? In the analysis we have chosen 6.3%, the aviation fuel production fraction for 2006, to be a fixed aviation fuel fraction for the period 2008 to 2026. Historically this number has increased from 4.2% to 6.3%. Technically, aviation fuel is part of the middle distillate fraction together with diesel. An increasingly strong global demand for diesel can make it hard to increase the aviation fraction and we could consequently expect that it will be less in the future.

Technically it is possible to make aviation fuel a larger part of the petroleum product mix with proper investments, but there are no political visions or stimulus as there are no great awareness of the challenges to come.

9.4 Efficiency increases

Contrary to the car industry, the aviation industry has continually made improvement in aircraft efficiency. Between 1970 and 2007, efficiency has been improved by 70% roughly equivalent to 3% per year. Is it realistic to expect a subsequent 50%, or a 5% per year, reduction of aviation fuel consumption to be achieved by 2020? We believe that scenario B is unlikely to happen and that scenario C with an extrapolation of the trends during the last 20 years is the most probable scenario.

10 Conclusion

The most positive outlook for crude oil production in this study is still a very pessimistic scenario for the aviation industry. Only with a very successful development of fuel efficiency increases that more or less keeps the aviation fuel demand at current levels could it be possible for traffic to grow by 5% a year.

The aviation industry outlook on future traffic does not look realistic in the light of future crude oil production, taken that the aviation fuel percentage of refinery output cannot be increased hugely. The outlook of this article suggests that the aviation industry needs to rethink their position when it comes to future growth in air traffic since it is dependent on the availability of conventional aviation fuel originating from crude oil. Even the 'business as usual' scenario of crude oil production requires big efficiency increases to the aviation fleet to maintain current rates of traffic growth.

The worst-case supply scenario creates a lack of aviation fuel in all of the demand scenarios discussed. The percentage of aviation fuel of produced oil products would need to increase from 6.3 % up to 30% of crude oil production in the most diverse case (Figure 4). Alternative fuels can play a role in increasing the amount of available fuel, but it seems

unrealistic that it could provide a large contribution soon, taking into account the work still to be done in that area. The possibility of biofuels replacing conventional jet fuel is limited, considering the large amount that would be needed. However, the development of bio-jet fuel is still important for the future aviation industry.

A post Kyoto political agenda to reduce oil consumption will have the same effect on aviation fuel production as a natural decline in the crude oil production. In the World Economic Outlook by the International Monetary Fund (IMF), the world real GDP growth will be back to be between 4 and 5 percent in 2011 (IMF, 2009). Political decisions or decline in aviation fuel production will affect future GDP growth, so it is advisable to revise economic outlooks and include a more holistic view of economic growth where fuel requirement and supply outlooks also are integrated.

Moriarty and Honnery (2008) speculate that the future of transportation is low-mobility, since transport is a derived demand. In a future world with decreasing supply of fuel, the current BAU-outlooks from within the aviation industry are unrealistic. The industry might be forced to adapt to a future with less aviation transport and the new challenges that would bring. Consequently, we conclude that “*when the winds of change are blowing, some seek shelter while others set sails for new oceans*”

Acknowledgements

We would like to give our sincerest appreciation to Mike Farmery, global fuel technical and quality manager of Shell Aviation Limited, for his valuable comments and suggestions on fuel related material. We would also like to thank Robert Hirsch for constructive discussions. One of us, E.N., would like to thank Stena AB for support during part of the work. Finally, we would like to thank Simon Snowden of Liverpool University for proofreading.

References

- Advisory Council for Aeronautics Research in Europe, 2001.** *Meeting society's needs and winning global leadership*, January 2001, see also: <http://www.acare4europe.com/docs/Vision%202020.pdf>
- Air BP, 2000.** *Handbook of products*, see also: http://www.bp.com/liveassets/bp_internet/aviation/air_bp/STAGING/local_assets/downloads_pdfs/a/air_bp_products_handbook_04004_1.pdf (accessed February 2008)
- Air New Zealand, 2009.** *Biofuel Test Flight*, <http://www.airnewzealand.co.uk/aboutus/biofuel-test/default.htm> (accessed 2009-01-16)
- Airbus, 2007.** *Global Market Forecast 2007-2026*, see also: <http://www.airbus.com/en/corporate/gmf/>
- Aleklett, K., 2007.** *Peak Oil and the Evolving Strategies of Oil Importing and Exporting Countries*, OECD Transport Forum discussion paper no. 2007-17, December 2007. See also: <http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DiscussionPaper17.pdf>
- Aleklett, K., Campbell, C., 2003.** *The Peak and Decline of World Oil and Gas Production*, Minerals & Energy – Raw Material Report, 18, 5-20
- Association of European Airlines (AEA), 2008.** *Aviation and Environment: Facts, achievements, goals*. See also: http://files.aea.be/Downloads/Aviation_and_Environment.pdf
- ATW, 2009.** *Continental follows with algae*, news article by Jerome Green Chandler, Eco-Aviation Today, January 12, 2009, Page 2, see also: <http://www.atwonline.com/channels/eco/article.html?articleID=2613>
- Bentley, R., Boyle, G., 2007.** *Global oil production: Forecasts and methodologies*, Environment and Planning B: Planning and Design, 34, 609-626
- Biol, F., 2008.** *statements in an interview by George Monbiot*, The Guardian, 15 December 2008, see also: <http://www.guardian.co.uk/business/2008/dec/15/oil-peak-energy-iea>
- Boeing, 2007.** *Current Market Outlook 2007, Summary outlook*, see also: <http://www.boeing.com/commercial/cmo> (accessed March 2008)
- BP, 2008.** *Statistical Review of World Energy 2008*, See also: <http://www.bp.com>

- Brandt, A.R., 2007.** *Testing Hubbert*, Energy Policy, 35, 3074-3088
- Campbell, C., 2008.** *Oil and gas production profiles 2008 base case*, December 2008, see also: http://www.aspo-ireland.org/contentFiles/newsletterPDFs/newsletter96_200812.pdf
- Carlson, W.B., 2007.** *Analysis of World Oil Production Based on the Fitting of the Logistic Function and its Derivatives*, Energy Sources, Part B: Economics, Planning, and Policy, 2, 421-428
- Daggett D., Hadaller R., Hendricks R., Walther R., 2006.** *Alternative fuels and their potential impact on aviation*, paper presented at the 25th Congress of the International Council of the Aeronautical Sciences (ICAS) hosted by the German Society for Aeronautics and Astronautics, Hamburg, Germany, September 3–8, 2006, NASA TM 2006-214365, see also: <http://gltrs.grc.nasa.gov/reports/2006/TM-2006-214365.pdf>
- European Economic and Social Committee, 2009.** *European demand for oil must be reduced by over 50% by 2050!* press release from 9 January 2009, CES/09/1, see also: <http://europa.eu/rapid/pressReleasesAction.do?reference=CES/09/1>
- EU, 2009.** *Is civil aviation a major CO2 problem? See also:* http://ec.europa.eu/transport/air/environment/environment_en.htm
- Farmery M., 2008.** *FAME contamination in jet fuel- action needed*, Presentation at IATA, Shanghai, November 2008
- Gallaher L., 2008.** *Supply Chain Study potential carryover of FAME into jet*, Presentation at IATA, Shanghai November 2008
- Moriarty, P., Honnery, D., 2008.** *Low-mobility: The future of transport*, Futures, 40, 865-872
- IMF, 2009, April.** World Economic Outlook, <http://www.imf.org/external/pubs/ft/weo/2009/01/pdf/text.pdf>
- International Air Transport Association (IATA), 2009.** *Focus on Reducing Emissions - IATA Calls for Governments-Industry Alignment on Emissions*, press release from 31 march 2009, see also: <http://www.iata.org/pressroom/pr/2009-03-31-01.htm>
- International Civil Aviation Organization, 2009.** *Statements from the environment agenda*, see also: <http://www.icao.int/env/>
- International Energy Agency, 2008a.** *World Energy Outlook 2008*
- International Energy Agency, 2008b.** *Key World Energy Statistics 2008 and previous editions*, see also: http://www.iea.org/textbase/nppdf/free/2008/key_stats_2008.pdf
- Joint Inspection Group, 2008a.** *Product Quality*, Bulletin No. 21, November 2008
- Joint Inspection Group, 2008b.** *Product Quality*, Bulletin No. 20, October 2008
- Nygren, E., 2009.** *Aviation Fuels and Peak Oil*, diploma thesis from Uppsala University, see also: <http://www.tsl.uu.se/uhdsg/Publications/Aviationfuels.pdf>
- Preem, 2008.** *About our refineries*, see also: <http://www.preem.se> (accessed April 2008)
- Robelius, F., 2007.** *Giant Oil Fields - The Highway to Oil: Giant Oil Fields and their Importance for Future Oil Production*, doctoral thesis from the Faculty of Science and Technology, see also: <http://publications.uu.se/abstract.xsql?dbid=7625>
- Swedish Institute for Transport and Communication Analyses (SIKA), 2008.** *Civil Aviation 2007*, see also: http://www.sika-institute.se/Doclib/2008/Statistik/ss_2008_12.pdf
- Upstream, 2008.** *IEA sees \$100 in 2010 to 2015*, see also: <http://www.upstreamonline.com/live/article168774.ece>
- UK Industry Task Force on Peak Oil & Energy Security, 2008.** *The Oil Crunch - securing the UK's energy future*, October 2008, see also: <http://peakoil.solarcentury.com/wp-content/uploads/2008/10/oil-report-final.pdf>
- Virgin Atlantic, 2008.** *Biofuel demonstration*, see also: <http://www.virgin-atlantic.com/en/gb/allaboutus/environment/biofuel.jsp> (accessed 2009-01-24)
- Wernersson, C., 2008.** *personal communication*, Shell Raffinaderi AB
- Åhman, C., 2008.** *personal communication*, Preemraff Göteborg