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Exploring Linkages between Aircraft Technologies, Climate Change Considerations and Patents

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Introduction

The aircraft industry is at the same time one of the most globalised and more concentrated industry worldwide. It relies on a complex spatially dispersed supply chain that depends on the global demand. It is also highly concentrated in few firms and in few countries. Actually, it is a very concentrated global oligopolistic sector. For each sub-sector by output (large and regional civilian aircraft, business jets, and helicopters)[1] there are only a few competitors. Yet at the same time there is an increasing internationalisation of the industry as participant firms have increased their world outsourcing to a large network of suppliers of subassemblies and parts (such as engines, structures, landing gear and avionics).

Today, more than 15,000 aircraft service nearly 10,000 airports operating routes over approximately 15 million km in total length.[2] Nearly 2.3 billion passengers flew on the world airlines in 2010.[3] While air transport carries around 5 percent of volume of world trade, it is more than 35 percent by value of world's trade shipments.[4] The aircraft industry generates 33 million jobs worldwide and of this 5.5 million people work directly in the aviation industry.[5] Additionally, air transport contributes with nearly 8 percent of the world gross domestic product and consumes around 10 percent of the fuel produced for transport.[6]

The aircraft industry is hierarchically organised into "tiers".[7] The first category includes airframe assemblers (prime contractors) such Airbus, Boeing, Bombardier and Embraer. These firms concentrate the design, assembling and marketing of aircrafts. They also determine to a great extent the market and subassemblies from the other categories. The second category includes manufacturers of propulsion systems such as General Electric, Pratt & Whitney and Rolls Royce. The producers of on-board avionics, such as Honeywell and Sextant Avionique are included in this level. The third category includes manufacturers of a great diversity of electronic, hydraulic systems and fuselage parts with a handful of firms dominating each segment. These tiers reflect a very integrated value chain with high levels of specialisation and concentration under each layer mentioned.

The impact of aviation over Green House Gases (GHG) Emissions is not insignificant. Air transport generates about 2 to 3 percent of the world's carbon dioxide emissions[8], despite the fact that a jet aircraft coming off the production line today is around 80 percent more fuel efficient per passenger-seat kilometre than one delivered in the 1960s.[9] It is projected that GHG emissions from air transport will continue to increase as the passenger traffic is also expected to grow at an average rate of 4.8 percent per year through the year 2036.[10]

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[1] For the purposes of this paper "aircraft" is defined as "any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface". See Annex I of the International Civil Aviation organization (ICAO) Convention of 1944 last revised in 2006.

[2] Capoccitti Sam, Khare Anshuman, and Mildenberger Udo (2010). *Aviation Industry - Mitigating Climate Change Impacts through Technology and Policy.* Journal of Technology Management & Innovation. Volume 5, Issue 2.

[3] ICAO (2010). *Environmental Report.*

[4] Oxford Economics (2009). *Aviation: The Real World Wide Web.*

[5] *Ibid.*

[6] ICAO (2010).

[7] Niosi Jorge & Zhegu Majlinda (2005). *Aerospace Clusters: Local or Global Knowledge Spillovers?* Industry and Innovation, Vol. 12, No. 1, 1–25, March.

[8] Intergovernmental Panel on Climate change (IPCC) (1999). Special IPCC report. Aviation and the Global Atmosphere. Summary for Policy makers. Also, IPCC (2007). Fourth Assessment Report: Climate Change.

[9] *Ibid.*

[10] ICAO (2010).

The higher is the impact of climate change over populations, natural events, food, other economic activities and infrastructure, the more the pressure there will be over this and other sectors in contributing to the reduction of emissions. For the reduction of air transport emissions, technological advancements are perhaps one of the most important hopes.

The aircraft industry is highly capital and technology intensive with long payback periods. It is characterised by imperfect competition, non-homogeneous products and major economies of scale and hence scale dynamically increasing returns. It also has extremely high initial and fixed development costs, making the entry of new competitors difficult. Besides this, the industry is prone to severe demand fluctuations, hardly experienced by other industries.

The aircraft R&D system is characterised by its complex or systemic technology nature. This implies that the quantity and types of knowledge incorporated are extremely large and diverse. It is a particular wide area of technological innovation where multiple and parallel R&D lines converge. Government support and intervention in R&D has been present since the creation of the industry due to its strategic and defence value. The aircraft industry has always enjoyed governmental support including subsides and public contracts in order to ensure the viability, economies of scale, competiveness and the highest possible level of technological progress. The use of patents, industrial designs, trade secrets, strategic licensing, know how sharing schemes among assemblers, propulsion systems and parts producers have been the preferred technology protection schemes of the industry for their intangible assets.

The objective of this chapter is to identify preliminary linkages among technological advancement in the aircraft industry, climate change considerations and patents. The idea is to start understanding how its R&D model works; how new technological advancements can contribute to GHG emissions mitigation objectives; which are the most promising technological groups for mitigation purposes; and to what extent intellectual property and more specifically patents is being used as protection tool. This chapter will address and identify some characteristic of the industry; the role of technology in the aircraft industry; links between air transport and climate change; and technological groups that can contribute to climate change mitigation. It will also draw some preliminary findings on patenting trends in promising technological groups that could contribute to GHG mitigation.

Technology in the Aircraft Industry

The aircraft industry is a strategic sector, meaning a sector where there is substantial rent, for the return to labour and capital is exceptionally high, operating in the frontier of technological development. It is key driver of technological innovation employing skilled labour, is highly profitable, and creates large arrays of positive externalities or technological spillovers to the rest of the economy with profound effects on the economic growth.[11]

Government policies can create enduring effects on competition and international trade by targeting a given sector that has spillover effect. In this case, the overall effects on the economy and on its competitive position in a whole chain of related sectors will be widespread and profound.[12]

[11] Krugman, Paul R (1986). S*trategic Trade Policy and the New International Economics*. The MIT Press, Cambridge Massachusetts, London England.

[12] Borrus, Michael, D'Andrea Tysson Laura, Zysman John (1986). *Creating advantages: How Government Policies Shape International Trade in the Semiconductor Industry*. In: Krugman, Paul R (1986). *Strategic Trade Policy and the New International Economics*. The MIT Press, Cambridge Massachusetts, London England.

Aircraft technologies are complex or systemic technologies, meaning that the quantity and types of knowledge incorporated is extremely large and diverse; originating in different areas of knowledge and resulting frequently from the convergence of the knowledge originated in separate areas of research suggesting that technological innovations do not necessarily derives from empirical knowledge. Complex technologies are science-based technologies that originate in the field of R&D activities and respond more to a *scientific-push* rather than a *demand-pull.*

Complex technology incorporates different explicit and tacit knowledge,[13] a synthesis of them, and new knowledge resulting from this combination. Complex technologies are synthetic systems producing effects going beyond the sum of the all incorporated knowledge.[14] Technological systems incorporate such a diversity of knowledge that are difficult to be managed by a single person specialised in a given area of knowledge:

"The design of a modern airplane demands the ability to understand the problems and opportunities involved in integrating advanced mechanical techniques, digital information technology, new materials, and other specialised sets of technologies. Engineering design teams in the aircraft industry typically contain about 100 technical specialties. The design activity requires systems capability that may constitute a temporary knowledge monopoly built on … the most complex kinds of organisational learning. In the design of an aircraft, systems integration involves the ability to synthesise participation from a range of network partners. There is no way to achieve analytical understanding and control of integration of this type; the capability is, in part, experience-based, experimental, and embodied in the structure and processes of the network."[15]

Large firms have developed systemic forms of integration of accumulated scientific knowledge incorporated in complex organised systems. Complex technologies arise from different areas of knowledge and define a capacity of assimilation of technological knowledge relatively high, so that it is not difficult for competitors to find alternative ways to innovate, a fact that reduce seriously the value of patents as an instrument to protect innovations.[16]

Besides complex technologies benefit for rapid global adoption, hence firms are more motivated by a process of imitation rather than by the control, (through patents) of the innovation. This is why the monopoly incentive offered by the patent systems is less relevant in the case of advanced complex technologies.[17]

In the traditional patent system diffusion occur through licensing. Licensing is also current for complex technologies. Yet in this case patents have a different role. Today technology innovation, particularly in complex technology, take place in *networks* frequently on the basis of the development of incremental innovations, that attempt to exploit the *networks externalities* of the technological system. The market accepts some of these innovations only because of these externalities.

[13] Polanyi Michael (1967). The Tacit Dimension. Doubleday Anchor NJ, Garden City.
[14] Bifani Paolo (2010). *La Globalizacion, la otra caja de Pandora?* Universidad De Guadalajara.
[15] Rycroft Robert &. Kash W. Don E, 1999, Innovation Policy for Complex Technologies; Issues on Science and Technology National Academy of Sciences.
[16] Mansfield Edwin, M. Scwartz & S. Wagner (1981). *Imitation costs and Patents an Empirical Study.* 91 Economic Journal, 907-918.
[17] Rycroft Robert, Kash W.E. Don; (1999). *The complexity Challenge: Technology Innovation for the 21ST Century*.

For many complex technologies, it is convenient that innovation materialise in waves where several networks share the same objective and own similar innovative capabilities. In these conditions it is convenient for the competitors to cooperate among them, in a given phase of the innovative process, and to define technical standards to assure complementarity and compatibility.

Such a co-operation is possible when rival firms are patents owners of different components of a complex technology. This situation has been tackled through the "creation" of patents pools. Each firm of the sector transfer their patents to the pool and each member of the pool can utilise them under the conditions previously established by the members. These pools have been relevant for the transfer of non-patentable information/knowledge among firms of the same sector and have been particularly important for the standardisation process inside specific industrial segments.

In complex technologies involving important number of interacting components, every firm depend upon the access to the technology developed and patented by the rival firm. If a firm is prevented to accede to a basic component needed for its innovation, is in a disadvantaged competitive position and encounter the risk to see its innovative process blocked although possessing the capabilities to incorporate the most advanced components. This situation can produce an 'inflation" of patent applications for every firm if it is motivated by strategic or market considerations to patent as much as possible components, parts, and sub-components in order to create a strong competitive position in the negotiations over cross licensing.

So there is a radical distinction among the patenting strategies of conventional technologies and complex advanced technologies. For the former the firm attitude is basically offensive and exclusive in the sense that its strategy is to impede, through the patenting, that the rivals can use the technological innovation.

On the contrary in the latter patenting has a defensive character: not to be excluded from the access to a given innovation related to its activities, and do not lose a market position. In complex advanced technologies the patent is an essential instrument of negotiation in order to avoid exclusion and marginalisation. This is a clear in the electronic sector, which actually is an important supplier of the aircraft industry. With increasing complexity of technological systems every firms attempt to patent as much as possible components, parts, and subsystems, and by doing so to enhance its competitive position.

The use of patent as an instrument of negotiation has resulted in increasing tacit or explicit agreements inside the industrial segment concerning the trajectory of incremental or relatively trivial innovations. There are relatively general commercial agreements on patents lasting several years leading the involved firms to a revitalisation of the concept and practice of patent pools. The pool of patents is a mechanism typically practiced by oligopoly to create barriers to entry of new competitors, largely used in the pharmaceutical sector, and may lead to creation of cartels.

From the social perspective the pool of patents has important costs. Legally patent pools are in principle considered an unfair competitive practice infringing antitrust regulations. However, if they fulfil some test such as the need to share some essential technologies they can pass the antitrust review. These agreements, known as information exchange agreements and the pool of patents are in themselves mechanisms that on one side reduce costs, and on the other accelerate the rate of incremental technological innovations attempting to extend the life span or trajectory of substantive or radical technological innovation, to recover the cost of the innovation and to capture additional rents.[18]

However, they slow down the radical technological innovations. Incremental innovations, while not "technologically interesting", can be economically important. Learning by doing extends beyond the design and production phases into the actual use of an aircraft. Through extended use the performance characteristics of an aircraft design and its elaborately differentiated but interdependent parts become better understood, allowing the full exploitation of the model's potential through incremental improvements.[19]

Complex technological systems associated with the increasing use of standards of components, parts, and subsystems confer leading firm advantages for the creation of barriers to entry. Aircraft industry features very standardised products, both mandatory standards arising from regulations as well as internal to the oligopoly. Standardisation permits greater flexibility in the assemblage and favours the process of incremental innovation. Latecomers seeking to enter the aircraft sector will therefore encounter extensive regulatory and quasi-regulatory regimes.

However, the requirement to conform both to international mandatory standards and to the oligopoly internal standards at the outset renders almost impossible any new entry. So there are not only technological barriers to entry but also obstacles arising from regulatory compliance, marketing and outright political influence.

Due to its highly concentration the aircraft industry is prone to natural monopoly. At the origin of this tendency toward a natural monopoly, foremost, is the impressive technological innovation of aircraft manufacturing which limit the number of potential entrants. Aircraft producers integrate numerous technologies and systems and subsystems, originating from a diversity of industries. A modern jet aircraft incorporate millions of extremely complex components, - more than 6 million parts compose a Boeing 747-400,[20] including a wide range of seemingly unrelated technologies: materials, propulsion, electronics, hydraulics, aerodynamics, and so on.

Although internal technological innovation is fundamental, it is also relevant the technological innovation exogenous to the industry: "*The aircraft industry is unusual in the extent to which it has benefited from the inter-industry flow of innovations...reflect[ing]...the high degree of systemic complexity embodied in its products…outside industries like metallurgy, petroleum, and electronics, have provided a steady stream of innovations, that have substantially improved aircraft performance.*"[21]

Another major exogenous source of innovations to the commercial aircraft industry is the military sector where many technologies largely used by the civil aircraft industry originated, for example the jet engine.

The aircraft industry is also featured by technological uncertainty. The aircraft performance is very dependent upon the interactions of the numerous complex systems it includes. These interactions, however, are difficult to anticipate in advance: Defects are frequently acknowledged only after test flights. Technological uncertainty, and the consequent risk, compounded with high costs contribute further to the tendency toward concentration.

[18] Bifani Paolo (2010).
[19] Mowery, David and Rosenberg, Nathan (1982). The Commercial Aircraft Industry in Richard Nelson ed. Government and Technical Progress (New York: Pergamon Press).
[20] Boeing. *Boeing 747-400 Fun Facts.* See www.boeing.com/commercial/747family/pf/pf_facts.html, accessed 22 of July 2012.
[21] Mowery, David and Rosenberg, Nathan (1982).

Clusters of technology-complex industry are characterised by intra-industry and inter-industry flows of specific scientific and technological knowledge, also coming from universities and R&D institutions. A crucial characteristic of technological and industrial clusters is the relevance of knowledge and technological spillovers. Spillovers are the leakage or exchange of useful knowledge. A patent disclosure is a typical exchange, licensing, publications, technical meetings, the movement of people, and informal interpersonal communications are also mechanisms favouring spillovers.

In aircraft clusters, knowledge spillovers are technology based and centred on a supply chain linking the assemblage with their suppliers. The following spillover channels [22] have been traditionally identified:

- the competition between foreign subsidiaries and local firms (horizontal spillovers);
- the development and/or the conversion of existing domestic firms;
- the creation of supplier customer relationships between transnational enterprises and domestic firms (vertical spillovers);
- the establishment of licensing agreements or the commercialisation of patents;
- the diffusion of hi-tech, innovative products or machinery required for the application of new technologies;
- the transfer of human capital, skills and knowledge through the labour market.

During last decade new spillover channels such as outsourcing and subcontracting[23] and offsets agreements[24] have become a regular practice of complex technology industries, and particularly in the aircraft one. Offsets, carried out through foreign subcontracts, technology transfer, co-production with foreign partners, FDI, training transactions or licensed production are a relevant mechanism for international knowledge diffusion, and transfer of technology. Offsets agreements have been an important internationalisation mechanism of the US aircraft industry: From 1993 to 2006, aircraft industry related offsets agreements represent more than 50 percent of the total volume of US offsets.[25]

Prime contractors bring together resources and competencies, distributed on international basis, through their network of subsidiaries, commercial units, joint ventures, strategic alliances and agreements. Peripheral units assure the access to cluster-specific resources and competencies, such as raw material costs, process and products innovations and technologies, local skilled labour force, as well as relationships with university and research institutions.

Modularity, complexity and technological variety of aircraft products defined the organisation of international manufacturers, as assemblers or system integrators, sustained by an international network of subcontracting firms. This international supply chain is the vehicle by which knowledge usually flows from the top down and leads to a global concentration, and consolidation of the operations in few clusters, as well as to an international network of knowledge and technological spillovers.

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[22] Blomströmm and Kokko (2002). *Multinational Corporations and Spillovers*. Journal of Economic Surveys 12(2): 1-31.
[23] Niosi, Jorge & Zhegu Majlinda (2010). Multinational Corporations, Value Chains and Knowledge Spillovers in the Global Aircraft Industry. International Journal of Institutions and Economies. Vol. 2, No.2 0ctober (pp 109-141).
[24] Mowery, D. (1997) "Origins, Definitions, and Consequences of Offsets", in Wessner,C.W. and Wolff, A.W. (eds), Policy Issues in Aerospace Offsets, Washington, D.C.: National Academy Press.
[25] US Department of Commerce, Bureau of Industry and Security. Offsets in Defense Trade (2007). Eleventh Report to Congress. www.bis.doc.gov, accessed on August 11, 2012.

The global dimension of the aircraft industry is relevant from the technological perspective for there is growing research activity particularly in emerging countries, reflected in an number of patents resulting from the incipient international interdependence and collaboration of the R&D activities. In a world of complex technologies, technological leadership does not mean domination on the final stage but rather the production of key technological subsystem. Complex technological systems entail the creation of highly specialised arrangements among suppliers, customers and political authority as well as specific relationships to regulators and legislators and therefore to the political power. Yet citations to patents and licensing are of scarce utility as measurement methods for these firms do not usually publish scientific papers, or license technology and their processes are most often protected through secrecy rather than patents.

Government Support and Technology Development

The very high fixed initial costs, the long pay back periods, the increasing R&D tends to deter private investment in the aircraft industry. As a high value-added sector, it depends on rapid technological progress and the presence of important learning curves (effects). So huge scale returns together with learning curves makes industry protection in this sector theoretically valid, hence justifying the continuous use of industrial protection policies since its inception.[26]

Besides this, some economists consider that concentrating on learning is socially optimal[27] and consequently may justify the adoption of import bans because may have welfare enhancing effects. The unmistakable presence of these market failures in the aircraft industry is a valid argument suggesting the convenience of public intervention. Most probably these reasons were considered by the US Department of Justice when approved the Boeing-McDonnell-Douglas merger, and by doing so bypassing the spirit of antitrust regulations.

These aspects together with strategic considerations, such as national security expected spillovers both to downstream as well as up-stream industries and services as well to other sectors of the economy, has justified different forms of government support through subsidies, export subsidies, governmental procurement preferences, and market protection. For example, Airbus is directly and explicitly subsidised by the participating governments, while Boeing is indirectly subsidised by military sales and by the ability to apply commercially the knowledge gained from military developments, (particularly engine developments).

In its turn Embraer was a state-owned enterprise until its privatisation in 1994 although the government continued to fund part of Embraer's R&D activities and exports through the Proex export financing scheme. Similarly, Bombardier also received subsidies in the form of low interest loans and assistance programmes. The World Trade Organisation (WTO) has continuously declared all subsidies estimated at billions of US dollars as inconsistent with the WTO Subsidies and Countervailing Duties Agreement (1994) in a long series of high profile cases since 1999.

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[26] Baldwin Richard, & Krugman Paul. *Industrial Policy and International Competition in Wide-Bodied Jet Aircraft* (2008). In: Robert E. Baldwin/ Ed. *Trade Policy and Empirical Analysis*. National Bureau of Economic Research Conference Report series. University of Chicago Press.

[27] Dasgupta Partha & Stiglitz Joseph. 1988. *Learning by Doing* (1998). Market Structure and Industrial and Trade Policies. Oxford Economic Papers. June 40 (2).

Air Transport and Climate Change

Due to cross border nature of air travel, emissions of GHG are dispersed all along travel itineraries. This makes the control of emissions on international travel a global problem, as national measures alone would be ineffective. International aviation emissions are currently excluded from the Kyoto targets. Instead, Article 2, paragraph 2 of the Kyoto Protocol states that the responsibility for limiting or reducing greenhouse gas emissions from aviation bunker fuels shall fall to the Annex I Parties, working through the International Civil Aviation Organisation (ICAO).

In response to this challenge, ICAO Members agreed on a historical resolution[28] in 2009 containing main aspiration goals to stabilise carbon emissions. These goals include the following: A) improving fuel efficiency by 2 percent annually to 2050; B) achieving a collective medium-term aspirational goal of capping aviation's carbon emissions from 2020; and; C) agreeing on a global CO_2 standard for aircraft engines with a target date of 2013. Several implementing measures are being taken at the multilateral level to advance these goals including the use of market-based measures, technological mapping, development of standards, and a series of public private and private-private cooperation arrangements. The International Air Transport Association (IATA) is also contributing to these goals by deploying a four-pillar strategy: Technology investments, efficient infrastructure, effective operations and positive economic measures.

As mentioned above, the air transport is responsible for 2 to 3 percent of global carbon dioxide emissions. A peculiar characteristic of aircraft emissions is that they have a very strong short term warming impact owing to non-CO_2 GHG.[29] Aircraft emissions of nitrous oxides (NOx) and the formation of condensations trail (contrails) from water vapour at near stratospheric levels imply that the real impact on global warming is much higher and as possible as much as 10 percent.[30] Nitrogen oxides and water vapour from aircraft increase the formation of cirrus clouds and create contrails. They release also hydrocarbons and particles, mainly sulphate from sulphur oxides and soot. Together NOx and water vapour account for almost two thirds of aviation impacts on the atmosphere.[31] Therefore mitigation policies in the aircraft industry have to take into account other GHG besides CO_2.

Air travel is the fastest growing source of greenhouse gases and it is estimated that by the year 2050 the aircraft could account for up to 15 percent of the total global warming from human activities[32] unless more radical technological alternatives are found. The transport sector, including aviation, is a very inelastic market, so despite the sharp increase on oil prices there is a very little effect on demand. The fuel efficiency of commercial aircraft is likely to improve by 20 percent by 2015 compared to 1997, and may reach 40 to 50 percent by 2050. However, this anticipated annual improvement of 1 to 2 percent would be largely outclassed by percent annual growth in traffic of about 5 percent with consequent annual increase on CO_2 emissions of 3- 4 percent[33].

[28] ICAO. Resolution 37-19 (2009). See http://legacy.icao.int/env/A37_Res19_en.pdf , accessed the 10 of August 2012.
[29] Tickell Oliver (2008). *Kyoto 2 how to manage the Global Greenhouse*. Zed Books London /New York
[30] IPCC (1999) and (2007)
[31] Newsom Carey &Cairns Sally (2006). *Predict and Decide – Aviation, Climate Change and UK Policy*. Oxford University.
[32] IPCC (1999) and (2007).
[33] UNEP. *How to Cut Greenhouse Gas Emissions and Munimise Global Warning* (2007).

Fossil fuel is not expected to be replaced in the near future despite the fact its replacement is being pursued, therefore improvements in aerodynamics, weight reductions, alternative fuels, and engine design are the main areas of improvement to counter the dependence on fossil fuels. In the past increasing efficiency has been achieved by improvement in engine technology that increases fuel efficiency and consequently reduces CO_2 and NOx and water vapour emissions.

Key Technological Groups for Air Transport GHG Emissions Mitigation

Technological advancements in the civil aircraft sector are multipurpose. They seek to improve the efficacy and safety of exiting flying devices for human and cargo transportation but also reduced production costs, higher environmental performance, and passenger comfort. All these objectives do not have the same level of importance in the aircraft industry. The aircraft industry is a heavily regulated sector due to the fact that planes will ultimately transport people and could have high impacts over the earth surface in case of failure. In the regard, concerns over effectiveness and safety of airplanes are of summit importance. For example, safety is an imperative in the R&D of any technology seeking to advance any additional goals mentioned, as no company can sacrifice it at the expense of improvements in other areas.

The quest toward more efficiency, reduction of production and operation costs, and environmental performance has already shaped significant levels of improvement of certain aircraft related technologies. For example, over the past 40 years the aircraft industry and fuel providers have improved fuel efficiency by 70 percent.[34]

Between 2001 and 2008 alone the aircraft industry improved fuel efficiency by 16 percent.[35] Additionally, since the late 1990's aircraft operations (landing and routing) have become 20 percent more fuel-efficient and are expected to continue improving by 1.3 percent annually.[36]These advances show that environmental concerns and emissions control are not new to the aircraft and air transport industries, as those advances have close links with efficiency gains. It also shows the impact of high oil prices and the level of future oil reserves over R&D priorities in industries that produce goods that are intensive on fossil fuels such as aircraft and automotive ones.

Aircraft related technologies would play a key role in the advancement of the ambitious targets set in the IATA 2050 Environmental Vision and in ICAO members actions plans. Targets, such as building zero-emissions commercial aircrafts within 50 years or in an average improvement in fuel efficiency of 1.5 percent per year from 2009 onwards, require new and aggressive R&D efforts. All stakeholders recognise that technology development is fundamental pillar for the achievement of emission reduction targets in the air transport sector. Technology development has been explicitly incorporated in all multilateral emissions mitigation plans so far issued.

Due to the complex nature of the aircraft industry and the huge numbers of parts and devices that conform an airplane, understanding on which are the most relevant technologies is not an easy task. Even in many cases, technology development is not linear as one technology may be incompatible with others and only one R&D line may be chosen at the end for a particular model. So the degree of coordination and supportiveness between R&D lines is crucial for commercially successful outputs.

34 IATA (2010). *A global approach to reduce aviation emissions*
35 *Ibid*
36 WIPO (2009). *Keeping airplanes up and carbon output down*

It is not within the scope of this paper to undertake new technological mappings that could point at technologies that would support emission reduction targets, but to explore preliminary links between key technologies and intellectual property protection. In this regard, the best effort so far undertaken in assessing how relevant aircraft technologies can improve environmental performance and realise GHG reduction targets is the IATA Technology Roadmap Report.

The IATA's Technology Roadmap Report (2009)[37] assess technological opportunities for the current and future aircraft industry, particularly it assess how relevant aircraft technologies can improve environmental performance and to met GHG reduction targets. It identifies four groups of technologies that can "reduce, neutralise or eventually eliminate the carbon footprint of the aviation business."[38] These groups are: A) airframe and new composite material technologies; B) engine technologies; C) alternative fuels and D) air traffic management.

Table 1 summarises which are the technologies that fall within each technological group identified by the Roadmap as well as expected availability over time and their expected GHG mitigation benefit expressed in fuel burn reductions. The time horizon availability is defined in three periods:

- Period I: The technology is available today (it can be a retrofit or incorporated with some modifications in the near future);
- Period II: The technology will be available by 2020; and
- Period III: The technology will be available after 2020 and probably before 2050

[37] IATA. *Technology Roadmap Report* (2009). Third Edition.
[38] *Ibid*

Table 1: Technological Grouping of Key Technologies For GHG Mitigation and Period of Availability			
Technological Group	Coverage	Illustrative list of technologies against time horizon availability	Estimated GHG mitigation impacts in terms of fuel burn savings
A. Airframe and new materials	Aerodynamics, composite and light materials, on-board systems, and new frame designs.	Period I: Structural riblets, wind and wing tips, wireless optical connections, lithium batteries, natural and hybrid laminar flow.	They could have an impact over fuel burn reduction between 3 to 5 percent.
		Period II and III: Hybrid body and truss-braced wings, full cells, wireless flight control systems, morphing materials and airframe.	1 to 25 percent in fuel burn reduction.
B. Engines	New engines architecture, engines powered with alternative fuels/inputs, improved combustion, new materials and components for engines.	Period I: Engine retrofits, advanced combustor, engine replacement and variable geometry chevron.	1 to 2 percent in fuel burn reduction
		Period II: New engine core concepts (2rd generation); open rotor, advanced direct drive systems, geared turbofan, and counter rotating fan.	10 to 15 percent in fuel burn reduction.
		Period III: New engine core concepts (3rd generation); thermal management, adaptive and active flow control, ubiquitous composites, active stability management.	10 to 25 percent in fuel burn reduction.
C. Alternative fuels	Biofuels, cleaner fossil fuels and hydrogen.	Period I: Biomass, Hydrogenated oil, Liquid gas, trans esterification fuels.	60 to 90 percent in fuel burn reduction.
		Period II: Liquid gas, liquid methane, compress natural gas, and ethanol.	20 to 90 percent in fuel burn reduction as compared to period I.
		Period III: Liquid hydrogen	Carbon neutral fly footprint.
D. Air traffic systems	New electronic and operational data, management, navigation, surveillance, and performance systems.	No estimates available	No estimates available.
Source: Table prepared by authors based on data and analysis of IATA Technological Roadmap (2009).			

Among the air technology groups identified in Table 1, alternative fuels technologies have the higher and more immediate impact over fuel burn reductions between 60 to 90 percent depending of the type of fuel used[39] and in consequence over GHG emissions. One of the reasons for the importance of alternative fuels technologies for the aircraft industry, in the short term, is that aircrafts need high power-to-weight ratios in their engines in order to be able to take off, cruise and land. While other energy and fuel alternatives are being developed for aviation such solar, electric and hydrogen propelled aircrafts, it is expected that they will only be feasible in the medium term (mostly at the end of period III). Several biofuels blends for aircraft started to be tested since 2008[40] in commercial flights.

Today, one of the longer and most successful biofuel tests was the one recently carried out by Nestle Oil and Lufthansa, with Nestle Oil's "NExBTL renewable aviation fuel". This fuel was used on a total of 1,187 flights between Frankfurt and Hamburg during a six-month trial essayed between late 2011 and early 2012.[41] This shows that the air biofuel option as a feasible commercial alternative seems to be quite close.

As the alternative fuel option makes its way, it will be fundamental to ensure that when using biofuels, they are sustainably harvested. Negative impacts over arable land use, water use, deforestation, stock deviation, and food security have been deeply voiced concerns over the biofuel option. Bio-fuels could mitigate some aircraft emissions, but the production of bio-fuels to meet the aircraft industry's specifications and quantity demand is currently untested. Today, aviation consumes nearly 240 million tons of kerosene a year.[42]

To replace the current aviation fuel with bio-fuels from productive arable land that does not compete with food production would require nearly 1.4 million square kilometers of land, which is greater than twice the area of France.[43]

The second-generation biofuels based on non-food crops feedstock such as jatropha, algae and agricultural wastes could be less controversial. Although algae have been explored as a potential source of aviation fuel, most experts do not believe that cost effective algae derived fuels could be produced within a practical timeframe that would allow bio-fuels to make any substantial contribution to climate change policies. More optimistic scenarios are offered in relation the production of second-generation and more advanced biofuels expecting that about 50 percent of their feedstock will be obtained from wastes and residues by 2050.[44] This, however, would need clarification over the impact of deviating agricultural resides that are currently used as fertilised and feedstock for animals on traditional agriculture.

Taking into consideration these opportunities and risks, it is important to highlight that due to the fact that only future medium and long-term alternative clean technologies can address the power-to-weight ratio in commercial aircrafts, air biofuels seem to be one of the most immediate and environmentally preferable option today, especially when compared to the use of current fossil fuels.

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[39] *Ibid*
[40] Virgin Atlantic and Air New Zealand tested the first air biofuels in 747 planes in 2008.
[41] European Biofuels Technology Platform (2012). *Biofuels for air travel*. See http://www.biofuelstp.eu/air.html. Accessed 23 of July 2012.
[42] Jeff Gazard. *Biofueld or Biofooled?* (2009). Aviation and the Environment. Aviation Environment Federation.
[43] *Ibid*
[44] International Energy Agency (IEA) (2011). *Technology road map biofuels for transport*.

The second technological group with more immediate impact over GHG emission is the one on airframe technologies and new composite materials.[45] They can significantly reduce weight, aerodynamic drag and improve cruise and landing operations. It has been estimated that they could bring relatively rapid fuel burn saving of 3 to 5 percent.[46]

For example, in the new Boeing Dreamliner 787, fifty percent of the primary structure - including the fuselage and wing – will be made of composite material, potentially reducing fuel consumption by 20 percent.[47] It is expected that significant changes in the airframe design will emerge within period II and III.

New engine technologies, including new concepts and design, will also show significant impacts, especially over Periods II and III. Advances in engine technologies will include changes to allow the use of new alternative fuels. Both alternative fuels and engine R&D, if properly coordinated and incentivised, have the greater potential for advancing environmental and emissions targets by the aircraft industry.

Some of the most promising technologies to become available after 2020 (Periods II and III) will imply important design and structural changes in new aircraft models as well as very significant changes in airport infrastructure. Fuel cells use hydrogen to produce heat and electricity without combustion, so reducing the use of conventional fuel and consequently reducing also emissions of GHG.

Full cell technologies, which might have the highest potential for developing a zero emission commercial aircraft by 2050, will imply radical airplanes and airports configurations with totally different engines, structures, tanks and stoking facilities. Instead, some of the currently available technologies, such as efficient engines or alternative fuels, will imply no change, little adaptation or acceptable levels of modification over existing airplanes with relatively low costs.

Beside the technology groups identified, converging technological efforts toward greener, larger and more efficient aircrafts is already bringing some fruits. Recent planes such as the A380 series and the Boeing 787 Dreamliner are good examples among long-range planes. The A380 series burns 17 percent less fuel per passenger that any other type of plane.[48] The Boeing 787 has a 20 percent improvement in fuel burn if compared with similar sizes planes.[49]

This shows that the converging efforts in new aircraft models can provide longer steps toward emission reduction goals. However, a new model takes time and considerable technological, financial and testing efforts before it is approved for commercial operations.

Even if one new air technology proves its GHG mitigation emissions and commercial potential, there will be a need to issue new international standards and to overcome existing o new regulatory approvals, delaying their commercial availability. In the case of aircraft biofuels, this has been addressed, to certain extent, by the fact that they can and must fulfil the same standards and certification process than other drop-in fuels.

[45] Composite materials are usually defined as a combination of two or more organic or inorganic components such as glass, boron and carbon fibers.
[46] IATA (2009).
[47] World Bank. *Air transport and energy-efficiency* (2012).
[48] IATA (2009).
[49] *Ibid*

For example, to be approved aircraft biofuels can be required to fulfil international standards such as ASTM (American Society for Testing and Materials) D1655, D4054 and D7566 applicable to technical specifications, qualifications and approval of aviation turbine fuels, fuel additives and fuels containing synthesised hydrocarbons."[50]

In order to make non drop-in fuels (such as the case of liquid natural gas or hydrogen) a feasible option in the medium term, new engines, stock and infrastructure facilities will be needed. These changes will also demand specific standards, regulations and approval processes not yet in place.

Preliminary Linkages between Patens and Aircraft Technologies Relevant to GHG Emission Mitigation

Patents were used to protect incipient aircraft technologies since the beginning of the airplane development. The Wright brothers filled their first patent for a "Flying Machine" (Construction and Design of 1902 Glider) in 1903 (Patent No. 821.393).[51] Several "essential" patents for flying machines fly control devices and engines by the Wright brothers and other aircraft builders' pioneers such as Glenn Curtis followed this patent. These patents were even the source of one of the first "patent wars" and the creation of the first government driven patent pool in 1917: The Aircraft Manufacturers Association in 1917. The creation of this patent pool is considered to be a landmark decision that facilitated the development of more modern aircrafts to be utilised in the first war and in the subsequent aviation development.

Patent provisions in international intellectual property conventions and treaties apply to all aircraft technology groups identified above. The particular cross border nature of the air transport business, has even allowed the inclusion of important exception to patentability in the international intellectual property system. Article 5ter of the Paris Convention for the Protection of Industrial Property (of 1883 and last revised in 1979)[52] incorporates the so-called "foreign vessels, aircrafts and vehicles" exception.

Under this provision, Parties do not consider as infringement of the patent holder rights the use in foreign vessels of other countries of the Paris Union of devices subject to a patent in the body and different parts of the vessel, when such vessel temporarily or accidentally enters the waters of the said country, provided they are used for the needs of the vessel. The same applies to devices forming part of the construction, operation or accessories of aircrafts and land vehicles. The key benefit of this provision was to facilitate free trade, ensure uninterrupted international travel and to reduce tensions between countries over the treatment of vessels flying their flag.[53]

This provision is fully in force and is part of the Agreement on Trade Related Aspects of Intellectual Property Rights of 1994 (TRIPS Agreement) by direct incorporation of certain Paris Convention provisions under article its 2.1.

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[50] See for example ASTM International Standard D7566 at the ASTM web site at: www.astm.org/Standards/D7566.htm, accessed the 23 of July 2012.
[51] Wright State University (2009). *Wright Brothers' Patents*. See www.libraries.wright.edu/special/wright_brothers/patents/ accessed the 24 of June 2012.
[52] See full and exact text at Paris Convention at www.wipo.int/treaties/en/ip/paris/trtdocs_wo020.html, acceded the 24 of July 2012.
[53] See Christopher Garrison (2006). *Exception to patent rights in developing countries*. ICTSD and UNCTAD, Issue Paper No. 17.

The civil aircraft industry is considered as one of the most innovative technological sectors today. This has been the consequence, as indicated above, of its particular market structure, governmental interventions and its R&D model. These particularities include the existence of a very limited number of leading firms, high entry barriers, the strategic value of the sector for governments (especially in relation to defence), a significant amount of subsides going into the sector (including in R&D), and the existence of big governmental contracts to develop new aircraft models and technologies.

Patents, trade secrets and trademarks are widely used by the aircraft industry to protect the intangible assets. 31,273 patents applications were found under simple search on aircraft technologies under the International Patent Classification (IPC) for B64 C to F subclasses[54] during the period 2002-2012.[55]

This number of patents applications covers of all type of aircraft technologies including those that do not support emission mitigation goals. It includes international applications under the Patent Cooperation Treaty (PCT) and those made in national patent offices. This number, while significant, it is not enormous if we consider that the number of patents under the whole transport family was 65,526 patents and in the case of the eclectic machinery, apparatus and energy (another active sector in relation to GHG mitigation technologies) was more than 100,000 patents only in 2009.[56]

Reasons for this is that, due to high entry barriers and the assembling and component nature of this sector, aircraft producers tend to heavily rely on trade secrets and know how sharing mechanisms with their key providers more than on patents to protect their intangible assets.

Figure 1 below provides a view of the top 10 filing offices/countries on aircraft patents. Patent data in figure 1 includes international applications made under the PCT. It does not cover applications made to various national patent offices unless applicants have also chosen an international application under the PCT.[57]

The data cover patents from residents and non-residents. The European Patent Office (EPO) with more than 12,650 patents and the PCT system with more than 8,648 are among the offices that receive more applications on aircraft technologies. Developing countries listed include Brazil, which counts with an important aircraft industry lead by Embraer, followed by the Republic of Korea, Israel, South Africa, Mexico and Argentina. Figure 1 also shows how emerging economies are becoming important actors in patent filing terms in this sector for protection purposes in those countries but also abroad.

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[54] Search criteria used in the patent scope search were IPC: "B64C or B64D or B64F". The IPC B64 subclass includes aircraft aviation and cosmonautics. More specifically, B64C includes airplanes and helicopters. B64D includes equipment for fitting in or to aircraft; flying suits; parachutes; arrangements or mounting of power plants or propulsion transmissions. B64F includes ground or aircraft-carrier-deck installations. All these subclasses are directly related to the aircraft building and parts. However, there are relevant patents for aircraft parts and components outside this classification such as lithium batteries or fuel cells.

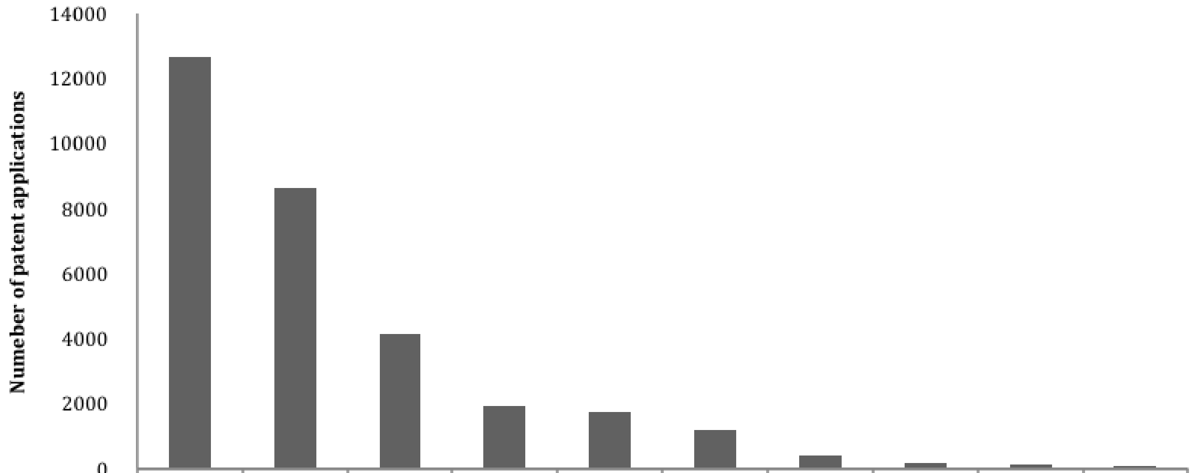
[55] This search was carried out with the **WIPO's patentscope** search tool and data. See patent scope database at http://patentscope.wipo.int/search/en/search.jsf , accessed 24 of July 2012.

[56] WIPO (2012). *World Intellectual Property Indicators 2011*.

[57] A significant aspect of this preliminary patent search based on the WIPO's patenscope data is that it does not cover well US, Canadian, Japanese and Chinese patents unless applications have been made through the PCT system. In consequence it is recommended to complement this preliminary search with specific searches on similar key words and IPC subclasses in local languages in national databases in order to have a less Eurocentric vision of the patent landscape.

Main patent applicants under IPC B64 C to F subclasses include the traditional leaders in the aircraft sector such as Airbus Operations GMBH with 758 patents, Boeing Corporation with 744, the Boeing Company with 714, and Airbus France with 513 over the same period.

Figure 1:
Top 10 patent applicats under subclasses B64 (C to F) of the IPC per office/country (2002-2012)



	European Patent Office	PCT	Spain	Russian Fed.	Brazil	Rep. of Korea	Israel	South Africa	Mexico	Argentina
Séries1	12650	8648	4177	1913	1744	1209	390	173	133	109

Source: Prepared by the authors based on data from WIPO patentscope (2012) Only patents in English and some in Portuguese.

There is not yet a patent landscape on the technological groups identified by the IATA Technology Road map. There are some general patent landscapes made on biofuels and fuel cells with no disaggregated figures for the aircraft industry.[58] Moreover, there are some new patent classifications on clean energy by the EPO and World Intellectual Property Organisation (WIPO) but none focuses on specific technologies for aircraft sector. For example, the WIPO IPC green inventory covers transport in general, rail vehicles, marine vessel propulsion and cosmonautic vehicles using solar energy[59], but it does not cover air transport.

When trying to understand the level of patenting in aircraft technologies relevant for emissions mitigation, this paper will focus on some of the most relevant ones including new gas engines, fuel cell, biofuels and solar powered aircrafts. These technologies are among those with a significant potential for fuel burn savings and emission mitigation in the IATA Technology Road map (2009).

This paper utilise a simple patent search methodology based on key words and IPC classification by utilising data of WIPO's patent scope. This methodology has been chosen due to the fact that the objective of this paper is to identify preliminary linkages and not to undertake a full patent landscape report on the aircraft sector. "Key terms" chosen to give an idea of patent activity based on some key technologies identified by IATA's Technology Roadmap included in Table 2.

[58] See WIPO. Patent landscape reports at *www.wipo.int/patentscope/en/programs/patent_landscapes/published_reports.html, accessed the 24 of* July 2012.
[59] See WIPO (2012). *IPC Green inventory*. See the inventory at: *www.wipo.int/classifications/ipc/en/est/ ,* accessed the 10 of August 2012.

Table 2: Key Terms for Preliminary Patent Search on Patents Related to Aircraft Technologies with Potential for GHG Emissions Reduction	
Key words utilised	Corresponding IPC classification numbers
"Aircraft" and "gas turbine/engine"	B64 C to F; C22; C23; F01 to F04; F23; G01.
"Aircraft" and "composite materials"	B64 C to D; B29; B32; C04 and C08; and F16.
"Aircraft" and "fuel cell"	A47; B64 C to F; H01; F01, F02 and F17.
"Aircraft biofuels"	B64 C to F; A61; C06, C07, C10 and C12; H01; B01; F02 and F26; and G01.
"Engine retrofit"	A62 and B64.
"Aircraft" and "hydrogen powered"	B01; B64 and F02.
"Aircraft" and "solar powered"	A63; B64B to H; H01 and H04.

Figure 2 shows the result of preliminary patent searches on aircraft technologies with potential GHG emissions mitigation. The segment with more patent activity is aircraft gas turbines/engines with more than a 1,000 patents over the last 10 years. Main patent applicants for Aircraft gas turbine/engines during this period include engine and parts producers such as MTU Aero Engines GMBH with 110 patents, General Electric with 76, SNECMA with 48, and United Technologies Corp with 47. These numbers shows that investment in this technology still is a key interest of the aircraft industry.

At this level it is not possible to determine if new gas turbines as well as aircraft engine retrofits counted in figure 2 will have a potential reduction effect on GHG mitigation. For that it will be necessary to set technical and efficiency criteria to identify relevant patents and tag them one by one in the WIPO patentscope database.

140 patents were identified in relations to aircraft composite materials. These materials can have important impact over weight, solidity and resistance to external factors and therefore over fuel burn. Main applicants include traditional aircraft producers such as the Boeing Company and Boeing CO with 8 patents each and Airbus Operations with 5.

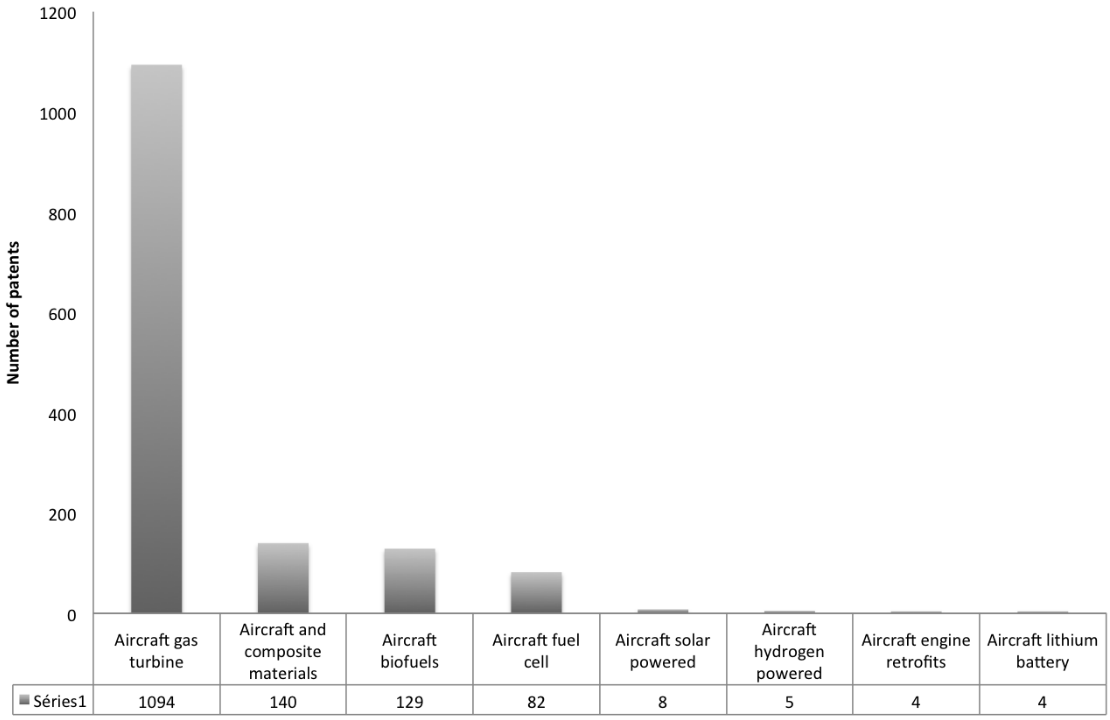
Aircraft biofuels can be a preferable environmental technology if compared to existing fossil fuels. Aircraft biofuels accounted about 130 patents. Main patent applicants include Sony Corp with 8 patents, Amyris biotechnologies with 7, BP Oil International Limited with 5, Shell *Internationale Research Maatshappij* B.V. with 4 and the *Instituto Nacional de Tecnologia of Brazil* with 3 patents. This list shows that oil companies, biotechnology firms and public research centres are the leading entities in developing the aircraft biofuel option.

Fuel cells for aircrafts, solar and hydrogen powered aircrafts, and aircraft lithium batteries are the technologies with the high emissions mitigation potential. So at this stage they represent a more direct technological route for a zero emissions aircraft model. All together there are about 100 patents on this later group of technologies. This confirms the longer R&D timeframe for technical and commercial availability mentioned in the IATA Technology Roadmap (2009) for this type of technologies.

A recent review of patent application on biofuels in general has been evidenced that patent applications filed prior to 2009 had a significant focus on new biofuel starter materials, along with new and streamlined processes.[60] Recent publications emerging in 2011 and 2012 appear to be shifting in the direction of working with known biofuel materials and improving the material and/or the process.[61] There are also groups of publications focused on fuel optimisation through the addition of other components and/or better engine design.

The main applicant aircraft fuel cells are again leading aircraft companies such as Airbus Operations GMBH with 18 patents, Airbus GMBH with 9, Airbus Deutschland with 9. In the case of biofuels, aircraft fuel cell and in solar powered aircrafts about 70 percent of patent applications were published during the last 5 years. All patents applications on hydrogen-powered aircraft and aircraft lithium batteries were introduced after 2005.

Figure 2
Patents on seleted aircraft tecnologies with potential for GHG emissions mitigation (2002-2012).

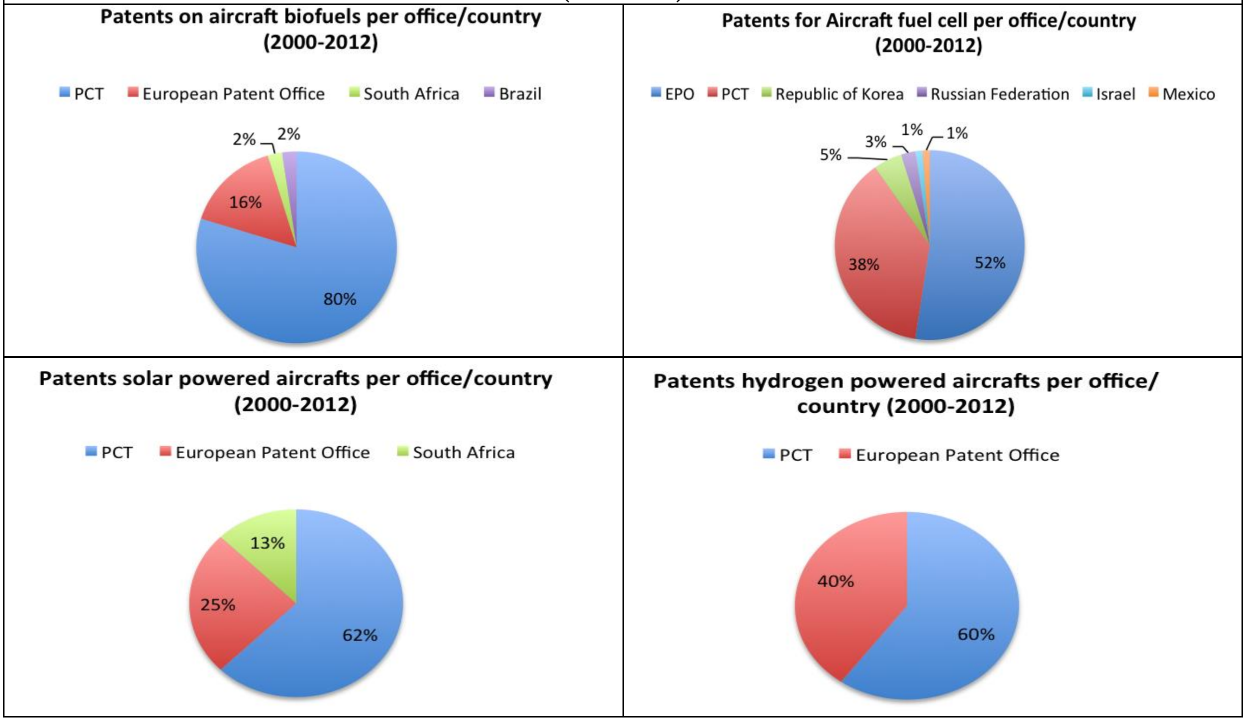


Source: Prepared by the authors based on data from WIPO patentscope (2012). Some patents related to biofuels were found in Portuguese.

Figure 3 shows the results of preliminary patent searches on aircraft biofuels, fuel cells, and solar and hydrogen powered aircrafts per office over the last 10 years. Most of the patent activity occurred under the PCT and the EPO. As in previous cases, the some emerging countries are slowly starting to make their way into these technologies. The presence of Brazil and South Africa among the innovators on aircraft biofuels should not be a surprise as they have long standing policies on biofuels as an alternative. In the case of fuel cells, patent applications in the Republic of Korea, Russia, Israel and Mexico indicate a wider level of interest by multiple applications including in the aircraft business.

[60] Thompson, Sandra (2012). A review of recent biofuel patent trends. Industrial Biotechnology. 8 (1) pp. 15-17.
[61] *Ibid*

Figure 3: Percentage of Patent in Selected Aircraft Technologies with GHG Mitigation Potential (2000-2012)



Source: Prepared by the authors based on data from WIPO patentscope (2012). Some patents related to biofuels were found in English and Portuguese.

Conclusions

New aircraft technologies are perceived as perhaps the most important vehicle to reduce and hopefully eliminate GHG emissions within the next 40 years. New technologies can make significant contributions to GHG emissions reductions in fuel terms, per aircraft, per passenger or per cargo weight. However, as growth rate of the air passenger traffic has been estimated at 4.8 percent, emissions will remain a significant challenge for the industry as they may also continue to grow in absolute terms regardless of current efforts. In this regard, the quest toward a zero emissions airplane for large passenger and cargo transport will be the only way to make a decisive contribution in phase out of GHG emissions from air transport.

Advances in technology might not be sufficient to counteract growth in air traffic demand and consequently projected fuel burn will increase by more than 150 percent. Impacts of technological advances in future global emissions are a function of the opportunity for the introduction of new aircrafts into the industry.

Most of the effort directed toward R&D in those technologies is being pushed by a series of factors including fuels cost, internationally agreed targets under ICAO and IATA, efficiency and competiveness, significant governmental intervention, consumer demands and corporate image. It is not foreseen that this new race among R&D lines seeking a lower GHG emissions will substantially change the current market structure among leading firms in aircraft industries due to high entry costs, complex technological systems and low levels of competition. The only exception could be new entrants from China but this was not part of the scope of the analysis. New R&D lines for GHG reduction can, however, bring more dynamism and stronger competition in the propulsion, parts and components layers of the business in the near future.

Technology mappings, done so far, point at the relevance of technologies with GHG mitigation potential that can be introduced with no or little changes. These technologies can bring some reductions in fuel burn efficiency and lower GHG emissions within the next 10 to 15 years. However, higher levels of fuel savings, engine shifts and radical changes in aircraft design are expected only to occur by 2050. The fact that the aircraft industry belongs to complex technology systems may also imply that technological advances occurring in other sectors can later be adapted and brought in. Parallel but not yet convergent technological advancements in the automotive, fuel, new materials, and the electronics and communications sector may well change the path or content of future technologies developments in the aircraft industry.

Due to the level of governmental support given to the aircraft sector and the amount litigation that it has generated in the WTO, one option that needs further exploration is to redirect support toward open, public and collaborative research models. While it might be considered naïve, especially due to the concentration levels of the industry, options for open, public and collaborative research models that focus on the generation of public technological goods that support emissions mitigation targets need to be explored. These models might speed up results without further distorting markets. The value of additional innovation schemes such as prize systems and open patent pools need to be further analysed in the current market, technological context and patent landscape.

It has been evidenced that the aircraft industry, relies only to a certain extent on patents for the protection of their technological assets. Trade secrets, trademarks and intra supply chain arrangements also play an important role. When undertaking some preliminary patent searches using WIPO patent scope, patents related to engines and turbines emerge as the main area of interest so far with more than 1,000 patents. Leading applicants are the engine and turbine manufacturers more than aircraft producers. This seems to be reflecting last decade R&D priorities, which were mostly pointing at fuel and engine efficiency due to high fuel costs plus interests in higher engine and turbine performance.

Even when using wide search criteria, patenting activity in other aircraft technology lines that could have a positive impact over GHG emission reduction is low (composite materials, biofuels, fuel cell, hydrogen and solar powered planes). Patenting in these technological groups go from less than 140 to about a dozen patents per group over the last 10 years. Among these, patenting in aircraft composite materials and biofuels are the areas with the higher level of activity. Most of these patents have been filed after 2005, showing the typical time gap between technological needs, R&D priorities, investment and filing at patent office. In the case of composite material, traditional aircraft industries are present. In biofuels, oil companies and alternative energy firms are taking the lead. Firms and research centres from Russia, Republic of Korea, Brazil, Mexico and South Africa were found among the applicants but with lower numbers.

As mentioned above, the search undertook was preliminary and relatively wide. A more precise methodological approach will be needed to better define which inventions have a positive impact over GHG mitigation among different technological groups. This would imply select relevant technological categories under the IPC, tag relevant patent applications, undertake a time frame comparison, and verify what information could be obtained with current patent databases.

For example, number of patents, filing dates, applicants (by resident and non-resident), country data, etc. Based on more precise criteria, searches could be then carried out not only under WIPO patent scope but also in relevant patent offices of leading and emerging economies in different languages.

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