Review of alternative fuels for sustainable aviation from TRANSCEND

Posada Duque, J.A.; Stepchuk, I.; van der Sman, Elisabeth; Palmeros Parada, M.D.M.; Osseweijer, P.

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Clean Sky 2 Programme, the Technology Evaluator (TE) is a dedicated evaluation platform. It has the key role of assessing the environmental impact of the technologies developed in this programme and their level of success towards the ACARE 2050 environmental and mobility goals. GLIMPSE2050 is a Clean Sky 2 TE project. It expands the aircraft technology-oriented focus of the Clean Sky 2 Programme by evaluating at global level the potential effects up to 2050 of regulations and policies that are currently discussed and potentially introduced until 2040 to reduce the environmental impact of aviation. Herewith, it estimates which environmental reductions can be achieved by these regulations and policies in addition to those brought by Clean Sky 2 technologies. More specifically, GLIMPSE2050 compares the environmental performance of two scenarios. The first scenario is a projection of the air transport system up to 2050 based on autonomous economic, demographical and technological developments but without the regulations and policies. The second scenario is the same projection of the air transport system up to 2050, but with the selected regulations and policies introduced. The presentation will provide an overview of GLIMPSE2050. It will address the approach to select the regulations and policies and to carry out the assessments as well as present selected results.

Review of novel propulsion technologies for sustainable aviation from TRANSCEND

Mr. Johan Kos ((Royal Netherlands Aerospace Centre NLR)), *Jaap van Muijden, Alte I. de Boer, Oscar Kogenhop, Edward R. Rademaker*

Novel propulsion technologies and alternative fuels are key technologies for reducing the environmental impact of aviation and its impact on climate change. The TRANSCEND (Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains) project in the Clean Sky 2 Technology Evaluator evaluates the potential contribution of these technologies to FlightPath 2050 and related zero net emission goals for the period 2035-2050. The technologies evaluated are complementary to the propulsion (and aircraft) technologies developed in Clean Sky 2 and evaluated in its Technology Evaluator. In addition, TRANSCEND prepares roadmaps for selected promising novel propulsion and alternative fuels towards their full-scale entry-into-service in the period 2035-2050. This presentation introduces the TRANSCEND project and reviews novel propulsion technologies both for aircraft powered by sustainable replacements of kerosene and for aircraft powered by hydrogen. The review focuses on the identification of the technologies, their preliminary evaluation for different classes of aircraft, and their allocation to classes of aircraft. Four categories of novel propulsion have been reviewed: gas-turbine based propulsion (both for drop-in and for non-drop-in energy sources), electric propulsion, and hybrid-electric propulsion. Based on these categories, a number of classes of propulsion concepts with numerous underlying novel propulsion technologies will be presented for potential aircraft application before 2050, allocated to aircraft seat classes. In the complementary presentation by John Posada Duque the review of the alternative fuels for sustainable aviation is presented.

Review of alternative fuels for sustainable aviation from TRANSCEND

Mr. John Posada (TU Delft, Department of Biotechnology), *Inna Stepchuk, Elisabeth van der Sman, Mar Palmeros-Parada, Patricia Osseweijer*

The TRANSCEND project (as part of the Clean Sky 2 Technology Evaluator) aims to develop roadmaps for full scale entry-into-service of selected propulsion technologies and alternative fuels in the period 2035-2050, in line the emission target of FlightPath-2050 for the period 2035-2050. In this work we present the selection of six sustainable aviation fuels (SAFs) that will be included in TRANSCEND road-mapping. The full context of TRANSCEND and its findings for promising propulsion technologies are introduced in the complementary presentation: “Review of novel propulsion technologies for sustainable aviation from TRANSCEND” by Johan Kos. The reviewed SAFs included bio-based fuels and e-fuels as drop-in SAFs, and non-drop-in energy sources (here hydrogen).

As part of the literature review, 19 groups of production technologies for SAF were initially identified, from which 5 technologies were discarded in the screening process due to either potential limitations on scalability or it very early technological development stage (i.e. very low Technology Readiness Levels). Subsequently, the 14 remaining technologies were comparatively analyzed for both their unitary production costs (i.e. costs per unit of usable energy [€/MJ]) and unitary greenhouse gas (GHG) emissions (i.e. CO2-eq. per unit of usable energy [CO2-eq./MJ]). As a result, five promising SAF production routes were pre-selected for further discussion with experts in a workshop; and at the end of the session six SAFs were selected for further evaluation in the roadmap, they are: hydroprocessed esters and fatty acids (HEFA), Fisher-Tropsch process (FT), fast pyrolysis (FP), Alcohol to Jet (ATJ), power-to-liquid (PtL) for e-fuel via Fisher-Tropsch, and alkaline electrolysis (AE) for hydrogen. Finally, the data collected on the life cycle GHG emissions, for most the relevant alternative energy sources and production routes, were used to develop an open Microsoft Excel based tool (the "Ecological Balance Sheet") to quickly estimate a range of expected GHG emissions and the potential emissions savings of a production chain (based on similar systems already reported in literature).

GLOWOPT: Development of climate functions for aircraft design

Ms. Kathrin Deck ((TU Delft), *Volker Grewe, Feijia Yin, Irene Dedoussi, Roelof Vos, Pieter-Jan Proesmans, Florian Linke, Kaushik Radhakrishnan, Malte Niklaß, Benjamin Lührs*

Aviation ensures mobility for both passengers and goods. It is important as a transport sector for connections on and between continents. Nevertheless, aviation also contributes to anthropogenic climate change. The effects are usually divided in CO2 and non-CO2 effects and therefore not only CO2 emissions but also other emissions (e.g., NOx , water vapour or soot) and contrails are covered. To reduce the effects of aviation's climate impact, several mitigation options are applied. One approach are climate change functions, which will be addressed here. The concept of climate change functions was used in previous projects, e.g. REACT4C, WeCare, ATM4E. The goal of these functions was to optimize the aircraft routes regarding the calculated climate impact. Climate change functions measure the climate impact per unit emission for a specific day, which considers the current meteorological conditions. Climate change functions were previously used to optimize the aircraft routings. The concept should now be applied for the optimization of the aircraft design as well since the promising concept is currently missing for the application of aircraft design optimization. The climate functions for aircraft design will connect the aircraft design with the climate impact of various emission in order to be able to optimize the aircraft design. For the calculation of the functions, it is necessary to define a specific application. This application results from a combination of aircraft design parameters. Aircraft design parameters can be for example flight altitude, climb rate, speed or range. Based on a resulting emission inventory, the temperature response can be calculated with the model "AirClim". This model calculates with the input, first, the radiative forcing and based on that the temperature change. The final development step is the verification of the climate functions.

Reducing emissions through fleet and flight network optimisation – the Clean Sky project REIVON

Dr. Thomas Rötger (ENVISA), *Gabriel Casas, Hans Dorries, Ling Lim, Bethan Owen, André van Velzen, Florian Linke, Benjamin Lührs, Kaushik Radhakrishnan*

The Clean Sky 2 Technology project REIVON investigates to what extent the CO2 emissions of global aviation can be reduced via an aircraft size/range optimised fleet and flight network. For the latter, two main approaches are investigated, namely splitting long-haul flights into shorter legs and reducing flight frequencies on busy routes to the necessary minimum using larger aircraft. In addition, REIVON analyses potential measures to establish an air transport system with optimised aircraft, flight network and frequencies, and assesses its impact on stakeholders (passengers, aircraft manufacturers, airlines, airports