Summary of the 2019 Aviation Decarbonization Forum

HOTEL AC MONTREAL | MONTRÉAL, QUEBEC | CANADA

TUESDAY, FEBRUARY 12, 2019 FROM 8:00 AM TO 4:30 PM

Hosted by the International Coalition for Sustainable Aviation

Introduction

On Tuesday, February 12, the International Coalition for Sustainable Aviation[1] presented the first annual Aviation Decarbonization Forum—an exclusive event for ICAO Council members, permanent representatives, and their advisers to receive the most comprehensive, up-to-date information about how aviation can reduce its climate impact. Overall, 20 participants from national governments (Council members, permanent representatives to ICAO, and other nominated officials) attended in person, with four government participants representing countries in Latin America and Small Island States joining remotely via videoconference. These participants were joined by seven members of ICSA, and Chris Lyle the forum's moderator and

Seven international academic experts presented on a range of topics over the course of the day, with ample time for audience discussion. For a full agenda of the forum please turn to Appendix 1.

[1] **The International Coalition for Sustainable Aviation (ICSA)** works to reduce pollution from air travel. ICSA is the only environmental civil society group accredited as an observer by the International Civil Aviation Organization (ICAO), the United Nations standard-setting body for international air travel. ICSA member organizations include Aviation Environment Federation, Carbon Market Watch, Environmental Defense Fund, the International Council on Clean Transportation, Transport & Environment, and WWF.

For more information, please visit www.icsa-aviation.org

The event was conducted under the Chatham House Rule of non-attribution of the plenary exchange to promote an open exchange of ideas. Please feel free to share this summary on an individual basis with interested parties without claim of consensus or agreement. This summary and the PowerPoint slide presentations can also be accessed from the ICSA website at: https://www.icsa-aviation.org/aviation-decarbonizaton-forum-presentations-february-2019/.

Key insights from the event

Target setting to address aviation's climate impact

- There are clear benefits for policy makers to aim at preventing warming above 1.5°C versus 2°C.
- There is limited long-term potential for offsetting given that there will be little opportunity to outsource emissions reductions to other sectors in a more carbon constrained world.
- When policy makers set a long-term emissions pathway for a sector (like aviation), they can evaluate all the emissions reductions potential from individual initiatives and technologies from the bottom-up or take a top-down approach whereby the policy maker could look at targets that are based on some preconceived level of emissions reduction ambition. Bottom-up and top-down approaches can be conducted together.
- In the analysis presented by Dr. Martin Cames from the Öko-Institut e.V., the ATAG 2050 target would lead to emissions 29% higher than they need to be for aviation to align itself with a 2°C pathway (the RCP2.6 pathway). Thus, this target is not aligned with the temperature goals of the Paris Agreement.
- Contrary to much of the media coverage of the IMO GHG strategy, it not only has a long-term 2050 target (70% lower CO_2 intensity from 2008 levels by 2050) but also a mid-term

target (40% lower CO_2 intensity from 2008 levels by 2030. This could be instructive for how ICAO might think about setting a long-term goal.

Developing more efficient aircraft

- Among transport modes, aviation is uniquely sensitive to weight effects, limiting the solution space.
- Baseline new aircraft fuel efficiency improvement is 1 to 1.5% per year, plus operational efficiencies on top. The challenge is to accelerate the 2% per year current trend to 3%+ recognizing the need to protect safety, certification delay, high risk of investment failure, among others.
- Electric aircraft are coming for general aviation and regional flights. Hybrid electrics are more likely for most commercial flights. Drop-in alternative fuels for the existing fleet will also be important for the sector.
- Further efficiency gains through advanced configurations--blended wing body, truss-based wing, distributed propulsion, etc.--are important but will require substantial R&D support. Some approaches could be paired to hydrogen. Smaller jumps--folding wingtips, re-engines with geared turbofan, etc.--are already underway.
- It is very difficult in the current structure of the industry to imagine one of the airframe manufacturers making the massive investment required to commercialize a revolutionary design, and that therefore government intervention might be required.
- There is no technology silver bullet: We need an "all of the above" approach for more GHG efficient aviation. This includes faster incremental improvements, much more R&D, accelerated fleet renewal, "drop-in" alternative fuels, better procedures (e.g. climate optimized routing), compensation (CORSIA and beyond), stronger incentives (legislation and societal pressure), and limiting and even reversing growth—all this preferably soon.

Sustainable alternative fuels

- Dr. Malins noted that reaching 100% alternative fuels for aviation will be massively challenging and costly.
- Dr. Malins noted that CORSIA will create very small additional incentive for SAF usage by airlines compared to the value of existing alternative fuels incentives for road transport.

Bio-based

- The Energy Transitions Commission's view is that waste is the only sustainable source of biofuel feedstock.
- Panelists noted that biofuels for aviation or any sector is certainly not the most efficient use of biomass on the whole; however, one panelist pointed out that there are many factors at play in determining whether a biofuel can be or is "sustainable" including location, water constraints, etc.

Power-to-liquids (PtL)

- PtL could cost more than two times than if it is coming from air capture. But when one expands the definition of costs to include the impacts of climate change on human societies, this cost is likely to be worth it.
- Chris Malins cautioned in overstating the cost of air capture for PtL, as it would still be secondary to electricity costs to run the core PtL production process and could be secondary to other elements of capital cost as well.
- PtL has some clear environmental sustainability advantages over biofuels--namely a considerably lower water footprint and lower land demand by a conservatively estimated factor of eight, even for high biofuel yields.
- Fast action is needed to realize the promise of PtL, if the technology is to play a major role in reducing emissions from aviation by 2050. No other solution would use a good amount of existing infrastructure that employs sustainable renewables for air transport.
- Business aviation may be where we start with PtL.

- Additionally, remote airports might potentially be good candidates to supply with this fuel, given costs of transporting fuel to these places.
- We also might think about more pilots and investments in areas where renewable electricity is cheap--e.g. 2 cents/kWh in Mexico. Dubai could be another place.
- We need to pay more and invest in PtL technology.
- As for specific policy levers, Dr. Harry Lehmann believes that perhaps a feed-in tariff scheme could work to encourage production.

Non-CO_2 effects

- Dr. Grewe noted that while aerosol impact on clouds is still uncertain, we can still calculate that, overall, aviation contributes about 5% of manmade global warming. About 50% of this warming is due to CO_2 and roughly the other half due to other non-CO_2 climate forcers.
- Optimizing flight paths to avoid climate-sensitive areas could substantially reduce the climate impact of aviation at low cost increase, even as this will have some impact on air traffic patterns.
- New methods are almost here that will help policy makers and others account for non-CO_2 effects on a flight-by-flight basis and converting these into a CO_2 equivalent.

Welcome

Tim Johnson, Director or Aviation Environment Federation, opened the Aviation Decarbonization Forum on behalf of ICSA. He introduced ICSA as an organization representing environmental NGOs at ICAO since 1998. ICSA is actively involved in CAEP and its working groups, and in recent years ICSA has played a significant role in tackling the sector's impact on climate change through the development of the CO_2 standard, CORSIA, and the discussions around sustainable alternative fuels.

Tim explained ICSA's rationale to host this meeting.

Tim then introduced the Aviation Decarbonization Forum's moderator, Chris Lyle, Chief Executive of the Canada-based consultancy Air Transport Economics.

Moderator's framing of the day

Mr. Lyle noted that the aviation decarbonization discussion has been going on for a very long time--dating all the way back to the formation of the Kyoto Protocol, which then led to the ICAO "basket of measures" and so forth.

Mr. Lyle framed the day around three guiding questions:

- The first: "where are we now in terms of the climate change crisis and what is aviation's contribution to that crisis?"
- The second: "where do we want to go"? In other words, how quickly do we need to cut carbon and other emissions to be on track to achieve the Paris climate targets?
- And finally: "how do we get there?" That is, what are the technological and policy solutions needed and how quickly do we need to deploy them?

Mr. Lyle noted that much of the conversation during the day would be framed around the third question: "how do we get there?" But the first session (The Global Decarbonization Challenge and Aviation within It) would ask the first 2 questions: "Where are we?" and "where do we want to go?"

Mr. Lyle noted that countries in ICAO have been reflecting on these questions for years. Every ICAO Assembly since 2010 has requested the Council to explore the feasibility of a long-term goal for international aviation emissions. However, there has been very little discussion on this in the Council even as the Paris Agreement sets out a long-term vision for decarbonization and last year the IMO agreed to a long-term decarbonization goal as well. That doesn't mean that modelling of aviation decarbonization pathways is not happening—it's just largely happening outside the walls of ICAO, Mr. Lyle explained. The first session of the day, "The Global Decarbonization Challenge and Aviation within It," should help all of us conceptualize how the ICAO Council might go about exploring long-term decarbonizations goals when it decides to take up this task.

The Global Decarbonization Challenge and Aviation within It

Part 1

LINK TO SLIDE PRESENTATION:

Overview of the IPCC Special Report Global Warming of 1.5°C (Dr. Heleen de Coninck, Associate Professor, Innovation Studies, Environmental Science Department, Radboud University, Faculty of Science)

Dr. Heleen de Coninck started her presentation by remarking that she is struck by the comparison between ICAO scientific body and the Intergovernmental Panel on Climate Change (IPCC). IPCC doesn't create original science, but instead assesses the peer-reviewed literature. The Special Report on 1.5°C was requested by countries at the same time the Paris Agreement was completed in 2015. This IPCC report was reviewed several times. There was an expert review first; then experts and government reviewed it; then governments reviewed the summary for policymakers, which is approved in a line-by-line approval process. If there wasn't an approval session with government, there probably wouldn't be the same impact as there was when the report was released in October 2018.

In 2015, the state of the science and the models were geared to the 2°C limit. So, when the Paris Agreement mentioned the 1.5°C limit, countries in the UNFCCC wanted to know if 1.5°C limit was still possible. As a result, they requested the Special Report on 1.5°C. Thousands of studies were looked at, with over a thousand reviewers and tens of thousands of comments. All comments and responses will eventually be posted publicly.

Key messages from the report were:

- We are already experiencing 1°C of global warming
- At the current rate, we would reach 1.5°C between 2030 and 2052
- There are clear benefits to limiting warming to 1.5°C, compared to 2°C
- We can still limit warming to 1.5°C but this requires unprecedented changes
- Limiting warming to 1.5°C would go hand in hand with achieving other societal goals

It is important to underline the differences between 2°C and 1.5°C. Achieving 1.5°C would likely mean:

- Less extreme weather where people live, including extreme heat and rainfall
- By 2100, global mean sea level rise will be around 10 cm lower, but may continue to rise for centuries
- Coral reefs disappearing almost completely under 2°C of warming vs. some remaining under 1.5°C of warming.
- Ice-free North Pole every 100 under 1.5°C vs. every 10 years under a 2°C scenario.

- In 2050, hundreds of millions of people fewer at risk under a 1.5°C scenario.

Here are some high-level pathways to achieve 1.5°C compared to 2°C:

- To limit warming to 1.5°C, CO_2 emissions would have to fall by about 45% by 2030 (from 2010 levels), compared to 25% for 2°C.
- To limit warming to 1.5°C, CO_2 emissions would need to reach 'net zero' around 2050, compared to around 2070 for 2°C.

Some 1.5°C pathways have "overshoot," meaning that you exceed the temperature but, through carbon dioxide removal, return to the temperature limit (whether 1.5°C or 2°C) before 2100. With the 1.5°C pathways that have overshoot, you would still have some of the irreversible impacts (in Figure 1 P4 is a high-overshoot pathway; the others are limited or no overshoot of 1.5°C).

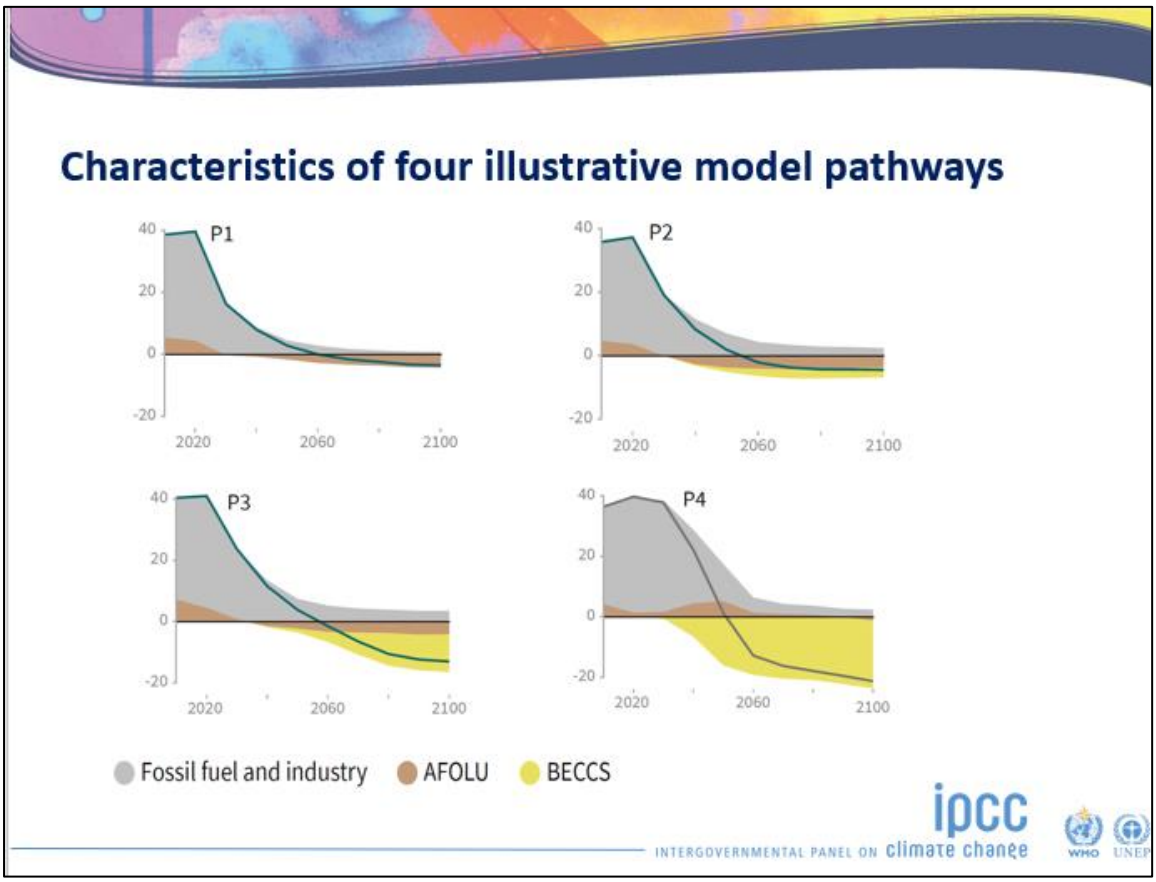
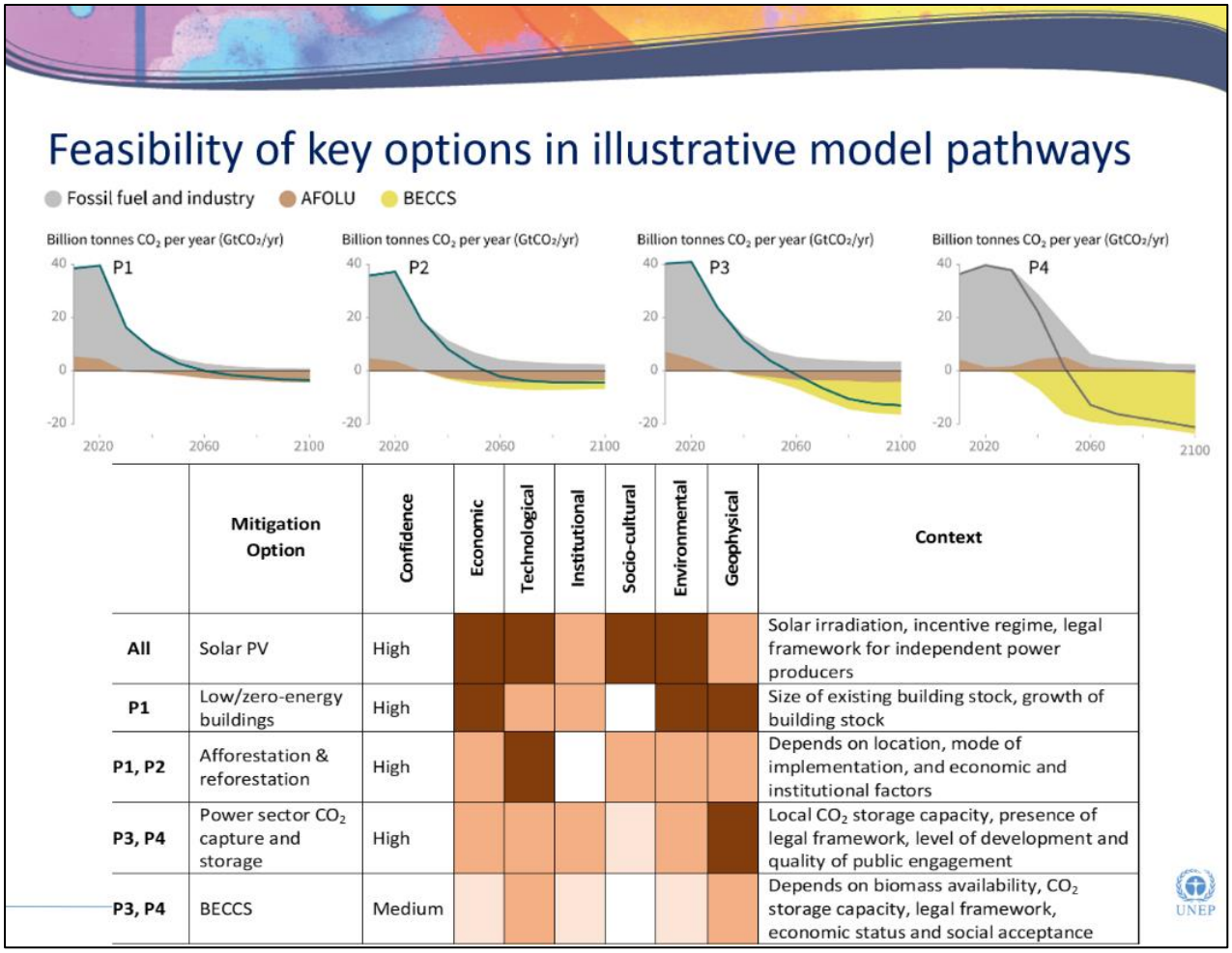


Figure 1: Four illustrative model pathways to meet 1.5°C.

The fact that there are multiple pathways indicates that policy makers still have choices in terms of how to achieve 1.5°C. But 20GT of negative CO_2 emissions in Pathway 4 should give us pause. Bioenergy with Carbon Capture and Storage (BECCS) still need research to make them a reality and allow us to follow pathways P2, P3 or P4.

How feasible the transition is to 1.5°C can depend on the pathway. Figure 2 below evaluates the different scenarios using a set of criteria.



	Mitigation Option	Confidence	Economic	Technological	Institutional	Socio-cultural	Environmental	Geophysical	Context
All	Solar PV	High							Solar irradiation, incentive regime, legal framework for independent power producers
P1	Low/zero-energy buildings	High							Size of existing building stock, growth of building stock
P1, P2	Afforestation & reforestation	High							Depends on location, mode of implementation, and economic and institutional factors
P3, P4	Power sector CO_2 capture and storage	High							Local CO_2 storage capacity, presence of legal framework, level of development and quality of public engagement
P3, P4	BECCS	Medium							Depends on biomass availability, CO_2 storage capacity, legal framework, economic status and social acceptance

Figure 2: Four illustrative pathways to meet 1.5°C and an assessment of the feasibility of dominant mitigation options within those pathways.

Dr. de Coninck remarked that there was not much discussion on aviation in the IPCC SR1.5 report. The authors had to cover a lot, so all sectors have the same complaint of limited treatment per sector.

Dr. de Coninck's main message for aviation is that there is limited potential for offsetting given that eventually there will be little opportunity to outsource emissions reductions in a more carbon constrained world.

Part 2

LINK TO SLIDE PRESENTATION:

The Global Decarbonization Challenge and Aviation within It: Where Are We Now, Where are we going? What should aviation's fair share of these emissions reductions be and how does this compare to ATAG's 2050 aspirational target? (Dr. Martin Cames, Head of Energy & Climate Division, Öko-Institut)

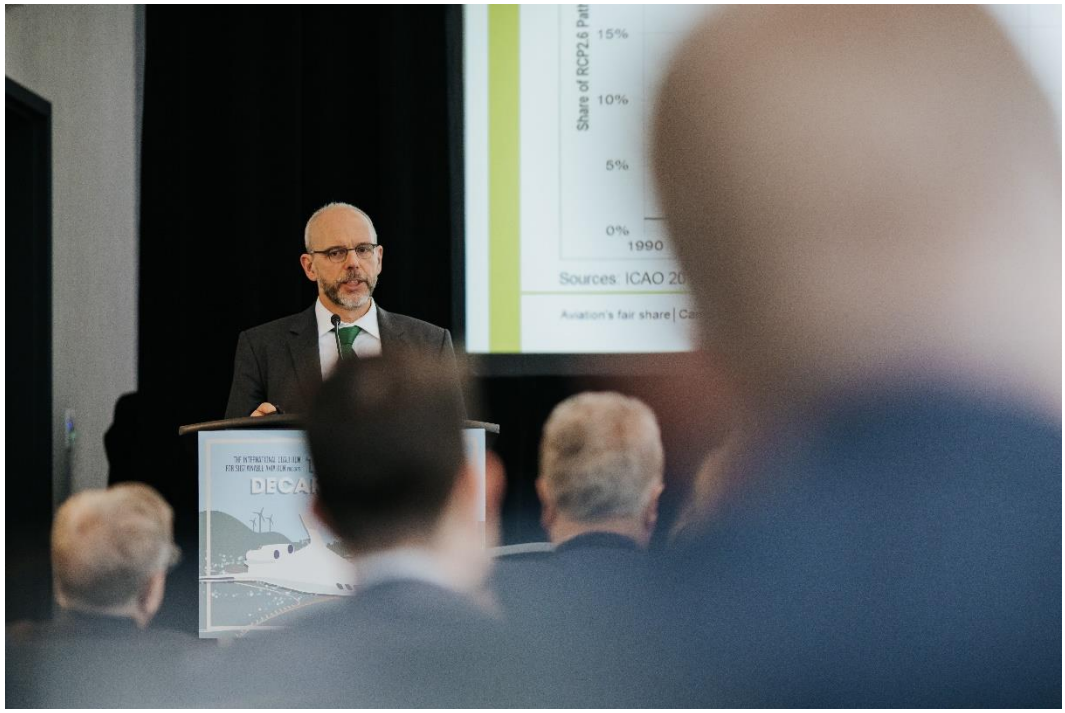
Dr. Martin Cames started out by saying that while Dr. Heleen de Coninck explained the global challenge of climate change from her position as an author of the IPCC Special Report on 1.5°C, the purpose of his presentation is to explore what aviation's fair share of that global effort might be.

Dr. Cames began by providing some background on the current levels of aviation emissions and non-CO_2 impacts, and projections of how they will grow in the future.

Dr. Cames explained how the IPCC has created representative concentration pathways (or RCPs) and each of these global pathways are associated with a certain level of temperature increase and certainty around these levels of temperature increases. There are several RCPs, but only one is really in line with 2°C target--RCP2.6. Therefore RCP2.6 was selected as reference for the comparison of other pathways.

Right now, international aviation's share is about 2% of global CO_2 emissions but it could rise to between 14% and 18% if other sectors would decarbonize consistent with the 2°C pathway (RCP2.6) while aviation's emissions would remain unaddressed.

Dr. Cames explained that policy makers have two ways to think about setting a target (which may not be mutually exclusive approaches):



Bottom up approach: Look at technological and operational reduction potential within aviation. If you look at the reduction potential beyond aviation too (e.g. how much CORSIA could contribute), this potential is virtually unlimited.

Top down approach: Two methods to determine targets can be distinguished.

- One way is that we look at the proportion of aviation now and project that constant share into the future. We could compare it to a certain country's climate trajectory too.
- We could use the carbon budget approach too. That would mean calculating the amount of carbon left to burn at a global level based on certain temperature levels, and then allocating each sector a piece of that remaining carbon.

CORSIA has an underlying target as well, so it is an example of a top down approach that has been set at ICAO.

When one is evaluating potential targets, what is important is the area under the curves—they represent the cumulative amount of emissions over a period of time (See Figures 3 and 4).

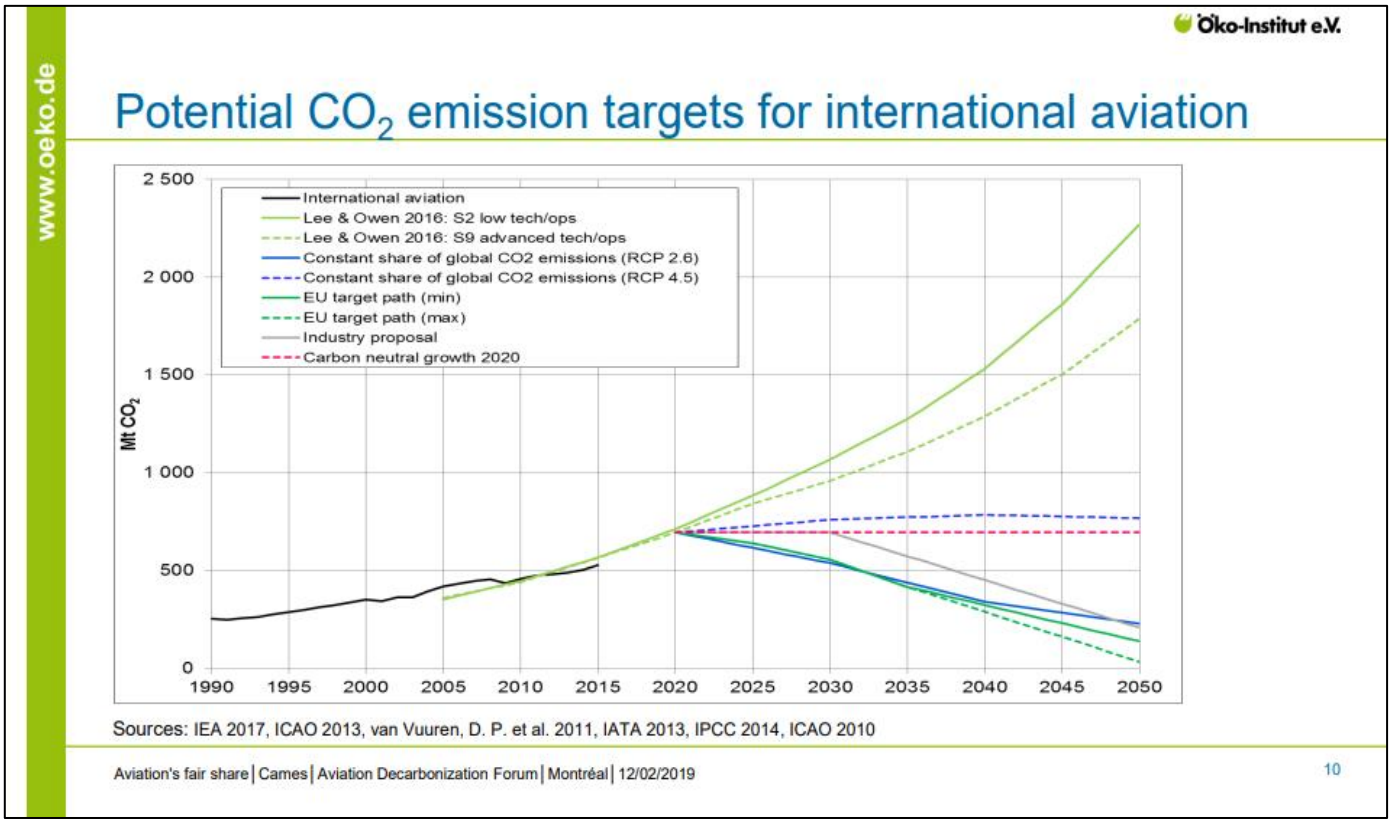


Figure 3: Potential CO_2 emissions targets for international aviation. The blue lines are illustrative targets that hold aviation's current share of emissions constant in the RCP2.6 and RCP4.5 pathways. The green lines show a pathway that would be consistent with the anticipated decarbonization target of the EU.

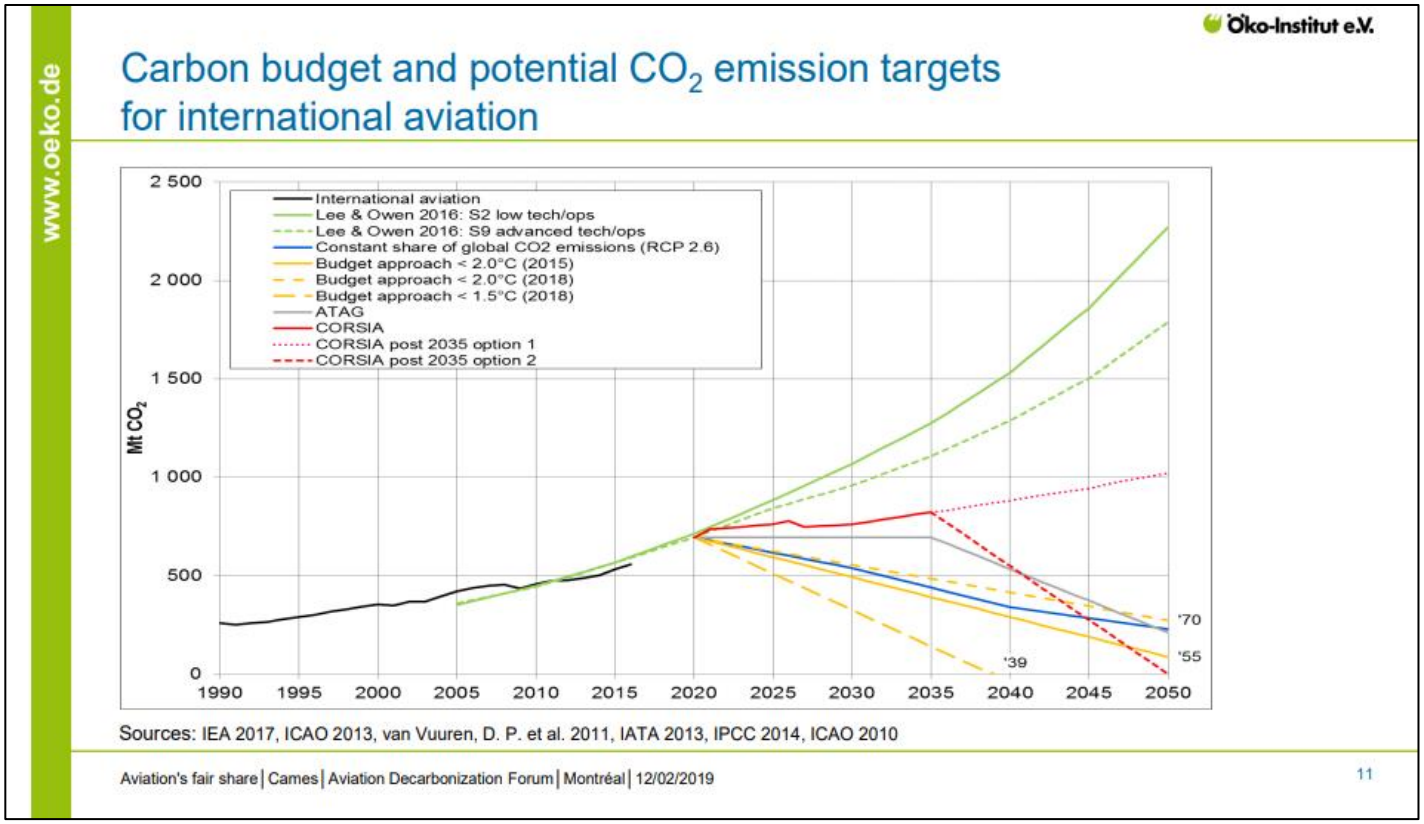


Figure 4: Carbon budgets and potential CO_2 emissions targets for international aviation. This graph uses a carbon budget approach to understand what aviation's target could be under 2°C and 1.5°C scenarios. It also projects two different emission scenarios depending on whether CORSIA is renewed after 2035.

One insight from these figures is that if we would meet the 1.5°C budget, according to this analysis, we would have to decarbonize aviation by 2040.

Figure 5 looks at how these different pathways deviate from a pathway that assumes aviation keeps its CO_2 emissions share constant under an RCP2.6 scenario.

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Aggregated CO_2 emissions 2021 to 2050 and deviation from 2°C pathway

	Gt CO_2 2021-50	Deviation from RCP 2.6
Lee & Owen 2016: S2 low tech/ops	41,4	213%
Lee & Owen 2016: S9 advanced tech/ops	35,3	167%
CORSIA post 2035 option 1	26,2	99%
Constant share of global CO2 emissions (RCP 4.5)	22,8	73%
Carbon neutral growth 2020	20,9	58%
CORSIA post 2035 option 2	18,1	37%
ATAG	17,0	29%
Budget approach < 2.0°C (2018)	14,3	9%
Constant share of global CO2 emissions (RCP 2.6)	**13,2**	**0%**
EU target path (min)	12,7	-4%
EU target path (max)	11,8	-10%
Budget approach < 2.0°C (2015)	11,5	-13%
Budget approach < 1.5°C (2018)	6,2	-53%

Sources: Authors' own calculations

Aviation's fair share | Cames | Aviation Decarbonization Forum | Montréal | 12/02/2019 12

Figure 5: How much do targets deviate from a pathway whereby aviation keeps its CO_2 emissions share constant in an RCP2.6 scenario?

One insight from this is that even the ATAG 2050 target is off by 29% from an RCP2.6 pathway.

Dr. Cames ended with the following conclusions:

- Targets indicate a responsibility but not necessarily a cap on emissions unless a separate policy is developed to constrain a sector like aviation to meet the target.
- Aviation is really included in the Paris Agreement (contrary to the dominant narrative in the media), because it includes *all* human-created emissions, under which aviation emissions would fall.
- Aviation will need to explain its contribution under the Paris Agreement in the Global Stocktake on the Agreement--the process whereby countries will assess progress towards the

achievement of the Paris Agreement and its temperature goals.

- Aviation must significantly increase its ambition to reduce emissions. The International Maritime Organization (IMO) did a top down approach and this has triggered other commitments from companies like Maersk even, though they don't currently know how to achieve this target. Perhaps a long-term target for aviation could trigger the same type of commitments.

Plenary discussion

Question from the audience: "Would P1 or P4 be more realistic?". (Refer to Figure 2 for context.) Dr. de Coninck's response was that we have time to develop technologies for both scenarios, but both are unrealistic or having difficulties in their own ways. P1 means that energy demand drops significantly. Some developing countries have interpreted this scenario as meaning that they would not be able to grow their economies. P4 has significant land emissions reductions. P3 is closer to what is happening currently. Another

response SR 1.5 authors have received is that the share of nuclear energy goes up. But IPCC did not recommend this; this is a common misperception. P4 has a greater overshoot, so more lasting impacts. The tradeoffs for P4 are considerable so it is probably less useful for developing countries looking to achieve the Sustainable Development Goals (SDGs).

Question from the audience: "ICAO has CNG2020 but no long-term objective. IMO does not have a detailed program as we understand, but they have a long-term objective. What were the technical and political reasons for IMO to reach this decision? Did they develop the long-term pathway because they didn't have as many policies as ICAO being developed?"
Dr. Cames explained that IMO decided on its initial GHG strategy. Now IMO will develop policies. A proposal on slow steaming, for example, could be coming up in IMO. It is ironic that IMO is looking at slow steaming and aviation has been considering supersonics.

Regarding the IMO GHG strategy: it is true that is was a top down target, but it includes interim targets. A 2030 target and 2050. This doesn't get reported in the media, but each target is important. And it could be instructive for how ICAO might think about setting a long-term goal.

Question from the audience: "Why did Dr. Cames' analysis use the EU as an example of a region/country for which to base an emissions pathway for aviation?"
Dr. Cames explained that the EU was used as a benchmark, because productivity of aviation and the rate of technological change is similar to that of the EU. It was used as a way to show what an appropriate target for the sector could look like. Target setting is inherently a policy decision.

Question from the audience: "What are prospects for CDR (carbon dioxide removal)? And what might be some interesting intersectoral linkages?"

Dr. de Coninck explained that e-fuels are a good example, and this topic will be discussed later in the day by Dr. Harry Lehmann. But in short, if CO_2 is captured it could make e-fuels more cost effective because of a dedicated stream of CO_2 that is needed to synthesize fuels. One would need excess renewable electricity to make these fuels or one is just exacerbating climate change by using "brown power" to make e-fuels.

Question from the audience: "Could you advise us on what the right target would be?"

Dr. Cames noted that researchers cannot provide an answer as it is a policy decision. But as an adviser to a government, he would say that we should strive to decarbonize by 2050 and need to decarbonize by 2070 at the latest. If that cannot be managed within the sector, offsets remain an option, also because non-CO_2 effects would remain with sustainable fuels. So, offsetting may the only option to address them. If the world is on a decarbonization pathway, the offset supply will decline accordingly. There might be some potential for offsetting with negative emissions technologies. However, the supply of these negative emissions technologies in general and as offsets, is uncertain.

Unlocking greater near-term efficiency, while transitioning to the next generation of planes

LINK TO SLIDE PRESENTATION:

Unlocking greater near-term efficiency, while transitioning to the next generation of planes: "There is no quick fix" (Ir. Joris Melkert, TU Delft, Aerospace Engineering)

Ir. Melkert began his presentation by showing the audience how tube-and-wing aircraft designs have changed only marginally since the 1960s.

He described the "snowball effect" in aviation and how it affects the development of new, more efficient planes and their payload: in order to carry 1 kg more payload, 1 kg more lift is required. This is easy to generate, but more lift means more drag. Thrust can overcome drag, but more thrust means bigger engines, and in turn more fuel and more mass. The snowball effect could be a factor of six (e.g. 1 kg of additional payload could require adding 6 kg to the takeoff weight). Ir. Melkert gave the example of paper air sickness bags which weigh between 6 to 9.5 grams. At this weight, an estimated 38.6 tonnes of air sickness bags are transported on planes each year. Plastic bags, he noted, would only add 2.2 grams per bag. Considering these figures, weight really matters when trying to minimize the snowball effect.

Ir. Melkert then analyzed recent trends:

- Recent efficiency trends indicate about 1 to 1.5% annual efficiency improvements. Propellers are improving faster but not enough designs are brought to the market anymore.
- Noise improvements are likewise amazing, but they are not enough either.

- Among manufacturers, there is some balance in the market between Airbus and Boeing.
- Average net profit for one ticket sales is typically less than 10 USD/per ticket (US is an outlier here).

What about electric aircraft?: There is two-seater available for purchase in Slovenia now; Airbus is aiming to bring a turboelectric plane into service by 2029, among other electric plane start-up efforts, but their capability right now is really only for flight across a distance like the English Channel. The main barrier to electric aircraft is that they must use low energy density (volumetric and gravimetric) for Li batteries with 50 to 60x lower energy density. Ir. Melkert noted that we will have electric aircraft at some point, but it

won't be for long-haul flights. It would be more likely for general aviation. Hybrid electrics are more likely for commercial aviation.

What about hydrogen to power planes?: Hydrogen has high gravimetric density. It could be burned in gas turbines, but even

better is its use in fuel cells and motors. However, it has low volumetric energy density, so fuel tanks will need to displace cargo on wing and tube designs.

What about alternative fuels?: Ir. Melkert described a project from TU Delft that developed a Cessna Citation to run off gas-to-liquid kerosene. He mentioned that gas to liquids (GtL) is another alternative fuel and it would improve local air quality, but it doesn't solve the climate change problem. Power-to-liquids (PtL), if run by renewable energy, would better address climate change.

Alternative plane configurations are possible: Here are some examples Ir. Melkert described (see Ir. Melkert's slides for the associated visuals):

- Blended wing body, truss-based wing, ion drive? – possible but not very likely to happen soon.
- The Sugar Project: very long, thin wings (high aspect ratio), almost like a glider
- The new Boeing 777x will have foldable wingtips which will lead to increased aerodynamic efficiency.
- We may also see larger propeller drive aircraft in the future. Some might have open rotor propellers, but that may require a configuration change. Safety (e.g. blade off without an engine nacelle to contain) is worrying.
- Distributed propulsion (i.e. multiple small propellers across a wing is possible, but this will take time to develop too.
- Some quick near-term fixes could include: larger engines, bigger is better (e.g. the Boeing 777X engines and Boeing 737 MAX engines are much bigger than their predecessors). Also, wingtips give you several percentage points of fuel reductions.

Ir. Melkert outlined the key conclusions from his presentation:

- There is no overall quick fix towards significantly greater plane efficiency. It will not shift immediately.
- We need much more R&D

- Replace old aircraft sooner (fleet renewal)
- We need to look into alternative "drop-in" fuels
- We need better procedures (climate-optimized routing)
- We need to compensate (CORSIA and beyond)
- We need stronger incentives (legislation + societal pressure)
- We need to limit the growth, preferably by reducing soon

Plenary discussion

Question from the audience: "You mention limits to growth of aviation. For an aeronautical engineer, it seems that you don't have confidence in the technology being able to develop fast enough. Would this be a correct characterization?"

Ir. Melkert shared his view that for us to achieve the Paris Agreement we must limit growth on some level. We can't allow one branch of transport to continue growing unabated. The audience member who asked the question shared that s/he believed we shouldn't focus on a single sector; we will need to limit growth elsewhere too in other sectors. We should first consider a suite of broad solutions, and then if necessary, limits on growth.

One participant noted that some are starting to think about the negative impacts of "overtourism". For example, in Barcelona and Venice taxation is being considered to address the impacts of overtourism.

Question from the audience: "We have a goal in ICAO of 2% annual efficiency gains from technology right now. Can that rate move higher over the next 20 years?"

Ir. Melkert explained that the 1% per year efficiency gains from new aircraft will likely continue; operational improvements will be needed too. There is a challenge in getting from 2% per year efficiency to 3 to 5% per year. Each new aircraft has to be at least as safe as the last one, and we have to take into account the certification delay for new aircraft (five to 10 years).

Question from the audience: "How can we institutionalize flying slower?"

Ir. Melkert said this is a tricky thing, because it bumps up against the air traffic management (ATM) system. Having big variations in speed are Air Traffic Control (ATC) concerns. Everyone needs to fly slower together so the ATM system is functioning. Weather prediction tools have helped with air delay, whereby we see less and less air delay and more ground holds.

Question from the audience: "Could you talk about hydrogen storage as in issue? What technologies could address this? Is zero carbon flight possible using hydrogen?"

Dr. Melkert said that H2 is a light gas, so it must be either compressed or cooled; it needs to be stored in round shapes, which may require differently shaped fuselages (e.g. double bubble configuration). Thin skins may be possible but there are safety concerns. H2 releases water so the non-CO_2 atmospheric effect is not fully addressed.

Question from the audience: "Ir. Melkert, if you were God, would you push for high speed rail or open rotor to become the new engine?"

Ir. Melkert believes that they could be mixed and matched. An open rotor has serious noise issues, comparatively. Having HSR on the continent would be great. Easyjet said they would transition to open rotor by 2015, which obviously did not happen. EasyJet also recently made an announcement on getting all electric aircraft by 2030.

Question from the audience: "What role might government goals, standards, and incentives play in helping increase plane efficiency?"

Ir. Melkert feels that government policy has an enormous role to play in this transition. An absolute cap will be important. More R&D funding for the blended wing body is one good example of how governments can help provide incentives for this transition.

Question from the audience: "Derivative vs. clean sheet designs – is there anything governments can do?"

Ir. Melkert said that there are no government targets relating to this question. The engines give you snowball effects--and are the "source of all misery", but it's an integrated approach: many knobs need to be turned together. Re-engining with a geared turbofan will become the norm for next generation aircraft.

Question from the audience: "With regard to turboprops, is the main pushback against these about noise or is it due to turboprops flying slower?"

Ir. Melkert felt that the customer doesn't want turboprops. Supersonic aircraft development is coming back, but he didn't think overland flight bans would be lifted. Supersonics may get hit by airport congestion too; they are potentially only viable as business jets, not for commercial aviation.

Question from the audience: "I'm interested in the innovation aspects. Is there scope for new entrants to the aviation sector, or are the entry barriers to high? What about more competition to develop better engines?"

Ir. Melkert mentioned that there are barriers to entry and that being a financially viable business in the sector has its challenges. He repeated the old aviation adage: "How do you become a millionaire? Invest a billion dollars in an airline." Money in the aviation sector is in parts and maintenance. Investments to design and build planes or run an airline are huge--one needs multiple state sponsors. There is high risk in this sector. How much money will it take to develop a new aircraft? Probably 10-12 USD billion to start. Pan Am saved Boeing at one point from going bankrupt, Airbus had a similar same problem when it developed the A380, when it almost went under. This is not all bad news if you're focus is on safety. We have roughly 15 accidents per year with one fatality, you'd have to fly every day for 6,200 years in order to likely be in an accident at these rates.

Future of Liquid Aviation Fuels

Part 1

LINK TO SLIDE PRESENTATION:

Alternative Fuels: Flightpath to 2050? (Dr. Chris Malins, Cerulogy)

Dr. Malins started his presentation by saying that, as discussed earlier in the day, we see considerable growth in aviation demand, little potential for electrification, and as a result aviation requires drop-in fuels to some extent to have a license to operate.

An alternative jet fuel demand scenario from ICAO suggests that around 600 MMT/year will be needed in 2050 if we're to have 100% alternative jet fuels for aviation. If you compare that to current global biodiesel production which is maybe 30 MMT/year, this 600MMT/year is massive, and this 30MMT/year (a relatively small amount) already comes with a number of controversies (e.g. impacts on food prices and having higher emissions than fossil fuels

in some cases due to land use changes). **Reaching 100% alternative fuels for aviation will be massively challenging and costly.**

Dr. Malins explained that there are 4 main pathways to get alternative fuel: HEFA (basically hydrogenating oils to get jet fuel), Biomass-to-jet (woody material feedstock--a harder, more expensive technology but cheaper feedstocks), Alcohol-to-jet (demonstrated), Power-to-jet (developing).

HEFA:

- The main advantage here is that it's been demonstrated. We know the costs. The downside: the cost is going to be well more than the cost of current jet fuel. It will not be cheaper than conventional fossil jet fuel in the foreseeable future because vegetable oils have many competing uses: eating, cosmetics, heat. Indirect emissions: very significant, worse for biodiesel than for ethanol, most current feedstocks are believed to be worse for the climate than fossil jet. Preferred feedstock: palm oil (cheap, good for hydrotreating), PFAD → drives deforestation. Food vs. fuel.

Biomass-to-jet:

- We can do it technically speaking, but it has not been successfully commercialized yet. One technology option is pyrolysis. This produces an acidic and nasty substance, but you can upgrade it to jet fuel. One advantage is that it has a relatively low feedstock cost (cheaper than HEFA). It could be cheaper than jet fuel in the long run if you keep feedstock costs down and reduce capital costs. Another technology is biomass gasification followed by Fischer-Tropsch synthesis – this technology has been demonstrated in the past for gas-to-liquids and coal-to-liquids. However, biomass processing introduces additional issues of materials handling and potential contamination. It has very high capital costs too, needing very large facilities to achieve economies of scale for existing technology. If short-term costs are high, where does it go from there? There are also sustainability concerns

for any biomass-to-liquid technology, because you are taking biomass out of ecosystems.

Alcohol-to-jet:

- Lanzatech demonstrated this pathway on the Washington State to London route. Advantages: it is potentially a bit cheaper than HEFA for feedstock as it can build off an established ethanol production system (e.g. in US and Brazil especially). The downside to alcohol-to-jet: one takes a biofuel developed for a certain purpose (suitable for road fuel) and turns it into another biofuel (for aviation) and in the process you lose volume energy. Cost will still be a problem in most cases. With conventional ethanol from food crops, you also have all the old sustainability issues.

Power-to-jet:

- The advantages for power-to-jet (i.e. power-to-liquids): it has low sustainability risk, a higher energy density, it does not directly touch the food market, and the cost of renewable electricity is falling which could help power-to-jet's costs

decrease. Problems: very inefficient use of electricity compared to other uses of electricity (maybe 50% conversion of electrical energy to chemical energy) such as in battery vehicles for road transport, it's not commercially demonstrated, and it could be very expensive. Price parity requires 2 to 3 Euros/kWh, whereas it is currently 10 Euro/kWh in Europe.

Dr. Malins explained that the airlines' biofuel use is trailing aspirational targets that have been set in the past. For example, the EU target is 2 million tonnes per year by 2020; the US' target was 2 billion gallons by 2020. These targets have been missed by a mile.

Dr. Malins noted that some policy makers are beginning to reflect on how to set modal priorities for alternative fuels and have begun to differentiate between different types of fuels in new policies in North America and in Europe. For example, European policy makers recently agreed the new EU REDD II policy framework which gives preference to aviation fuel deployment. The contribution of advanced fuels supplied in the aviation and maritime sectors are to be considered 1.2 times their energy content. From Dr. Malins' perspective, the focus on providing incentives to biofuel usage in aviation over road transport might be misguided in the near term. Given that technologies are very similar, in technology development terms it's okay to focus on road transport first, allowing competition between modes if airlines are willing to invest. In the short term while liquid fuels dominate road transport, it's not yet clear why alternative fuel resources should be prioritized to aviation.

One driver that could push more fuel into aviation is that, in some cases, airlines might be looking at multiple policy incentives. For example, EU RED II and CORSIA. Dr. Malins noted, however, that CORSIA will create a very small additional incentive for SAF usage by airlines.

Dr. Malins explained that the cost of CO_2 abatement using aviation biofuels (the cost of reducing emissions with aviation biofuels) is high. Dr. Malins cited figures that suggest that abatement could cost 200 to 400 Euros/tonne CO_2e, and in the case of power-to-liquids jet fuel 500 euros/tonne.

Dr. Malins cautioned that the land requirements to develop enough of a supply (sustainable or otherwise) are considerable and should be a main area of concern for policy makers and airlines. For example, fueling EU aviation on power-to-liquids could require covering an area of land the size of Greece with renewable electricity generation capacity. Doing the same with biomass-to-liquids (perennial grasses on marginal land) would take something like four times that area, which would be around the size of Ukraine. It is unclear if society will support this. Plus, using vegetable oils (via the HEFA pathway) will massively impact food markets. Palm oil is particularly bad on a life-cycle emissions basis.

Dr. Malins noted that even if you cover CO_2 with biofuels or power-to-liquids, it doesn't address non-CO_2 effects. In Dr. Malins' opinion, the sum of these concerns naturally should lead to a discussion on policy approaches to manage aviation demand (i.e. influencing consumers' behavior, so they fly less).

Dr. Malins reiterated some of his key messages which were:

- There are four pathways for alternative fuels, all at higher cost than conventional jet fuels.
- Massive volumes of alternative fuels will be needed for 2050.
- Near-term options are horrible (e.g. palm oil); and
- Non-CO_2 effects from aviation are a big problem but cannot be addressed by switching to cleaner fuels.

Part 2

LINK TO SLIDE PRESENTATION:

Why We Need Power-to-Liquid-Based Fuel Solutions for a Sustainable Future of Aviation (Dr. Harry Lehmann, General Director, Environmental Planning and Sustainability Strategies, Federal Environment Agency (UBA), Germany)

Dr. Harry Lehmann started his presentation on power-to-liquids aviation fuels by explaining how the technology started being considered in the German Federal Environment Agency (UBA). The German long-term climate goal is 80 to 95% reductions in GHGs by 2050. This target includes harder to decarbonize sectors like shipping, aviation, and steel. If such a target is going to be met, what will this mean for these sectors? Air transport is important and, in the context of meeting this ambitious goal, cannot be overlooked.

In 2014, UBA conducted a study on what would need to happen to achieve a GHG-Neutral Germany by 2050. This study that identified that agriculture and air transport would need to be "cross-coupled"

to other sectors in order to meet the 2050 target. In the case of aviation, could renewable electricity provide power for the aviation sector? This study also found that there was no quick fix, so what should we do for the next 30 years? Existing infrastructure should be used wherever possible → led to discussions of biofuels and PtL. This led to 2016 studies done by UBA which indicated that if "part" of air transport moves to PtL, this could be a significant solution.

Dr. Lehmann further explained the logic of why UBA turned to power to liquids. Ways to reduce emissions from aviation: 1) avoiding more flights; 2) increasing efficiency of aviation; 3) encouraging of modal shift overall, can lower GHG from transport overall through a modal shift, potential by 50% in Germany. But the rest of the emissions reductions have to come from alternative fuels. We can have that be electricity for cars, but we need something else for aviation. As a result, one needs to use either biofuels (not the solution for Germany) or power to liquids (PtL). And PtL needs more research, investments, and cost reductions to become viable. (See Figure 6 for a visual of this logic.)

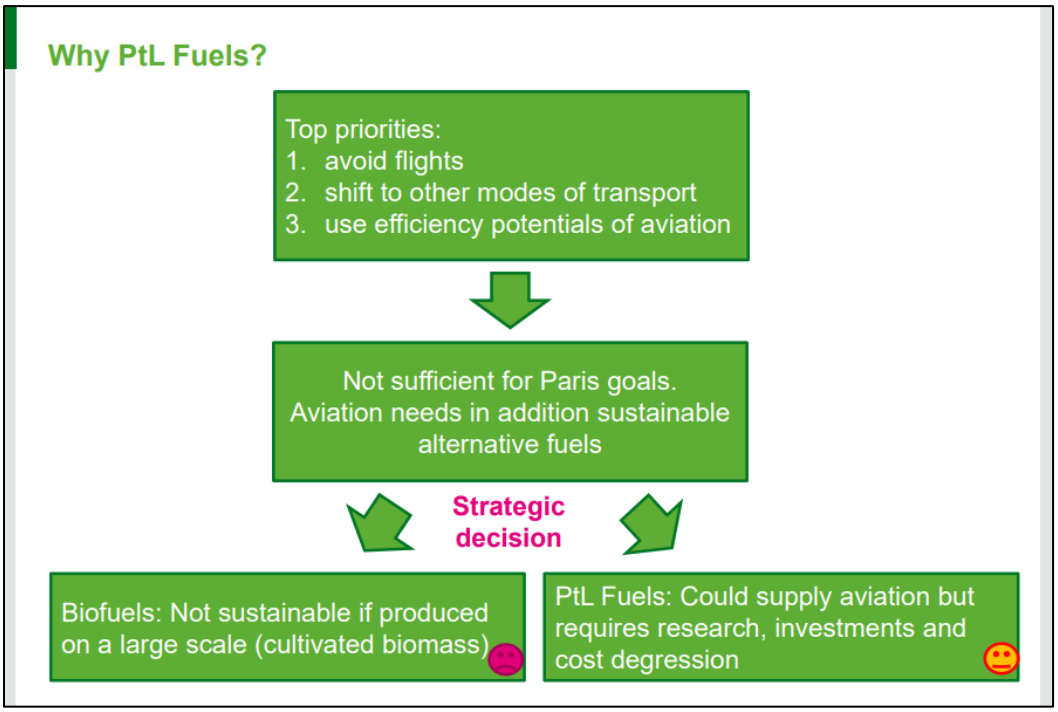


Figure 6: Why are power-to-liquid fuels needed for aviation?

Dr. Lehmann then explained generally how PtL production works, which is summarized in Figure 7.

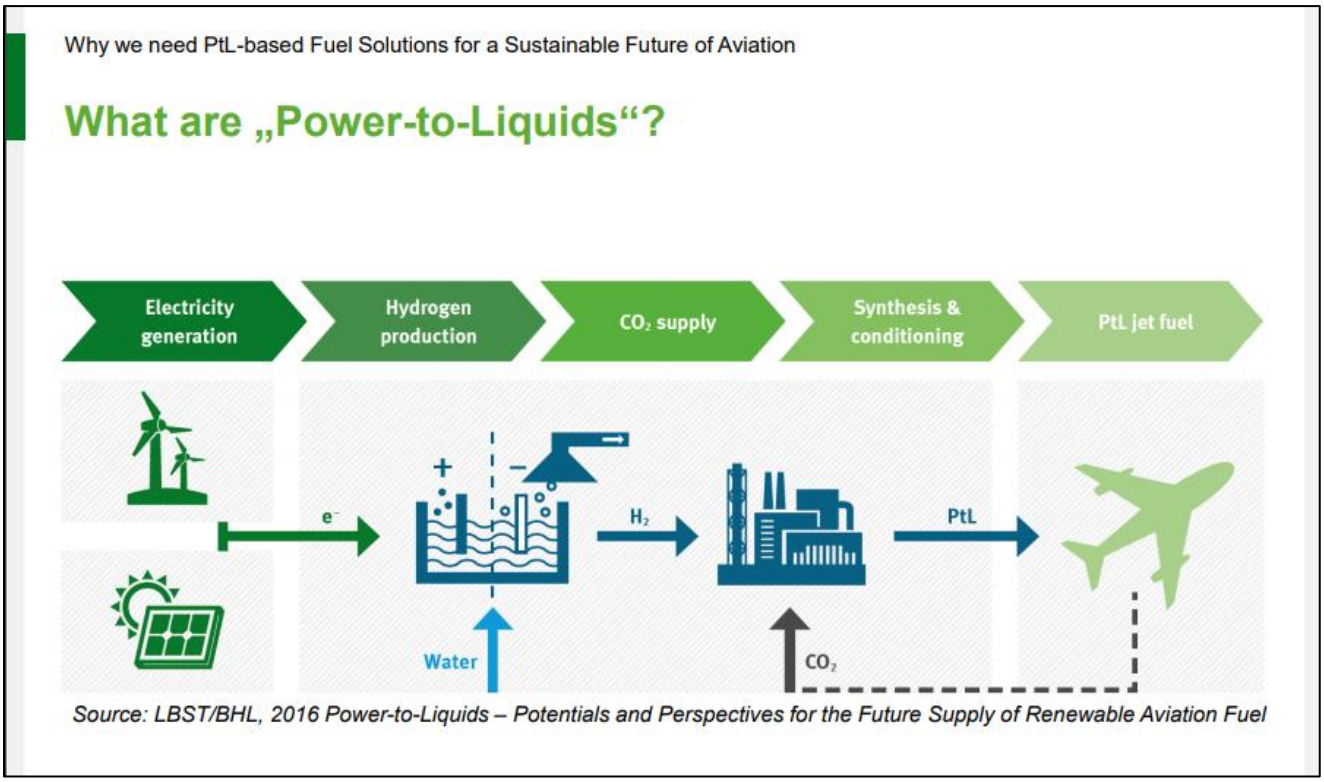


Figure 7: What is the power-to-liquid productions process?

Dr. Lehmann then compared PtL against other aviation liquid fuels, which showed that in terms of emissions, land use, and water demand, PtL is far superior.

- **Emissions:** PtL can be low- to zero-emissions depending on the electricity energy sources.
- **Land use:** Mileage per hectare is 8000 km/ha-yr, so 5+ times less land intensive than biofuels.
- **Water demand:** This is also estimated to be much lower than all other fuels pathways.

Dr. Lehmann explained that PtL costs are higher compared to conventional jet fuel--especially if the CO_2 source used in

production comes from air capture. Projected jet fuel costs in 2050 has crude oil around 800 euros/tonne. PtL could cost more than two times that if it is coming from air capture. But when one considers a full accounting of costs and considers the impacts of climate change on human societies.

Dr. Lehmann noted that there is potential use of "excess" renewable electricity in some cases currently around the world now.

Also, in Dr. Lehmann's view, contrary to some perceptions about PtL, it is at technology readiness level 8+. (Note the reader: Technology Readiness Levels (TRLs) are rated on a scale of 1-9 with 9 being the most mature technology.)

Currently BMU is working on scenarios for -95% emissions reductions. As part of this, they are looking at PtL for all sectors together--e.g. steel. There will be a technology learning curve, so let's start early.

Dr. Lehmann concluded that:

- Fast action is needed to realize the promise of PtL. No other solution would use a good amount of existing infrastructure that employs sustainable renewables for air transport. He would suggest having a quota for these fuels, perhaps even 50% of drop-in fuel should be PtL. It would be double the cost, but it's manageable. Dr. Lehmann concluded this point by saying that climate change must be solved, so let's not talk about cost--this is about survival.
- Business aviation may be where we start. Remote airports might potentially be good candidates to supply with this fuel, given costs of transporting fuel to these places.
- We need to pay more and invest in this technology.
- As for policy, perhaps a feed-in tariff scheme could work to encourage production. We might think about more pilots and investments in areas where renewable electricity is cheap--e.g. 2 cents/kWh in Mexico. Dubai could be another place.

Summary: Need to decarbonize, need sustainable aviation fuel, near net-zero GHG emissions, better than biofuels, need fast and sufficient introduction to bring down the production costs.

Plenary discussion

Question from the audience: "Could you say more about PtL demonstration projects? What are the building blocks to make these projects work? For example, how viable is this for remote airports?"

Dr. Lehmann responded that flying in fuels for airports is a bad idea. PtL can be produced in a decentralized manner. BMU is studying the pros and cons of remote development. PtL might work well for business aviation too.

Question from the audience: "How would a feed-in tariff work for fuels?"

Dr. Lehmann said it provides an additional price signal. Used to create bankability for the system.

Dr. Malins added that the bankability is enormously important -- even regulatory targets are not being met. Raft of incentive schemes that have been enormously high, 2013 study on why these renewable diesel scheme don't work (see also this 2018 study from Chris which furthers this theme--hugely subsidized. RIN (Renewable Identification Number) upwards of 1 USD/gallon in Europe, Low Carbon Fuel Standard (LCFS) in California is on the order of 1 USD/gallon. Why didn't this work? Biomass subsidies at the US level (renewable fuels) were annually renewed so pricing was not predictable. LCFS was under a legal challenge, so it was also not predictable → so you ignore it over 20 years. There's not enough value confidence. These incentives are almost useless in reality unless you already have an investment. You need a structure that has provides reliable policy subsidies.

Question from the audience: ATAG is talking about having a 2% target in 2025. Should ICAO take a stand on this? Dr. Lehmann said having a quota is important, but the rules must be clear.

Question from the audience: What role is there for offsets for aviation? Dr. Malins said that offsets are even cheaper than e-fuels or palm oil renewable proposals. The focus needs to be on sustainability for both. Enhanced oil recovery credits are now an issue being looked at in ICAO. For all of these discussions, sustainability criteria are a critical foundation.

Question from the audience: Can you say something about willingness to pay for these fuels from the airlines? We've talked about costs and technology but not on willingness to pay. Is there any evidence of airlines will to pay more for these in the future? Dr. Malins responded by saying believes that WTP (willingness to pay) as far as we can see is zero. Airlines have no interest in increasing their costs, which is not unusual of an industry. Sky NRG has a niche market, but there is very little willingness to pay extra at scale. Airlines are committed to decarbonization, asking that this should cost less than jet fuel. This is understandable but not a real WTP. Research suggests that biomass to liquid (BtL) *could* create

net savings, but PtL will be even more expensive, so why would a company go for PtL. You need an effective central policy framework to make this really work. Now fuel SAF producers can link up with companies' corporate social responsibility (CSR) strategies and find niche markets, but there is nothing to suggest that a scale-up for sustainable aviation fuels is coming unless you have national or international action driving it.

Dr. Malins continue by saying, when we consider companies' WTP, however, we should hope that it increases for environmental goods like sustainable aviation fuels. What are the costs to live on this Earth? At the end of the day, we should be willing to pay more collectively, but perhaps not as individuals. The future will require higher costs for cleaner, quieter aircraft. But, for example, right now it is cheaper to fly in Europe than to take the trains.

Question from the audience: What would you say the role of incentives (carrots) vs. mandates (sticks) in developing sound SAF

policies? For example, IMO has a fuel mandate: isn't it the case that mandates are the way to go? Also, there is an equity perspective at play here: why should German taxpayers be expected to subsidize these fuels?
Dr. Lehmann first replied by clarifying that a feed-in tariff should not be viewed as a tax, because it is paid for by the consumer.

Dr. Malins added that long-term, we shouldn't do anything to make aviation cheaper, but in the short-term, it might be less of an issue. From the SAF producer's standpoint, SAF mandates are a kind of incentive. But we should realize that policy uncertainty under a mandate can be as large as for incentives.

Dr. Martin Cames weighed in as well on this question of policy, saying that one needs both carrots and sticks. Having complementary or even overlapping policies can be good especially when one fails. For example, in Germany when research on 1 MW turbines didn't deliver results it became the feed-in tariffs that actually facilitated the deployment of renewable energy in an effective way.

Question from the audience: What's the potential of scaling up e-fuels/PtL and would doing so be a different approach than with biofuels? A (CM): Economies of scale for FT are large (?), but some of the technologies may have their own niches. Electrolyzers don't need to be large, so maybe smaller niche. Interested to know if models of distributed generation will work. History will tell us. A (HL): example of turbines: up to 5 MW possible, need to involve the fuel providers as well.

Addressing Non-CO_2 Effects of Aviation

LINK TO SLIDE PRESENTATION:

Addressing non-CO_2 effects of aviation (Dr. Volker Grewe, Professor, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen and Chair for Climate Effects of Aviation, Delft University of Technology)

Dr. Volker Grewe began his presentation by giving a high-level overview of the science of non-CO_2 effects from air travel.

If you burn 1kg of kerosene you don't just get 3.15kg CO_2, you get 1.25kg of water vapor and many other gases and particles like NO_X, CO, VOC, SO_2 and particles that have either a direct or indirect impact on atmospheric composition that result in climate forcings (i.e. climate warming) (See Figure 8).

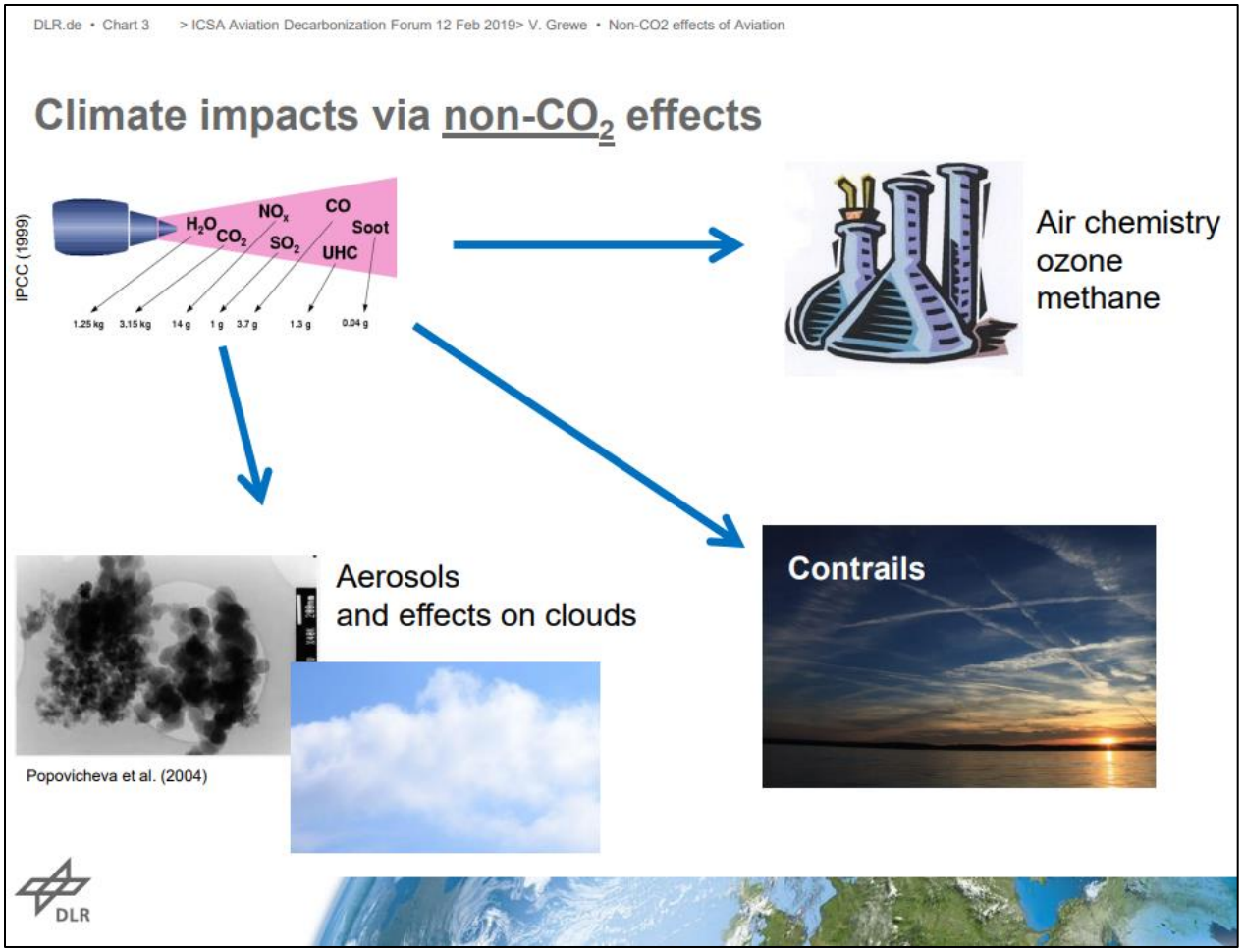


Figure 8: Climate Impacts of Non-CO_2 Effects

NO_X reacts to increase ozone or decrease methane concentrations depending on location. Water and particles aid contrail formation affecting overall levels of cloudiness.

New fuels/technologies: more hydrogen fuels will result in more contrails; supersonics will affect more sensitive parts of the atmosphere (See Figure 9).

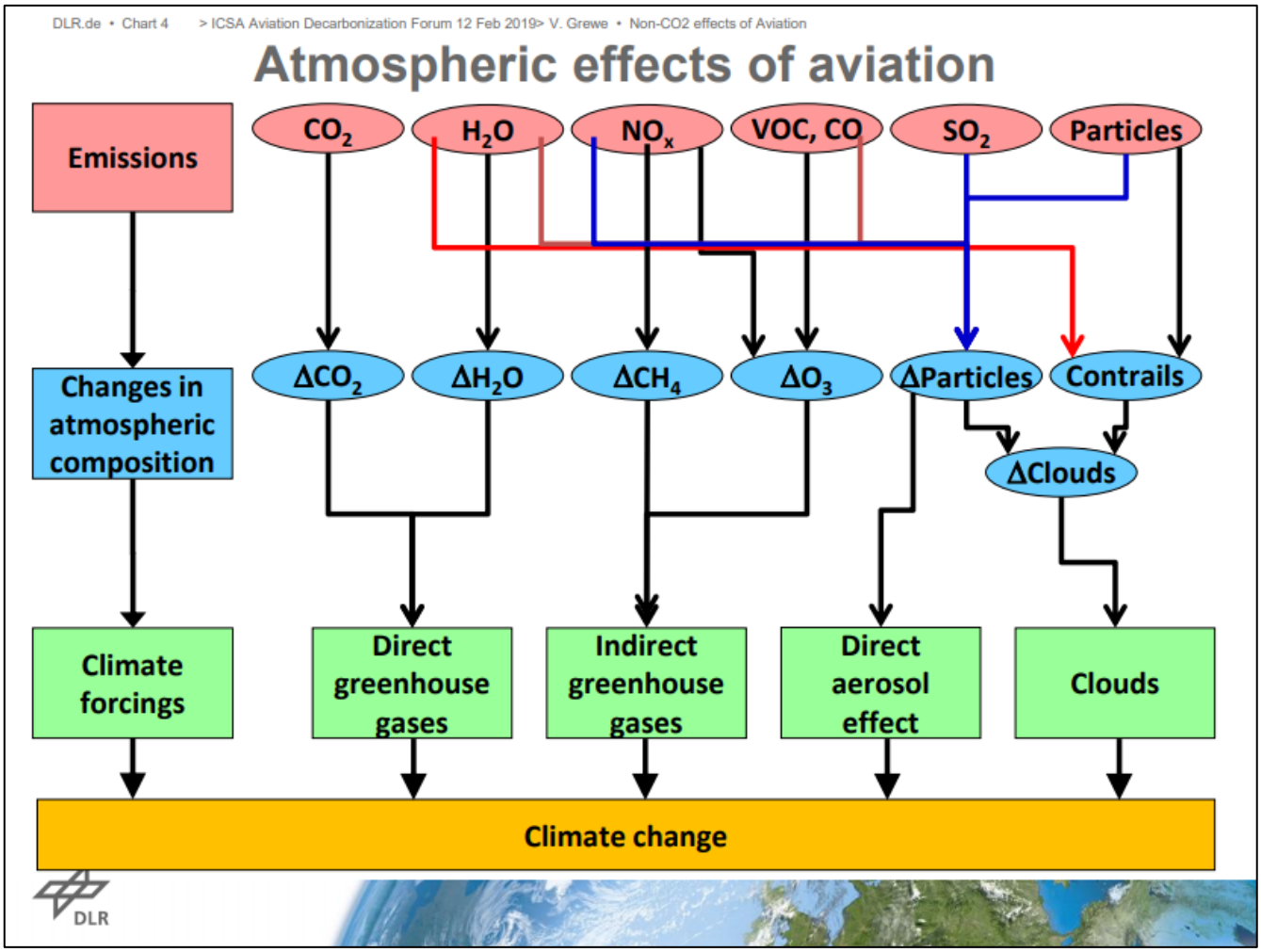


Figure 9: Atmospheric effects of aviation

Work by Dr. David Lee in 2005 compares overall warming/cooling effects using radiative forcing (RF) and shows that effects of non-CO_2 are even larger than CO_2 alone (See Figure 10.)

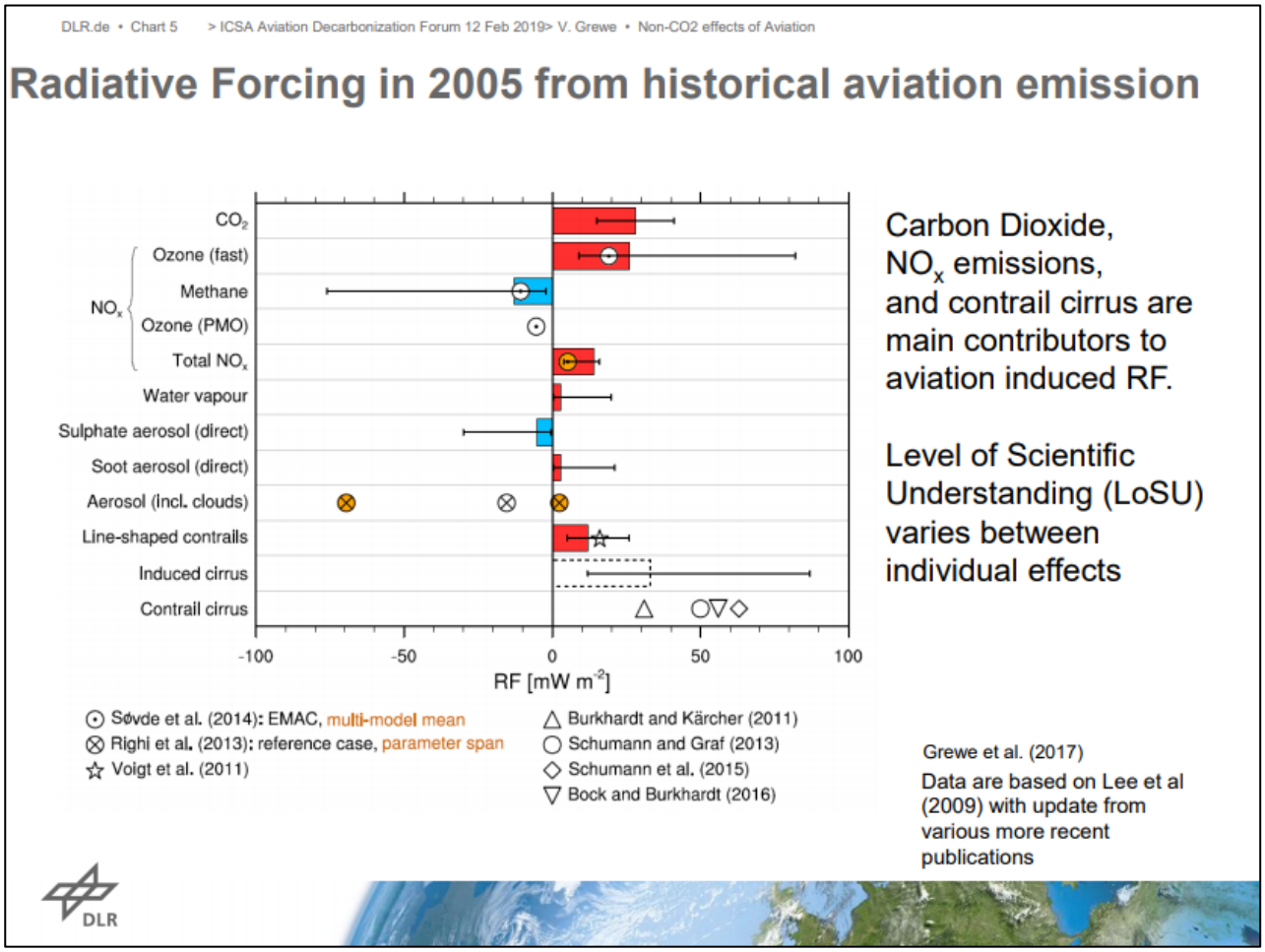


Figure 10: Radiative forcing in 2005 from historical aviation emissions

Contrails require cold air masses and low humidity to form. It also depends on aircraft type, as weight basically controls the strength of the vortex. Research shows it is possible to avoid 15% of contrail formation with only a 0.5% fuel penalty for doing so. (See Figure 11.)

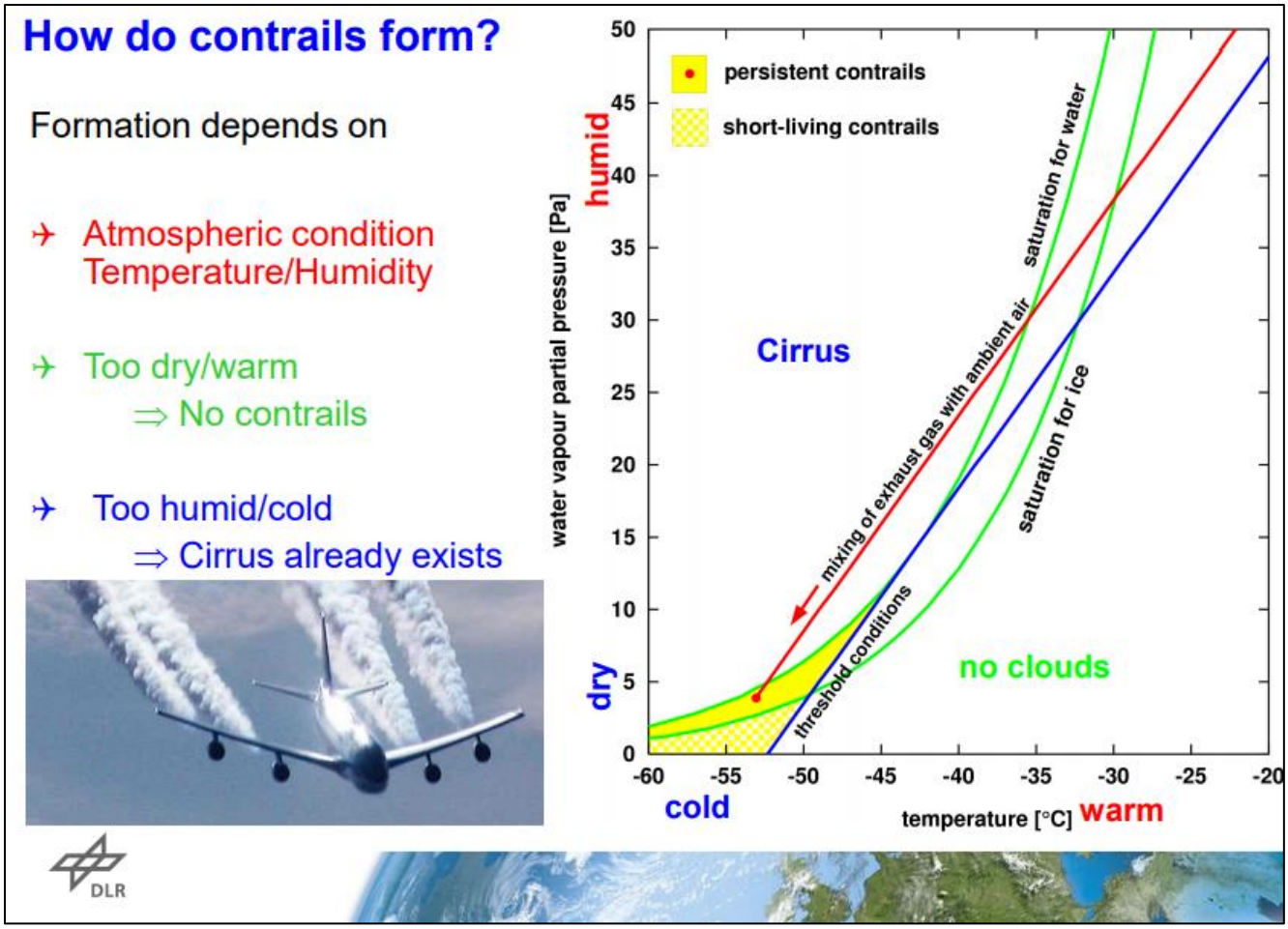


Figure 11: A schematic depicting how contrails form

Dr. Grewe noted that while aerosol impact on clouds is still uncertain, we can still calculate that, overall, aviation contributes about 5% of manmade global warming. More than 50% of this warming is due to CO_2 and some of it due to other non-CO_2 climate forcers.

Predicting weather patterns helps to plan flight paths to avoid sensitive areas of likely contrail formation. ATM4E and SESAR looking at how to manage traffic to optimize this with CO_2. (See Figure 12.)

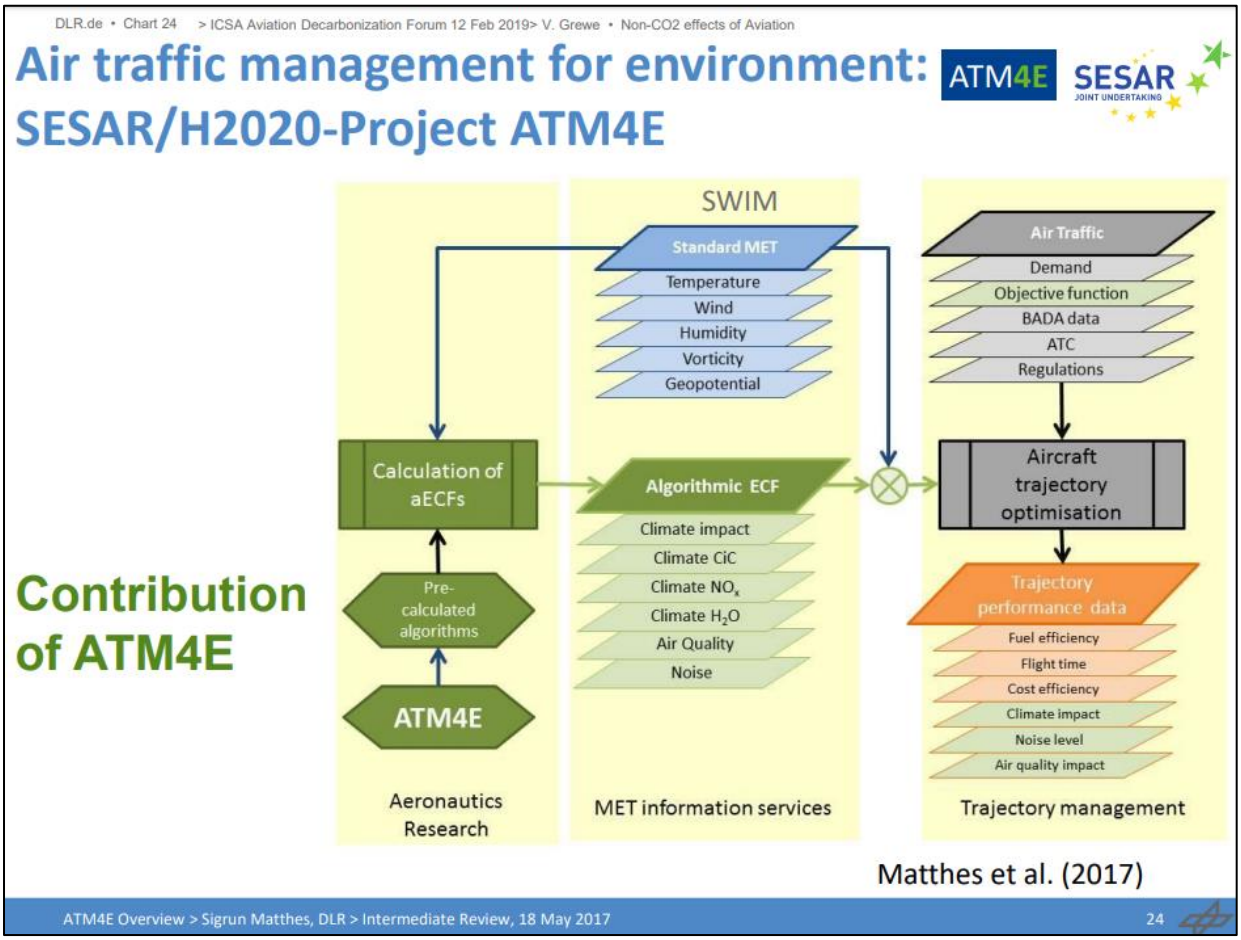


Figure 12: How the SESAR/H2020-Project ATM4E plans to include environmental considerations into air traffic management, including non-CO2 effects. The Aviation Transport Management for Environment's (ATM4E) contributions are included in this schematic in green.

New methods are emerging that will help policy makers and others account for non-CO_2 effects on a flight-by-flight basis and converting these effects into a CO_2 equivalent. There are trade-offs between accuracy and effort. This accounting would include information inputs relating to flight distance, altitude, latitude, etc. (See Figure 13)

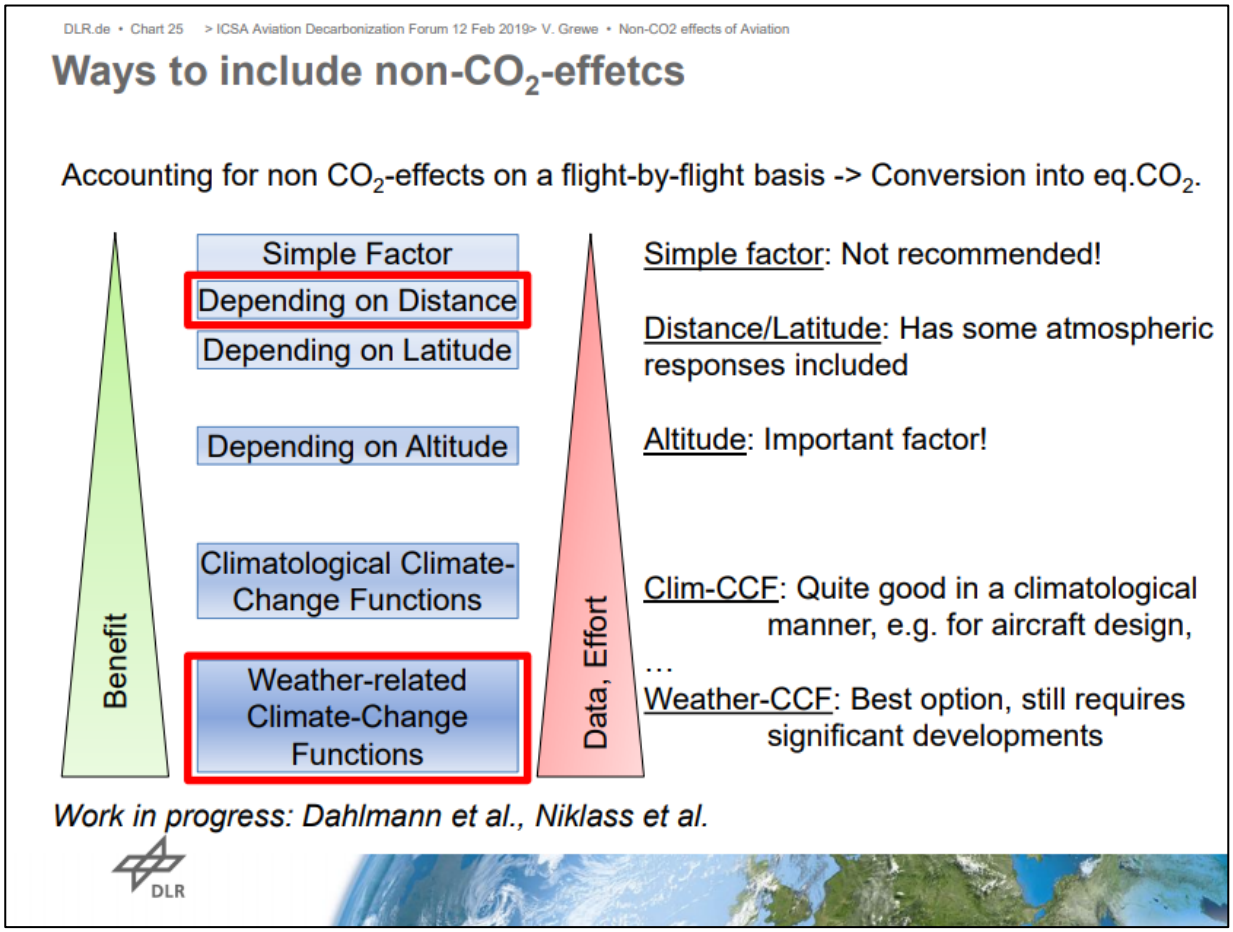


Figure 13: Ways to account for non-CO2 effects

At the close of Dr. Grewe's presentation, the moderator Chris Lyle noted a couple of key concepts of the presentation:

1. Non-CO_2 effects are at least 50% of the climate challenge; and
2. Optimizing flight paths to avoid climate-sensitive areas could substantially reduce the climate impact of aviation at a low-cost increase, even as this will have some impact on air traffic patterns.

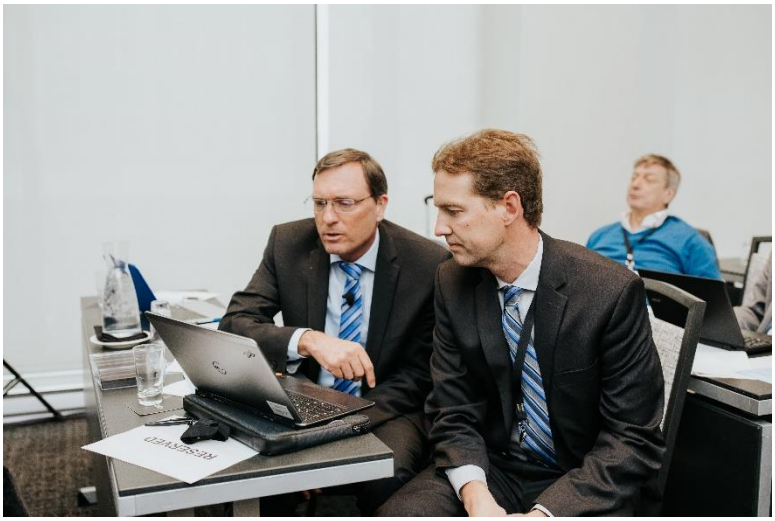
Plenary discussion

Question from the audience: "Would you agree that ICAO and industry should include some element of non-CO_2 it their work?"

Dr. Grewe began his answer by asking if it is better to leave something out or to use a best estimate. He would support the latter approach despite the fact that there will always be ongoing research. Because of the natural variability there will always be uncertainties, but one can live with these.

Question from the audience: "The David Lee graph is based on 2005. Have we anything more recent that has been developed? It could be very helpful for communicating that these are still accurate numbers at the very least. My impression is that because the 2005 piece is dated it could convey that no advances have been made in non-CO_2 science and measurement."

Dr. Grewe mentioned that Dr. David Lee and Dr. Piers Forster are working on a new update that should be out in 2019.



Question from the audience: "What would be required to control real time decisions on routings and altitude? What would be an appropriate multiplier for use in a market-based measure like CORSIA, for example, if the scope of CORSIA was extended to non-CO_2 effects?"

Dr. Grewe said that the simple 1.9 multiplier number hasn't changed, even as there have been changes in some of the understanding of the science, both positive and negative, for individual species of non-CO_2 effects. For example, contrail impact appears larger now, but, overall, the global mean is about the same. On the question of practical applications, you could monitor day-to-day operations and feed this information into fuel trajectories.

Question from the audience: "Sobering that you mention avoiding climate sensitive zones but otherwise there seems little one can do, right? What about setting fuel standards such that it changes the composition of it to regulate some non-CO_2 effects? And what is correlation of water vapor with altitude?"

Dr. Grewe said that altitude is really important in affecting the lifespan of contrails. Trials of those flying at flight level 430 have long lives and at supersonic altitudes could last almost 2 years. Changing altitude (i.e. moving down lower) could reduce contrails. NO_X is limited by thrust, but because the ICAO NO_X standard is expressed as a ratio it can increase in real terms for modern aircraft. In other words, increased stringency of a NO_X standard lowers the amount of NO_X emitted at a given level of thrust, but engines with higher thrust will emit more. So, replacing a medium sized aircraft with something newer but heavier may produce more NO_X. And biofuels can actually increase particulates, but PtL/e-fuels may reduce non-CO_2 effects, with a 50% blend predicted to reduce contrails by 20%.

Question from the audience: "Could a graphic measure the radiative forcings similar to Dr. David Lee's from 2009 be developed for supersonics specifically?"

Dr. Grewe noted that the IPCC's Special Report on aviation (Aviation and the Global Atmosphere, 1999) has some information that could be extrapolated for this purpose.

Questions from the audience: "How confident are you in the statement that synthetic fuels may reduce non-CO_2?"

Dr. Grewe said that there's good modelling that gives a clear sense of direction on this question, but the analysis is ongoing, and he can't give an accurate number as to whether it's 20%, 35% or something else.

Question from the audience: "If all non-CO_2 experts were here today, would they all agree with what you've said, and if they don't is that the fault of the scientific community?"
There are lots of uncertainties that individuals are working on where there isn't sufficient data for peer assessment, so more research is critical.

Question from the audience: "Which climate metric should we choose for non-CO_2?"
Dr. Grewe stated that there will probably be a long discussion between politicians and scientists about appropriate timeframes for non-CO_2 effects and how this can be reflected in policy, but it's not really a scientific issue; the information is there already.

Question from the audience: "Could you talk about how day and night influences non-CO_2 effects?"
Dr. Grewe said that day and night will only be an issue for contrails, where the impacts are worse at night.

Making Zero Carbon Aviation a Reality

LINK TO SLIDE PRESENTATION:

"Mission Possible: Reaching net-zero for aviation (& other hard to abate sectors) by mid-Century", presented by Adam Klauber, representing the Energy Transitions Commission (ETC)

Mr. Klauber began by introducing the Energy Transitions Commission (ETC) recent report, "Mission Impossible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century" (link to the report), from which the presentation would be based. He stated that the focus of the presentation is on CO_2 emissions.

The report is framed around limiting global CO_2 emissions to net-zero by around 2050, a target Mr. Klauber identifies as being more ambitious than IATA, and one that has the strong support of the ETC members. To get there, focus is placed on six major activities sorted into two categories: Heavy Industry (cement, steel and plastics) and

Heavy-Duty Transport (heavy road transport, shipping and aviation). These harder-to-abate activities could increase by 50% by mid-century and comprise 40% of global emissions under a business as usual scenario.

To mitigate these emissions, Mr. Klauber describes three routes/strategies to reach net zero emissions by 2050 in these sectors:

- **Demand management:** For example, according to ETC analysis, a 15% emission reduction for aviation could be achieved through demand management (air traffic management, load factor improvement, virtual meeting participation, and a modal shift to high-speed rail).
- **Energy efficiency:** Mr. Klauber cites the belief that step changes in energy efficiency will be realized, an example being the blended wing design, to secure 30-45% reductions.
- **Decarbonization technologies:** Deploying decarbonization technologies (electricity, biomass, carbon capture, and hydrogen) would need to take place across all sectors.

In real GDP terms, the decarbonization of harder-to-abate sectors would cost about 0.45% of global GDP, or roughly ~500 USD billion/year. This cost would be orders of magnitude higher than implementing CORSIA, but Mr. Klauber states that this is nonetheless what it takes to get aviation to the end goal. The total estimated increased costs to passengers are expected to be 10-20% (40-80 USD/ticket) more per long-distance flight in 2050.

Electrification is one of the major decarbonization approaches in the ETC report, plays its biggest role in aviation in the form of synfuels (another term for PtL). Electricity is expected to have five to six times greater demand in a decarbonized economy compared to the level of demand in 2014, and whether synfuel is more economical than biofuel depends on the price of electricity. In the case of aviation, a price of 30 USD/MWh or lower is where synfuel is viable as an alternative to conventional fossil-based jetfuel. It is

ETC's position that waste is the only sustainable source of biofuel feedstock. North and South America have the greatest capacity in biomass available for energy, in terms of having the highest EJ/capita. Biofuels and synfuels should be prioritized for aviation over other sectors.

Mr. Klauber presented an implementation timeline for the three routes to net zero aviation (See Figure 14). Some key insights are that:

- The need to manage aviation demand is now and will persist out to 2050.
- Efficiency technologies and syn-fuels should ideally be realized before 2030.
- Hydrogen fuel cell-hybrid and direct electric batteries for short-distance transport could be viable after 2040.

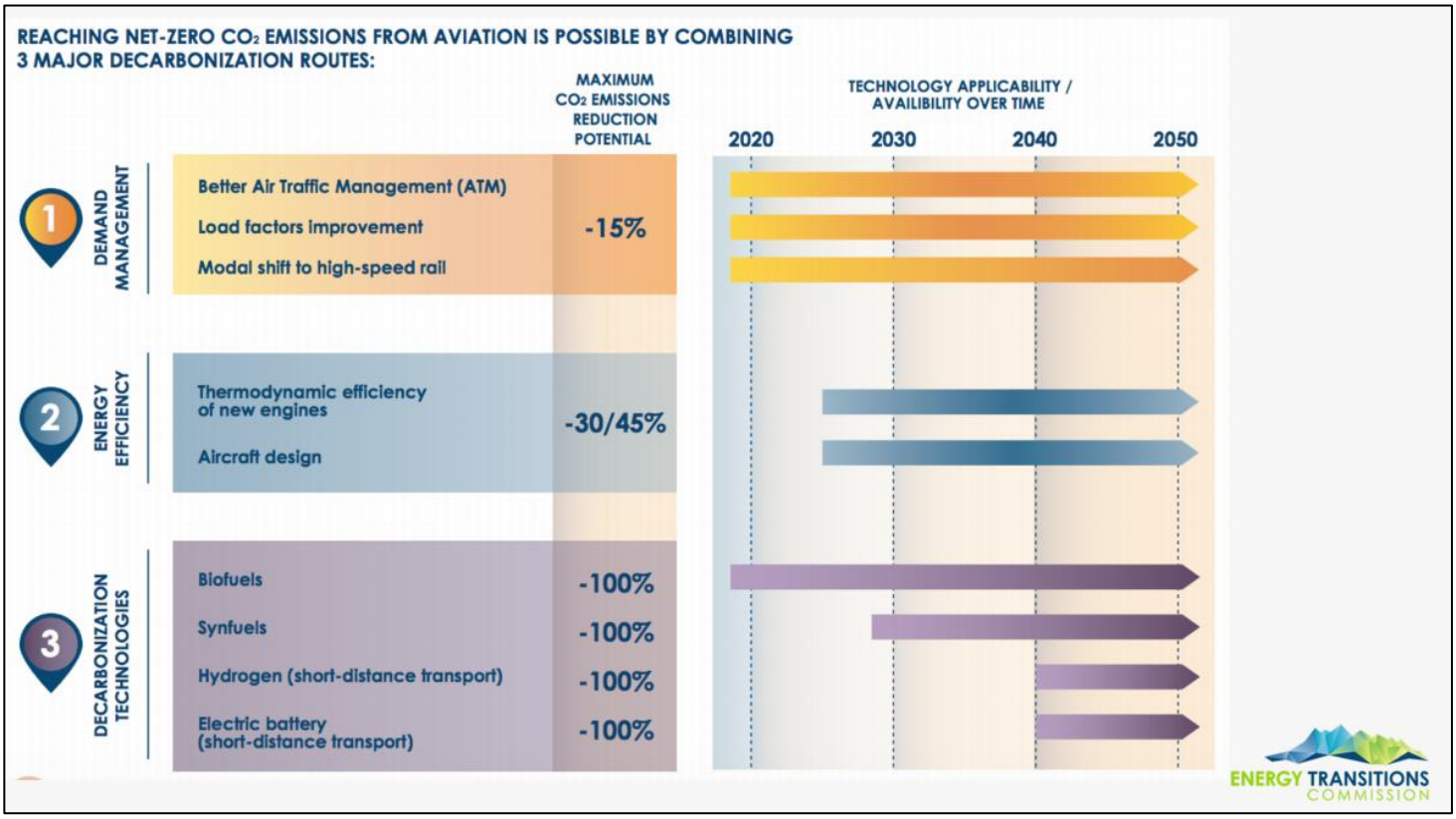


Figure 14: Timeline for the three decarbonization routes for aviation

Mr. Klauber then presented an illustrative pathway of aviation's final energy consumption compared to other hard-to-decarbonize sectors as presented in the ETC report. (See Figure 15). It showed that aviation in 2050 might optimally run on 10% electricity, 10% hydrogen, 50% bioenergy and bio-feedstock, and 30% synfuels (PtL).

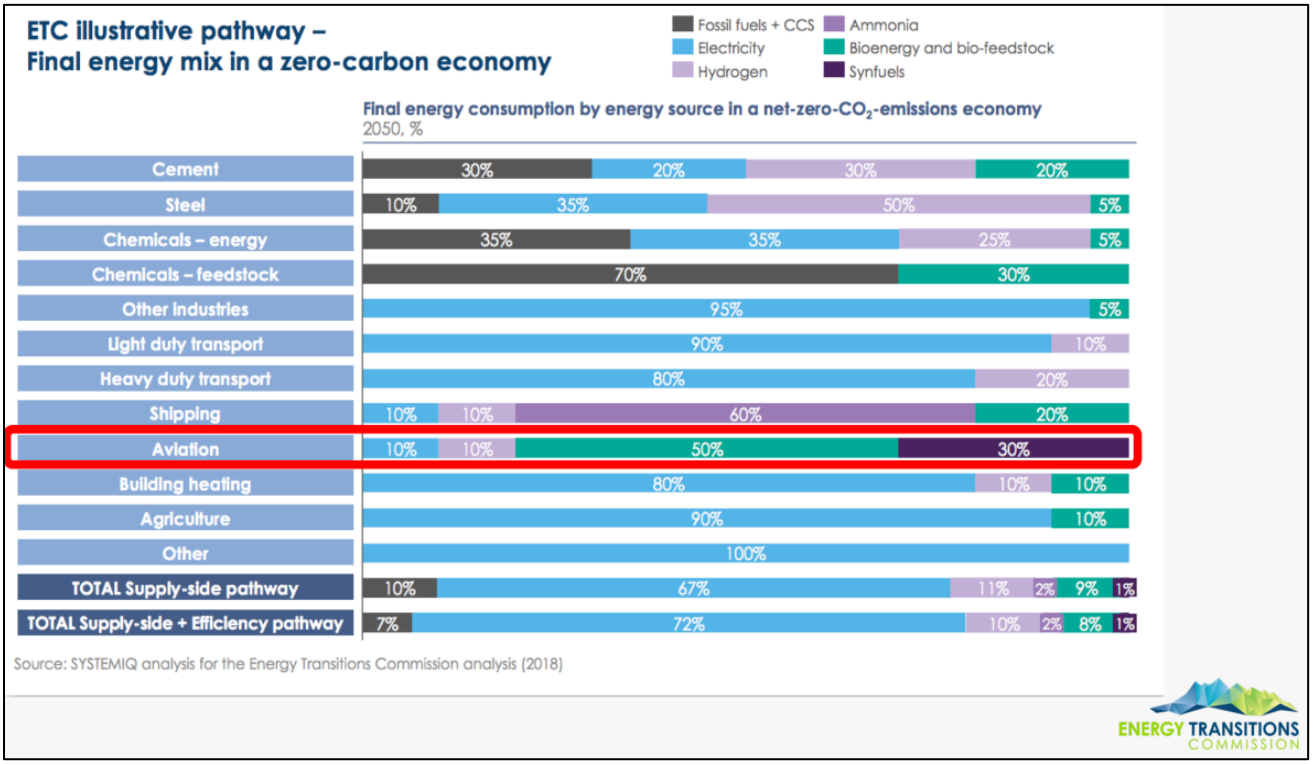


Figure 15: An illustrative pathway of aviation's final energy consumption compared to other hard-to-decarbonize sectors

Today, ETC is shifting from an analysis focus into specific solutions. Mr. Klauber stressed that there needs to be collective action in figuring out what coordinated efforts are required to ensure that higher costs–which will be necessary–don't destroy the industry.

Plenary discussion

Question from the audience: "How do we put this all together and drive it--of your top three recommended actions, which ones are being taken up by government and industry?"

Mr. Klauber said that they are still in the early days in terms of digesting this report. He identifies that there are policy movements in British Columbia, and that the LCFS on the west coast makes a difference. In California, they're looking at a 25% increase over

conventional fuel prices, which is considerably less than what is generally the case for other regions. On the corporate side, we now have the "Board Now" initiative from SkyNRG- commercial production facility. This could have demonstrable impact because there's currently only one commercial operating facility.

Question from the audience: "The final slide showed a vision for 100% electrification in road transport in 2050--my feeling is that that is credible for Germany and Europe but difficult to imagine at the global level. Is that realistic?"

Mr. Klauber responded that 100% electrification in road transport by 2050 certainly is difficult and requires international support and potentially some transfer of wealth would be required. However, points out that there are additional co-benefits to electrification to consider such as lower maintenance costs and, potentially, lower

fuel costs. How we reach this vision is potentially phase II for the Energy Transitions Commission (ETC).

Final Reflections and Close

Note: Responses from panelists in this section were not attributed by the designate note taker. Therefore, individual speakers are generically referred to as "panelist," in most cases.

Question from the moderator: "What are your primary takeaways from today?"

- Panelist: Non-CO_2 is at a point where it can be addressed by policy.
- Panelist: Confirmed that there is a clear need to move to include non-CO2 emissions for road mapping. It's not appropriate to continue implicitly ignoring these forcing effects in policy and planning. It feels like the demand management conversation is going to become necessary for the industry before 2050--so I'd like to see that coming forward more seriously.
- Panelist: We need to do more.
- Panelist: We have the technology today to go there and it's economically viable--but car, coal, energy industry people have learned that they have to slow down as much as possible to get back money from their stranded investments. In other words, we have an organized effort to prevent this transition. And we don't have the individuals that represent these industries in this conference room—those that need to learn about decarbonization options that we have presented here.
- Panelist: Industry needs a culture change. What is the license to operate for the airline industry? Aviation was always seen as a safe and fast way to operate, but we need to broaden the idea of what "safe" is. It's not "safe" anymore to cause climate change and push the planet beyond the 1.5°C limit.

What does that mean for ICAO's own mandate in this space? People are going to die due to climate change.

- Panelist: In terms of 2030 interim steps, that probably stands as the greatest contrast to the path that aviation is currently on. We cannot wait until CORSIA is set.

Question from the audience: "For those of us working in aviation at the global level--I was thinking about how our colleagues from other continents would react to this--how do you tell a country like Zambia, for example, to have demand management? I appreciate the information the speakers have provided, but our difficult work is to transmit that work to the entire world."

- Dr. Lehmann: I've lived in different parts of the world outside of Germany, and other countries see that if they want a part of the future they need to leapfrog and do things better than industrialized countries before them. That's why I'm optimistic.
- Panelist: Flying is an elite thing, it's not the same as energy. We must keep that in mind that maybe that opens the possibility of taxing it further—flying is not a human right.
- Panelist: However, every country has a different responsibility.

Question from the audience: "I have an observation, then a question. I took away the idea that the cost of decarbonization of aviation by mid-century are sizable but manageable but dwarf the current profit margins so collective action is required. This balance of regulation vs. free market competition is already difficult to navigate in the aviation industry--so what are the first steps working toward this action? Do you think some sort of absolute emissions target (mid- and long-term) is a step toward doing so?"

- Panelist: I don't think many people disagree that having a central target would push you in the right direction. But some of the deep decarbonization pathways for aviation that we've seen that have electrofuels/new aircraft design requires investment and I'm not sure aggregate targets are the right policy to ensure we get this investment. Governments need to be more willing to set policies that realistically provide real incentives for innovation, investment and deployment of these new technologies.
- Panelist: We need interim goals. Goals are nice, but not enough. There need to be incentives to bring in the tech. and some policing so the first-movers aren't penalized.
- Panelist: That's the turmoil of a global business.
- Panelist: On the consumer side, if people are prepared to spend 20% more on airfare, that'd be a good place to start too. But also thinking about adaptation and resilience investments in the US (fire/storm damage), we're talking about 40-50 USD billion this year alone. If we can direct that toward climate safety, we can give people a greater understanding that spending money now prevents damage in future.
- Panelist: As long as money is going to old technology, that's bad. People are investing in the wrong sectors still. If you want to make money moving forward, people need to know that you have to invest in the right technologies that won't be stranded assets.
- Panelist: When the International Maritime Organization (IMO) long-term shipping target was agreed, Maersk, a top shipping

company set their own target to align with IMO's. We need to push for the tech in startups and a target would provide a target for those initiatives. It's an important signal that goes beyond the sector. We are still waiting for an Elon Musk of aviation.
- Panelist: Well... maybe not quite Elon Musk…

Question from the audience: "The policy landscape is not enough right now, so what's your no-regrets policy solution if you were King?"

- Panelist: An innovation fee on tickets. We transport 4 billion people/year. What if we charged them 1 USD more--that's an innovation budget of 4 USD billion/year.
- Panelist: There is one policy that already exists but not known beyond UK: The UK Dept. of Transportation has introduced a 2030 target for development fuels. This policy places ~2 USD penalty on fuel suppliers if they can't meet a target for drop-in fuels from waste and residual sources. It's a significant value signal--a non-compliance cost. I think that's the best example of an effort to set an aviation fuel policy that will work in the world at the moment.

Question from the audience: "There need to be first movers and they should be in places like North America and Europe. I've heard that the biofuel policy in Europe hasn't delivered and has probably made the world and forest worst. Natural gas for shipping has gone wrong. Isn't there a risk for aviation biofuels?"

- Panelist: Absolutely. Given government structures that are available, and having interacted with ICAO, and looking at Indonesian palm oil, it's going to be very difficult to get this right and ICAO is a difficult way to do a complicated task well. There are no simple answers except that it must be a partnership between ICAO and industry, and countries that choose to require more.
- Dr. Lehmann: Biofuels for aviation is the wrong path. We need enough land for food, etc. If we go into biofuel for energy

future, we need to recognize the significant water demand from producing these fuels—water that we already need for food agriculture. Lastly, total climate effect is negative--we are spending money on the wrong thing. Please don't use direct biomass for fuel purposes.

- Dr. Malins: If you look at the total agricultural footprint of the world, 80% is directed to meat. Suppose we could reduce that by half, it would free up 40% of agricultural area in the world. There is more to biomass than "it is all wrong". It depends on where you are, whether water is constrained, etc. There are studies that show this. It's good to look carefully at the sustainability issues with biofuels but see it in connection with other issues as well.
- Dr. Lehmann: Yes, but even in the most optimistic projections, you can only deliver 30% of aviation fuels with biofuel. So, the question is, is that enough to create a policy that goes up to 2050. Why do we spend the resources taking up limited land area? We need to use power to liquid.
- Mr. Klauber: Palm oil is clearly a risk and an area where traceability (blockchain) can be used to avoid the most egregious cases.
- Dr. Malins: I'm skeptical about blockchain because garbage in garbage out (paraphrased).

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Acknowledgements

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Finally, ICSA would like to thank the government participants attending the event for their lively participation.

Appendix 1: Agenda for the Aviation Decarbonization Forum

Time	Session
8:00-9:00 am	**Registration and continental breakfast**
9:00-9:15 am	**Welcome and opening remarks** Moderator Chris Lyle, FRAeS, Chief Executive, Air Transport Economics *Speaker:* • Tim Johnson, Director, Aviation Environment Federation; ICAO CAEP Observer for the International Coalition for Sustainable Aviation (ICSA)
9:15-10:15 am	**The global decarbonization challenge and aviation within it: where are we now, where are we going?**

	What does the new IPCC special report on 1.5C tell us about how much we must reduce greenhouse gas emissions? What should aviation's fair share of these emissions reductions be and how does this compare to ATAG's 2050 aspirational target? *Speakers:* • Dr Heleen de Coninck, Associate Professor in Innovation Studies at the Environmental Science Department at Radboud University's Faculty of Science; Coordinating Lead Author for Chapter 4 the IPCC Special Report on 1.5C • Dr. Martin Cames, Head of Energy & Climate Division, Öko-Institut, Berlin
10:15-10:30 am	**Coffee break**
10:30-11:30 am	**Unlocking greater near-term efficiency, while transitioning to the next generation of aircraft** Airlines have strong incentives to increase airplane efficiency, but progress is not happening fast enough. This session will help audience members identify the barriers and potential solutions to unlocking near-term emissions reductions and understand what governments and industry must do to encourage radically more efficient plane designs to take to the skies. *Speaker:* Ir. Joris Melkert, TU Delft, Aerospace Engineering, The Netherlands
11:30 am-1 pm	**Future of liquid aviation fuels** Biofuels are looked to by the aviation industry as the primary technological advancement that will drive aviation's deep decarbonization. However, sustainability and commercialization challenges abound, indicating that aviation might additionally need *electrofuels* (a.k.a. *synfuels* or *power-to-liquids*). *Speakers:* • Dr. Chris Malins, Cerulogy, London • Dr. Harry Lehmann, General Director, Environmental Planning and Sustainability Strategies, Federal Environment Agency (UBA), Germany
1-2 pm	**Lunch**

2-3 pm	**Addressing non-CO_2 effects of aviation** While scientists studying the complex science of aviation non-CO_2 climate effects are still learning, they confidently estimate non-CO_2 impacts to be a sizable percentage of aviation's impact on the climate. What are the opportunities to finally begin tackling this part of aviation's impact on our climate? *Speaker:* Prof. Dr. Volker Grewe, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre,Oberpfaffenhofen (near Munich) Chair for Climate Effects of Aviation, Delft University of Technology
3-3:15 pm	**Coffee break**
3:15-3:40 pm	**Making zero-carbon aviation a reality** What can a comprehensive and meaningful vision of decarbonization look like for the aviation sector? The Energy Transition Commission's recent report *Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century* does just that, considering many of the technological transition questions discussed earlier in the day. *Speaker:* Adam Klauber, Representing the Energy Transition Commission
3:40:20-4:30	**Final reflections and close** Moderated discussion with all previous panelists.

Appendix 2: Other supporting resources referenced at the Aviation Decarbonization Forum or otherwise

Cames, M. et al. 2015. Emission Reduction Targets for International Aviation and Shipping. IP/A/ENVI/2015-11. Available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf

Energy Transitions Commission. 2018. Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century. Available at: http://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_ReportSummary_English.pdf

IPCC. 1999. Aviation and the Global Atmosphere. Available at: https://www.ipcc.ch/report/aviation-and-the-global-atmosphere-2/

IPCC. 2018. Summary for Policy Makers Global warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. ISBN 978-92-9169-151-7. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf

Malins, C. 2018.Building the perfect beast: Designing advanced alternative fuel policy to work. Cerulogy. Available at: http://www.cerulogy.com/wastes-and-residues/building-the-perfect-beast-designing-advanced-alternative-fuel-policy-to-work/

Miller, N. et al. 2013. Measuring and addressing investment risk in the second-generation biofuels industry. The International Council for

Clean Transportation. Available at: https://www.theicct.org/publications/measuring-and-addressing-investment-risk-second-generation-biofuels-industry.

Purr, K. et al. 2016. Integration of Power to Gas/ Power to Liquids into the ongoing transformation process. Umweltbundesamt. Available at: https://www.umweltbundesamt.de/en/publikationen/integration-of-power-to-gas-power-to-liquids-into

Schmidt, P. et al. 2016. Power-to-Liquids – Potentials and Perspectives for the Future Supply of Renewable Aviation Fuel. Umweltbundesamt. Available at: https://www.umweltbundesamt.de/en/publikationen/power-to-liquids-potentials-perspectives-for-the

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