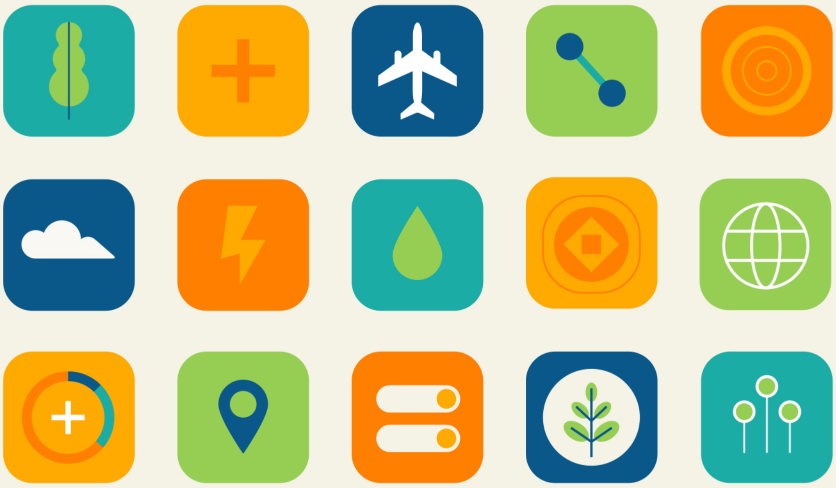
ICAO

INTERNATIONAL CIVIL AVIATION ORGANIZATION

REPORT ON THE FEASIBILITY OF A LONG-TERM ASPIRATIONAL GOAL (LTAG) FOR INTERNATIONAL CIVIL AVIATION CO_2 EMISSION REDUCTIONS

Appendix R1 Summary Sheets



ICAO COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION
MARCH/2022

APPENDIX R1

SUMMARY SHEETS

1. ABOUT THIS DOCUMENT

1.1 This appendix includes a set of "summary sheets" that provides a similar set of information for each of the LTAG-TG integrated scenarios. In each case, the information is shown for all three traffic forecasts (low, mid, and high) with prominence given to the mid traffic forecast.

1.2 Each summary sheet includes high-level information on the forecast level of growth, aircraft technologies, operational improvements, and fuels that are associated with the future CO_2 emissions.

1.3 Each summary sheet includes a "trends-like" wedge graphic that shows the relative contributions of aircraft technologies, operational improvements, and fuels that is associated with the integrated scenario. This is also shown below the graph with a table.

1.4 The summary sheets also include a roadmap for realizing the scenario, including information on costs and investments associated with each scenario. Information on geographical distributions of the information has also been supplied on the right-hand side of the summary sheets, if available.

1.5 The summary sheets also capture the benefits associated with the scenario (e.g. air quality benefits from the use of SAF).

1.6 These summary sheets have been designed to enable easy comparison of the three integrated scenarios.

1.7 Further information may be found in the following Appendices:

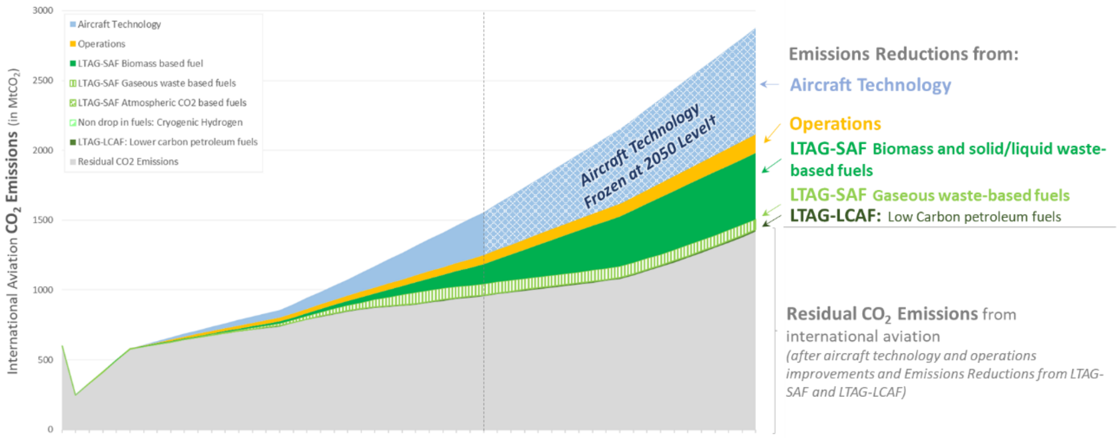
Scenario development	M1, Part A
Modelling methodology	M1, Part B
Cost and investment estimation	M1, Part C
Traffic forecasts	M2
Technology	M3
Operations	M4
Fuels	M5

2. INTEGRATED SCENARIO 1

2.1 **Scenario Description:** This low or nominal scenario represents the current (c. 2021) expectation of future available technologies, operational efficiencies, and fuel availability. It includes expected policy enablers for technology, operations and fuels and low systemic change, for example no substantial infrastructure changes. Of the three scenarios, it requires the lowest effort for delivery, though this could still be considerable for individual actors.

2.2 **Demand Growth Forecast:** The analysis uses the core assumptions and underlying traffic forecasts developed for the COVID-19 Trends analysis including the COVID-19 forecast extension from 2050 to 2070. The LTAG fleet evolution output matches exactly with the Environmental Trends analysis through 2050 in terms of total ASKs, ATKs and operations. For LTAG the fleet evolution forecast, and extension to 2070, was processed for the mid traffic forecast only and then used as the base for applying technology improvements as a post-process. A scalar post-process method was used to estimate the High and Low traffic demand scenarios. The results are consistent with previous Trends analyses and fit-for-purpose for LTAG.

2.3 CO_2 Emissions Results



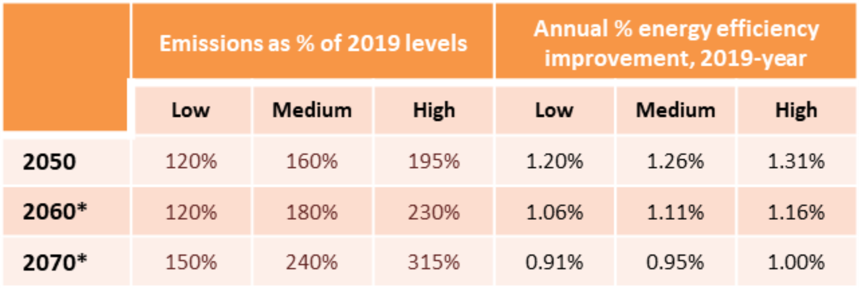
† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

2.3.1 **Annual emissions:** 950 (730-1160) $MtCO_2$ from international aviation in 2050 and 1420 (920-1880) $MtCO_2$ in 2070.

2.3.2 **Cumulative emissions:** 22 (18-26) $GtCO_2$ from international aviation from 2021-2050 and 45 (34-56) $GtCO_2$ from 2021-2070.

2050		2070	
Total emissions reductions (cf. IS0)	39%	**Total emissions reductions (cf. IS0)**	51%
Technology	20%	**Technology**	26%
Operations	4%	**Operations**	5%
Fuels	15%	**Fuels**	20%

2.4 CO₂ Emissions Results in the Context of the Current ICAO Aspirational Goals



	Emissions as % of 2019 levels			Annual % energy efficiency improvement, 2019-year		
	Low	Medium	High	Low	Medium	High
2050	120%	160%	195%	1.20%	1.26%	1.31%
2060*	120%	180%	230%	1.06%	1.11%	1.16%
2070*	150%	240%	315%	0.91%	0.95%	1.00%

2.4.1 **2020 levels:** As the LTAG-TG Terms of Reference were agreed before COVID-19, LTAG-TG identified that relating its results to "the actual 2020 levels" may no longer be appropriate, given the anomalous nature of international aviation CO_2 emissions in 2020. 2019 is therefore used as it is more representative of a pre-COVID-19 year and consistent with the CORSIA baseline for the Pilot Phase. Percentages are rounded to the nearest 5%.

2.4.2 **Global fuel efficiency:** Fuel efficiency improvement is an average over the whole period (i.e. 2019-2050, 2019-2060 and 2019-2070). It is expressed in terms of the energy used per revenue tonne kilometre performed (MJ/RTK) for consistency between scenarios. For IS1 and IS2 this is directly proportional to the fuel volume per RTK metric stated in Assembly Resolution A40-18. However, it is a system-level fuel efficiency metric rather than an aircraft-level one and may therefore not correlate exactly with the existing near-term aspirational ICAO climate goal.

2.4.3 **Uncertainty:** These estimates are subject to significant levels of uncertainty, arising from factors including but not limited to:

- (*) No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet. See Appendix M3.
- The fleet penetration rate is itself a source of uncertainty. Appendices M1 and M3 provide more information.
- Estimates attract more uncertainty further into the future. The level of confidence we can have both in the estimates used as inputs and the underlying demand forecasts decreases with time. See Appendix M2 for more information about the demand forecasts.
- These uncertainties arise primarily from the input data, the analysis methodology used is similar for all years. See Appendix M1 for a full description of the methodology.

2.5 Regional impacts summary (including developing states)

2.5.1 **Technology:** Aircraft technology and associated design decisions will continue to address the global market needs and will not vary by region. Aircraft operators in various regions or states will buy the best aircraft available that meet their needs.

2.5.2 **Operations:** Regional variances in implementation of operational measures are expected without any substantial infrastructure change and relatively conservative policy enablers.

2.5.3 **Fuels:** The uptake of LTAG-SAF/LTAG-LCAF is not anticipated to be consistent across all world regions due to differences in market dynamics (i.e. countries/regions with favourable low GHG fuel policies will attract greater volumes of these fuels). Additional regional variances are expected regarding the production of LTAG-SAF/LTAG-LCAF due to regional availability of feedstock resources (biomass, solid/liquid wastes). Finally, availability of waste CO/CO_2 resources will have additional regional variability as regions decarbonize at different rates out to 2070.

2.6 Impacts on noise and air quality

2.6.1 **Technology:** Noise and local air quality remain priorities, but improvements will generally not be permitted at the expense of energy use/carbon emissions. Increased operations will adversely impact the 65 DNL contours and emit more NO_x in absolute terms though this is not relevant for certification of individual aircraft designs. Some aircraft will continue to be designed with varying local airport noise rules and charges in mind, as today.

2.6.2 **Operations:** This scenario is not expected to have any impact on air quality. Some vertical flight efficiency measures such as continuous descent operations may provide benefits for local noise around airports

2.6.3 **Fuels:** This scenario is not expected to have any impact on noise. Some improvement in local air quality in airport communities is expected with LTAG-SAF use as these fuels contain low levels of aromatics and generally produce less soot (nvPM - non-volatile particulate matter). Early studies also indicate low aromatic fuels produce less nvPM at cruise altitude and could contribute to a reduction in contrail formation.

2.7 Measures

2.7.1 Technology (See Appendix M3):

- Advanced conventional/tube and wing aircraft in all classes
- T1 technology baskets

2.7.2 Operations (See Appendix M4):

- Conservative assumptions about rate and extent of ASBU elements and 15 additional operational measures, based on investment in ground and airborne systems and technologies.

- Relatively low rate of ASBU element deployment to optimise Horizontal, Vertical and Ground Flight Efficiency

2.7.3 **Fuels (See Appendix M5):**

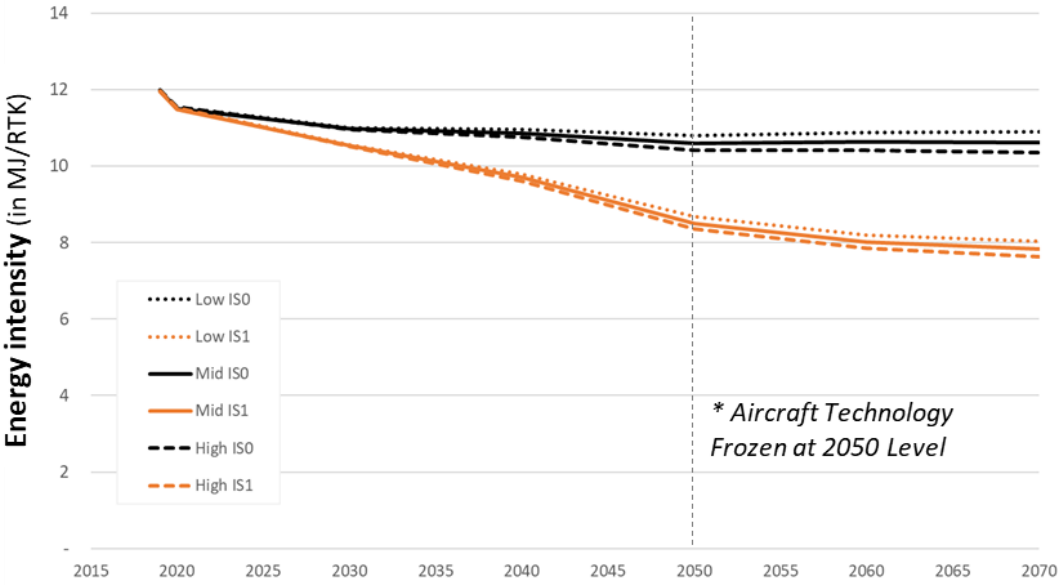
- Use of SAF/LCAF produced from:
  - waste (CO/CO_2) gases
  - feedstock from a variety of settings (e.g. oilseed cover crops
- With technology that enables blue/green hydrogen use for LTAG-SAF/LTAG-LCAF production.
- Use of these fuels at blend levels above 50%.

2.7.4 **System requirements:** Continued reliance on liquid hydrocarbon fuel means infrastructure changes are limited to those required for operational efficiency and growth only.

2.8 Additional metrics

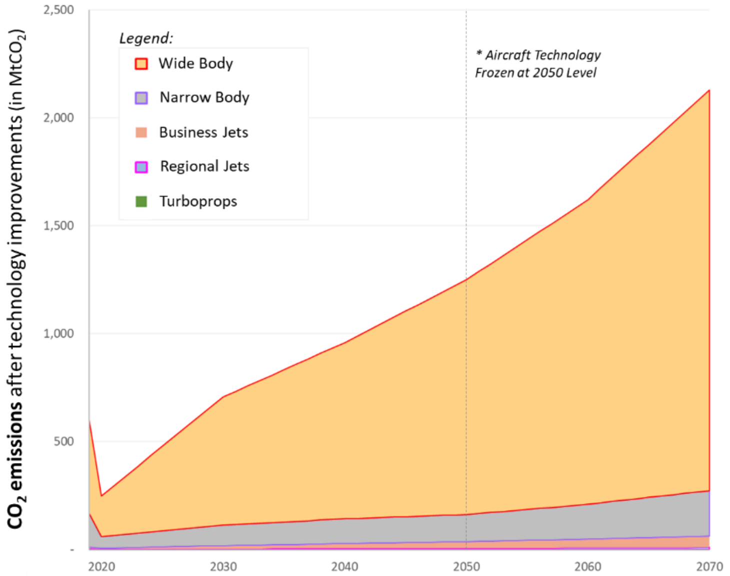
2.8.1 Technology

2.8.1.1 The following graph shows fuel energy intensity (in MJ/RTK) after aircraft technology improvement under LTAG-TG integrated scenario 1.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

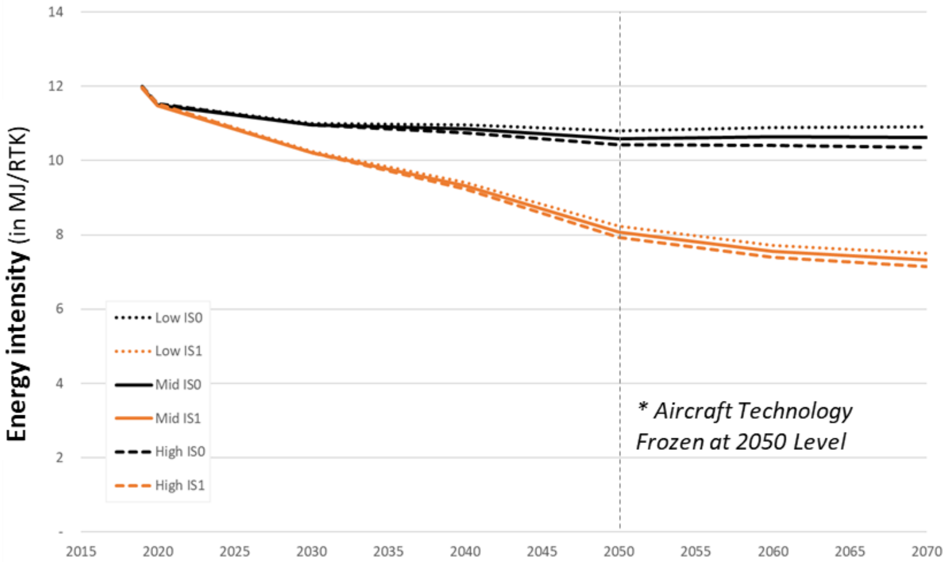
2.8.1.2 The following graph shows the CO_2 emissions from international aviation (after aircraft technology improvements) by aircraft class for LTAG-TG integrated scenario 1.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

2.8.2 **Operations**

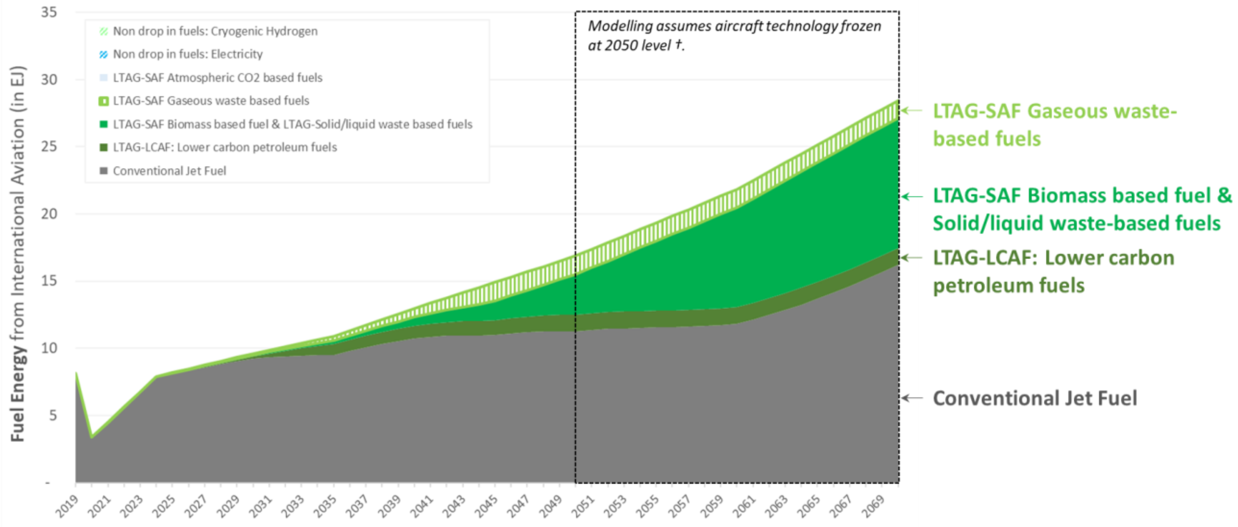
2.8.2.1 The following graph shows fuel energy intensity (in MJ/RTK) after aircraft technology and operational improvements under LTAG-TG integrated scenario 1.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

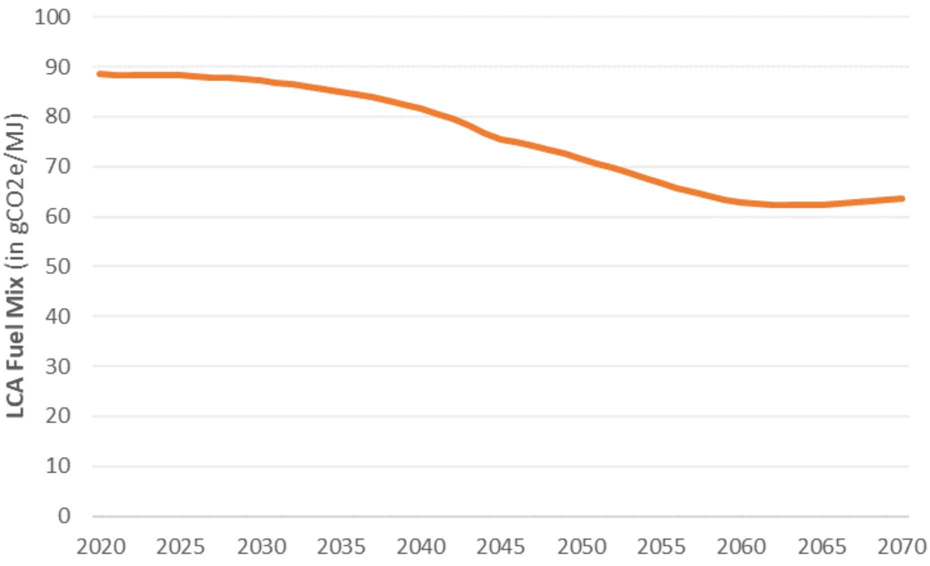
2.8.3 **Fuels**

2.8.3.1 The following graph shows total fleet-wide drop in fuel use over time, in MJ, by LTAG fuel category under LTAG-TG integrated scenario 1.



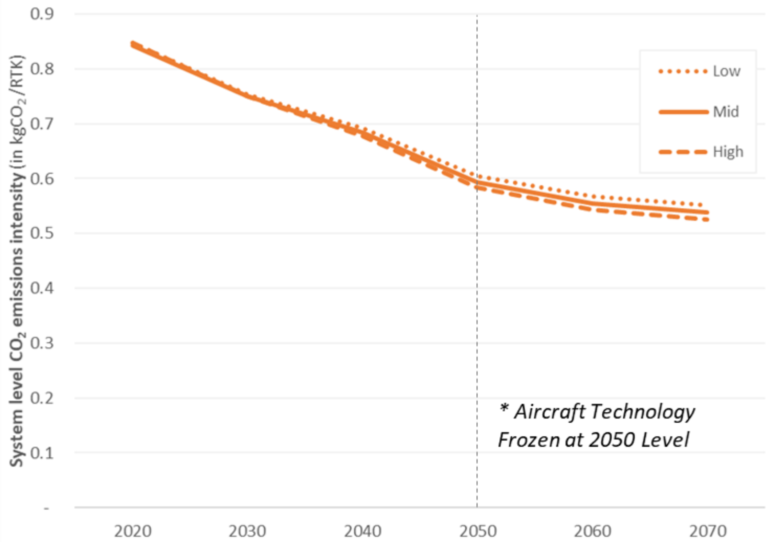
† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

2.8.3.2 The following graph shows the overall lifecycle emissions intensity of the global fuel mix, in gCO_2e/MJ



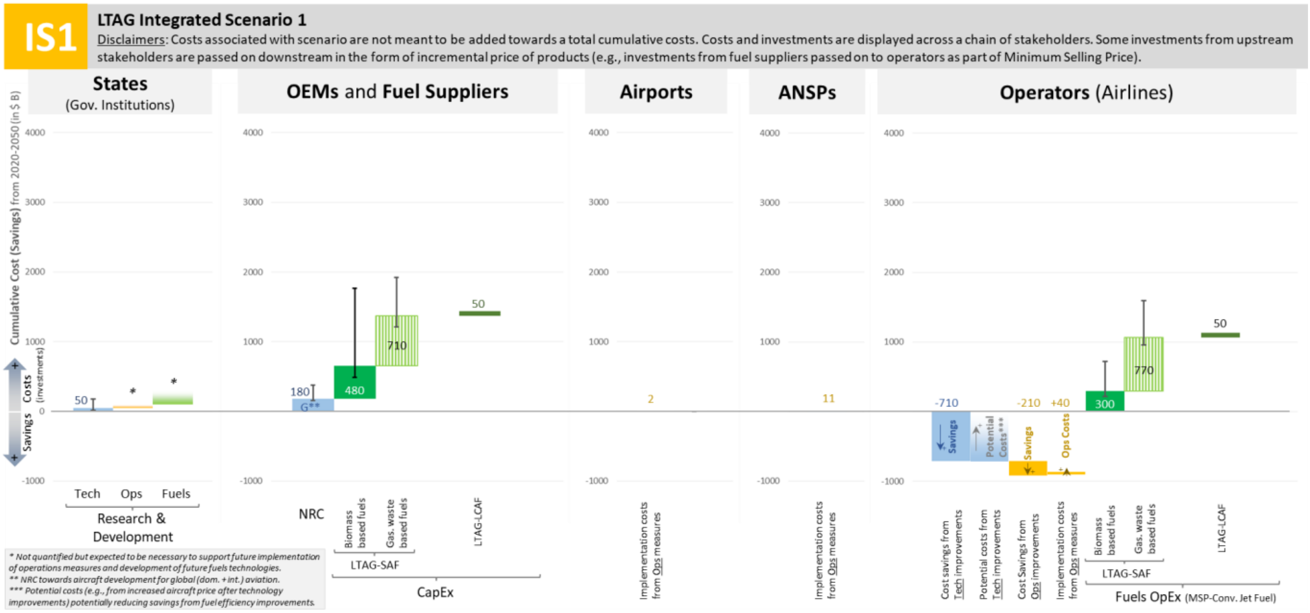
2.8.4 **System efficiency**

2.8.4.1 The following graph shows the emissions per unit of work (in $kgCO_2/RTK$) over the analysis period.



2.8.4.2 CO_2/RTK has been selected to show the overall emissions efficiency of the international aviation system in this scenario before the benefits of more efficient fuels are added. This metric is not appropriate to business jets. This metric is consistent with other reporting such as the CAEP Trends and industry assessments. This metric does rely on some assumptions about price and load factor (see Appendices M1 and M2).

2.9 Costs and investments



LTAG Integrated Scenario 1

Disclaimers: Costs associated with scenario are not meant to be added towards a total cumulative costs. Costs and investments are displayed across a chain of stakeholders. Some investments from upstream stakeholders are passed on downstream in the form of incremental price of products (e.g., investments from fuel suppliers passed on to operators as part of Minimum Selling Price).

** Not quantified but expected to be necessary to support future implementation of operations measures and development of future fuels technologies.*
*** NRC towards aircraft development for global (dom. + int.) aviation.*
**** Potential costs (e.g., from increased aircraft price after technology improvements) potentially reducing savings from fuel efficiency improvements.*

Note. - See section 2.12.2 below for results of cost and investments for LOW and HIGH traffic forecasts.

2.9.1 Technology

2.9.1.1 Investment by aircraft manufacturers: Around $180 billion (range $150-380B) between 2020 and 2050. On an annual basis this represents ≈ $6 billion per year.

2.9.1.2 R&D support by states: Up to $15-180 billion through 2050.

2.9.1.3 Reduced operator fuel costs: ≈ $710 billion from 2020-2050 but could require incremental investments to cover any incremental aircraft prices (after technology improvements).

2.9.2 Operations

2.9.2.1 Investment by airports: $2 billion

2.9.2.2 Investment by ANSPs: $11 billion

2.9.2.3 Investment by airlines: $40 billion

2.9.2.4 Reduced operator fuel costs: ≈ $210 billion from 2020-2050.

2.9.3 Fuels

2.9.3.1 SAF biomass-based fuels: Investment of ≈ $480 billion by 2050 (to cover 19% of international aviation energy use in 2050). Incremental cost to airlines of $300 billion.

2.9.3.2 Gaseous waste-based fuels: Investment of $710 billion (8% of energy use in 2050). Incremental cost to airlines of $770 billion.

2.9.3.3 LTAG-LCAF: Investment of $50 billion (7% of energy use in 2050). Incremental cost to airlines of $50 billion.

2.10 Roadmaps for implementation

2.10.1 Dependencies and Enablers

2.10.1.1 This scenario includes the following dependencies, interdependencies and assumed policies and incentives:

2.10.1.2 Technology

- Some aircraft will continue to be designed with varying local airport noise rules and charges in mind, as today.

2.10.1.3 Operations

- No impact of technology and fuels measures on operations in this scenario.

2.10.1.4 Fuel

- Aviation and ground transport have a level playing field with respect to alternative fuel use.
- Relatively low policy incentives exist for LTAG-SAF and LTAG-LCAF production.
- Technology evolution enables use of waste (CO/CO_2) gases for LTAG-SAF, feedstock from a variety of settings (e.g. oilseed cover crops) cover crops, and use of blue/green hydrogen for LTAG-SAF/LTAG-LCAF production.

2.10.2 Reporting Progress

2.10.2.1 **Requirement:** A process is anticipated for reporting progress towards any goal ultimately adopted. It would be preferable not to duplicate existing processes or place reporting expectations on non-state actors.

2.10.2.2 **Recommendation:** State Action Plans are voluntarily submitted by states under Article 10 of Res A40-18. ICAO provides guidance to states on submitting their Action Plans, including how to calculate the impact of measures. LTAG-TG believes the SAP process could be utilised to report progress towards any LTAG. The process would need to be adapted to include implemented as well as planned measures.

2.10.2.3 **Future work:** LTAG-TG has not sought to develop guidance, including metrics, for state reporting of progress. This could be an item for future work. The Assembly ‘encourages’ and ‘invites’ states to submit SAPs – there is no requirement (e.g. SARP) for states to report their progress to ICAO, except through CORSIA. Future work could also consider whether a process is required for non-state actors to report their progress to ICAO, to complement SAPs.

2.10.2.4 **Other sources of data:** It should also be noted that there are other existing ICAO processes which may produce relevant data including certification data against the ICAO CO_2 standard, and states' emissions reports to ICAO for the purposes of CORSIA (until 2035). Sources outside ICAO could also be relevant – such as industry data or fuel use statistics.

2.10.3 Review

2.10.3.1 **Requirement:** ICAO will need to review any goal ultimately adopted to ensure it remains appropriate, in light of information such as:

- progress towards the goal;
- technological developments;
- progress in other sectors (e.g. renewable energy);
- cost and other impacts on states and airlines; and
- the latest scientific knowledge, including on adaptation to climate change.

2.10.3.2 **Recommendation:** If progress is to be reported every three years through State Action Plans, it makes sense for ICAO's review of any goal to be triennial too. This would allow each CAEP meeting and Assembly to review progress and recommend/decide on any adjustments, in a similar way to the periodic reviews of CORSIA. Review more or less frequently than every three years is not recommended by technical experts. This review could use the information collected through the reporting processes (see left) as well as contextual information such the latest scientific knowledge on climate, as summarised by the CAEP Impacts and Science Group.

2.10.3.3 **Other sources of data:** ICAO could also consider using non-state information to inform its reviews, including for example on SAF availability, technology development and deployment of operational measures.

2.10.4 Capacity building

2.10.4.1 Potential needs for capacity building and assistance identified by LTAG-TG to realise this scenario include:

- Providing concrete solutions to help states reach goals, while understanding likely costs.
- Capacity building on measurement and monitoring of CO_2 emissions from international aviation.
- Workshops on solutions that are already available to be implemented, preferably with examples of successful implementation.

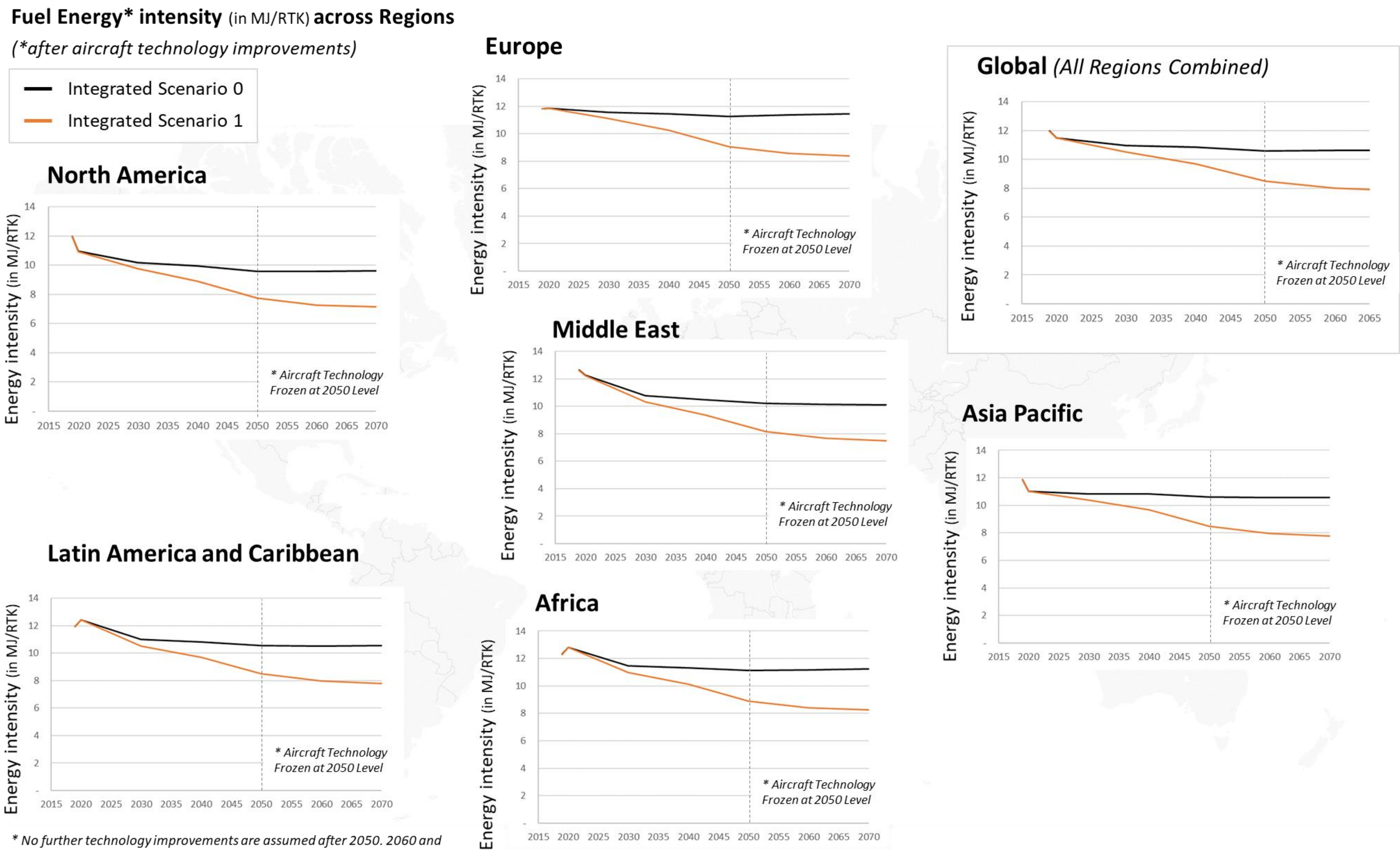
- Potentially a similar training programme to the successful ACT CORSIA.

2.10.4.2 This is not an exhaustive list or a recommendation but is provided for transparency only.

2.11 Regional breakdown

2.11.1 Technology

2.11.1.1 The following graphs show fuel (energy) intensity in MJ/RTK across ICAO regions based on fuel use after technology improvements (for integrated scenario 1).

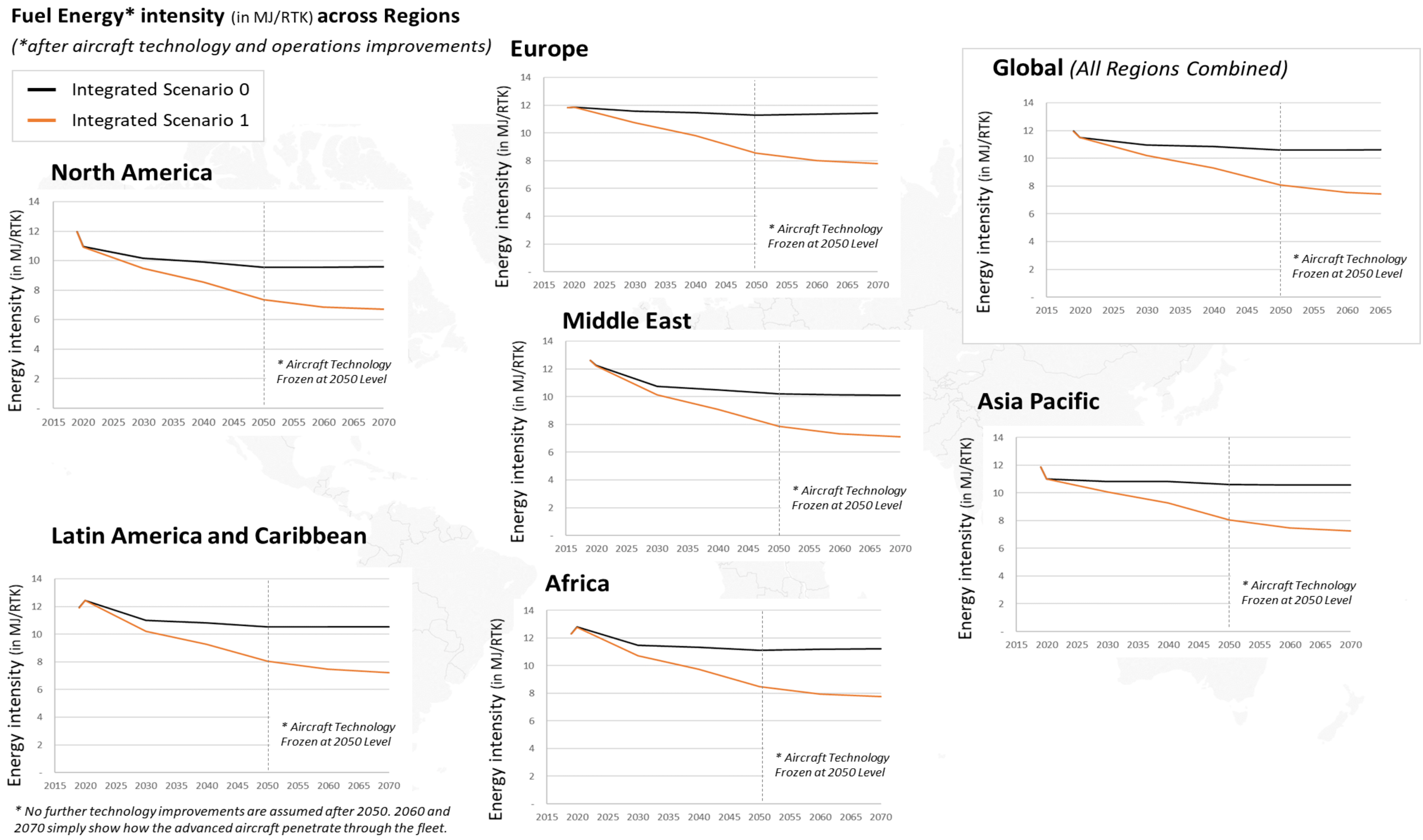


Fuel Energy* intensity (in MJ/RTK) **across Regions**

*(*after aircraft technology improvements)*

** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

2.11.1.2 The following graphs show fuel (energy) intensity in MJ/RTK across ICAO regions based on fuel use after technology and operations improvements (for integrated scenario 1).



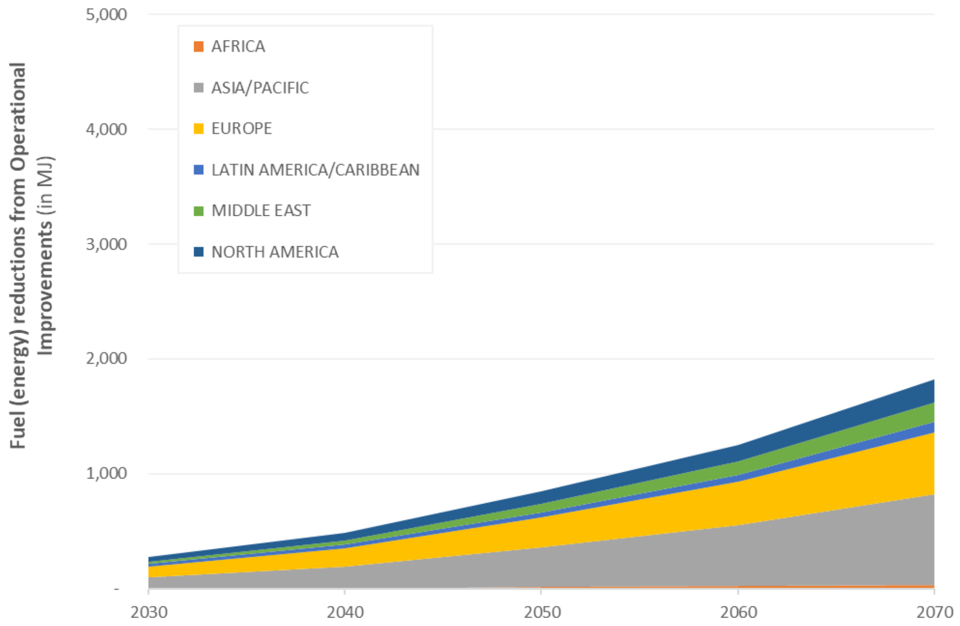
Fuel Energy* intensity (in MJ/RTK) **across Regions**

*(*after aircraft technology and operations improvements)*

** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

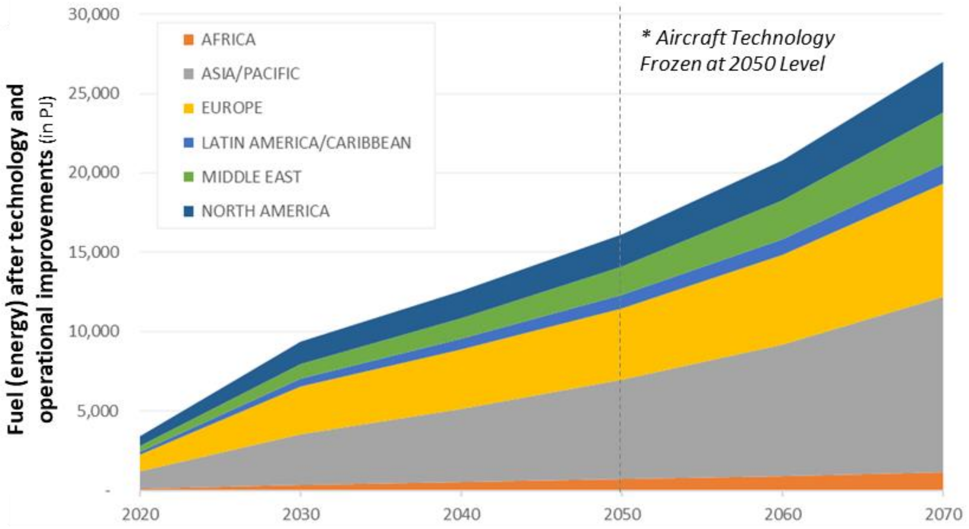
2.11.2 **Operations**

2.11.2.1 The following graph shows regional distribution of fuel (energy) reductions from operational improvements under LTAG-TG integrated scenario 1.



2.11.3 **Fuels**

2.11.3.1 The following graphs show total fleet wide fuel use over time in MJ by ICAO region. This data is based on the state of departure in line with CAEP Trends methodology.



** Aircraft Technology Frozen at 2050 Level*

** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

2.11.3.2 Aviation fuel production, by fuel category, by ICAO region

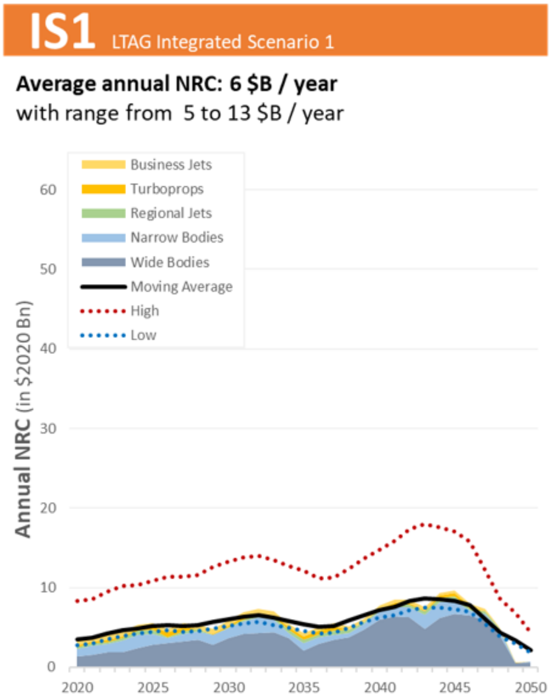
2.11.3.2.1 **LTAG-SAF:** The production and uptake of LTAG-SAF will have regional variability due to feedstock availability and market incentives. The production of LTAG-SAF will depend on resource availability including biomass, solid/liquid wastes and waste CO/CO_2. As economies decarbonize, the availability of waste CO/CO_2 from industrial processes will decrease. The rate at which a region decarbonizes will thus impact LTAG-SAF from waste CO/CO_2 resources. ICAO regions with limited biomass and solid/liquid waste resources will be constrained in overall LTAG-SAF production capacity. Uptake of LTAG-SAF will vary according to regional incentives for low GHG fuels. In regions where these fuels are prioritized and incentivized through established policies, fuel producers and users will be supported to provide and purchase, respectively, these fuels. For example, markets with policies that provide tax credits or mandates for low GHG transportation fuels will lower costs for these fuels and thereby encourage their production and use.

2.11.3.2.2 **LTAG-LCAF:** The production of LTAG-LCAF largely depends on the level of deployment of key mitigation technologies (e.g. renewable integration, CCS, green/blue hydrogen, etc.). Regional variations of market conditions and government incentives will determine the investment and uptake of this type of fuel. Different emissions reduction technologies and practices have varying levels of readiness and attainability in different regions due to various factors including the renewable potential, infrastructure availability, and fiscal environment. The production of LTAG-LCAF depends on the implementation of mitigation measures across the jet fuel supply chain and the scale of adoption in each region.

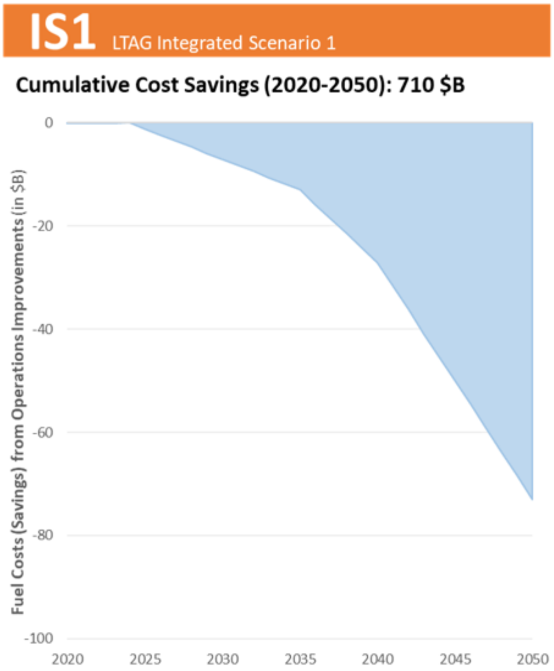
2.11.4 Costs and investments

2.11.4.1 Distribution of costs and investments over time

2.11.4.1.1 Technology

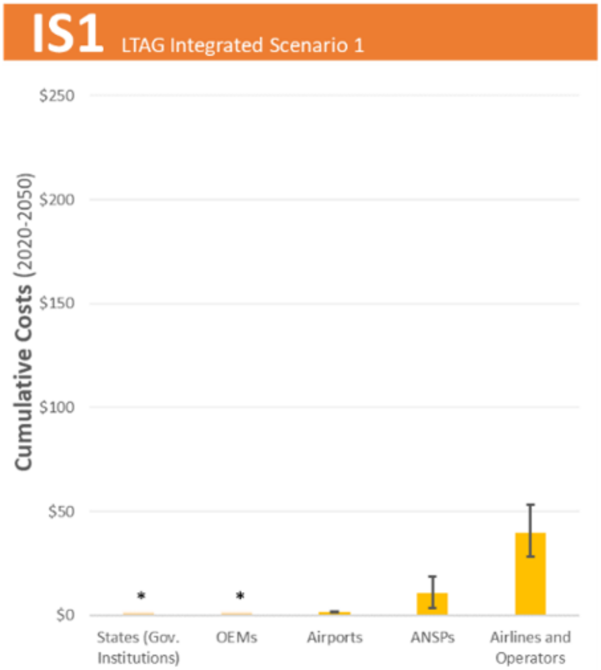

IS1 LTAG Integrated Scenario 1

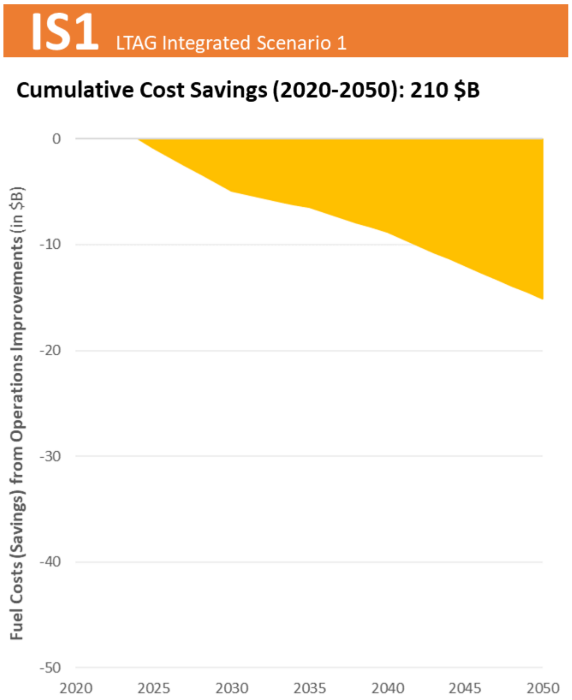
Average annual NRC: 6 $B / year
with range from 5 to 13 $B / year


IS1 LTAG Integrated Scenario 1

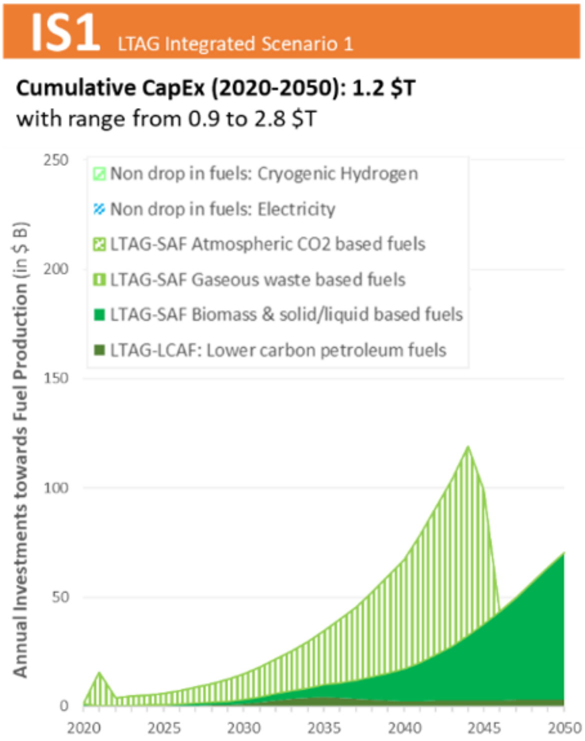
Cumulative Cost Savings (2020-2050): 710 $B

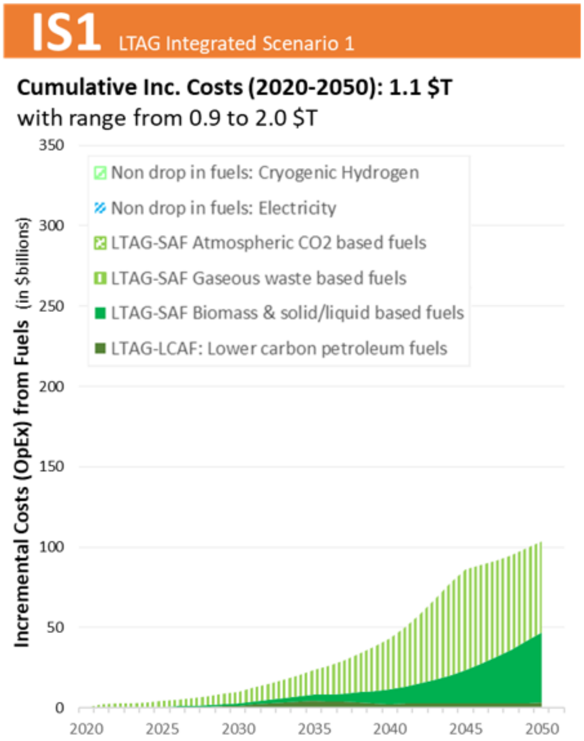
2.11.4.1.2 Operations





2.11.4.1.3 Fuels



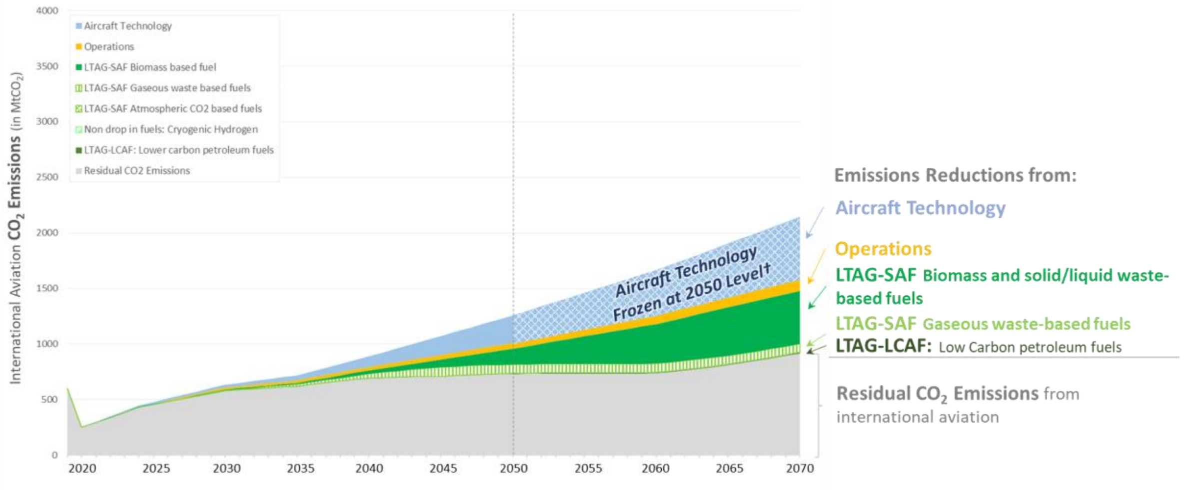


2.11.4.2 Appendix M1, Attachment C provides additional information on the potential regional distribution of costs and investments when data (where data is available).

2.12 Impact of Traffic Forecasts

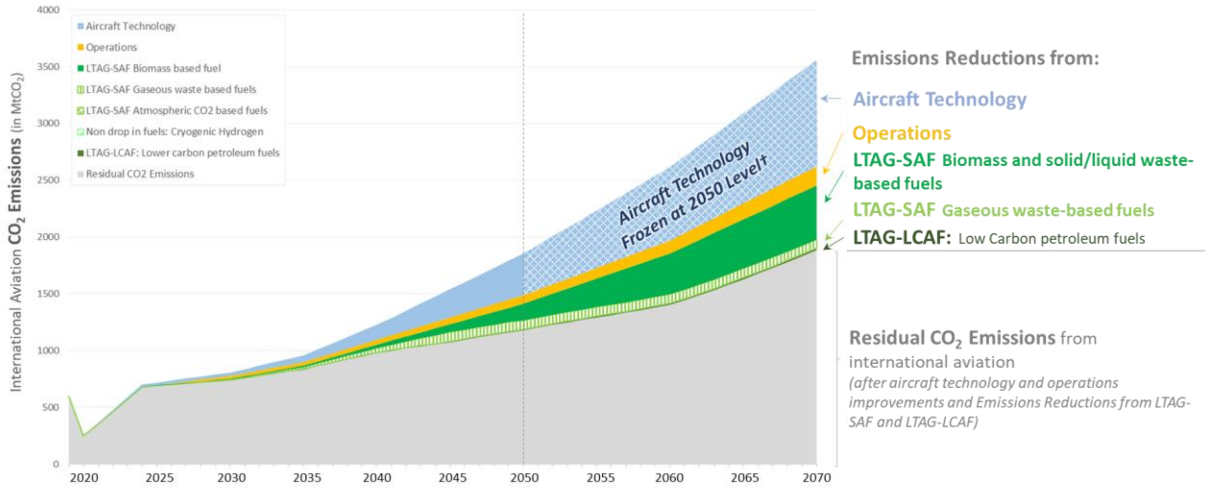
2.12.1 CO_2 emissions

2.12.1.1 Low traffic forecast



† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

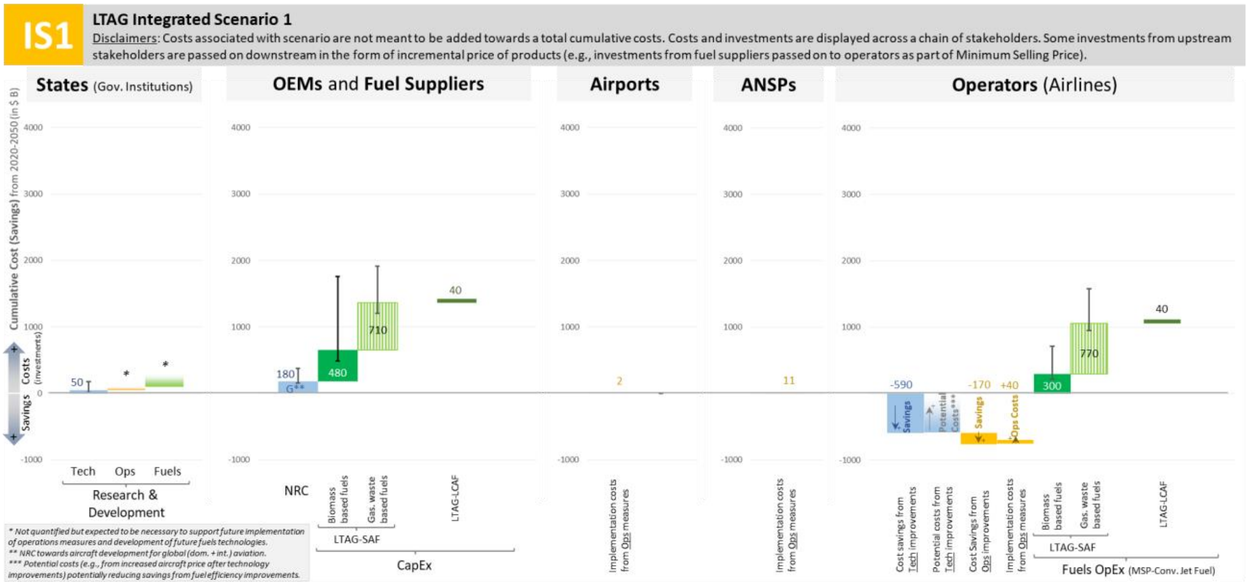
2.12.1.2 High traffic forecast



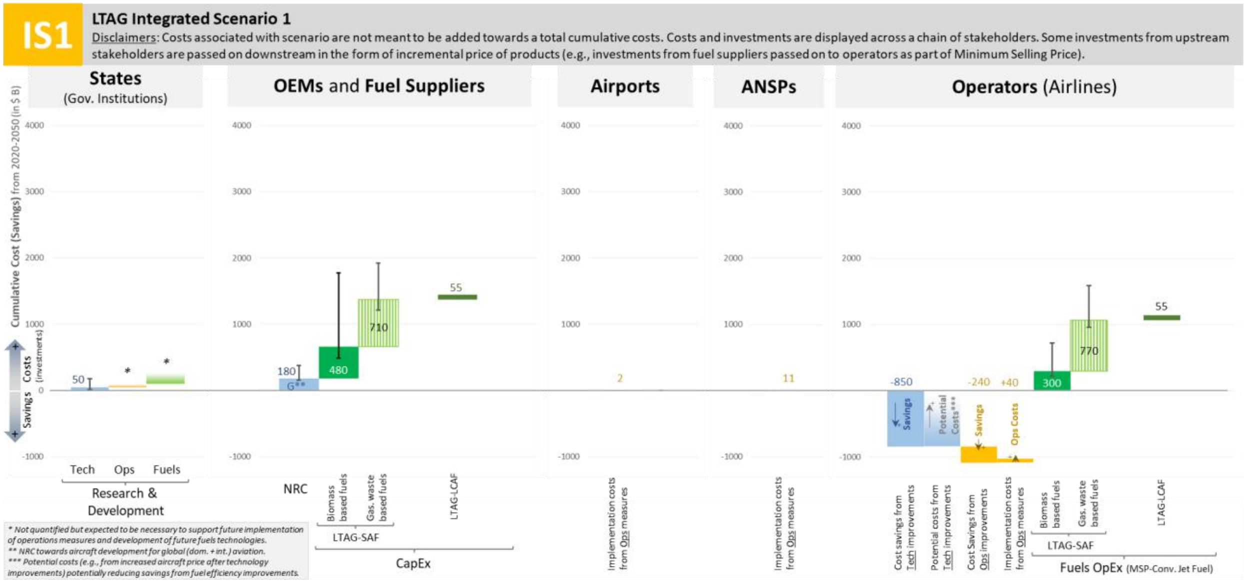
† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

2.12.2 Costs and investments

2.12.2.1 Low traffic forecast



2.12.2.2 High traffic forecast

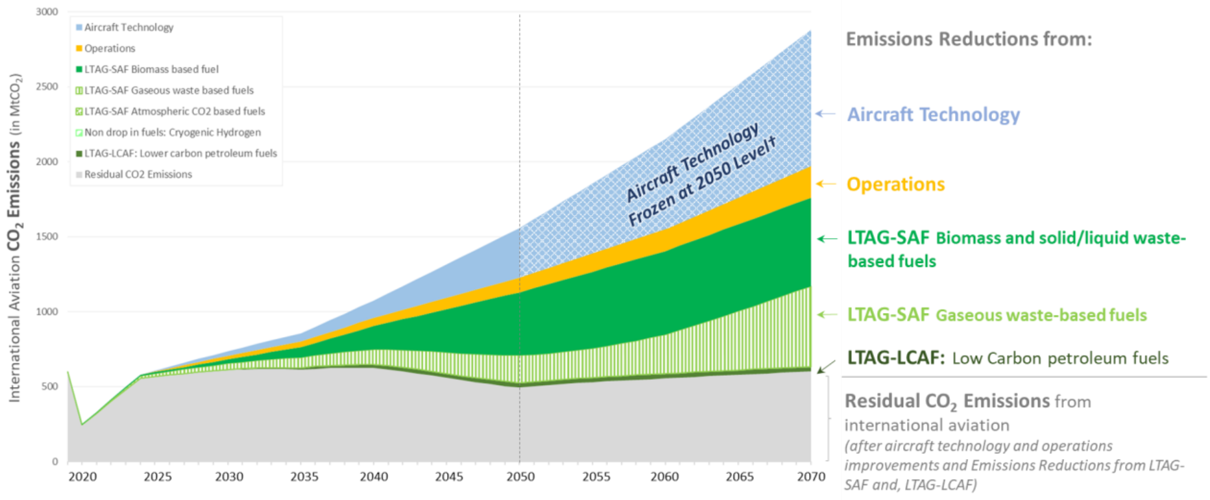


3. INTEGRATED SCENARIO 2

3.1 **Scenario Description:** This increased or further ambition scenario represents an approximate mid-point between the two other scenarios – faster rollout of future technologies, increased operational efficiencies and higher fuel availability. It assumes increased policy enablers for technology, operations and fuels and increased systemic change, for example limited infrastructure changes. Of the three scenarios, it requires medium effort for delivery.

3.2 **Demand Growth Forecast:** The analysis uses the core assumptions and underlying traffic forecasts developed for the COVID-19 Trends analysis including the COVID-19 forecast extension from 2050 to 2070. The LTAG fleet evolution output matches exactly with the Environmental Trends analysis through 2050 in terms of total ASKs, ATKs and operations. For LTAG the fleet evolution forecast, and extension to 2070, was processed for the mid traffic forecast only and then used as the base for applying technology improvements as a post-process. A scalar post-process method was used to estimate the High and Low traffic demand scenarios. The results are consistent with previous Trends analyses and fit-for-purpose for LTAG.

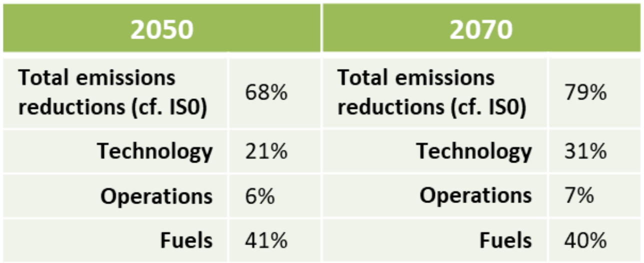
3.3 CO_2 Emissions Results



† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

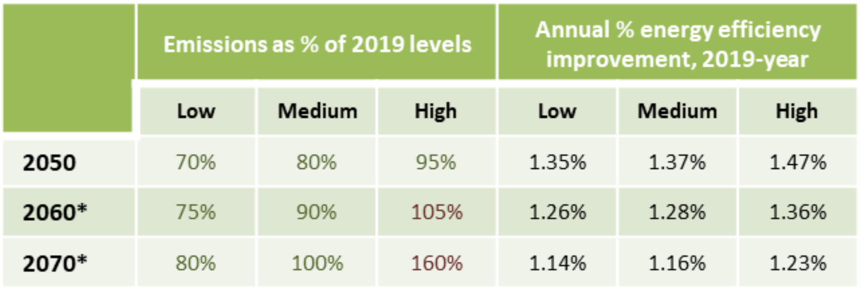
3.3.1 **Annual emissions:** 495 (420-570) $MtCO_2$ from international aviation in 2050 and 600 (490-950) $MtCO_2$ in 2070.

3.3.2 **Cumulative emissions:** 17 (14-20) $GtCO_2$ from international aviation from 2021-2050 and 28 (23-34) $GtCO_2$ from 2021-2070.



2050		2070	
Total emissions reductions (cf. IS0)	68%	Total emissions reductions (cf. IS0)	79%
Technology	21%	Technology	31%
Operations	6%	Operations	7%
Fuels	41%	Fuels	40%

3.4 CO_2 Emissions Results in the Context of the Current ICAO Aspirational Goals



	Emissions as % of 2019 levels			Annual % energy efficiency improvement, 2019-year		
	Low	Medium	High	Low	Medium	High
2050	70%	80%	95%	1.35%	1.37%	1.47%
2060*	75%	90%	105%	1.26%	1.28%	1.36%
2070*	80%	100%	160%	1.14%	1.16%	1.23%

3.4.1 **2020 levels:** As the LTAG-TG Terms of Reference were agreed before COVID-19, LTAG-TG identified that relating its results to “the actual 2020 levels” may no longer be appropriate, given the anomalous nature of international aviation CO_2 emissions in 2020. 2019 is therefore used as it is more representative of a pre-COVID-19 year and consistent with the CORSIA baseline for the Pilot Phase. Percentages are rounded to the nearest 5%.

3.4.2 **Global fuel efficiency:** Fuel efficiency improvement is an average over the whole period (i.e. 2019-2050, 2019-2060 and 2019-2070). It is expressed in terms of the energy used per revenue tonne kilometre performed (MJ/RTK) for consistency between scenarios. For IS1 and IS2 this is directly proportional to the fuel volume per RTK metric stated in Assembly Resolution A40-18.However, it is a system-level fuel efficiency metric rather than an aircraft-level one and may therefore not correlate exactly with the existing near-term aspirational ICAO climate goal.

3.4.3 **Uncertainty:** These estimates are subject to significant levels of uncertainty, arising from factors including but not limited to:

- (*) No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet. See Appendix M3.
- The fleet penetration rate is itself a source of uncertainty. Appendices M1 and M3 provide more information.

- Estimates attract more uncertainty further into the future. The level of confidence we can have both in the estimates used as inputs and the underlying demand forecasts decreases with time. See Appendix M2 for more information about the demand forecasts.

- These uncertainties arise primarily from the input data, the analysis methodology used is similar for all years. See Appendix M1 for a full description of the methodology.

3.5 Regional impacts summary (inc. developing states)

3.5.1 **Technology:** Aircraft technology and associated design decisions will continue to address the global market needs and will not vary by region. Aircraft operators in various regions or states will buy the best aircraft available that meet their needs.

3.5.2 **Operations:** Regional variances in implementation of operational measures are expected with limited infrastructure changes and increased policy enablers.

3.5.3 **Fuels:** The uptake of LTAG-SAF/LTAG-LCAF is not anticipated to be consistent across all world regions due to differences in market dynamics (i.e. countries/regions with favourable low GHG fuel policies will attract greater volumes of these fuels). Additional regional variances are expected regarding the production of LTAG-SAF/LTAG-LCAF due to regional availability of feedstock resources (biomass, solid/liquid wastes). Finally, availability of waste CO/CO_2 resources will have additional regional variability as regions decarbonize at different rates out to 2070.

3.6 Impacts on noise and air quality

3.6.1 **Technology:** Noise and local air quality remain priorities, but improvements will generally not be permitted at the expense of energy use/carbon emissions. Increased operations will adversely impact the 65 DNL contours and emit more NO_x in absolute terms though this is not relevant for certification of individual aircraft designs. Some aircraft will continue to be designed with varying local airport noise rules and charges in mind, as today.

3.6.2 **Operations:** This scenario is not expected to have any impact on air quality. Some vertical flight efficiency measures such as continuous descent operations may provide increased benefits for local noise around airports as the implementation rate increases.

3.6.3 **Fuels:** This scenario is not expected to have any impact on noise. Some improvement in local air quality in airport communities is expected with LTAG-SAF use as these fuels contain low levels of aromatics and generally produce less soot (nvPM - non-volatile particulate matter). Early studies also indicate low aromatic fuels produce less nvPM at cruise altitude and could contribute to a reduction in contrail formation.

3.7 Measures

3.7.1 Technology (See Appendix M3):

- Advanced Concept Aircraft characterized by significant step-changes in performance or capability replace currently dominant aircraft architectures, causing significant architectural / configuration changes at the airframe, propulsion, or combination level.

- T2 technology baskets

3.7.2 **Operations (See Appendix M4):**

- Medium assumptions about rate and extent of implementation of ASBU elements and 15 additional operational measures, based on investment in ground and airborne systems and technologies.

- Medium rate of ASBU element deployment to optimise Horizontal, Vertical and Ground Flight Efficiency

- Low rate of Innovative and Advanced Flight Efficiency measure deployment

3.7.3 **Fuels (See Appendix M5):**

- Use of SAF/LCAF produced from:
    - waste (CO/CO_2) gases
    - increased availability of feedstock from a variety of settings (e.g. oilseed cover crops

- Widespread use of blue/green hydrogen for LTAG-SAF/LTAG-LCAF production
    - Carbon capture, use and storage (CCUS) available

- Use of these fuels at blend levels up to 100%.

3.7.4 **System requirements:** Some limited infrastructure changes are required to accommodate alternative aircraft, such as:

- increased availability of ground charging (including renewable electricity) for hybrid electric aircraft in a range of classes

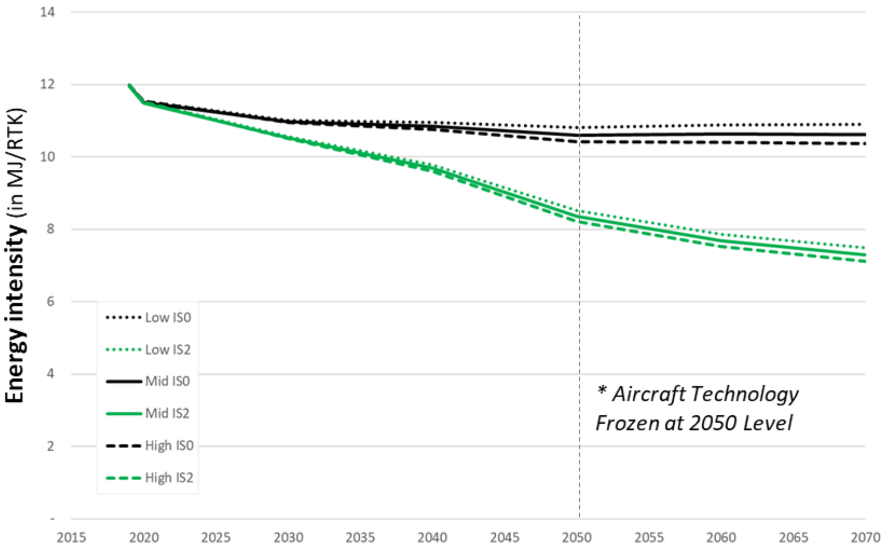
- Continued reliance on liquid hydrocarbon fuel means alternative aircraft infrastructure changes are limited and not expected to impact airport electric loads

- Some airport infrastructure changes required to accommodate alternative configurations

3.8 Additional metrics

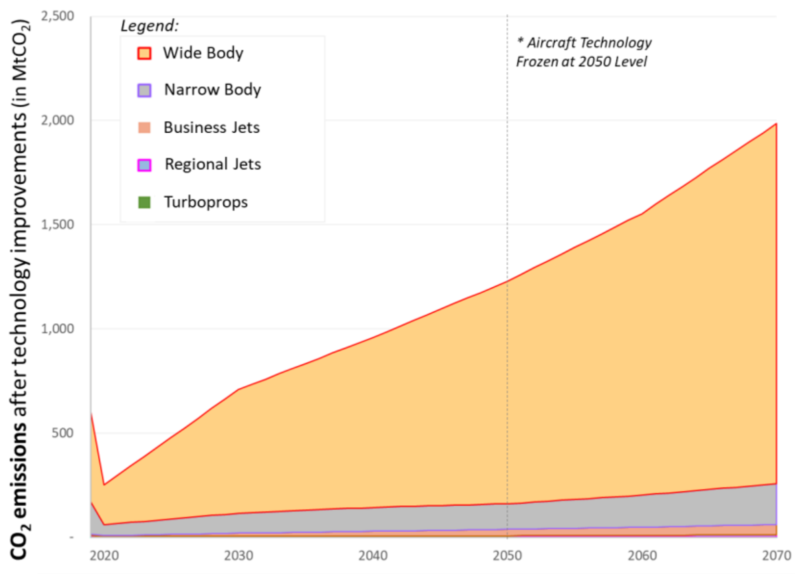
3.8.1 Technology

3.8.1.1 The following graph shows fuel energy intensity (in MJ/RTK) after aircraft technology improvement under LTAG-TG integrated scenario 2.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

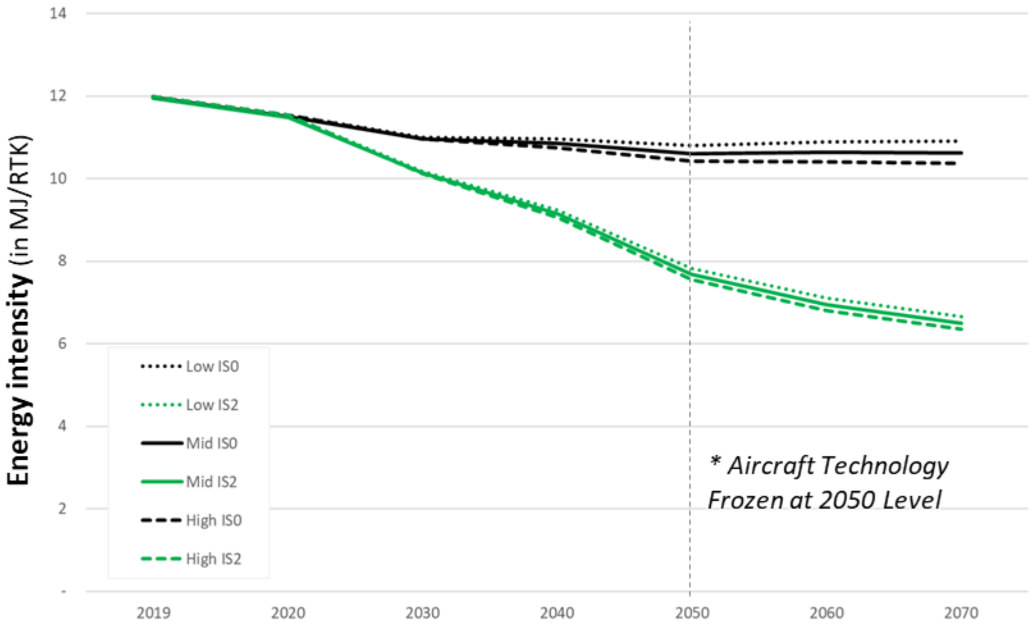
3.8.1.2 The following graph shows the CO$_2$ emissions from international aviation (after aircraft technology improvements) by aircraft class for LTAG-TG integrated scenario 2.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

3.8.2 **Operations**

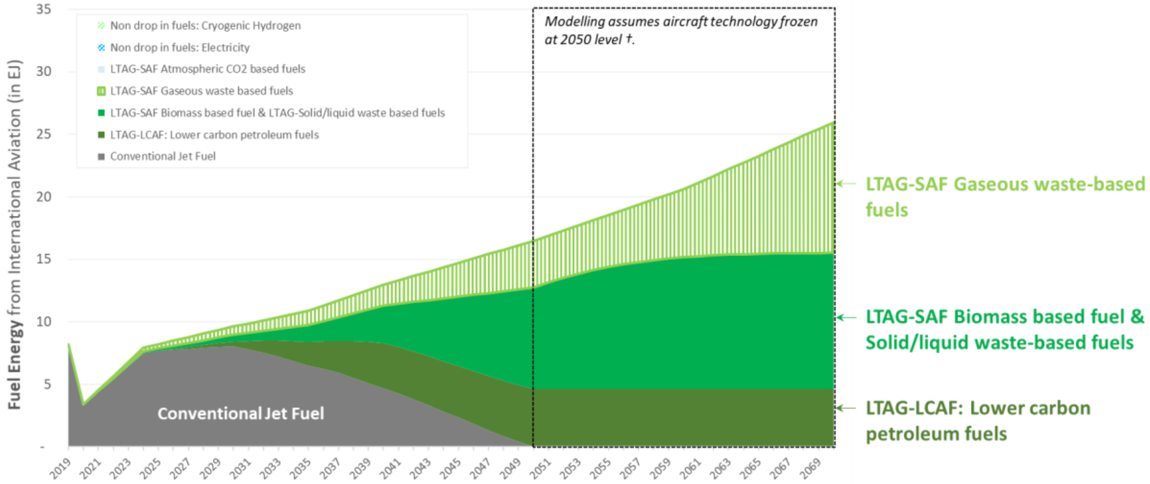
3.8.2.1 The following graph shows fuel energy intensity (in MJ/RTK) after aircraft technology and operational improvements under LTAG-TG integrated scenario 2.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

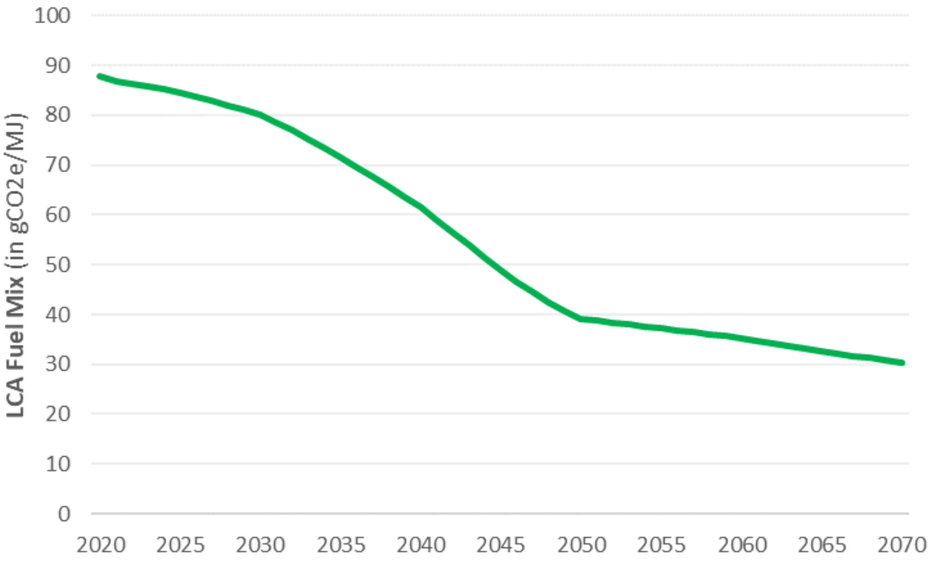
3.8.3 **Fuels**

3.8.3.1 The following graph shows total fleet-wide drop in fuel use over time, in MJ, by LTAG fuel category



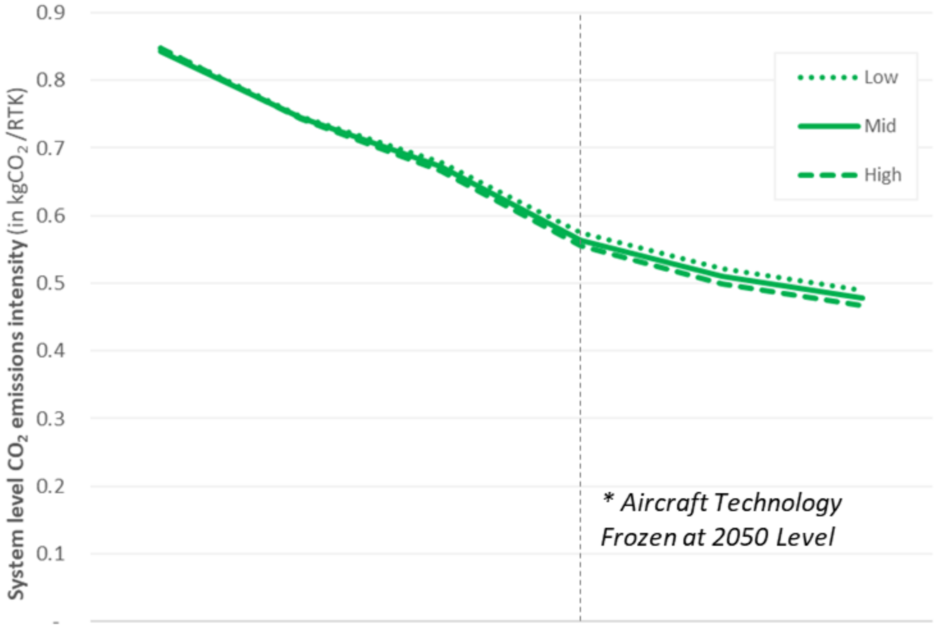
† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

3.8.3.2 The following graph shows the overall lifecycle emissions intensity of the global fuel mix, in gCO_2e/MJ



3.8.4 System efficiency

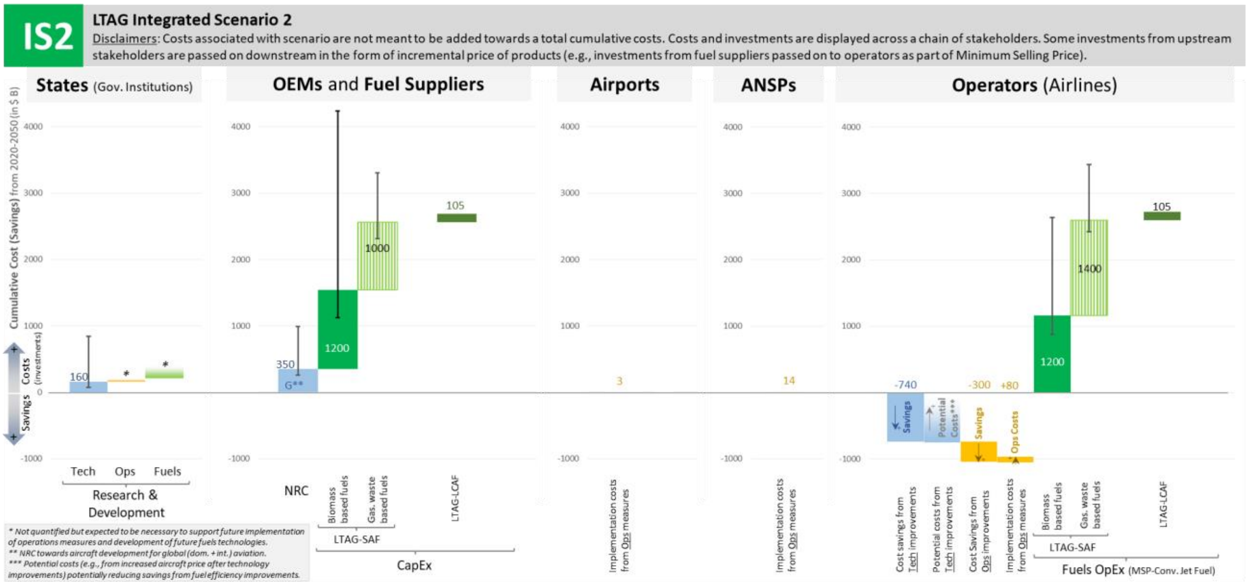
3.8.4.1 The following graph shows the emissions per unit of work (in $kgCO_2/RTK$) over the analysis period.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

3.8.4.2 CO_2/RTK has been selected to show the overall emissions efficiency of the international aviation system in this scenario before the benefits of more efficient fuels are added. This metric is not appropriate to business jets. This metric is consistent with other reporting such as the CAEP Trends and industry assessments. This metric does rely on some assumptions about price and load factor (see Appendix M1 and M2).

3.9 Costs and investments


LTAG Integrated Scenario 2

Disclaimers: Costs associated with scenario are not meant to be added towards a total cumulative costs. Costs and investments are displayed across a chain of stakeholders. Some investments from upstream stakeholders are passed on downstream in the form of incremental price of products (e.g., investments from fuel suppliers passed on to operators as part of Minimum Selling Price).

** Not quantified but expected to be necessary to support future implementation of operations measures and development of future fuels technologies.*
*** NRC towards aircraft development for global (dom. + int.) aviation.*
**** Potential costs (e.g., from increased aircraft price after technology improvements) potentially reducing savings from fuel efficiency improvements.*

Note. - See section 3.12.2 below for results of cost and investments for LOW and HIGH traffic forecasts.

3.9.1 **Technology**

3.9.1.1 Investment by aircraft manufacturers: Around $350 billion (range $260-990B) between 2020 and 2050. On an annual basis this represents ≈ $12 billion per year.

3.9.1.2 R&D support by states: Up to $75-840 billion through 2050.

3.9.1.3 Reduced operator fuel costs: ≈ $740 billion from 2020-2050 but could require incremental investments to cover any incremental aircraft prices (after technology improvements).

3.9.2 **Operations**

3.9.2.1 Investment by airports: $3 billion

3.9.2.2 Investment by ANSPs: $14 billion

3.9.2.3 Investment by airlines: $80 billion

3.9.2.4 Reduced operator fuel costs: ≈ $300 billion from 2020-2050.

3.9.3 **Fuels**

3.9.3.1 SAF biomass-based fuels: Investment of ≈ $1200 billion by 2050 (to cover 53% of international aviation energy use in 2050). Incremental cost to airlines of $1200 billion.

3.9.3.2 Gaseous waste-based fuels: Investment of $1000 billion (19% of energy use in 2050). Incremental cost to airlines of $1400 billion.

3.9.3.3 LTAG-LCAF: Investment of $105 billion (28% of energy use in 2050). Incremental cost to airlines of $105 billion.

3.10 **Roadmaps for implementation**

3.10.1 **Dependencies and Enablers**

3.10.1.1 This scenario includes the following dependencies, interdependencies and assumed policies and incentives:

3.10.1.2 **Technology**

- Some airport infrastructure changes required to accommodate alternative configurations

- Some aircraft will continue to be designed with varying local airport noise rules and charges in mind, as today.

3.10.1.3 Operations

- Increased use of electrical towing vehicles and ground power units necessitates higher availability of renewable electricity.

3.10.1.4 Fuel

- Electrification of ground transportation leads to increased availability of SAF as ground transport uses more electricity and less renewable fuels.

- Increased incentives lead to reduced SAF/LCAF fuel cost for users.

- Technology evolution enables widespread use of waste gases for SAF, increased feedstock availability, and widespread use of blue/green hydrogen for SAF/LCAF production. Carbon Capture Utilization and Storage (CCUS) is in use.

3.10.3 Reporting Progress

3.10.3.1 **Requirement:** A process is anticipated for reporting progress towards any goal ultimately adopted. It would be preferable not to duplicate existing processes or place reporting expectations on non-state actors.

3.10.3.2 **Recommendation:** State Action Plans are voluntarily submitted by states under Article 10 of Res A40-18. ICAO provides guidance to states on submitting their Action Plans, including how to calculate the impact of measures. LTAG-TG believes the SAP process could be utilised to report progress towards any LTAG. The process would need to be adapted to include implemented as well as planned measures.

3.10.3.3 **Future work:** LTAG-TG has not sought to develop guidance, including metrics, for state reporting of progress. This could be an item for future work. The Assembly 'encourages' and 'invites' states to submit SAPs – there is no requirement (e.g. SARP) for states to report their progress to ICAO, except through CORSIA. Future work could also consider whether a process is required for non-state actors to report their progress to ICAO, to complement SAPs.

3.10.3.4 **Other sources of data:** It should also be noted that there are other existing ICAO processes which may produce relevant data including certification data against the ICAO CO_2 standard, and states' emissions reports to ICAO for the purposes of CORSIA (until 2035). Sources outside ICAO could also be relevant – such as industry data or fuel use statistics.

3.10.4 Review

3.10.4.1 **Requirement:** ICAO will need to review any goal ultimately adopted to ensure it remains appropriate, in light of information such as:

- progress towards the goal;
- technological developments;
- progress in other sectors (e.g. renewable energy);
- cost and other impacts on states and airlines; and
- the latest scientific knowledge, including on adaptation to climate change.

3.10.4.2 **Recommendation:** If progress is to be reported every three years through State Action Plans, it makes sense for ICAO's review of any goal to be triennial too. This would allow each CAEP meeting and Assembly to review progress and recommend/decide on any adjustments, in a similar way to the periodic reviews of CORSIA. Review more or less frequently than every three years is not recommended by technical experts. This review could use the information collected through the reporting processes (see left) as well as contextual information such the latest scientific knowledge on climate, as summarised by the CAEP Impacts and Science Group.

3.10.4.3 **Other sources of data:** ICAO could also consider using non-state information to inform its reviews, including for example on SAF availability, technology development and deployment of operational measures.

3.10.5 Capacity building

3.10.5.1 Potential needs for capacity building and assistance identified by LTAG-TG to realise this scenario include:

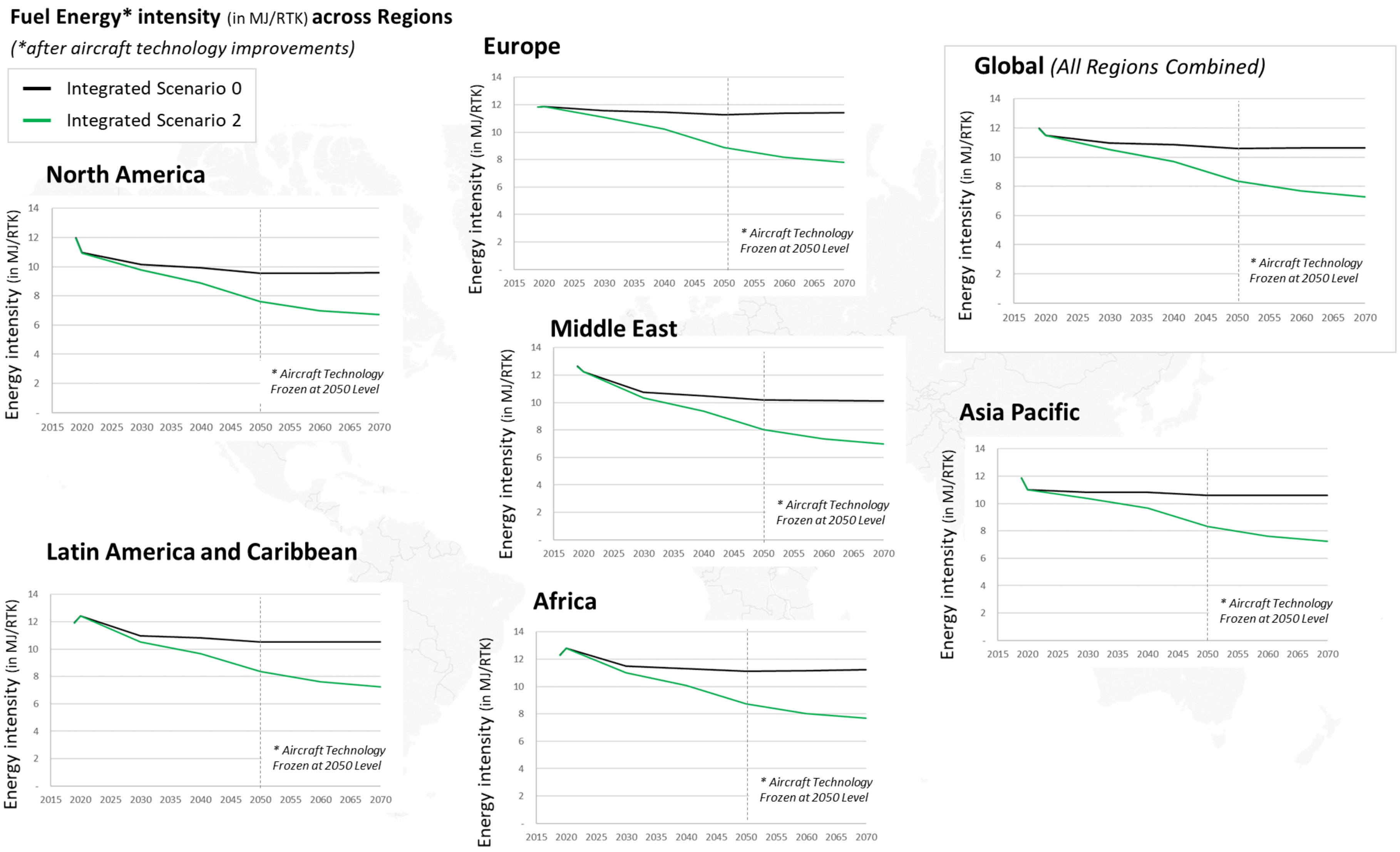
- Providing concrete solutions to help states reach goals, while understanding likely costs.
- Capacity building on measurement and monitoring of CO_2 emissions from international aviation.
- Workshops on solutions that are already available to be implemented, preferably with examples of successful implementation.
- Potentially a similar training programme to the successful ACT CORSIA.

3.10.5.2 This is not an exhaustive list or a recommendation but is provided for transparency only.

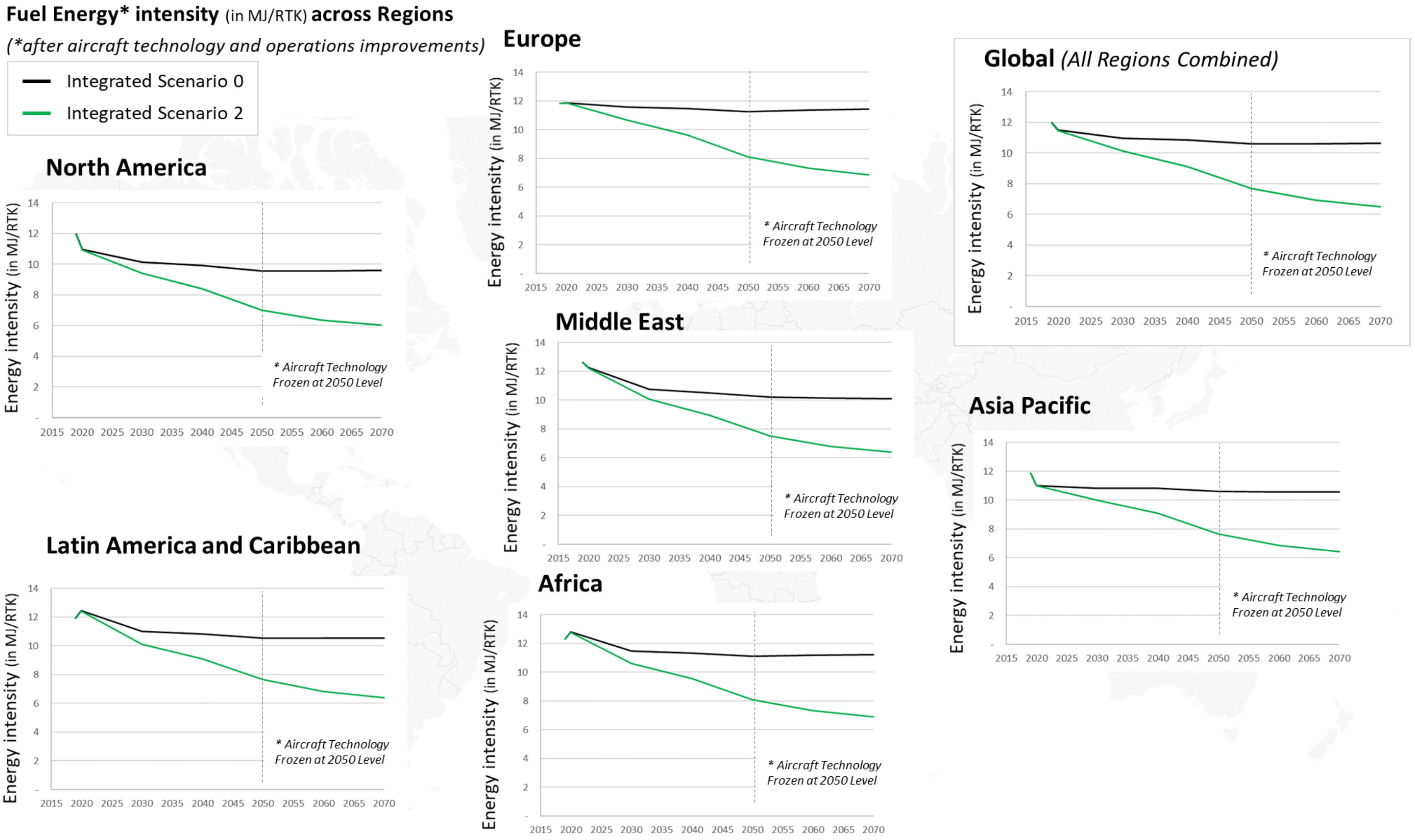
3.11 Regional breakdown

3.11.1 Technology

3.11.1.1 The following graphs show fuel (energy) intensity in MJ/RTK across ICAO regions based on fuel use after technology improvements (for integrated scenario 2).

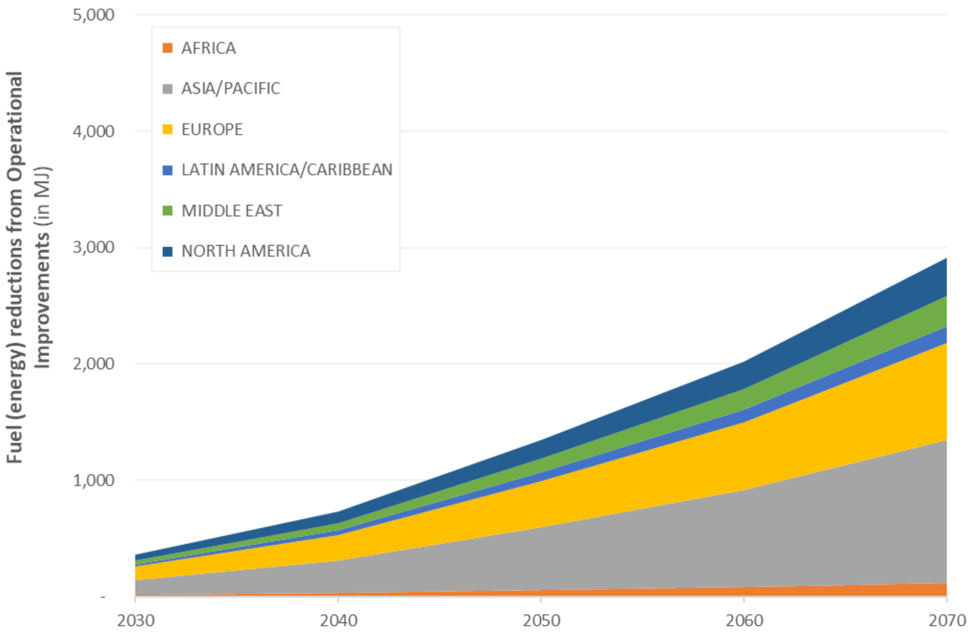

Fuel Energy* intensity (in MJ/RTK) across Regions
(*after aircraft technology improvements)
Integrated Scenario 0
Integrated Scenario 2
North America
Europe
Global (All Regions Combined)
Middle East
Asia Pacific
Latin America and Caribbean
Africa
Energy intensity (in MJ/RTK)
14
12
10
8
6
4
2
-
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
* Aircraft Technology Frozen at 2050 Level

3.11.1.2 The following graphs show fuel (energy) intensity in MJ/RTK across ICAO regions based on fuel use after technology and operational improvements (for integrated scenario 2).



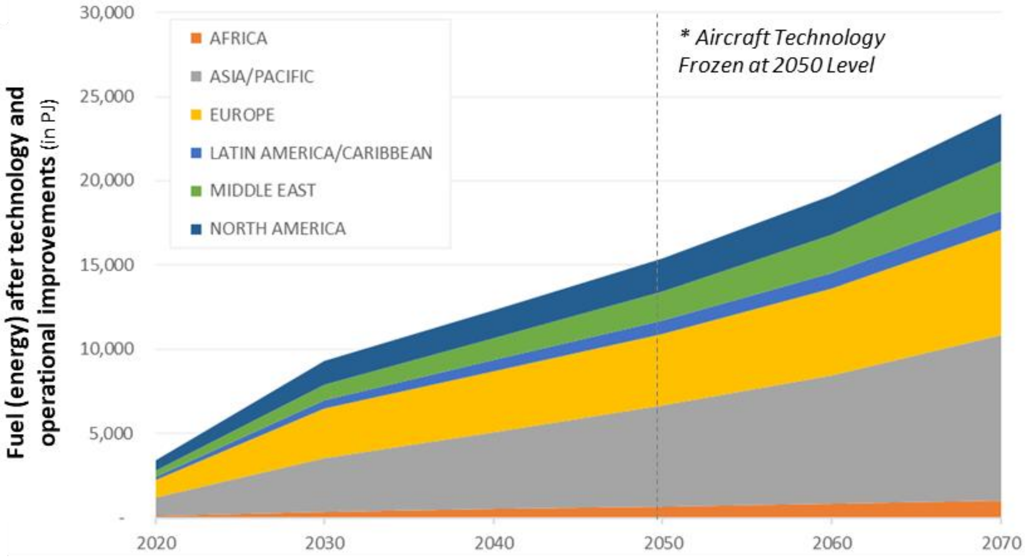
3.11.2 Operations

3.11.2.1 The following graph shows regional distribution of fuel (energy) reductions from operational improvements under LTAG-TG integrated scenario 2.



3.11.3 Fuels

3.11.3.1 The following graphs show total fleet wide fuel use over time in MJ by ICAO region. This data is based on the state of departure in line with CAEP Trends methodology.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

3.11.3.2 Aviation fuel production, by fuel category, by ICAO region

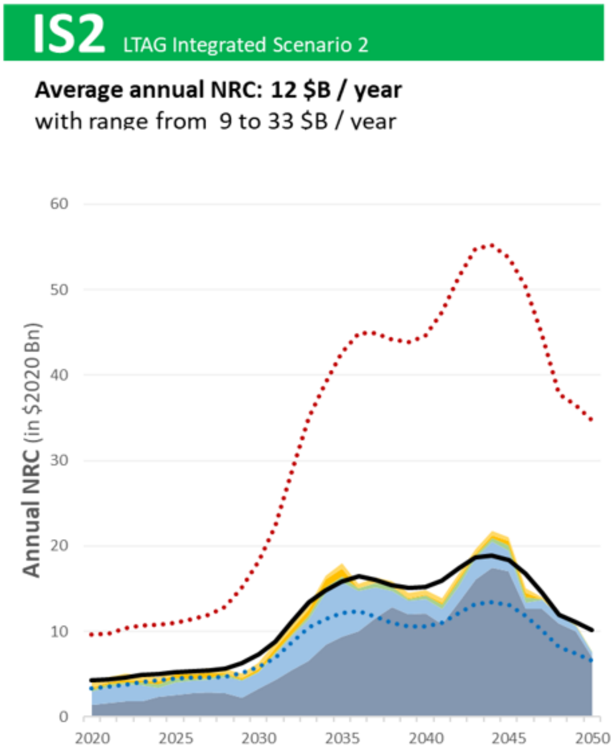
3.11.3.2.1 **LTAG-SAF:** The production and uptake of LTAG-SAF will have regional variability due to feedstock availability and market incentives. The production of LTAG-SAF will depend on resource availability including biomass, solid/liquid wastes and waste CO/CO_2. As economies decarbonize, the availability of waste CO/CO_2 from industrial processes will decrease. The rate at which a region decarbonizes will thus impact LTAG-SAF from waste CO/CO_2 resources. ICAO regions with limited biomass and solid/liquid waste resources will be constrained in overall LTAG-SAF production capacity. Uptake of LTAG-SAF will vary according to regional incentives for low GHG fuels. In regions where these fuels are prioritized and incentivized through established policies, fuel producers and users will be supported to provide and purchase, respectively, these fuels. For example, markets with policies that provide tax credits or mandates for low GHG transportation fuels will lower costs for these fuels and thereby encourage their production and use.

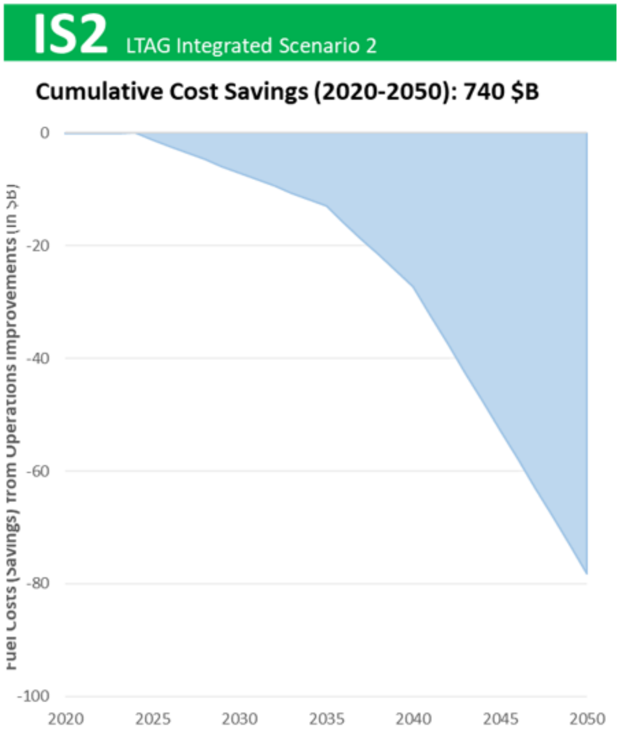
3.11.3.2.2 **LTAG-LCAF:** The production of LTAG-LCAF largely depends on the level of deployment of key mitigation technologies (e.g. renewable integration, CCS, green/blue hydrogen, etc.). Regional variations of market conditions and government incentives will determine the investment and uptake of this type of fuel. Different emissions reduction technologies and practices have varying levels of readiness and attainability in different regions due to various factors including the renewable potential, infrastructure availability, and fiscal environment. The production of LTAG-LCAF depends on the implementation of mitigation measures across the jet fuel supply chain and the scale of adoption in each region.

3.11.4 Costs and investments

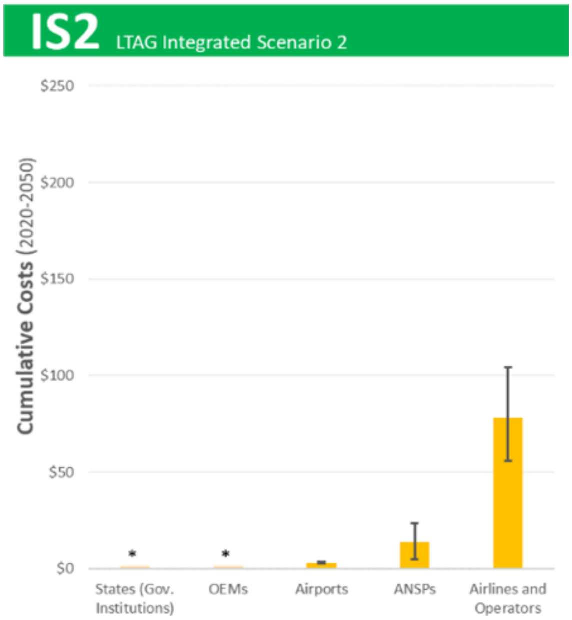
3.11.4.1 Distribution of costs and investments over time

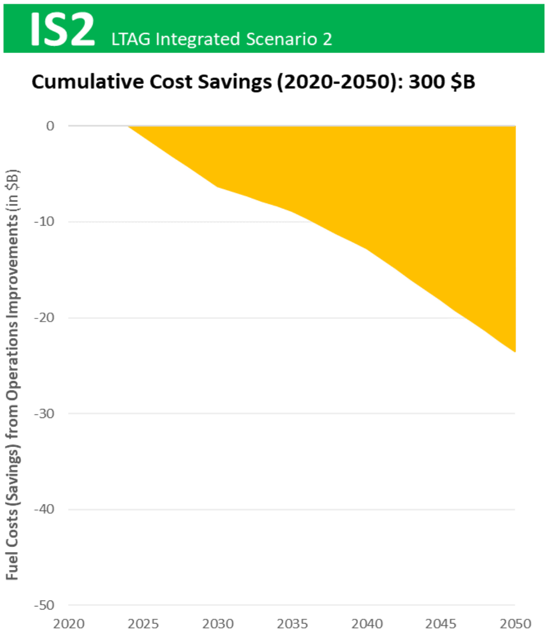
3.11.4.1.1 Technology



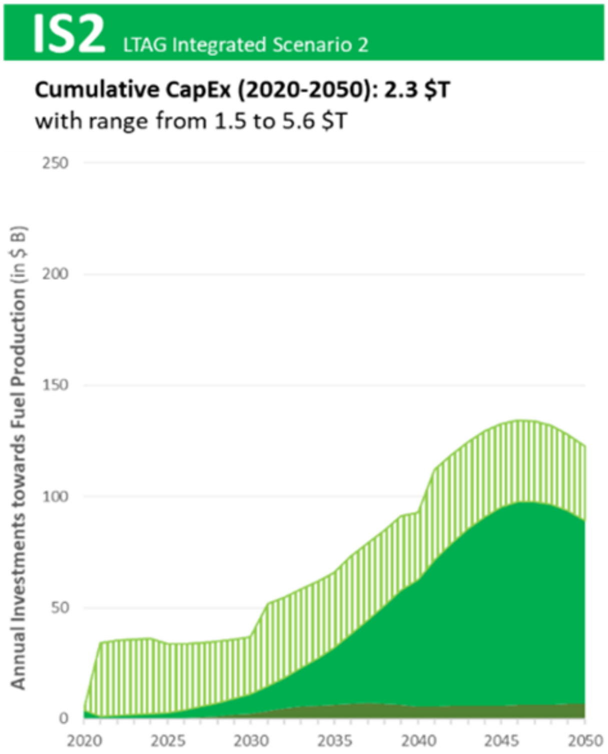


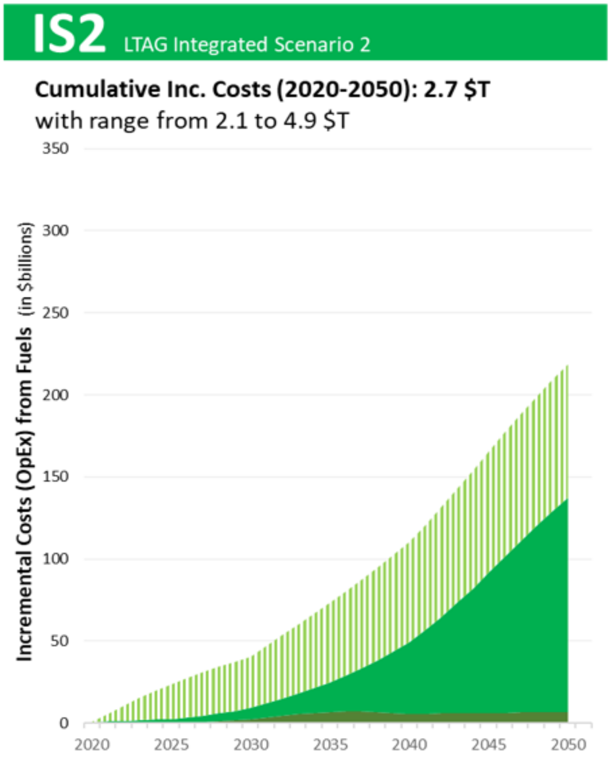
3.11.4.1.2 Operations





3.11.4.1.3 Fuels



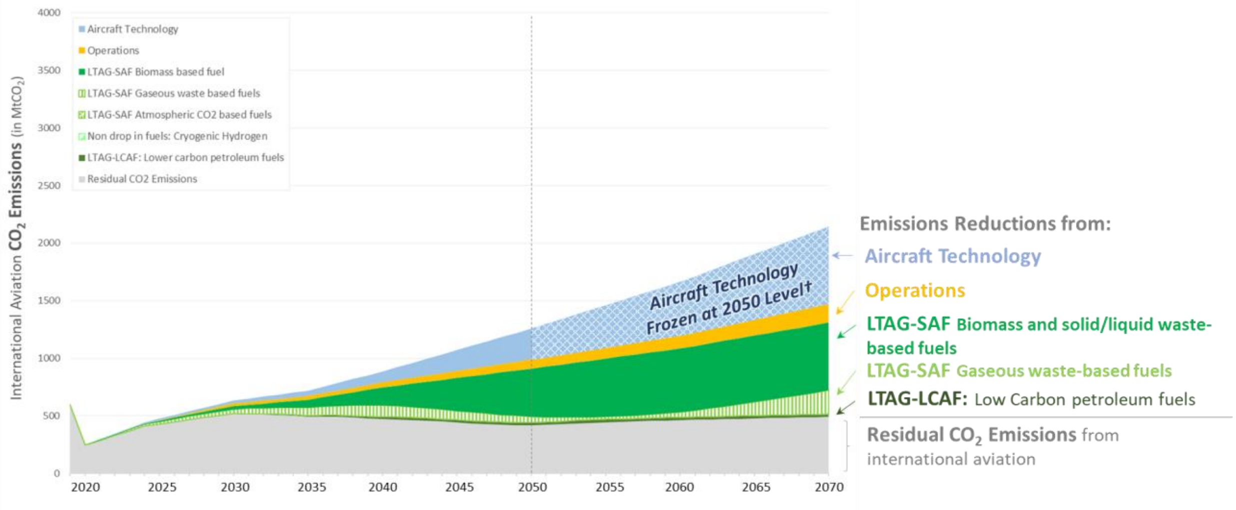


3.11.4.2 Appendix M1, Attachment C provides additional information on the potential regional distribution of costs and investments when data (where data is available).

3.12 Impact of Traffic Forecasts

3.12.1 CO_2 emissions

3.12.1.1 Low traffic forecast



Emissions Reductions from:

Aircraft Technology

Operations

LTAG-SAF Biomass and solid/liquid waste-based fuels

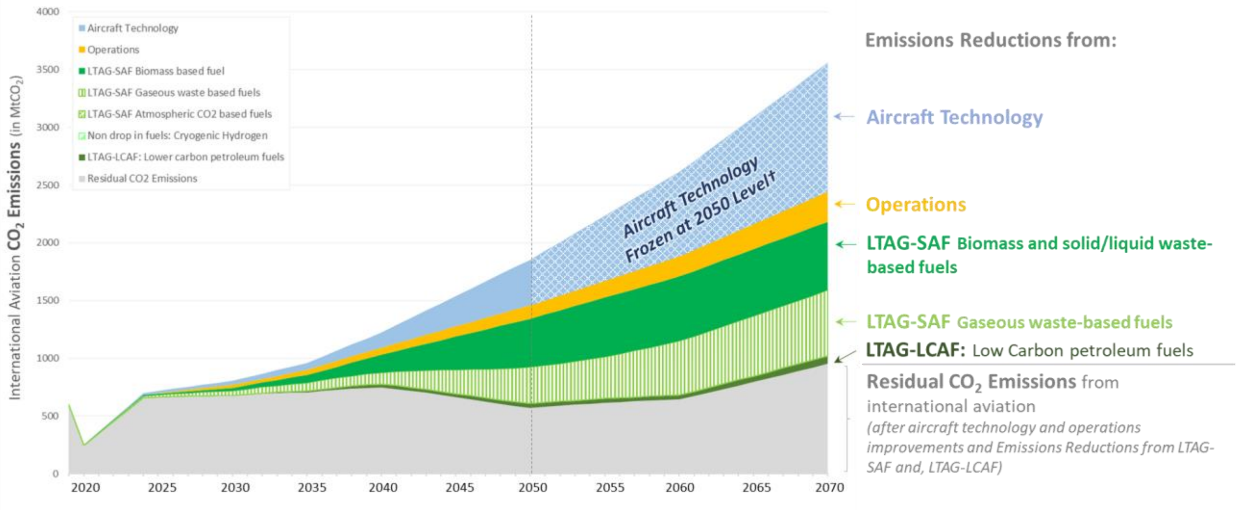
LTAG-SAF Gaseous waste-based fuels

LTAG-LCAF: Low Carbon petroleum fuels

Residual CO_2 Emissions from international aviation

† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

3.12.1.2 High traffic forecast



Emissions Reductions from:

Aircraft Technology

Operations

LTAG-SAF Biomass and solid/liquid waste-based fuels

LTAG-SAF Gaseous waste-based fuels

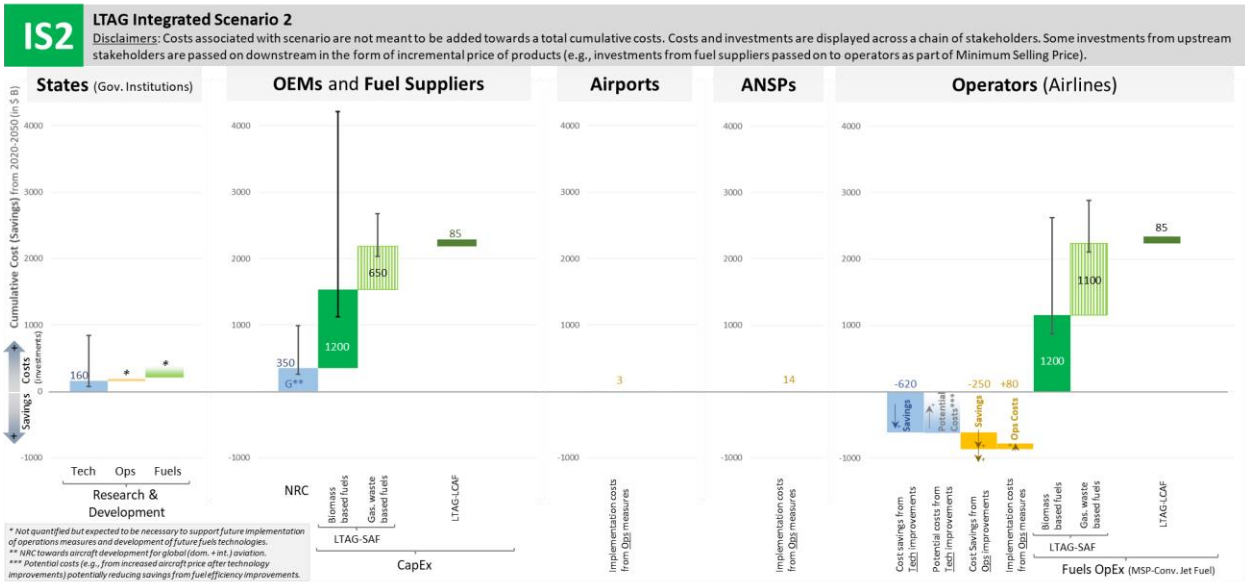
LTAG-LCAF: Low Carbon petroleum fuels

Residual CO_2 Emissions from international aviation
(after aircraft technology and operations improvements and Emissions Reductions from LTAG-SAF and, LTAG-LCAF)

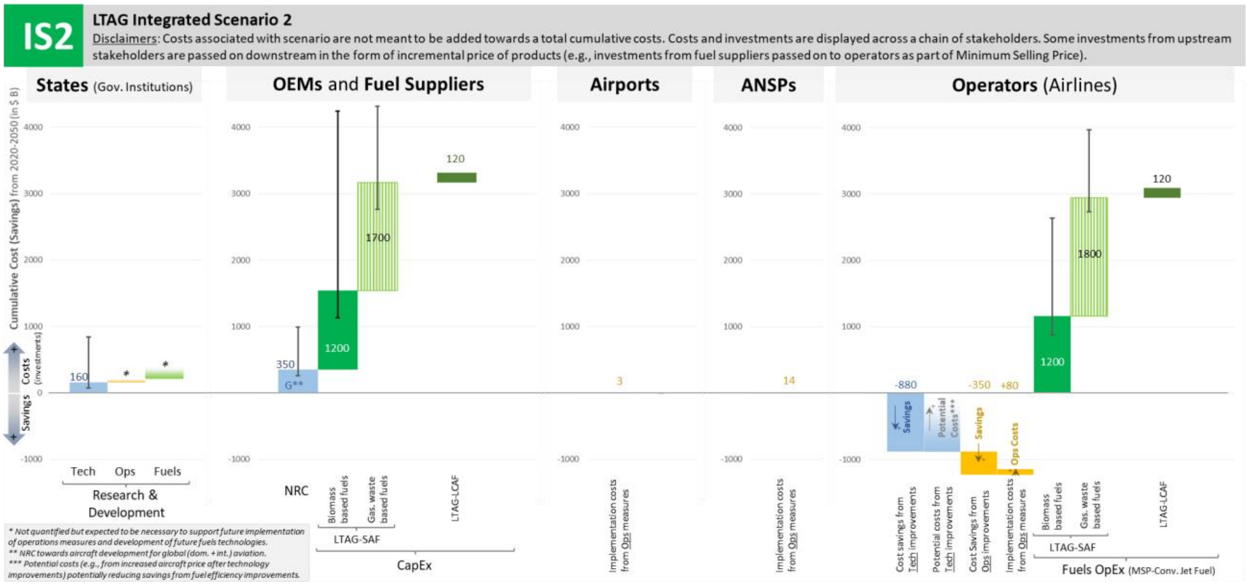
† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

3.12.2 **Costs and investments**

3.12.2.1 Low traffic forecast



3.12.2.2 High traffic forecast

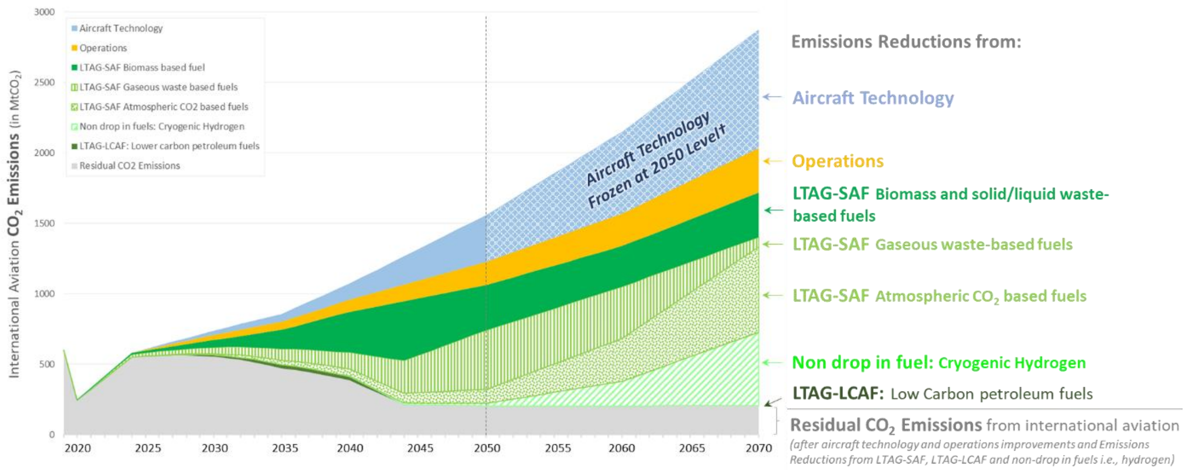


4. INTEGRATED SCENARIO 3

4.1 **Scenario Description:** This aggressive or speculative scenario represents the maximum possible effort in terms of future technology rollout, operational efficiencies, and fuel availability. It assumes maximum policy enablers for technology, operations, and fuels and high, internationally aligned systemic change, for example significant and broad change to airport and energy infrastructure. Of the three scenarios, it requires the highest effort for delivery.

4.2 **Demand Growth Forecast:** The analysis uses the core assumptions and underlying traffic forecasts developed for the COVID-19 Trends analysis including the COVID-19 forecast extension from 2050 to 2070. The LTAG fleet evolution output matches exactly with the Environmental Trends analysis through 2050 in terms of total ASKs, ATKs and operations. For LTAG the fleet evolution forecast, and extension to 2070, was processed for the mid traffic forecast only and then used as the base for applying technology improvements as a post-process. A scalar post-process method was used to estimate the High and Low traffic demand scenarios. The results are consistent with previous Trends analyses and fit-for-purpose for LTAG.

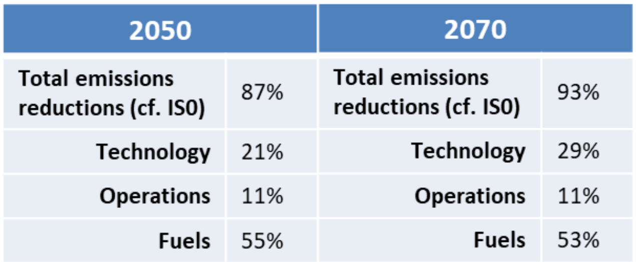
4.3 CO_2 Emissions Results



† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

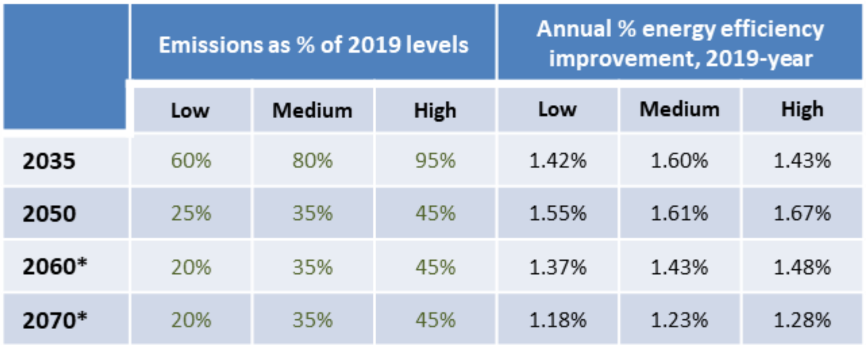
4.3.1 **Annual emissions:** 200 (150-260) $MtCO_2$ from international aviation in 2050 and 210 (130-285) $MtCO_2$ in 2070.

4.3.2 **Cumulative emissions:** 12 (10-15) $GtCO_2$ from international aviation from 2021-2050 and 16 (12-20) $GtCO_2$ from 2021-2070.



2050		2070	
Total emissions reductions (cf. IS0)	87%	Total emissions reductions (cf. IS0)	93%
Technology	21%	Technology	29%
Operations	11%	Operations	11%
Fuels	55%	Fuels	53%

4.4 CO_2 Emissions Results in the Context of the Current ICAO Aspirational Goals



	Emissions as % of 2019 levels			Annual % energy efficiency improvement, 2019-year		
	Low	Medium	High	Low	Medium	High
2035	60%	80%	95%	1.42%	1.60%	1.43%
2050	25%	35%	45%	1.55%	1.61%	1.67%
2060*	20%	35%	45%	1.37%	1.43%	1.48%
2070*	20%	35%	45%	1.18%	1.23%	1.28%

4.4.1 **2020 levels:** As the LTAG-TG Terms of Reference were agreed before COVID-19, LTAG-TG identified that relating its results to “the actual 2020 levels” may no longer be appropriate, given the anomalous nature of international aviation CO_2 emissions in 2020. 2019 is therefore used as it is more representative of a pre-COVID-19 year and consistent with the CORSIA baseline for the Pilot Phase. Percentages are rounded to the nearest 5%.

4.4.2 **Global fuel efficiency:** Fuel efficiency improvement is an average over the whole period (i.e. 2019-2050, 2019-2060 and 2019-2070). It is expressed in terms of the energy used per revenue tonne kilometre performed (MJ/RTK) for consistency between scenarios. For IS1 and IS2 this is directly proportional to the fuel volume per RTK metric stated in Assembly Resolution A40-18. However, it is a system-level fuel efficiency metric rather than an aircraft-level one and may therefore not correlate exactly with the existing near-term aspirational ICAO climate goal.

4.4.3 **Impact of non-drop-in fuels:** In this scenario, the impact of non-drop-in fuelled aircraft in this scenario after 2035 is not captured by the fuel efficiency metric in Assembly Resolution A40-18. Energy efficiency, in MJ/RTK, is therefore shown to capture both drop-in and non-drop-in fuels.

4.4.4 **Uncertainty:** These estimates are subject to significant levels of uncertainty, arising from factors including but not limited to:

- (*) No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet. See Appendix M3.
- The fleet penetration rate is itself a source of uncertainty. Appendices M1 and M3 provide more information.
- Estimates attract more uncertainty further into the future. The level of confidence we can have both in the estimates used as inputs and the underlying demand forecasts decreases with time. See Appendix M2 for more information about the demand forecasts.
- These uncertainties arise primarily from the input data, the analysis methodology used is similar for all years. See Appendix M1 for a full description of the methodology.

4.5 Regional impacts summary (inc. developing states)

4.5.1 **Technology:** Aircraft technology and associated design decisions will continue to address the global market needs and will not vary by region. Aircraft operators in various regions or states will buy the best aircraft available that meet their needs.

4.5.2 **Operations:** Regional variances in implementation of operational measures are increased with maximum infrastructure changes and highest policy enablers.

4.5.3 **Fuels:** The uptake of LTAG-SAF/LTAG-LCAF is not anticipated to be consistent across all world regions due to differences in market dynamics (i.e. countries/regions with favourable low GHG fuel policies will attract greater volumes of these fuels). Additional regional variances are expected regarding the production of LTAG-SAF/LTAG-LCAF due to regional availability of feedstock resources (biomass, solid/liquid wastes). Finally, availability of waste CO/CO_2 resources will have additional regional variability as regions decarbonize at different rates out to 2070. Cryogenic hydrogen uptake will not be consistent across all global regions due to variability in development of renewable electricity resources and significant infrastructure investments required to accommodate cryogenic hydrogen aviation systems.

4.6 Impacts on noise and air quality

4.6.1 **Technology:** Noise and local air quality remain priorities, but improvements will generally not be permitted at the expense of energy use/carbon emissions. Increased operations will adversely impact the 65 DNL contours and emit more NOx in absolute terms though this is not relevant for certification of individual aircraft designs. Some aircraft will continue to be designed with varying local airport noise rules and charges in mind, as today.

4.6.2 **Operations:** This scenario is not expected to have any impact on air quality. Some vertical flight efficiency measures such as continuous descent operations may provide increased benefits for local noise around airports as the implementation rate increases.

4.6.3 **Fuels:** This scenario is not expected to have any impact on noise. Some improvement in local air quality in airport communities is expected with LTAG-SAF use as these fuels contain low levels of aromatics and generally produce less soot (nvPM - non-volatile particulate matter). Early studies also indicate low aromatic fuels produce less nvPM at cruise altitude and could contribute to a reduction in contrail formation. Additionally, use of cryogenic hydrogen would eliminate nvPM emissions at ground and cruise conditions. The impact of hydrogen aircraft on contrail formation is not well characterized at this time.

4.7 Measures

4.7.1 Technology (See Appendix M3):

- Advanced Concept Aircraft, ACAs, characterized by significant step-changes in performance or capability replace currently dominant aircraft architectures *and* require major systemic changes such as significant infrastructure change at the airport and likely beyond.
- T3 technology baskets

4.7.2 Operations (See Appendix M4):

- Aggressive assumptions about rate and extent of implementation of ASBU elements and 15 additional operational measures, based on higher/accelerated investment in ground and airborne systems and technologies.
- High rate of ASBU element deployment to optimise Horizontal, Vertical and Ground Flight Efficiency
- Medium rate of Innovative and Advanced Flight Efficiency measure deployment

4.7.3 Fuels (See Appendix M5):

- Use of LTAG-SAF/LTAG-LCAF produced using:
    - waste (CO/CO_2) gases and atmospheric CO_2
    - further increased availability of feedstock from a variety of settings (e.g. oilseed cover crops)
    - widespread carbon capture, use and storage (CCUS)
- Use of these fuels approved at blend levels up to 100%.
- Cryogenic H_2 use in aircraft.

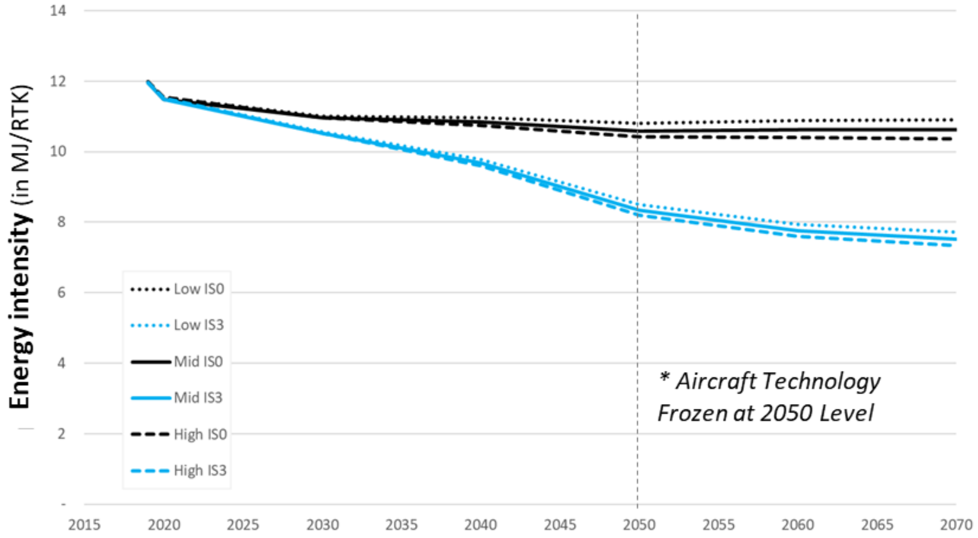
4.7.4 **System requirements:** High, internationally aligned systemic change - e.g. significant and broad change to airport and energy infrastructure. Major infrastructure changes are required to accommodate alternative aircraft, such as:

- Ground infrastructure to accommodate liquid hydrogen, battery or hydrogen fuel cell electric aircraft
- Airport infrastructure changes required to accommodate these alternative configurations

4.8 Additional metrics

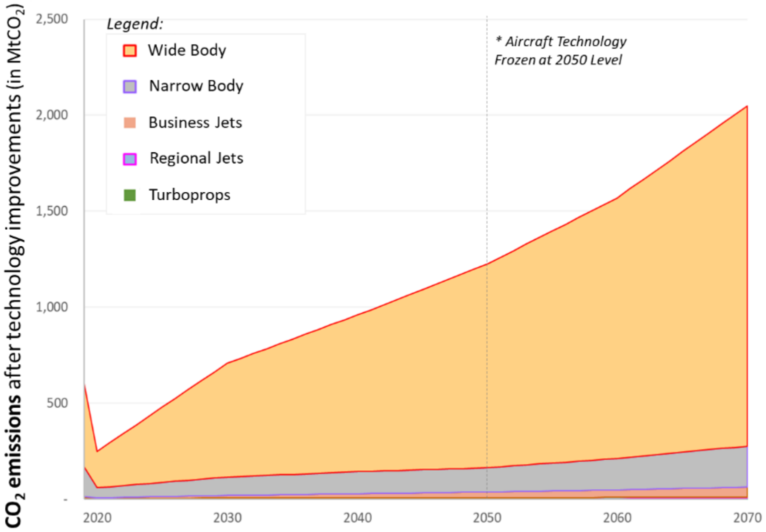
4.8.1 Technology

4.8.1.1 The following graph shows fuel energy intensity (in MJ/RTK) after aircraft technology improvement under LTAG-TG integrated scenario 3.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

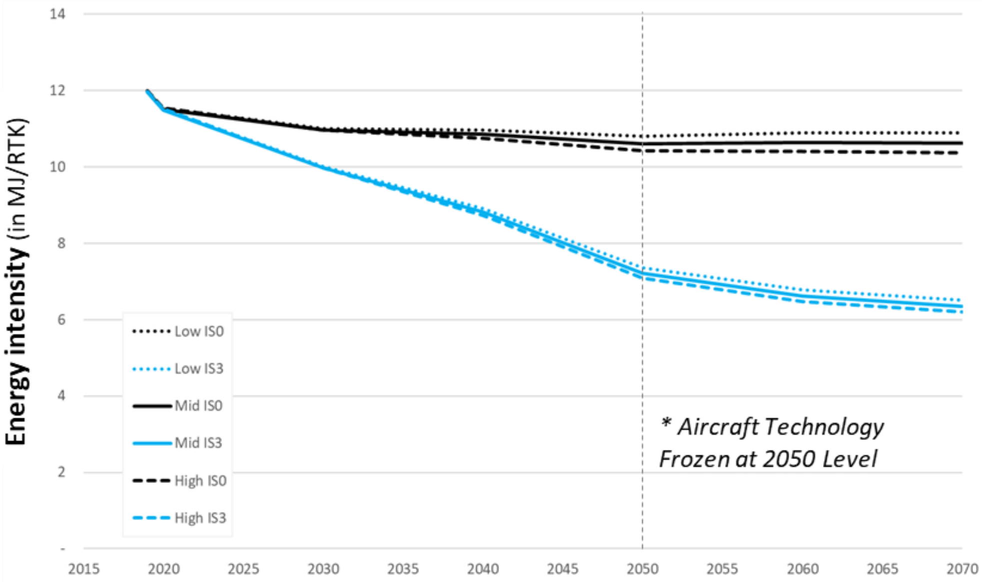
4.8.1.2 The following graph shows the CO_2 emissions from international aviation (after aircraft technology improvements) by aircraft class for LTAG-TG integrated scenario 3.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

4.8.2 Operations

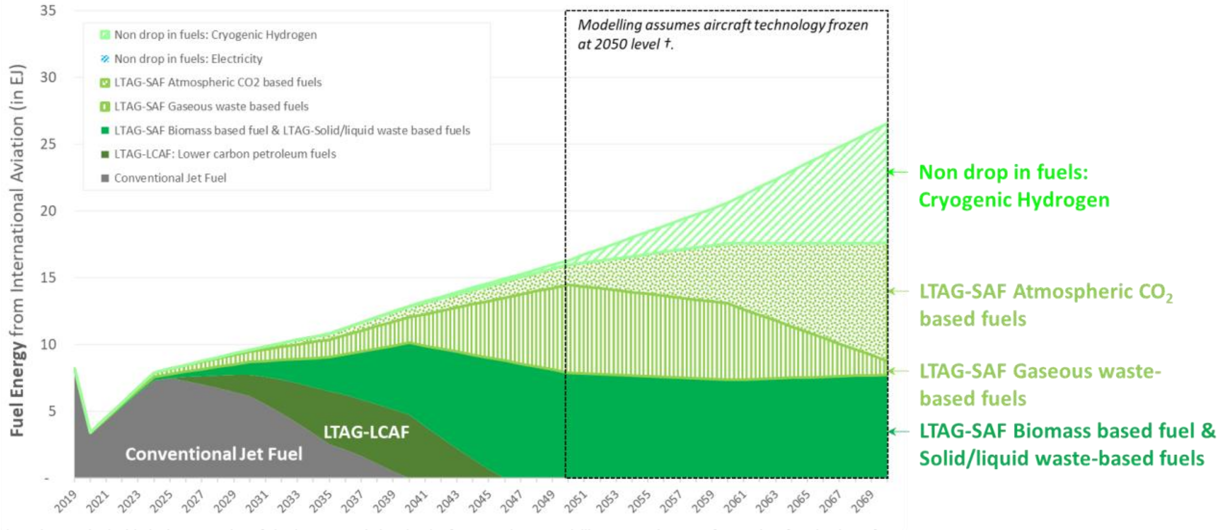
4.8.2.1 The following graph shows fuel energy intensity (in MJ/RTK) after aircraft technology and operational improvements under LTAG-TG integrated scenario 3.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

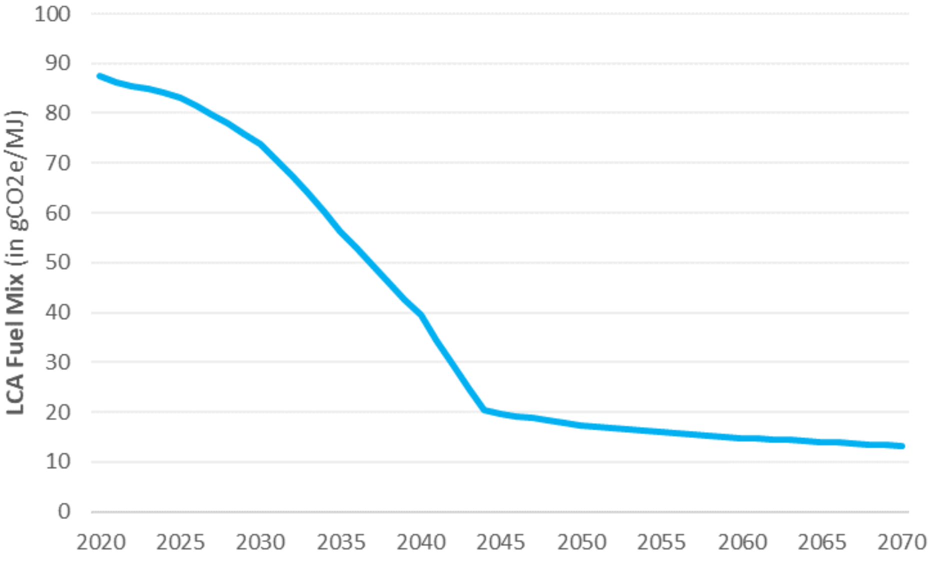
4.8.3 Fuels

4.8.3.1 The following graph shows total fleet-wide drop in fuel use over time, in MJ, by LTAG fuel category



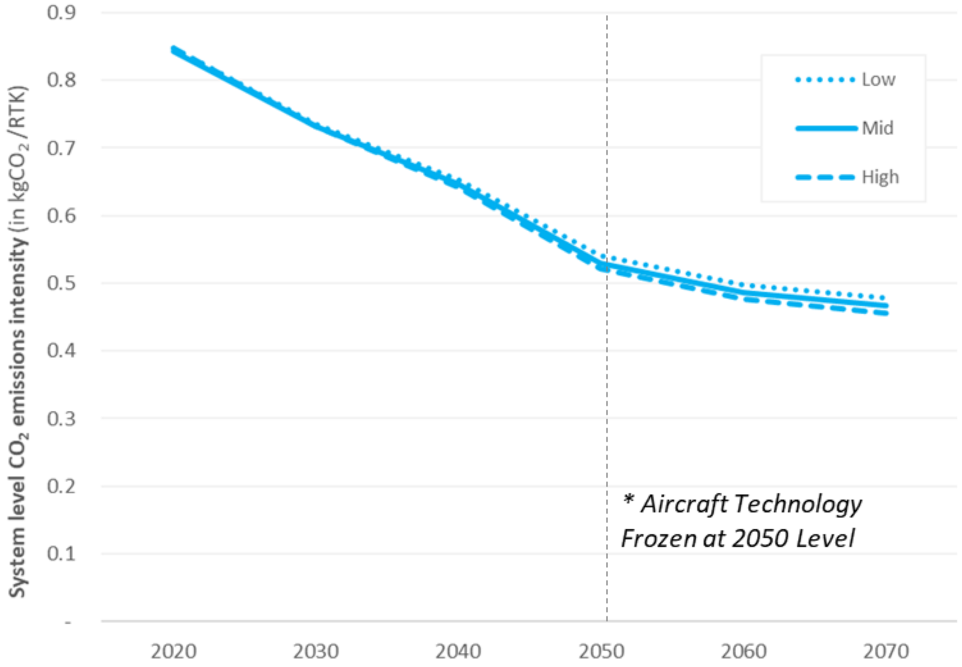
† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

4.8.3.2 The following graph shows the overall lifecycle emissions intensity of the global fuel mix, in gCO_2e/MJ



4.8.4 System efficiency

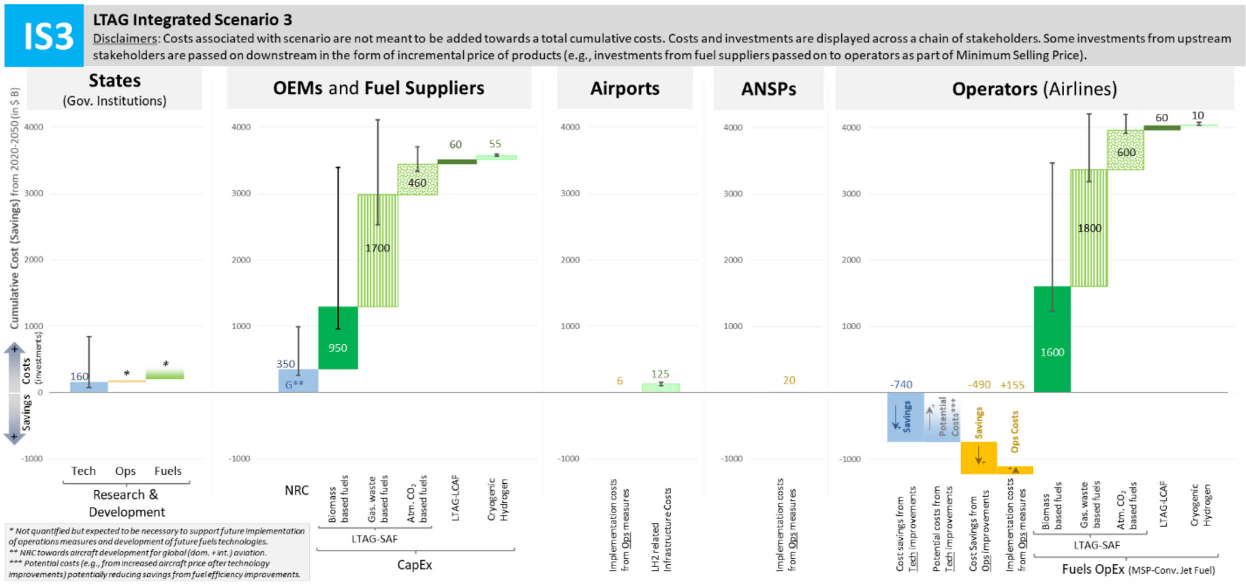
4.8.4.1 The following graph shows the emissions per unit of work (in $kgCO_2/RTK$) over the analysis period.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

4.8.4.2 CO_2/RTK has been selected to show the overall emissions efficiency of the international aviation system in this scenario before the benefits of more efficient fuels are added. This metric is not appropriate to business jets. This metric is consistent with other reporting such as the CAEP Trends and industry assessments. This metric does rely on some assumptions about price and load factor (see Appendix M1 and M2).

4.9 Costs and investments



LTAG Integrated Scenario 3

Disclaimers: Costs associated with scenario are not meant to be added towards a total cumulative costs. Costs and investments are displayed across a chain of stakeholders. Some investments from upstream stakeholders are passed on downstream in the form of incremental price of products (e.g., investments from fuel suppliers passed on to operators as part of Minimum Selling Price).

** Not quantified but expected to be necessary to support future implementation of operations measures and development of future fuels technologies.*
*** NRC towards aircraft development for global (dom. + int.) aviation.*
**** Potential costs (e.g., from increased aircraft price after technology improvements) potentially reducing savings from fuel efficiency improvements.*

Note. - See section 4.12.2 below for results of cost and investments for LOW and HIGH traffic forecasts.

4.9.1 Technology

4.9.1.1 Investment by aircraft manufacturers: Around $350 billion (range $260-1000B) between 2020 and 2050. On an annual basis this represents ≈ $12 billion per year.

4.9.1.2 R&D support by states: Up to $75-870 billion through 2050.

4.9.1.3 Reduced operator fuel costs: ≈ $740 billion from 2020-2050 but could require incremental investments to cover any incremental aircraft prices (after technology improvements).

4.9.2 Operations

4.9.2.1 Investment by airports: $6 billion

4.9.2.2 Investment by ANSPs: $20 billion

4.9.2.3 Investment by airlines: $155 billion

4.9.2.4 Reduced operator fuel costs: ≈ $4900 billion from 2020-2050.

4.9.3 Fuels

4.9.3.1 **SAF biomass-based fuels:** Investment of ≈ $950 billion by 2050 (to cover 42% of international aviation energy use in 2050). Incremental cost to airlines of $1600 billion.

4.9.3.2 **Gaseous waste-based fuels:** Investment of $1700 billion (46% of energy use in 2050). Incremental cost to airlines of $1800 billion.

4.9.3.3 **SAF from atmospheric CO_2:** Investment of $460 billion (10% of energy use in 2050). Incremental cost to airlines of $600 billion.

4.9.3.4 **LTAG-LCAF:** Investment of $60 billion (0% of energy use in 2050). Incremental cost to airlines of $60 billion.

4.9.3.5 **Hydrogen:** Investment of $55 billion (2% of energy use in 2050). Airport and infrastructure investments for hydrogen powered aircraft could be ≈ $125 billion by 2050. Incremental cost to airlines of $10 billion.

4.10 Roadmaps for implementation

4.10.1 Dependencies and Enablers

4.10.1.1 This scenario includes the following dependencies, interdependencies and assumed policies and incentives:

4.10.1.2 Technology

- Ground infrastructure to accommodate liquid hydrogen, battery or hydrogen fuel cell electric aircraft

- Airport infrastructure changes required to accommodate these alternative configurations

- Some aircraft will continue to be designed with varying local airport noise rules and charges in mind, as today.

4.10.1.3 Operations

- Higher/accelerated investment in ground and airborne systems and technologies.

4.10.1.4 Fuel

- Economy-wide deep decarbonisation is assumed.

- Extensive electrification of ground transportation and widespread availability of renewable energy.

- Large incentives lead to widespread use of low GHG fuels for aviation.

- Technology evolution enables widespread use of atmospheric CO_2 for SAF, further increases in feedstock availability, widespread use of CCUS, and sufficient H2 exists to enable cryogenic H2 use in aircraft.

- Infrastructure developed to enable use of non-drop-in fuels at airports around globe

4.10.2 Reporting Progress

4.10.2.1 **Requirement:** A process is anticipated for reporting progress towards any goal ultimately adopted. It would be preferable not to duplicate existing processes or place reporting expectations on non-state actors.

4.10.2.2 **Recommendation:** State Action Plans are voluntarily submitted by states under Article 10 of Res A40-18. ICAO provides guidance to states on submitting their Action Plans, including how to calculate the impact of measures. LTAG-TG believes the SAP process could be utilised to report progress towards any LTAG. The process would need to be adapted to include implemented as well as planned measures.

4.10.2.3 **Future work:** LTAG-TG has not sought to develop guidance, including metrics, for state reporting of progress. This could be an item for future work. The Assembly ‘encourages’ and ‘invites’ states to submit SAPs – there is no requirement (e.g. SARP) for states to report their progress to ICAO, except through CORSIA. Future work could also consider whether a process is required for non-state actors to report their progress to ICAO, to complement SAPs.

4.10.2.4 **Other sources of data:** It should also be noted that there are other existing ICAO processes which may produce relevant data including certification data against the ICAO CO_2 standard, and states' emissions reports to ICAO for the purposes of CORSIA (until 2035). Sources outside ICAO could also be relevant – such as industry data or fuel use statistics.

4.10.3 Review

4.10.3.1 **Requirement:** ICAO will need to review any goal ultimately adopted to ensure it remains appropriate, in light of information such as:

- progress towards the goal;
- technological developments;
- progress in other sectors (e.g. renewable energy);
- cost and other impacts on states and airlines; and
- the latest scientific knowledge, including on adaptation to climate change.

4.10.3.2 **Recommendation:** If progress is to be reported every three years through State Action Plans, it makes sense for ICAO's review of any goal to be triennial too. This would allow each CAEP meeting and Assembly to review progress and recommend/decide on any adjustments, in a similar way to the periodic reviews of CORSIA. Review more or less frequently than every three years is not recommended by technical experts. This review could use the information collected through the reporting processes (see left) as well as contextual information such the latest scientific knowledge on climate, as summarised by the CAEP Impacts and Science Group.

4.10.3.3 **Other sources of data:** ICAO could also consider using non-state information to inform its reviews, including for example on SAF availability, technology development and deployment of operational measures.

4.10.4 Capacity building

4.10.4.1 Potential needs for capacity building and assistance identified by LTAG-TG to realise this scenario include:

- Providing concrete solutions to help states reach goals, while understanding likely costs.
- Capacity building on measurement and monitoring of CO_2 emissions from international aviation.
- Workshops on solutions that are already available to be implemented, preferably with examples of successful implementation.
- Potentially a similar training programme to the successful ACT CORSIA.

4.10.4.2 This is not an exhaustive list or a recommendation but is provided for transparency only.

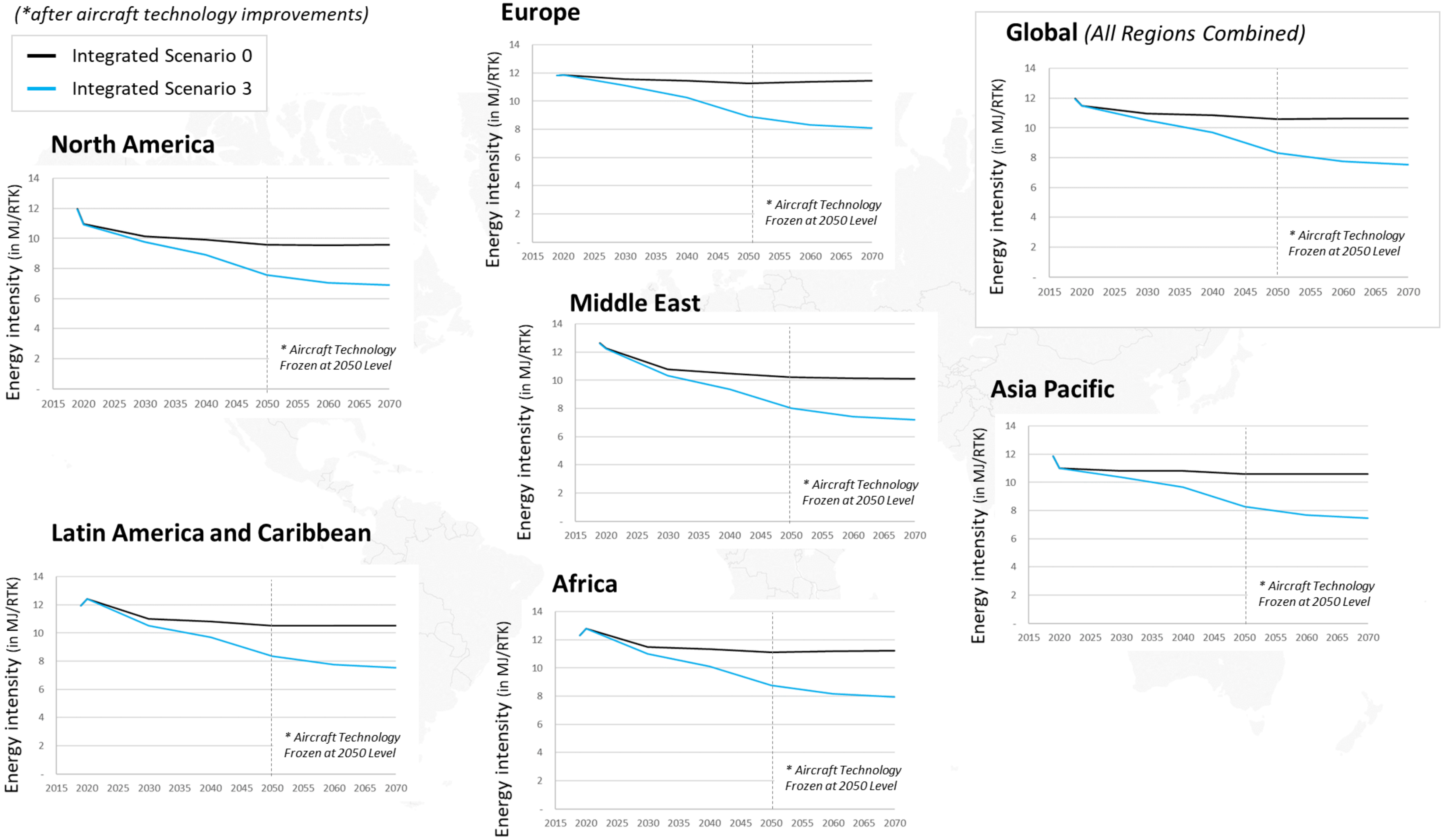
4.11 Regional breakdown

4.11.1 Technology

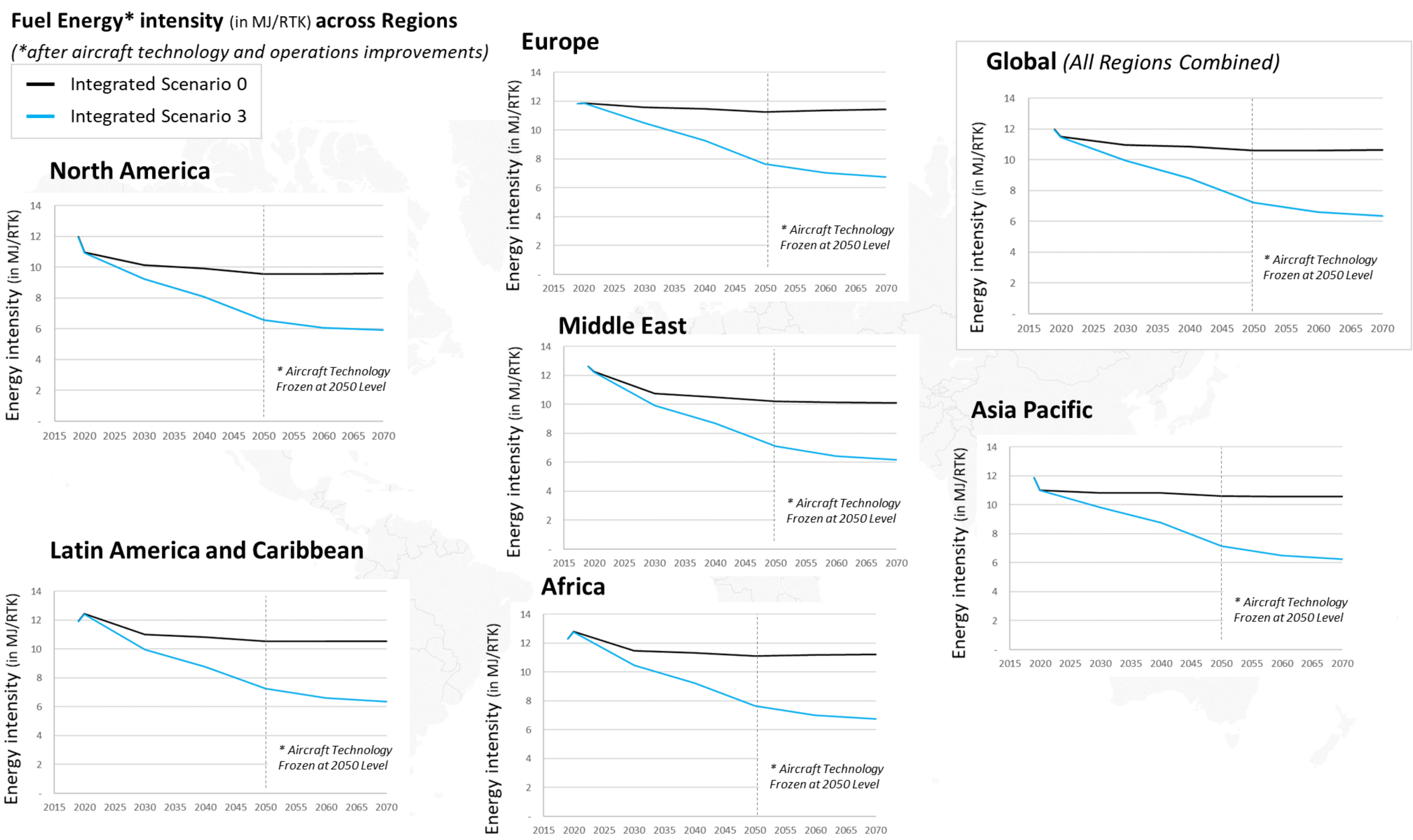
4.11.1.1 The following graphs show fuel (energy) intensity in MJ/RTK across ICAO regions based on fuel use after technology improvements (for integrated scenario 3).

Fuel Energy* intensity (in MJ/RTK) **across Regions**

*(*after aircraft technology improvements)*

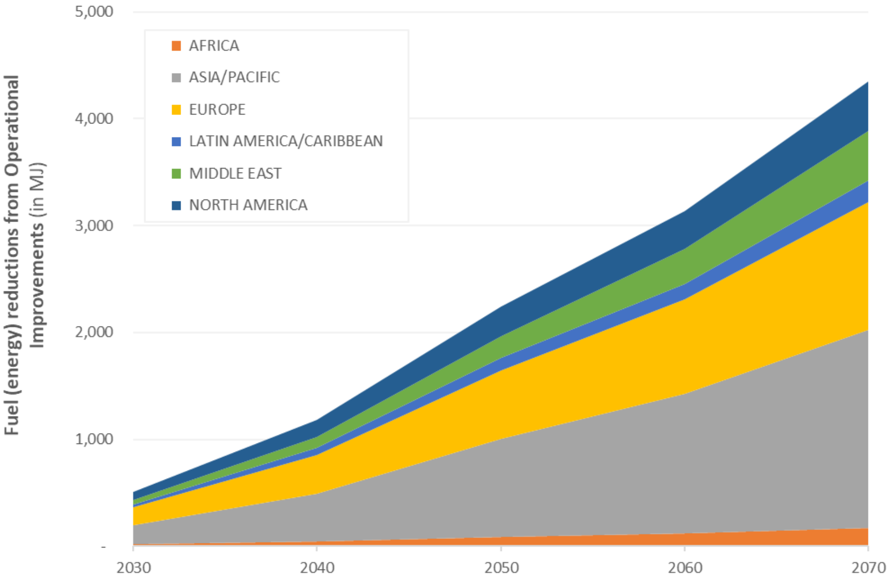


4.11.1.2 The following graphs show fuel (energy) intensity in MJ/RTK across ICAO regions based on fuel use after technology and operational improvements (for integrated scenario 3).



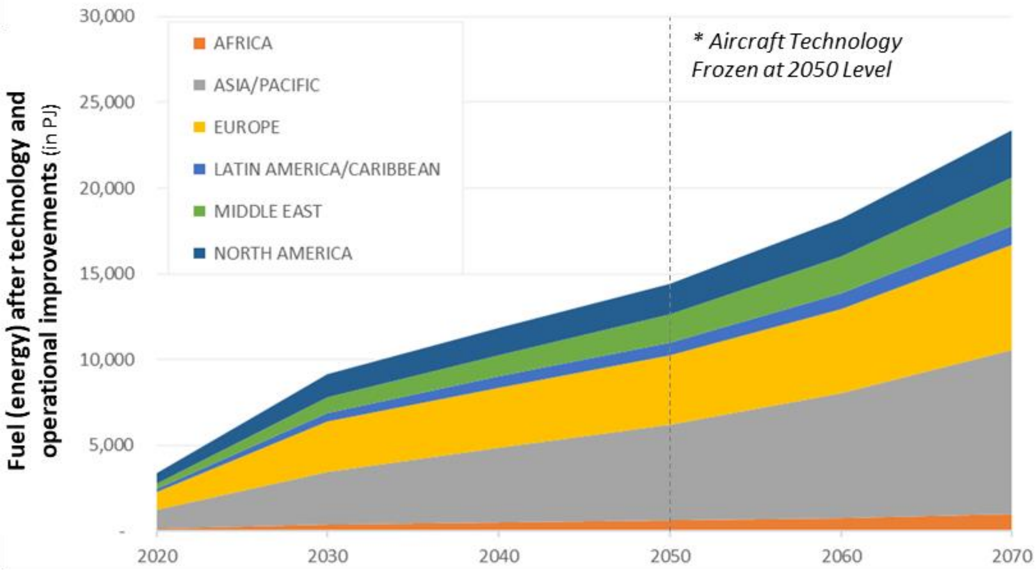
4.11.2 Operations

4.11.2.1 The following graph shows regional distribution of fuel (energy) reductions from operational improvements under LTAG-TG integrated scenario 3.



4.11.3 Fuels

4.11.3.1 The following graphs show total fleet wide fuel use over time in MJ by ICAO region. This data is based on the state of departure in line with CAEP Trends methodology.



** No further technology improvements are assumed after 2050. 2060 and 2070 simply show how the advanced aircraft penetrate through the fleet.*

4.11.3.2 Aviation fuel production, by fuel category, by ICAO region

4.11.3.2.1 **LTAG-SAF:** The production and uptake of LTAG-SAF will have regional variability due to feedstock availability and market incentives. The production of LTAG-SAF will depend on resource availability including biomass, solid/liquid wastes and waste CO/CO_2. As economies decarbonize, the availability of waste CO/CO_2 from industrial processes will decrease. The rate at which a region decarbonizes will thus impact LTAG-SAF from waste CO/CO_2 resources. ICAO regions with limited biomass and solid/liquid waste resources will be constrained in overall LTAG-SAF production capacity. Uptake of LTAG-SAF will vary according to regional incentives for low GHG fuels. In regions where these fuels are prioritized and incentivized through established policies, fuel producers and users will be supported to provide and purchase, respectively, these fuels. For example, markets with policies that provide tax credits or mandates for low GHG transportation fuels will lower costs for these fuels and thereby encourage their production and use.

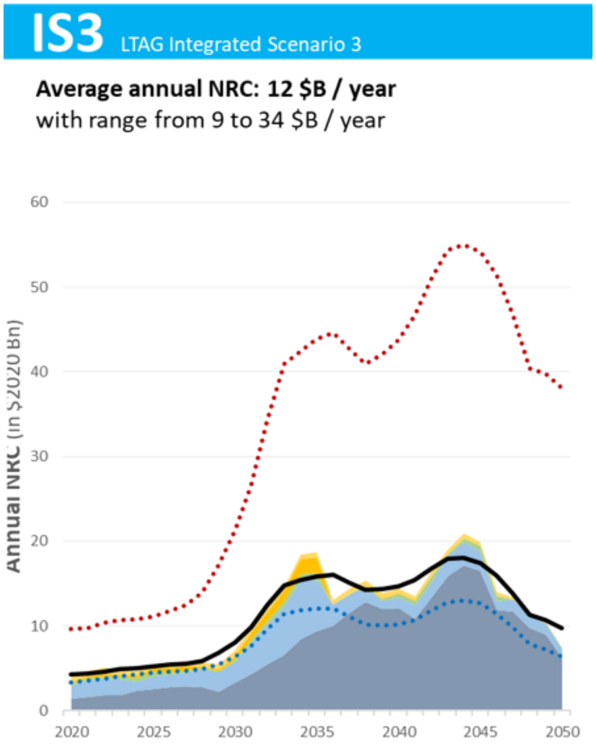
4.11.3.2.2 **LTAG-LCAF:** The production of LTAG-LCAF largely depends on the level of deployment of key mitigation technologies (e.g. renewable integration, CCS, green/blue hydrogen, etc.). Regional variations of market conditions and government incentives will determine the investment and uptake of this type of fuel. Different emissions reduction technologies and practices have varying levels of readiness and attainability in different regions due to various factors including the renewable potential, infrastructure availability, and fiscal environment. The production of LTAG-LCAF depends on the implementation of mitigation measures across the jet fuel supply chain and the scale of adoption in each region.

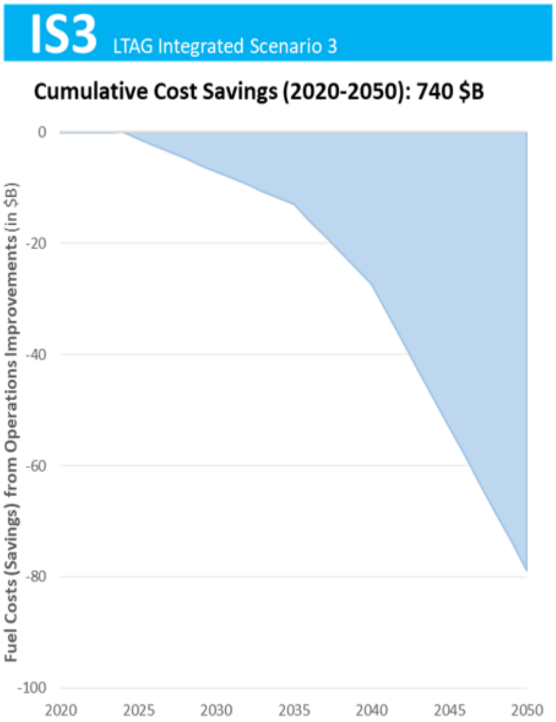
4.11.3.2.3 **Cryogenic hydrogen:** The production of cryogenic hydrogen (LH_2) will have regional variability due to renewable electricity availability and transportation infrastructure availability. The uptake of LH2 will also have regional variability due to varying levels of infrastructure investments required to support LH2 use at airports.

4.11.4 Costs and investments

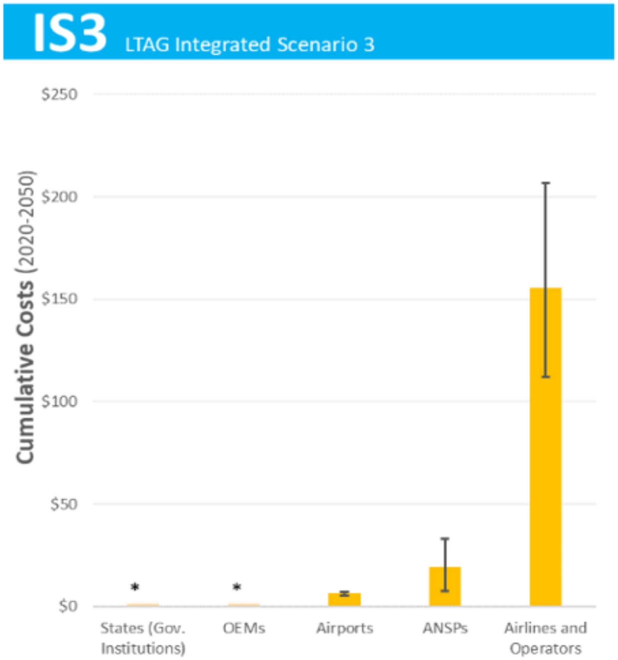
4.11.4.1 Distribution of costs and investments over time

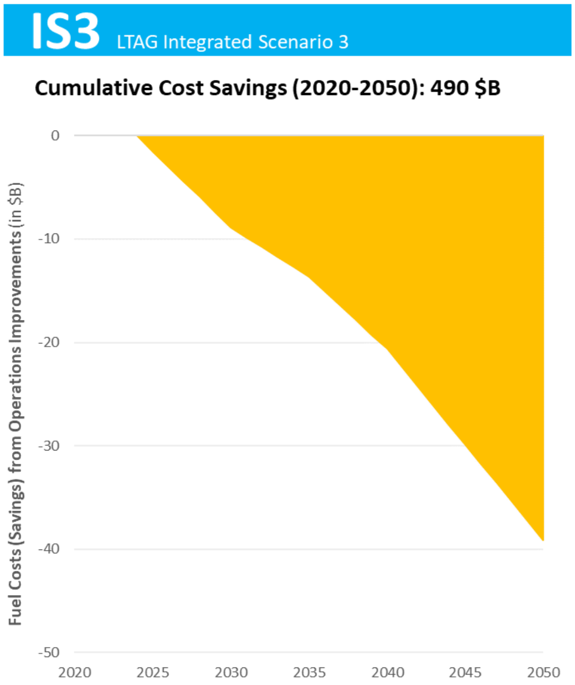
4.11.4.1.1 Technology



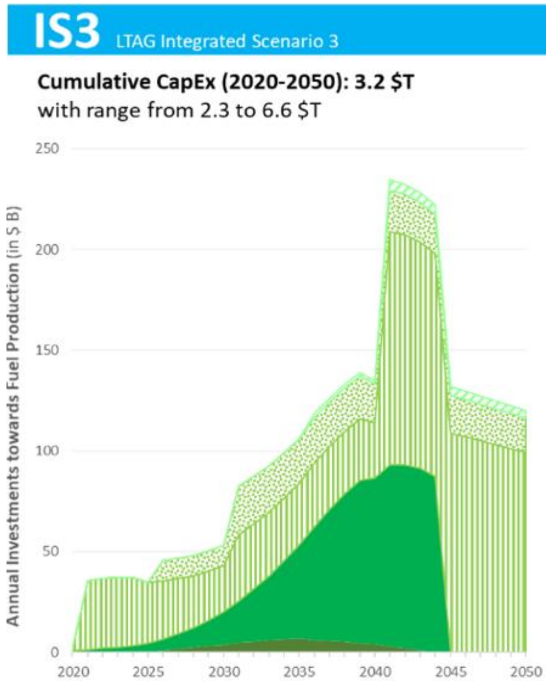


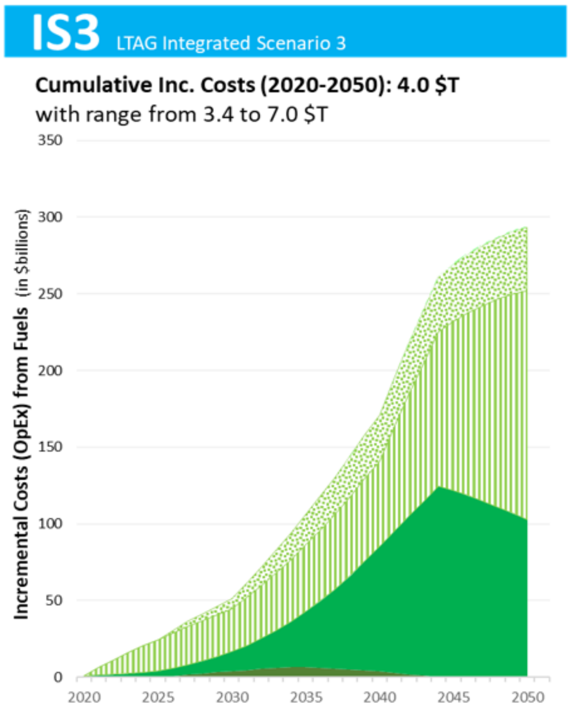
4.11.4.1.2 Operations





4.11.4.1.3 Fuels



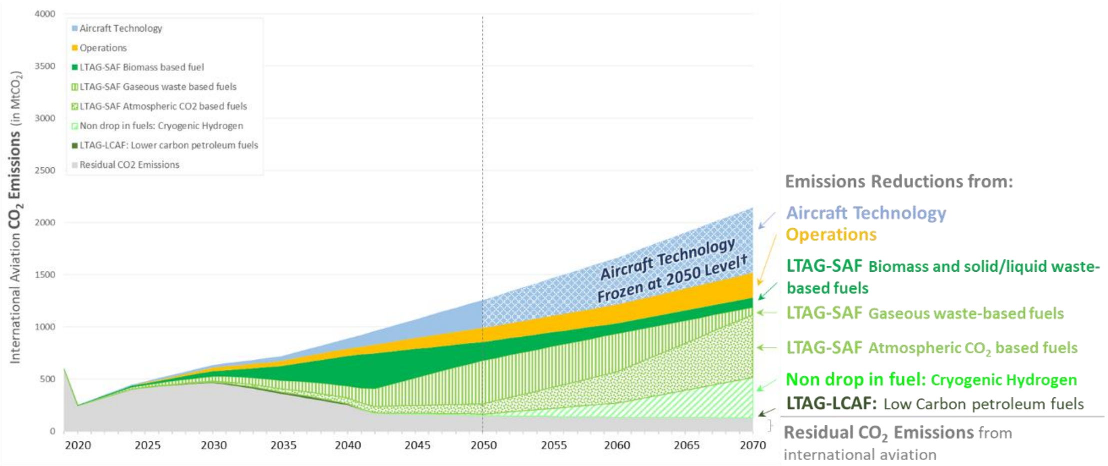


4.11.4.2 Appendix M1, Attachment C provides additional information on the potential regional distribution of costs and investments where data is available.

4.12 Impact of Traffic Forecasts

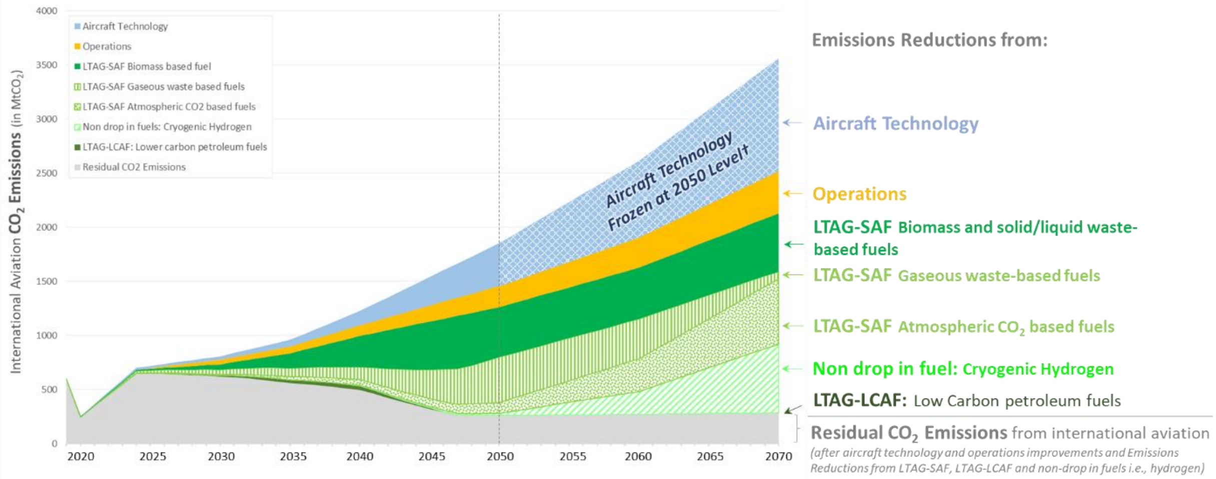
4.12.1 CO_2 emissions

4.12.1.1 Low traffic forecast



† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

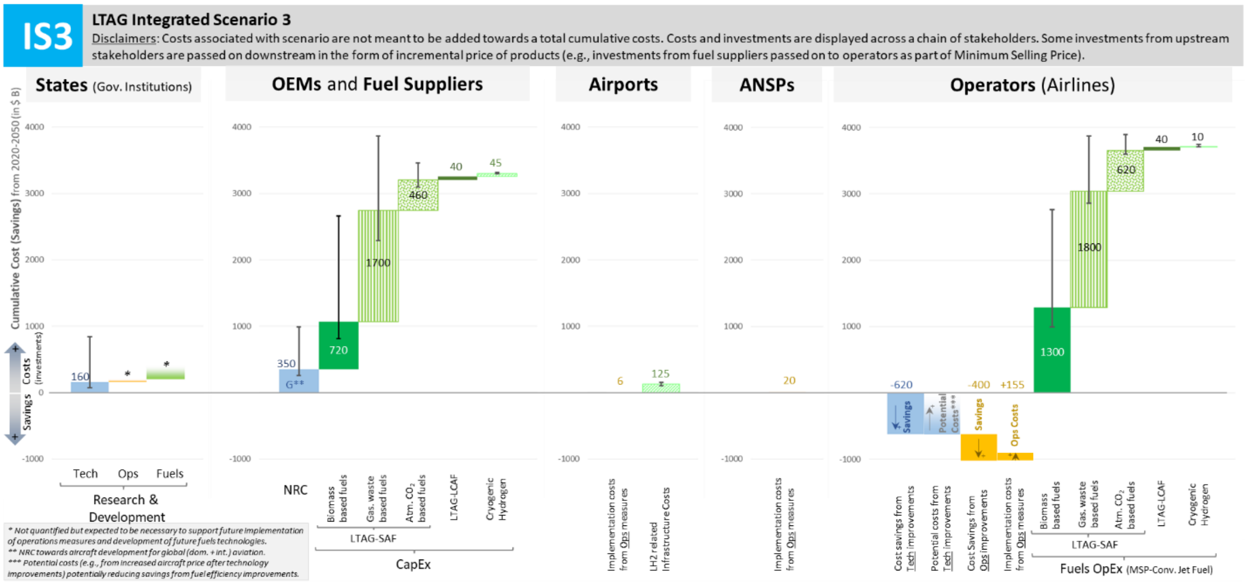
4.12.1.2 High traffic forecast



† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

4.12.2 Costs and investments

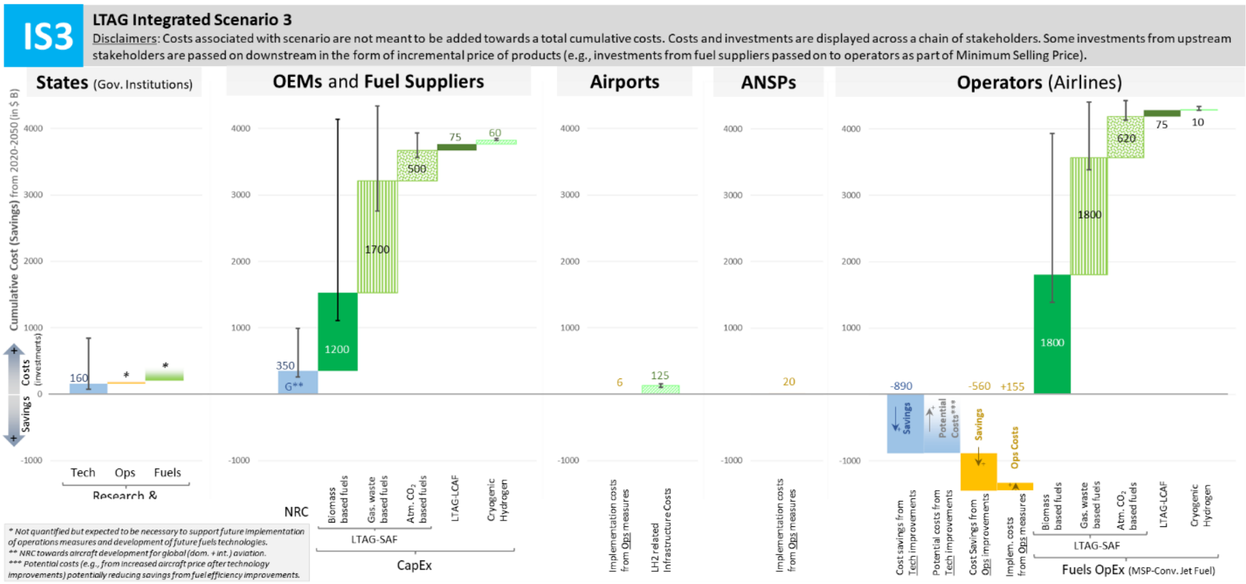
4.12.2.1 Low traffic forecast



Disclaimers: Costs associated with scenario are not meant to be added towards a total cumulative costs. Costs and investments are displayed across a chain of stakeholders. Some investments from upstream stakeholders are passed on downstream in the form of incremental price of products (e.g., investments from fuel suppliers passed on to operators as part of Minimum Selling Price).

** Not quantified but expected to be necessary to support future implementation of operations measures and development of future fuels technologies.*
*** NRC towards aircraft development for global (dom. + int.) aviation.*
**** Potential costs (e.g., from increased aircraft price after technology improvements) potentially reducing savings from fuel efficiency improvements.*

4.12.2.2 High traffic forecast



Disclaimers: Costs associated with scenario are not meant to be added towards a total cumulative costs. Costs and investments are displayed across a chain of stakeholders. Some investments from upstream stakeholders are passed on downstream in the form of incremental price of products (e.g., investments from fuel suppliers passed on to operators as part of Minimum Selling Price).

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**** Potential costs (e.g., from increased aircraft price after technology improvements) potentially reducing savings from fuel efficiency improvements.*

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