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# ICAO Report on Feasibility of a Long-term Aspirational Goal for International Civil Aviation $CO_2$ Emission Reductions (LTAG)

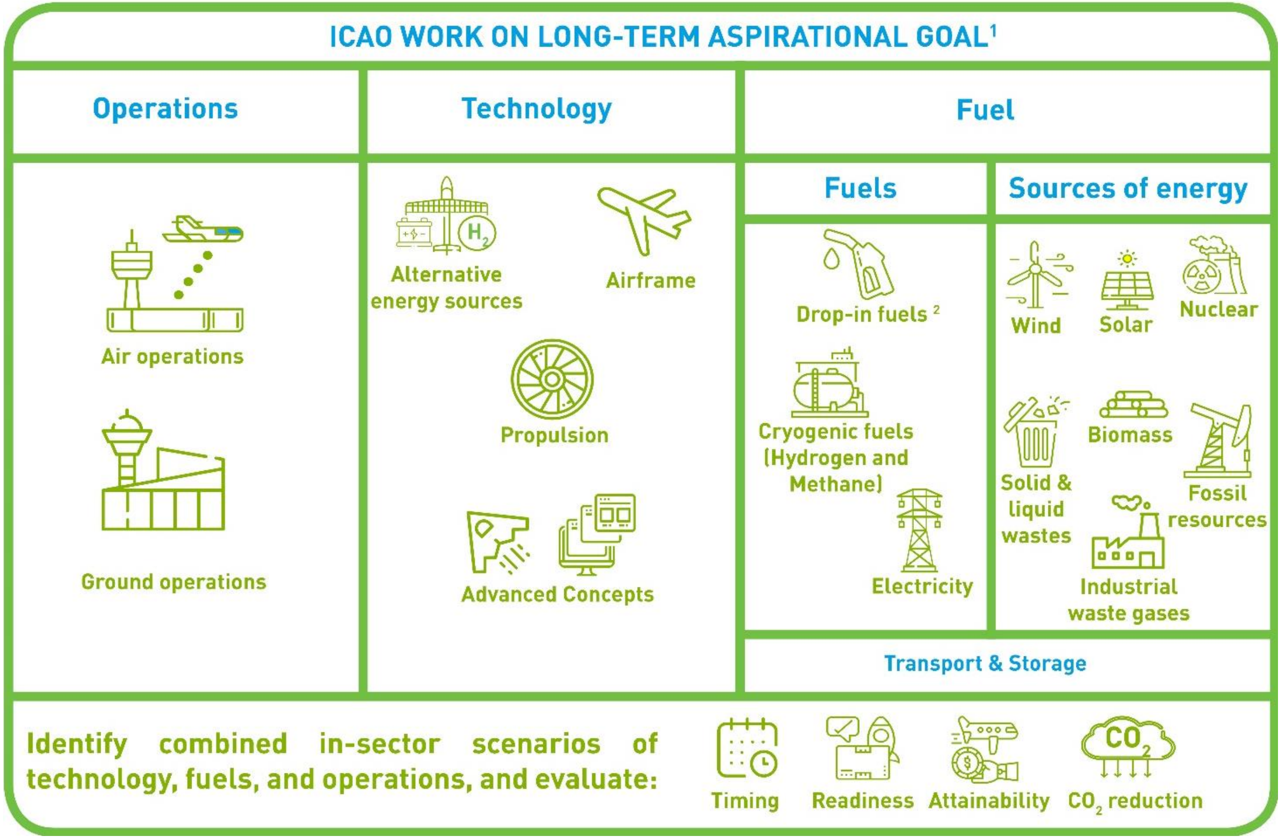
## Introduction to the ICAO LTAG process

# ICAO LTAG Process

## Open, transparent and inclusive:

## Innovations:

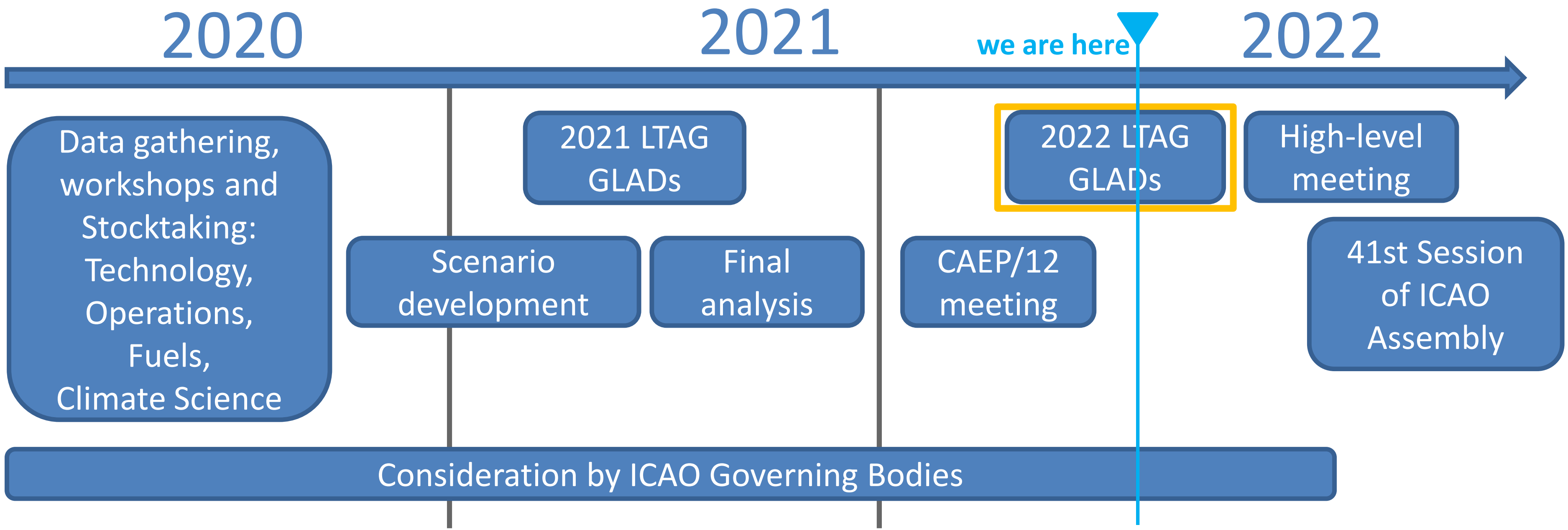
## In-sector focused:



# ICAO LTAG Work General Timeline



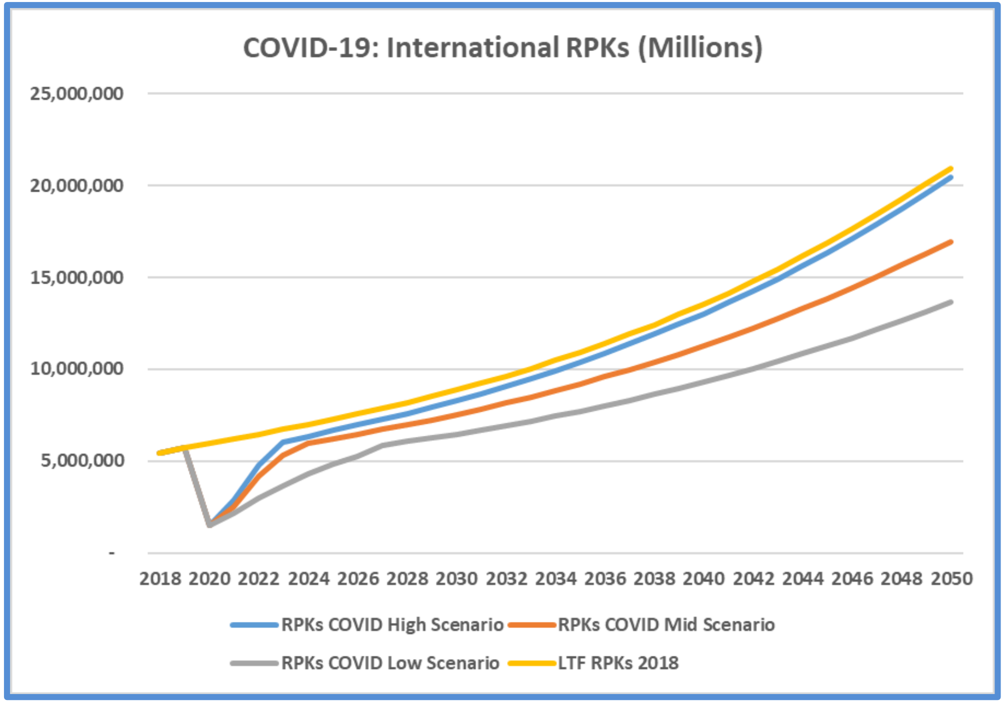
- CAEP/12 agreed to recommend for Council consideration the final report providing the results of the technical work on exploring the feasibility of a long-term global aspirational goal for international civil aviation $CO_2$ emissions reductions (LTAG).
- Final report available on the ICAO website.



# ICAO Traffic Demand Forecast

## ICAO developed traffic demand forecast scenarios incorporating near- and long-term effects of the COVID-19 pandemic

- **Passenger/Cargo Markets**
  - COVID-19 long-run economic forecast data from IHS Markit
  - IATA forecast information used for near-term recovery and 2020 downturn (back to 2019 levels)
  - Scenarios 2018-2050, extended to 2070
- **Business Jet Market**
  - Published data/reports used
  - Scenarios 2018-2050, extended to 2070



# LTAG Fleet Evolution

## COVID-19 Trends Extension

- All input assumptions same as Environmental Trends Projection run.
- Fleet evolution output exactly matches Trends through 2050.
- Consistent with ICAO ADAP projections.

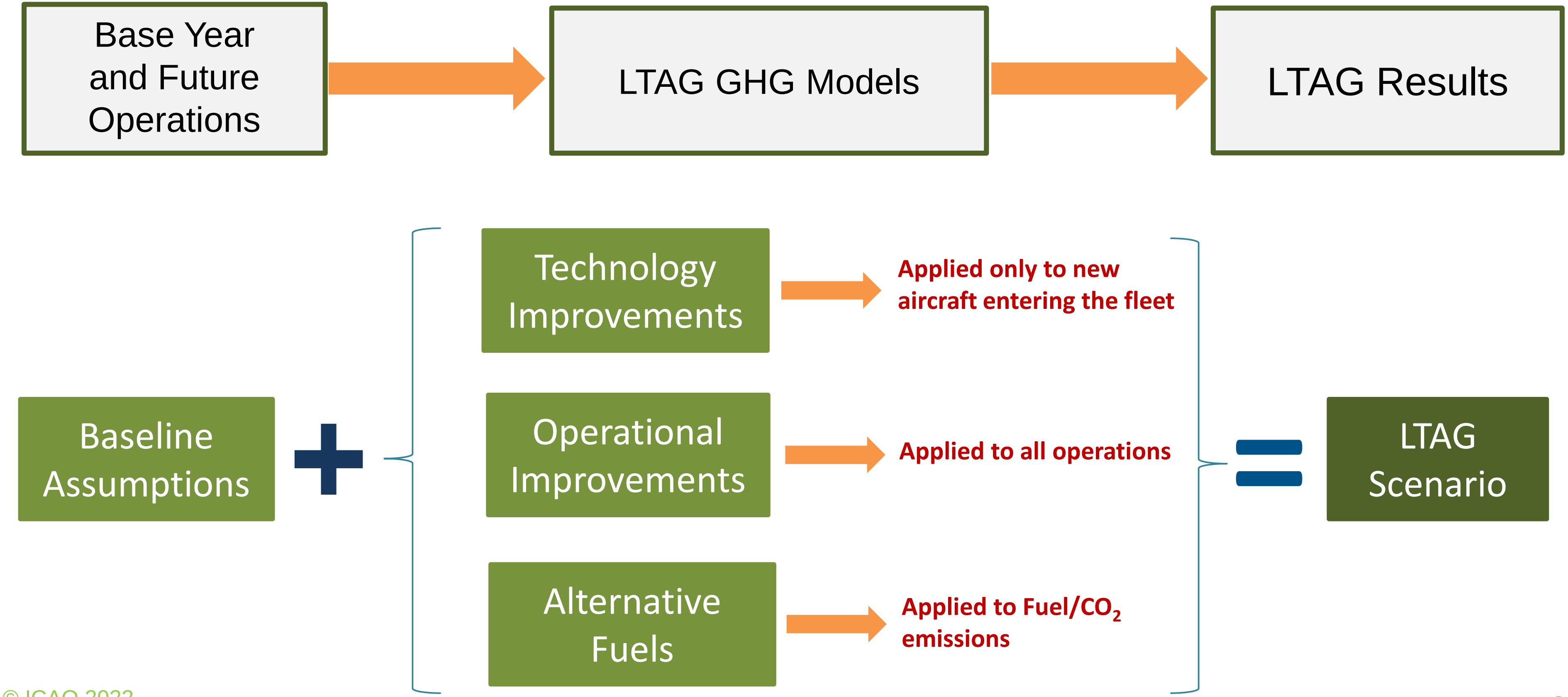
## Forecast Scenario

- Provides base fleet evolution data set to 2070
- Introduction of Advanced Tube and Wing (ATW) technology improvement and Advanced Concept Aircraft (ACA).

## Data

- Fleet Evolution Outputs by forecast target years (2040, 2050, 2060, 2070).
- ASKs/ATKs/Ops, in-service fleet by age.

# LTAG Modelling and Future Years Processing



# Scientific Input based on IPCC 2021 AR6

CAEP ISG reported on the allowed **global $CO_2$ emissions** for limiting global mean temperature increase to **1.5°C** or **2°C**, based on the IPCC's 2021 report.

- For warming of **1.5°C**, allowed cumulative global anthropogenic $CO_2$ emissions from **2020** are **400 gigatons (Gt)** of $CO_2$ at 67% probability and 500 Gt at 50% probability.
- For warming of **2°C**, the allowed cumulative emissions are **1150 Gt $CO_2$** at 67% probability and 1350 Gt at 50% probability.
- The uncertainty in these estimates is large from a range of physical factors including non-$CO_2$ effects from other greenhouse gases such as methane, nitrous oxide and fluorinated gases

# Allowed Emissions for Limiting Global Mean Temperature Increase

**Future emissions cause future additional warming, with total warming dominated by past and future $CO_2$ emissions**

**(a) Future annual emissions of $CO_2$ (left) and of a subset of key non-$CO_2$ drivers (right), across five illustrative scenarios**

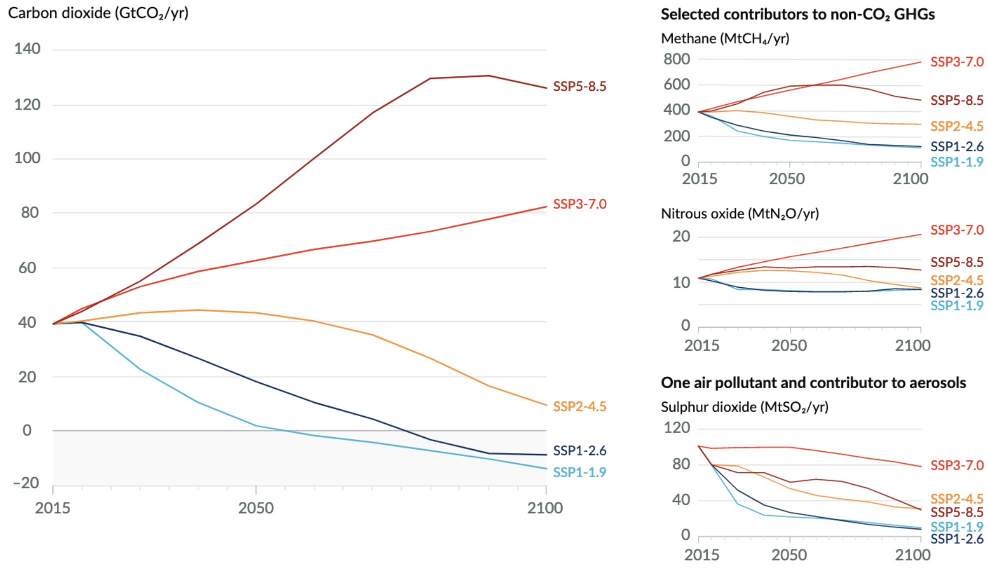



Figure SPM.4 (part of) from IPCC AR6 WG1, 2021

- CAEP used the **"very low emissions scenario"** (light blue line, SSP1-1.9), under which it is more likely than not that global temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.

- Under the **"low (and very low) emissions scenario(s)"** (dark blue line, SSP1-2.6), global warming of 2°C is extremely unlikely to be exceeded or unlikely to be exceeded.

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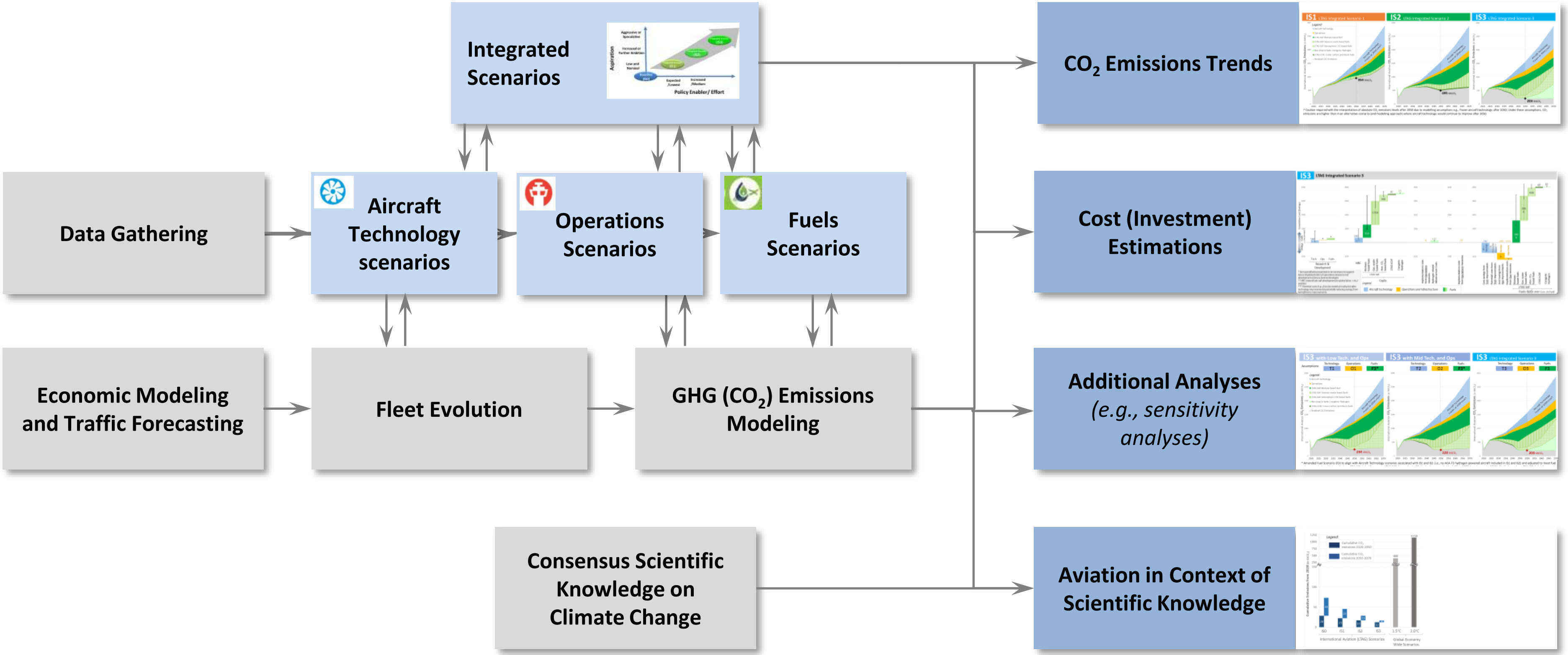
# ICAO Report on Feasibility of a Long-term Aspirational Goal for International Civil Aviation $CO_2$ Emission Reductions (LTAG)

# Structure

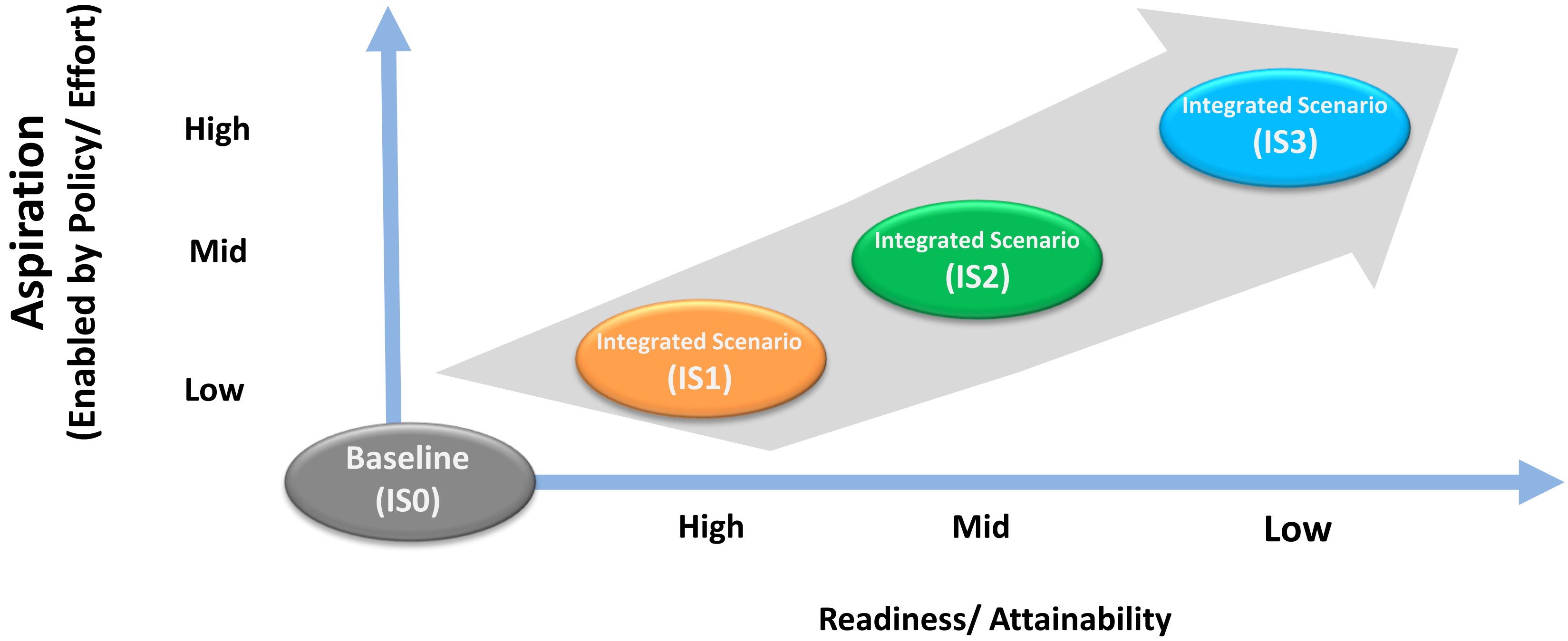
1. Overview of LTAG Work
2. LTAG Scenario Development
3. LTAG – Technology
4. LTAG – Operations
5. LTAG – Fuels

# 1 Overview of LTAG Work

# Methodology: Overview



# Methodology: Integrated Scenario

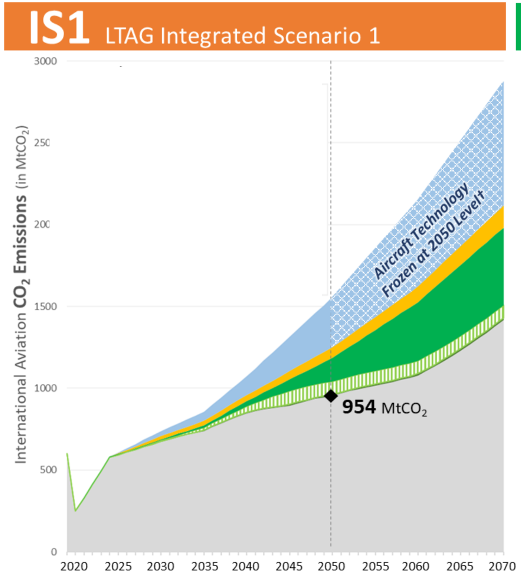


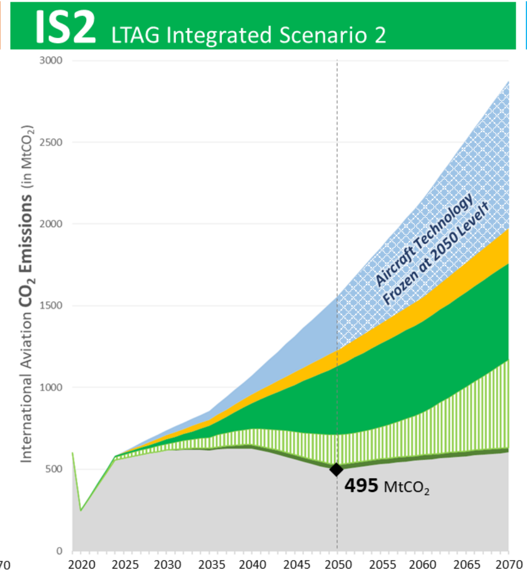
# Key Questions Addressed

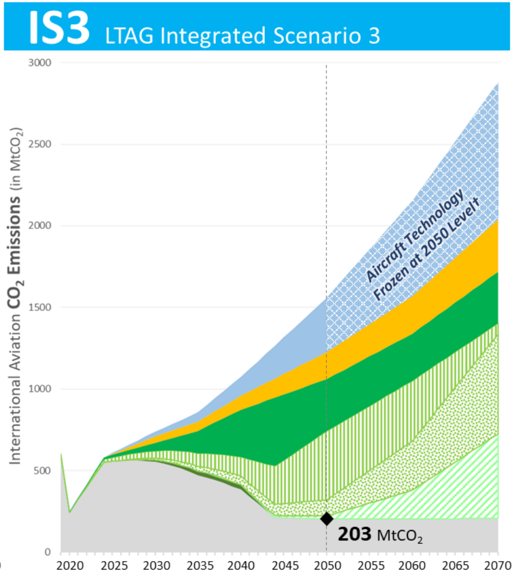
| | | *Addressed in LTAG Report:* | |
|---|---|---|---|
| Question 1: | **How could in-sector measures (i.e., technology, operations, and fuels) help reduce $CO_2$ emissions from international aviation through 2050 and beyond?** | *Section 4.2* | ✓ |
| Question 2: | **Given $CO_2$ emissions trends for each scenario, what would be the cumulative emissions from aviation? How do cumulative aviation emissions compare to requirements to limit the global temperature increase to 1.5°C and 2°C?** | *Section 4.3* | ✓ |
| Question 3: | **What investments are required to support the implementation of the in-sector measures associated with each scenario? What would be the cost impacts to aviation stakeholders?** | *Section 4.4* | ✓ |
| Question 4: | **What would be the impacts of various future aviation traffic levels?** | *Section 4.5* | ✓ |
| Question 5: | **How sensitive are the results to scenario assumptions?** | *Section 4.6* | ✓ |

# Question 1: Reductions in $CO_2$ emissions from international aviation through in-sector measures through 2050 and beyond

*Legend:*
- Aircraft Technology
- Operations
- LTAG-SAF Biomass based fuel
- LTAG-SAF Gaseous waste based fuels
- LTAG-SAF Atmospheric CO2 based fuels
- Non drop in fuels: Cryogenic Hydrogen
- LTAG-LCAF: Lower carbon petroleum fuels
- Residual CO2 Emissions






| Metrics | IS1 | IS2 | IS3 |
|---|---|---|---|
| $CO_2$ Emissions in 2050 after Reductions | **≈950 $MtCO_2$** in 2050 *(**160%** of 2019 $CO_2$ emissions)* | **≈500 $MtCO_2$** in 2050 *(**80%** of 2019 $CO_2$ emissions)* | **≈200 $MtCO_2$** in 2050 *(**35%** of 2019 $CO_2$ emissions)* |
| Reduction in 2050 from the Baseline | **39% total** through: Technologies - 20%, Operations - 4%, Fuels - 15% | **68% total** through: Technologies - 21%, Operations - 6%, Fuels - 41%) | **87% total** through: Technologies - 21%, Operations - 11%, Fuels - 55% |
| Cumulative residual Emissions from 2020 to 2070 | 23 $GtCO_2$ (2020 to 2050)<br>23 $GtCO_2$ (2051 to 2070) | 17 $GtCO_2$ (2020 to 2050)<br>11 $GtCO_2$ (2051 to 2070) | 12 $GtCO_2$ (2020 to 2050)<br>4 $GtCO_2$ (2051 to 2070) |

Question 1:

# $CO_2$ Emissions Reductions: High-level observations

## General observations

- Scenarios show the potential for substantial $CO_2$ reduction, however none of them reach zero $CO_2$ emissions (using in-sector measures only).
- There will be residual emissions despite 100% replacement of conventional jet fuel with novel fuels, due to consideration of fuels' life cycle emissions.
- As other aspects of economies reduce their emissions, the life cycle value should drop as well.
- With the scope of LTAG analysis limited to consider in-sector measures only, out of sector measures were not considered in the LTAG feasibility study.

## Technology observations

- Advanced tube and wing aircraft have a clear potential to improve the fuel (energy) efficiency of the international aviation system with some incremental contribution from aircraft with unconventional configurations.
- Technology wedge continues to grow after 2050 as these aircraft penetrate the fleet *(caution is required with the interpretation of results after 2050 due to frozen aircraft technology modelling assumptions).*
- Hydrogen powered aircraft would exhibit worse energy efficiency, relative to aircraft operating on drop-in fuels, noting that emissions reductions would come from life cycle emissions reductions from the hydrogen.

# Question 1: $CO_2$ Emissions Reductions: High-level observations

**Traffic observations**

- Overall traffic growth rate has an important impact on residual $CO_2$ emissions by 2050 and after.

**Operations observations**

- Analysis shows there are opportunities for operations to reduce $CO_2$ emissions through improvements in the performance of flights across all phases of flights, including unconventional measures such as formation flying.

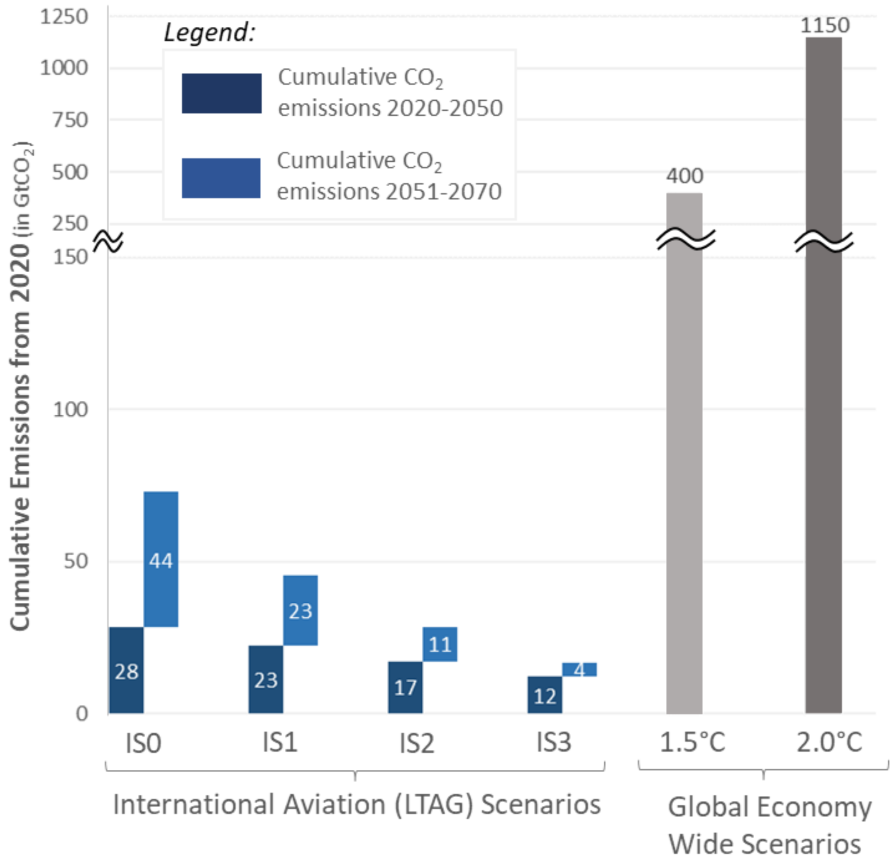
**Fuels observations**

- Drop-in fuels have the largest impact on residual $CO_2$ emissions driving overall reductions by 2050.
- Independent -to some extent- of technology and operations scenarios.
- Hydrogen is not expected to have a significant contribution by 2050 (with only 1.9% of energy share in 2050) but may increase in the 2050s and 2060s if technically feasible and commercially viable.

# *Question 2:* Future International Aviation Emissions in Context

- **Estimated cumulative residual global anthropogenic $CO_2$ emissions from the start of 2020 to limit global warming to 1.5°C is 400 $GtCO_2$ at 67% probability.**
  - International aviation share ~4.1-11.3%

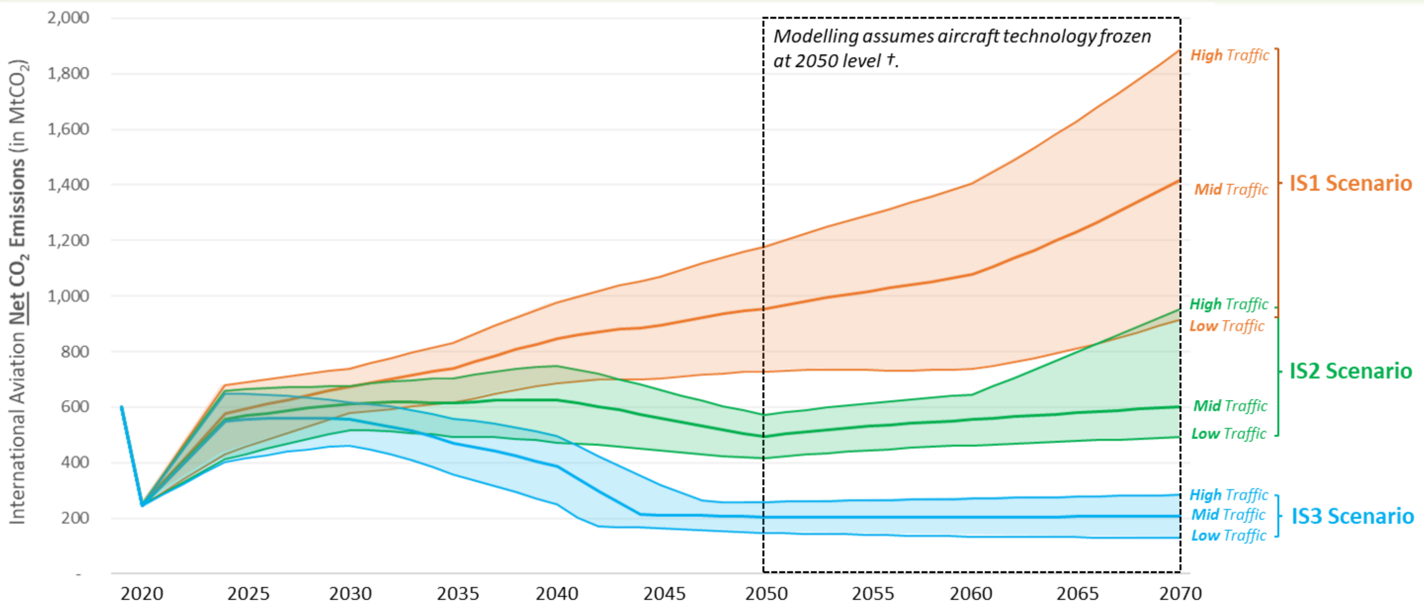
- **For a warming limit of 2°C, the remaining allowed carbon emissions are estimated to be 1150 $GtCO_2$ at 67% probability.**
  - International aviation share ~1.4-3.9%



# *Question 3:* Cost and Investments associated with Integrated Scenarios

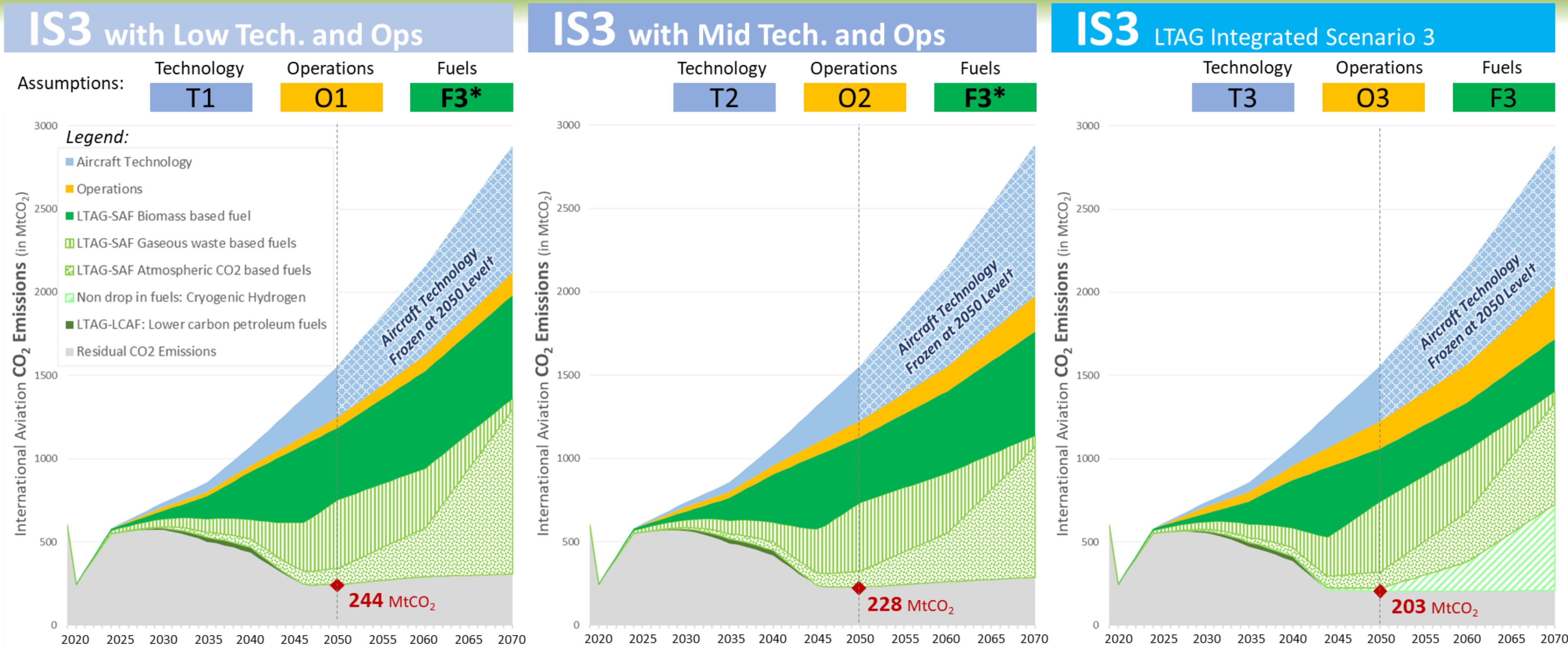
- **Costs and investments associated with the scenarios are largely driven by fuels (e.g., SAF).**
- **Acknowledging that incremental costs of fuels** (i.e., minimum selling price of SAF compared to conventional jet fuels) **further motivates fuel (energy) efficiency improvements from aircraft technology and operations.**
- **Aircraft technology and operational measures will also require some investments from governments and industry.**

# Impact of Aviation Traffic Forecast




| **$CO_2$ emissions in 2050 after emissions reductions** (from tech., ops and fuels) | IS1 | IS2 | IS3 |
|---|---|---|---|
| **High** (traffic) | 1160 $MtCO_2$ | 590 $MtCO_2$ | 260 $MtCO_2$ |
| **Medium** (traffic) | 950 $MtCO_2$ | 495 $MtCO_2$ | 200 $MtCO_2$ |
| **Low** (traffic) | 730 $MtCO_2$ | 420 $MtCO_2$ | 150 $MtCO_2$ |

# Sensitivity analysis of IS3 Scenario demonstrates the importance of fuels




**These results show that there are multiple paths that may result in similar levels of $CO_2$ emissions, and that the critical contribution from fuels to decouple the growth in international aviation traffic from its $CO_2$ emissions.**

# Considerations regarding LTAG Options

Based on the results of the LTAG feasibility study, technical **options for LTAG metrics** were identified below. This is not an exhaustive list and other formulations may of course be considered.

**Options using annual levels of emissions:**

- The annual level of emissions in 2050 e.g., 950, 500 or 200 $MtCO_2$
- Using a reference year earlier than 2050 may not give the long-term certainty expected to be a key benefit of adopting an LTAG
- Using a reference year after 2070 would be subject to increased uncertainty
- Intermediate waypoints in milestone years could add a trajectory to the emissions profile in times.

**Options using cumulative total emissions :**

- The cumulative total emissions from the international aviation sector by 2050, for example 23, 17 or 12 $GtCO_2$ (based on the Scenario).
- The cumulative total emissions from the sector would most closely translate into an atmospheric temperature response and allow for monitoring of progress without the need for intermediate waypoints.

- **Additional consideration:** With the scope of the LTAG study limited to consider in-sector measures only, 'out-of-sector' measures were not considered in the LTAG analysis.

# Other Impacts (non-exhaustive list)

## Impacts on aviation growth

- Potential impacts of the LTAG scenarios on aviation growth were **qualitatively** considered
- LTAG may increase operating costs and **some costs may be passed on to passengers**

## Regional impacts

- Most significant regional variations expected in **production and uptake of fuels** due to e.g. regional availability of feedstocks, renewable energy, infrastructure.

## Impacts on noise and air quality

- In all scenarios, **traffic growth increases total noise and $NO_x$ emissions**
- **Technology improvements** typically reduce noise and emissions alongside fuel burn
- **Operational efficiencies** may have co-benefits for noise but do not impact air quality
- **LTAG-SAF and cryogenic hydrogen** have co-benefits for air quality and contrail formation with no impact on noise

# Roadmaps for LTAG Implementation

## Implementation Roadmap

- ICAO CAEP considered technical aspects of implementation without prejudging future decisions

**Monitoring of progress**

- State Action Plans may be used for States to report progress towards a goal, without duplicating existing processes
- If a goal were adopted, ICAO could conduct future work on possible metrics, reporting mechanisms, etc.

**Review**

- ICAO may need to review any goal to ensure it remains appropriate
- A triennial review process could be considered similar to the CORSIA Periodic Review

**Capacity building**

- Possible needs for capacity building and assistance e.g.:
    - **workshops** on measures, including understanding costs
    - **assistance** on monitoring and measuring $CO_2$ emissions
    - an **overarching training programme** similar to ACT-CORSIA

# 2 LTAG Scenario Development

# The Overall Scenario Structure

| | | Forecast Demand Level (from FESG) | | |
|---|---|---|---|---|
| | | Low | Mid | High |
| Baseline for context | IS0 | | | |
| LTAG-TG Integrated Scenarios | IS1 | | | |
| | IS2 | | | |
| | IS3 | | | |

*The structure shows how the LTAG integrated scenarios were combined with the CAEP/12 COVID-impacted demand/traffic forecasts to produce results. Each cell in the matrix represents a time series that is a combination of a traffic forecast and an LTAG integrated (emissions reduction) scenario over the analysis period.*

# Summary of LTAG Integrated Scenarios

| **Baseline** (for context) | LTAG Integrated Scenarios | | |
|---|---|---|---|
| **Integrated Scenario 0 (IS0)** | **Integrated Scenario 1 (IS1)** | **Integrated Scenario 2 (IS2)** | **Integrated Scenario 3 (IS3)** |
| • 'Frozen' scenario | • 'Low / nominal' scenario | • 'Increased / further ambition' scenario | • 'Aggressive / speculative' scenario |
| • Projection of current technologies available in the base year (through fleet renewal) | • Current (c. 2021) expectation of future available technologies, operational efficiencies and fuel availability | • Faster rollout of future technologies, increased operational efficiencies and higher fuel availability | • Maximum possible effort in terms of future technology rollout, operational efficiencies, fuel availability |
| • No additional improvements from technology, operations and no emissions reductions from fuels (SAF) | • Expected policy enablers for technology, ops and fuels | • Increased policy enablers for technology, ops and fuels | • Maximum policy enablers for technology, ops and fuels. |
| • No systemic change – e.g. infrastructure changes to accommodate growth only | • Low systemic change – e.g. no substantial infrastructure changes | • Increased systemic change – e.g. limited infrastructure changes | • High, internationally aligned systemic change - e.g. significant and broad change to airport and energy infrastructure |

*Decreasing readiness and attainability. Increasing aspiration.*

# Composition of LTAG Integrated Scenarios

| | | | | | |
|---|---|---|---|---|---|
| **Long Term Forecast** | Low *or* | | Mid *or* | | High |
| **Fleet Composition** | Current (2018) Remaining Fleet + | Introduction of Advanced Tube & Wing + | Introduction of ACA with Limited Infrastructure Changes + | Introduction of ACA with Major Infrastructure Changes | |
| **Fleet Entry and Diffusion** | Low ACA Market Share *or* | | Mid ACA Market Share *or* | | High ACA Market Share |
| **Aircraft Configuration** | Currently (2018) Certified Aircraft | Advanced Tube & Wings (ATW) | ACA Airframe<br>ACA Propulsion (Drop-In) | ACA (Airframe + Prop) (Drop-In)<br>ACA Propulsion (Non Drop-In) | ACA Combinations (Airframe + Prop) (Non Drop-In)* |
| **Vehicle Technologies** | Frozen Technology at Current (2018) Level | T1 Technology Baskets 2030/2040/2050 | T2 Technology Baskets 2030/2040/2050 | T3 Technology Baskets 2030/2040/2050 | |
| **Operations** | Flight and Ground Operations Fixed at Current Capability | O1: Low Scenario Operational Assumptions | O2: Medium Scenario Operational Assumptions | O3: High Scenario Operational Assumptions | |
| **Infrastructure** | Incremental Changes to Accommodate New Growth Only | Changes Required to Accommodate Efficiency Changes | **Minor** Changes Required for Alternative Aircraft | **Major** Changes Required for Alternative Aircraft | |
| **Fuels** | Conventional Jet A-1 Fuel | F1: Availability of Drop-in Fuels (SAF & LCAF) | F2: Increased Availability of Drop-in Fuels | F3: Widespread Availability of Drop-in Fuels | F3: Non-drop-in Alternative Fuels |

*ACA - Advanced Concept Aircraft

# Costs and Investments Associated with Integrated Scenarios

- **Using a cost minus baseline approach, ICAO assessed the costs and investments associated with integrated scenarios.**
- **Assessed costs or savings from technology, operations and fuels measures across stakeholders. Quantified uncertainty.**

**Investments from States:**

- R&D to support aircraft technology developments.
- IS1: $15 to $180 billion through 2050.
- IS2 and IS3: $75 to $870 billion (to support advanced aircraft configuration and/or energy systems (i.e., hydrogen powered aircraft).

**Investments from OEMs:**

- IS1: ≈ $ 180 billion (2020-2050).
- IS2-3: ≈ $ 350 billion (2020 and 2050) to develop aircraft with unconventional configurations and hydrogen powered aircraft.

**Investments from fuel suppliers:**

- IS1: ≈ $ 1,300 billion
- IS2: ≈ $ 2,300 billion
- IS3: ≈ $ 3,200 billion

**Costs and investments for airports:**

- $ 2 to 6 billion across LTAG scenarios towards the implementation of operations measures airports
- IS3: ≈ $ 100-150 billion by 2050 of infrastructure investments for hydrogen aircraft.

**Costs and investments for ANSPs:**

- $ 11 to 20 billion

**Costs and investments for Airlines:**

- ≈ $ 710 to 740 billion reduced operating fuel costs from aircraft technology improvements (incremental fleet investments may be required).
- ≈ $ 210 to 490 billion reduced operating fuel costs from operational measures associated with $ 40 to 155 billion of implementation costs.
- Incremental fuel related costs *(minimum selling price of fuels minus conventional jet fuel price)*:
  - IS1: ≈ $ 1100 billion
  - IS2: ≈ $ 2700 billion
  - IS3: ≈ $ 4000 billion

Note. – All costs or investments are cumulative from 2020 to 2050.

Disclaimers: Costs associated with a given scenario are not meant to be added towards a total cumulative costs. Costs and investments are estimated and reported 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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# Key Take Away Messages on Scenarios

- The **integrated in-sector scenarios** of technology, fuels and operations that represent a **range of readiness and attainability** were created.
- The analysis shows impact on international aviation $CO_2$ emissions to 2070

| Integrated Scenario 1 | |
|---|---|
| | **2050** |
| **Residual $CO_2$** | 950 Mt |
| **vs. 2019** | 160% |
| **Reductions from baseline** | 39% |
| **Tech** | 20% |
| **Ops** | 4% |
| **Fuels** | 15% |
| **Energy efficiency improvement** | 1.11% p.a. |
| **Cost / investment** | Lowest |

| Integrated Scenario 2 | |
|---|---|
| | **2050** |
| **Residual $CO_2$** | 495 Mt |
| **vs. 2019** | 80% |
| **Reductions from baseline** | 68% |
| **Tech** | 21% |
| **Ops** | 6% |
| **Fuels** | 41% |
| **Energy efficiency improvement** | 1.37% p.a. |
| **Cost / investment** | Medium |

| Integrated Scenario 3 | |
|---|---|
| | **2050** |
| **Residual $CO_2$** | 200 Mt |
| **vs. 2019** | 35% |
| **Reductions from baseline** | 87% |
| **Tech** | 21% |
| **Ops** | 11% |
| **Fuels** | 55% |
| **Energy efficiency improvement** | 1.61% p.a. |
| **Cost / investment** | Highest |

# 3 LTAG – Technology

# LTAG Technology

**Objective -** assess the $CO_2$ reduction potential of new and evolutionary technologies for airframes, propulsion systems and advanced concepts (including energy storage).
The vehicle integration analysis completes the aircraft concept for further modelling in scenarios.

ICAO Documents

Stocktaking Questionnaires

External Sources

Data Input Review

**Airframe improvements** – aerodynamics, structures/materials, systems, and vehicle integration

**Propulsion system improvements –** improved turbofan, unducted propulsor, turboelectric, hybrid

**Advanced Concepts and Energy Storage** – hydrogen and electric aircraft concepts, flying wing, strut-braced wing

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# Aircraft Under Consideration

**Technology Reference Aircraft 2018**

- *Notional* DHC Dash 8-400
- *Notional* E190-E2
- *Notional* A320neo
- *Notional* A350-900
- *Notional* G650ER

**<u>Conventional</u>, including alternative energy sources**


**<u>Advanced Concepts</u>, including alternative energy sources**

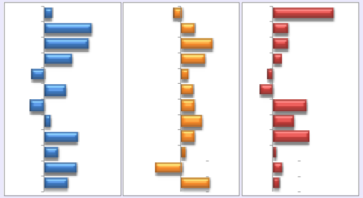
# Integrated Technology Modeling Process

### *Vehicle Analysis*

Vehicle Performance Characteristics

### *Technologies*

- Benefit
- Applicability
- Availability



ICAO CAEP input

External input

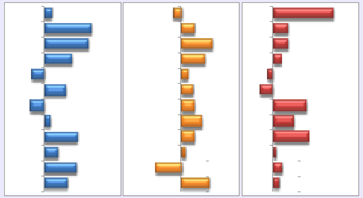
# Integrated Technology Modeling Process

### *Vehicle Analysis*

Vehicle Performance Characteristics

### *Technologies*

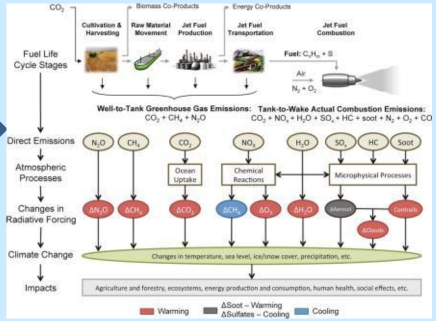
- Benefit
- Applicability
- Availability



ICAO CAEP input

External input

### *Alternative Fuels*




Fuel related input

# Integrated Technology Modeling Process

Forecast and Scenarios input

## *Scenario/Operations*

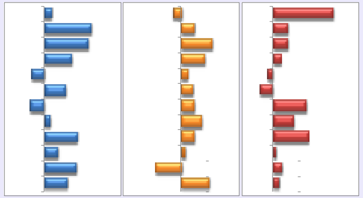
- Demand Forecast
- Aircraft Retirements
- Replacements Schedule
- New Product / Upgrade Availability

## *Vehicle Analysis*

Vehicle Performance Characteristics

## *Technologies*

- Benefit
- Applicability
- Availability

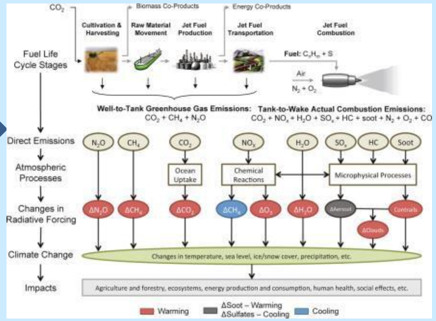


ICAO CAEP input

External input

Fuel related input

## *Alternative Fuels*




## *Fleet Analysis*

- FB/Operation
- Total Ops
- Total FB

Modelling

# Integrated Technology Modeling Process

Forecast and Scenarios input

### *Scenario/Operations*

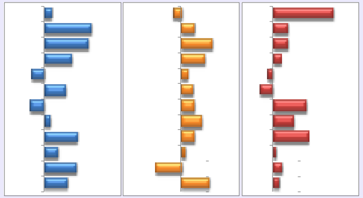
- Demand Forecast
- Aircraft Retirements
- Replacements Schedule
- New Product / Upgrade Availability

### *Vehicle Analysis*

Vehicle Performance Characteristics

### *Technologies*

- Benefit
- Applicability
- Availability

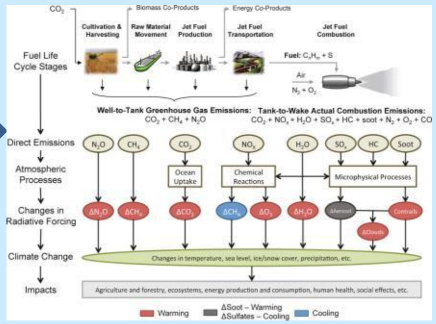


ICAO CAEP input

External input

Fuel related input

### *Alternative Fuels*

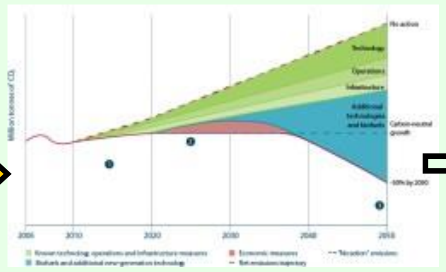



### *Fleet Analysis*

- FB/Operation
- Total Ops
- Total FB

Modelling

### *Fleet Impact*



**Deliverable**
Assess alternatives and provide recommendations

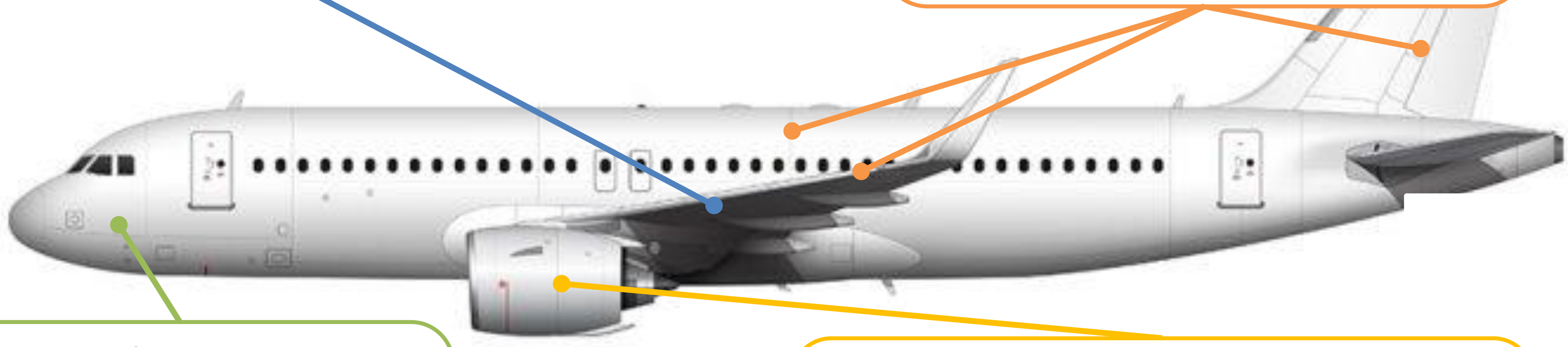
# Narrow Body ATW Technology Identification

**Aerodynamics**

- Excrescence Reduction
- Flow Control: HLFC / NLF, Riblets
- Active CG Control
- Advance Wingtip Devices
- MDAO – Configuration Integration

**Structures / Materials**

- Advanced Metallic Technologies
- Advanced Composite Technologies
- Optimized Local Design
- Multifunctional Design/Materials
- Advanced Load Alleviation
- Nacelle Improvements



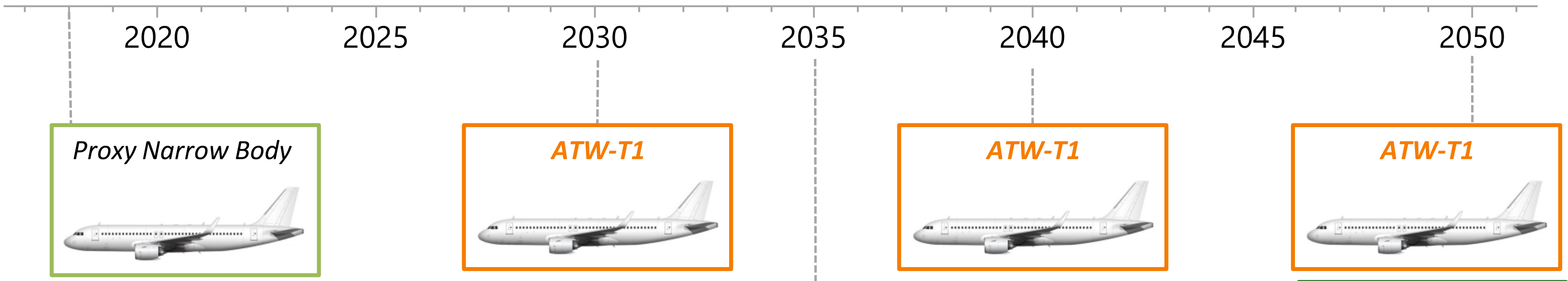
**Systems**

- More Electric A/C (replacement of various pneumatic systems with electrical equivalents)
- Adaptive ECS (Filtration and reconfiguration)

**Propulsion**

- Advanced Propulsion System
  - Higher OPR
  - Lower FPR
  - Component Weight Reductions
  - Component Efficiency Improvements

# Narrow Body - Potential Entry-into-Service (EIS)

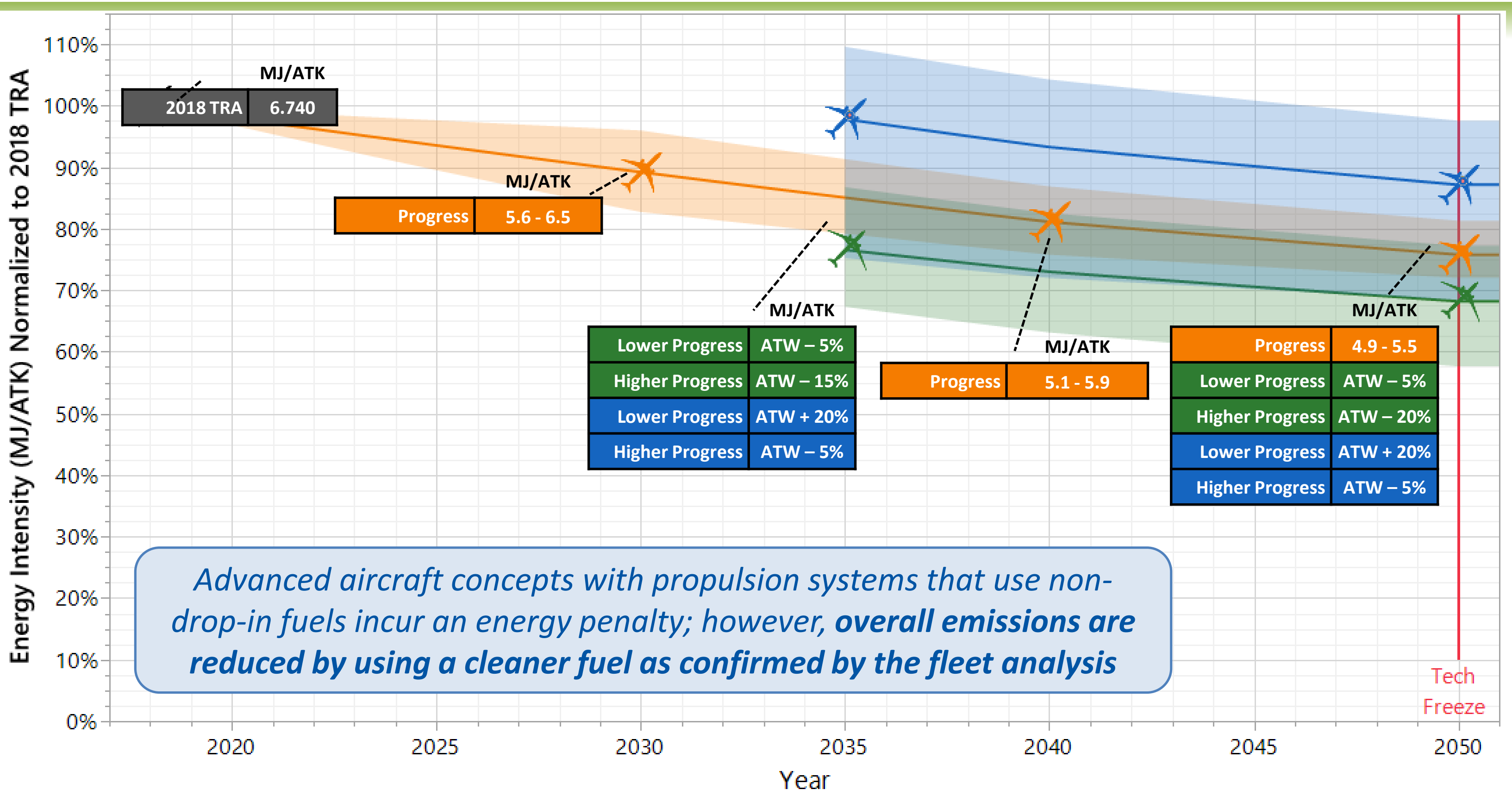



- Advanced concept aircraft were grouped under technology scenarios T2 and T3

- Potential entry into service for each vehicle class was determined based on the concepts' current technology and infrastructure readiness


**ATW:** Advanced Tube and Wing
**ACA:** Advanced Concept Aircraft

# Vehicle Perspective: Narrow Body Energy Trend




**Energy (fuel) efficiency improvement projections for various aircraft concepts under consideration**

# Key Take Away Messages on Technology

- Conventional Tube and Wing aircraft will continue to make incremental improvements in fuel consumption

- Proposed technology and concept alternatives are available for each class of vehicles: business jets, turboprops, regional jets, narrow and wide bodies

- Advanced concept aircraft can provide step changes in energy use
  - Life cycle carbon reduction benefits for non-drop-in fuels will depend heavily on the production methods
  - Advanced concepts require significant R&D as well as flight demonstration programs
  - Technical capability and maturity advances are necessary **but not sufficient** without infrastructural and regulatory considerations

| | Narrow Body Energy Intensity Relative to 2018 TRA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Progress Level | 2018 | 2030 | 2035 | | 2040 | 2050–2070 | | |
| Lower Progress | 100% | 96.01% | 86.8% | 110% | 86.9% | 81.32% | 77.3% | 97.6% |
| Medium Progress | | 89.22% | 76.6% | 97.8% | 81.1% | 75.80% | 68.2% | 87.2% |
| Higher Progress | | 82.74% | 67.3% | 75.2% | 75.8% | 72.03% | 57.6% | 68.4% |

# 4 LTAG – Operations

# Operations Categorization

| | | |
|---|---|---|
| ***Operational measures captured in ICAO CAEP work on Airports and Operations*** | + | ***Additional operational measures identified in LTAG work*** |

- Operations work included an updated to the baseline to take into account the following new sources of inefficiency:
  - ✓Horizontal flight inefficiency
  - ✓Vertical flight inefficiency
  - ✓Ground operations inefficiency
  - ✓Innovative flight inefficiency
  - ✓Advanced flight inefficiency

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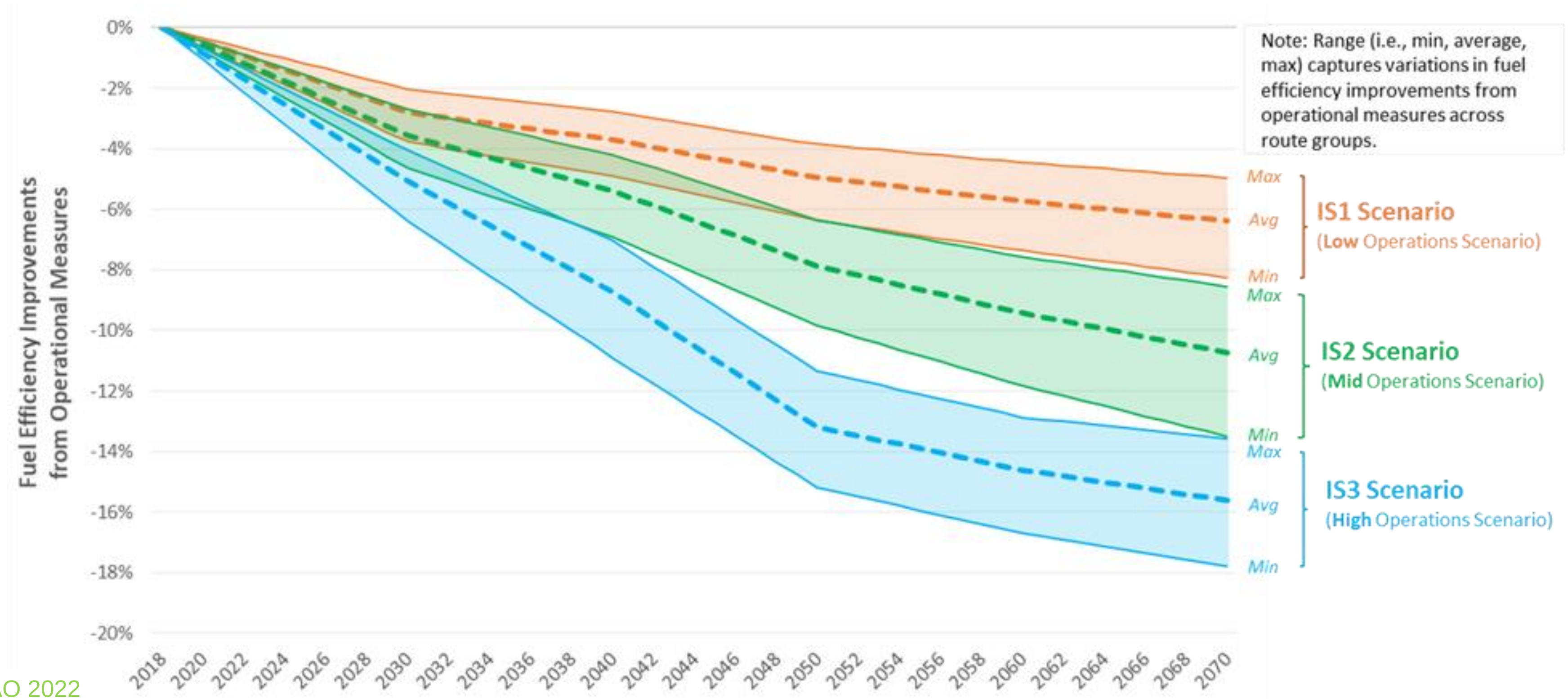
# Operations Scenario Definition

| | LTAG Scenarios | | |
|---|---|---|---|
| **Baseline** | **O1 Scenario**<br>**Low CO2 reduction from Operations** | **O2 Scenario**<br>**Mid CO2 reduction from Operations** | **O3 Scenario**<br>**High CO2 reduction from Operations** |
| No emissions reductions from operations after 2025 (implementation of ASBU blocks 0 and 1) | Conservative assumptions about rate and extent of implementation of operational measures, based on reduced/slower investment in ground and airborne systems and technologies.<br><br>Low rate of ASBU element deployment to optimise HFE, VFE and GFE. | Emissions reductions and operational efficiencies in line with existing "Rules of Thumb" developed by ICAO CAEP and new "Rules of Thumb" developed during the LTAG work for new measures.<br><br>Medium rate of ASBU element deployment to optimise HFE, VFE and GFE.<br><br>Low rate of operational measure deployment to optimise IFE and AFE. | Aggressive assumptions about rate and extent of implementation of operational measures, based on higher/accelerated investment in ground and airborne systems and technologies.<br><br>High rate of ASBU element deployment to optimise HFE, VFE and GFE.<br><br>Medium rate of operational measure deployment to optimise IFE and AFE. |

# Summary of fuel efficiency improvements from Operations

## Fuel efficiency improvements from operational measures across LTAG integrated scenarios



# Key Take Away Messages on Operations

- **Three scenarios defined for operations** to represent increasing levels of ambition – aligned with technology and fuels
- Analysis shows there are **opportunities for operations to reduce $CO_2$ emissions through improvements in the performance of flights across all phases**, including unconventional measures such as formation flying.

**Average Fuel efficiency improvements from operational measures across LTAG integrated scenarios**

| | O1 | O2 | O3 |
|---|---|---|---|
| 2035 | 3% | 4.5% | 7% |
| 2050 | 5% | 8% | 13% |
| 2070 | 6% | 11% | 16% |

# 5 LTAG – Fuels

# LTAG Fuels Approach

## Fuel Categorisation

- Carbon source
- Drop-in / non drop-in

## Scenario Definition

- IS1/F1, IS2/F2, IS3/F3
- Expectation on available technologies
- Fuel availability (readiness, attainability)

## Fuels Analyses

- Examined each fuel category
- Used scenario definitions
- Fuel production potential
- Lifecycle GHG saving
- Economics and infrastructure issues

## Unconstrained Scenarios

- Combined all fuel types from fuels analyses
- Production potential and life cycle GHG savings
- Volume > demand
- ATAG as reference

## Constrained Scenarios

- Combines all fuel types from fuels analyses
- Production potential and life cycle GHG savings
- Volume <= demand
- ATAG as reference
- Data is in spreadsheet
- Will re-evaluate based on final fuel use data

# Fuel Categorization

**Drop-in fuels**

| Fuel Category | Fuel Name | Carbon source in fuel feedstock |
|---|---|---|
| LTAG - Sustainable Aviation Fuels (LTAG-SAF) | Biomass-based fuel | Primary biomass products and co-products |
| | Solid/liquid waste-based fuels | By-products, residues, and wastes |
| | Gaseous waste-based fuels | Waste $CO/CO_2$ |
| | Atmospheric $CO_2$-based fuels | Atmospheric $CO_2$ |
| LTAG - Lower Carbon Aviation Fuels (LTAG-LCAF) | Lower carbon petroleum fuels | Petroleum |

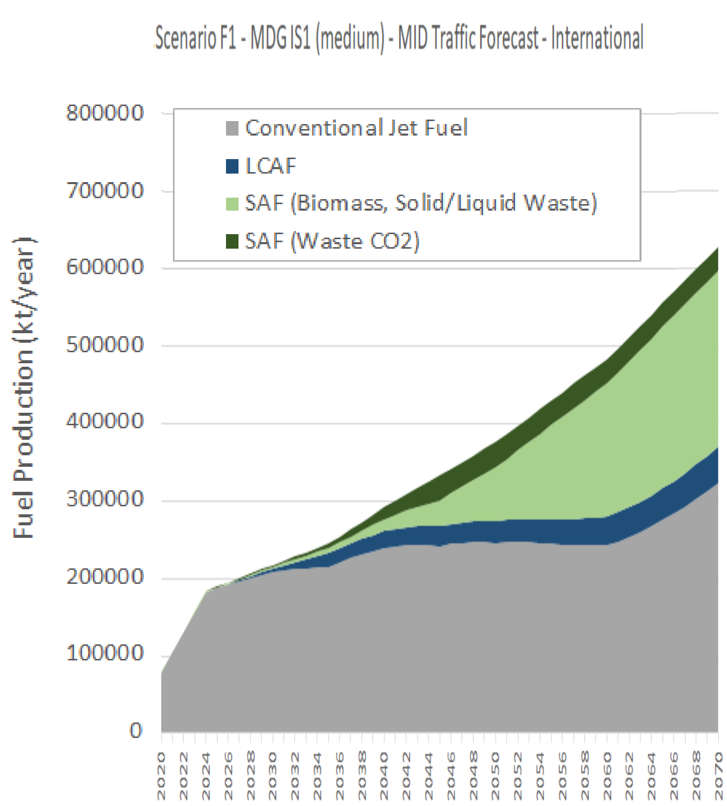
**Non drop-in fuels**

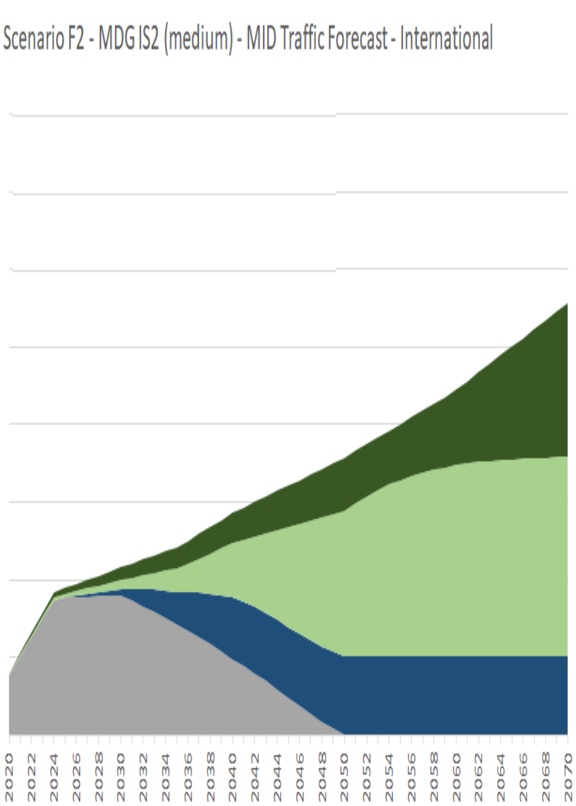
| Fuel Category | Fuel Name | Carbon source in fuel feedstock |
|---|---|---|
| Non drop-in fuels | Electricity | Not applicable |
| | Liquefied gas aviation fuels (ASKT) | Petroleum gas, "fat" natural gas, flare gas, and propane-butane gases |
| | Cryogenic hydrogen | Natural gas, by-products, non-carbon sources |

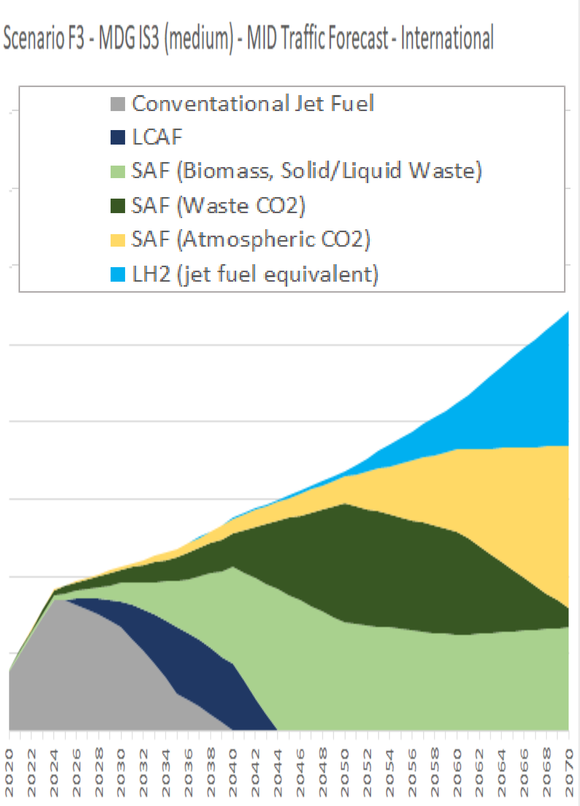
# Fuels Scenario Definitions

| | LTAG Scenarios | | |
|---|---|---|---|
| | **Fuel Scenario 1 (F1)**<br>**Low GHG reduction from Fuels**<br>**(LTAG-SAF and LTAG-LCAF)** | **Fuel Scenario 2 (F2)**<br>**Mid GHG reduction from Fuels**<br>**(LTAG-SAF and LTAG-LCAF)** | **Fuel Scenario 3 (F3)**<br>**High GHG reduction from Fuels**<br>**(LTAG-SAF, LTAG-LCAF and non-drop-in fuels)** |
| **Scenario Development** | **Emphasize low cost GHG reduction → select fuels by Minimum Selling Price** | **Prioritize cost effective GHG reduction → select fuels by Marginal Abatement Cost** | **Maximize $CO_2$ reduction → select fuels by Lifecycle Value** |
| **Approved Fuel Use** | ASTM Intl approves use of alternative jet fuels at **blend levels above 50%.** | ASTM Intl approve **use of 100% Synthesized Jet Fuel in existing aircraft and engines** without any modification. | |
| **Ground Transportation and Electrification** | **Ground transportation and aviation have level playing field** with respect to alternative fuel use. | **Electrification of ground transportation** leads to increased availability of SAF. | **Economy-wide deep decarbonisation.** Extensive electrification of ground transportation and widespread availability of renewable energy. |
| **Incentives** | **Low incentives** for LTAG-SAF/LTAG-LCAF production. | **Increased incentives** lead to **reduced LTAG-SAF/LTAG-LCAF fuel cost** for users. | **Large incentives lead to widespread use** of low GHG fuels for aviation. |
| **Fuel Availability** | Using waste gases ($CO/CO_2$) and variety of feedstocks (e.g., oilseed cover crops) for LTAG-SAF. | **Widespread use of waste gases** and increased feedstock availability for LTAG-SAF.<br><br>**SAF production exceeds jet fuel demand** | **Widespread use of atmospheric $CO_2$ for LTAG-SAF** and maximum LTAG-SAF feedstock availability.<br><br>**SAF production exceeds jet fuel demand** |
| | | | **Sufficient $H_2$ exists to enable use of cryogenic $H_2$ fuel in aircraft.** Infrastructure developed to enable use of non-drop-in fuels at airports around globe. |

# Scenario F1/IS1, F2/IS2, F3/IS3 - MID Traffic Forecast



# Key Take Away Messages on Fuel

- **Three scenarios defined for fuels** to represent increasing levels of ambition – aligned with technology and operations
- LTAG-SAF volumes exceed demand under F2 and F3
- Achievable **GHG savings** from alternative fuel use ranges from **20%** (F1) to **81%** (F3) in **2050**, and could be close to **90%** in **2070** (F3)

**Reductions in Lifecycle GHG Emissions***
**For Mid Traffic Forecast**

| | F1 | F2 | F3 |
|---|---|---|---|
| 2035 | 5% | 20% | 37% |
| 2050 | 20% | 56% | 81% |
| 2070 | 28% | 66% | 88% |

*Expressed as the Emissions Reduction Factor (ERF) given as a percent and calculated using: $\left(1 - \frac{LC_{fuel\ mix}}{LC}\right) \times 100$ where $LC_{fuel\ mix}$ is the lifecycle value of the fuel mix and LC is the lifecycle value of the baseline (89 $gCO_{2e}/MJ$)

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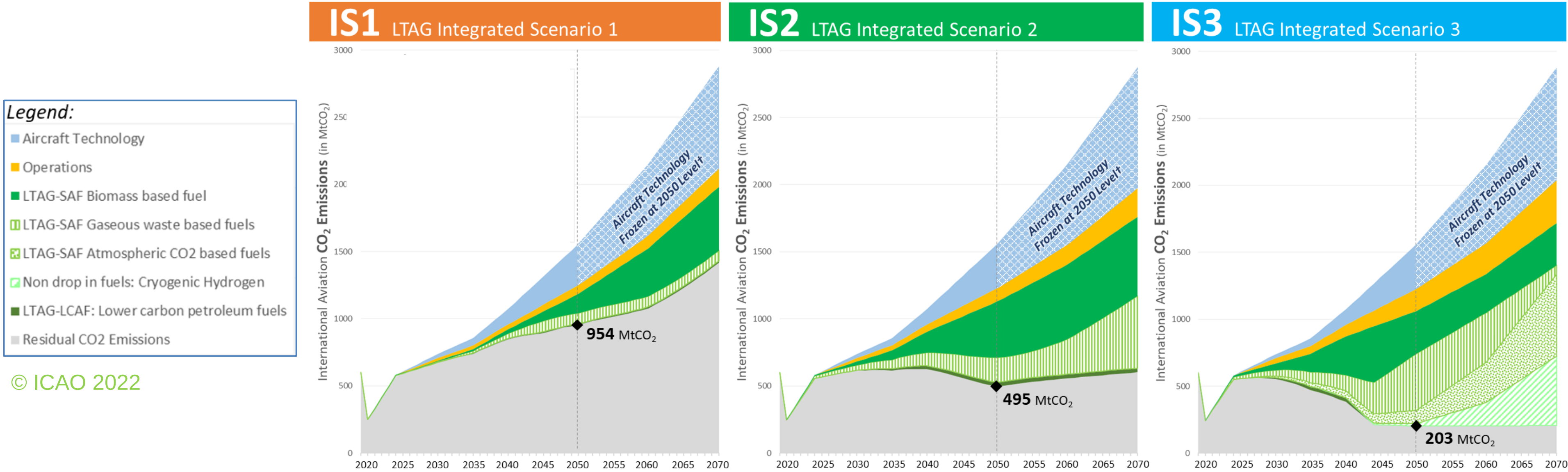
# Main takeaway from the LTAG Report






| Metrics | IS1 | IS2 | IS3 |
|---|---|---|---|
| $CO_2$ Emissions in 2050 after Reductions | **≈950 $MtCO_2$** in 2050<br>*(**160%** of 2019 $CO_2$ emissions)* | **≈500 $MtCO_2$** in 2050<br>*(**80%** of 2019 $CO_2$ emissions)* | **≈200 $MtCO_2$** in 2050<br>*(**35%** of 2019 $CO_2$ emissions)* |
| Reduction in 2050 from the Baseline | **39% total** through: Technologies - 20%, Operations - 4%, Fuels - 15% | **68% total** through: Technologies - 21%, Operations - 6%, Fuels - 41%) | **87% total** through: Technologies - 21%, Operations - 11%, Fuels - 55% |
| Cumulative residual Emissions from 2020 to 2070 | 23 $GtCO_2$ (2020 to 2050)<br>23 $GtCO_2$ (2051 to 2070) | 17 $GtCO_2$ (2020 to 2050)<br>11 $GtCO_2$ (2051 to 2070) | 12 $GtCO_2$ (2020 to 2050)<br>4 $GtCO_2$ (2051 to 2070) |

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THANK YOU