Aviation and Environment –
Global Strategies for Future Air Transport

Hamburg Aerospace Lecture – 11 May 2017

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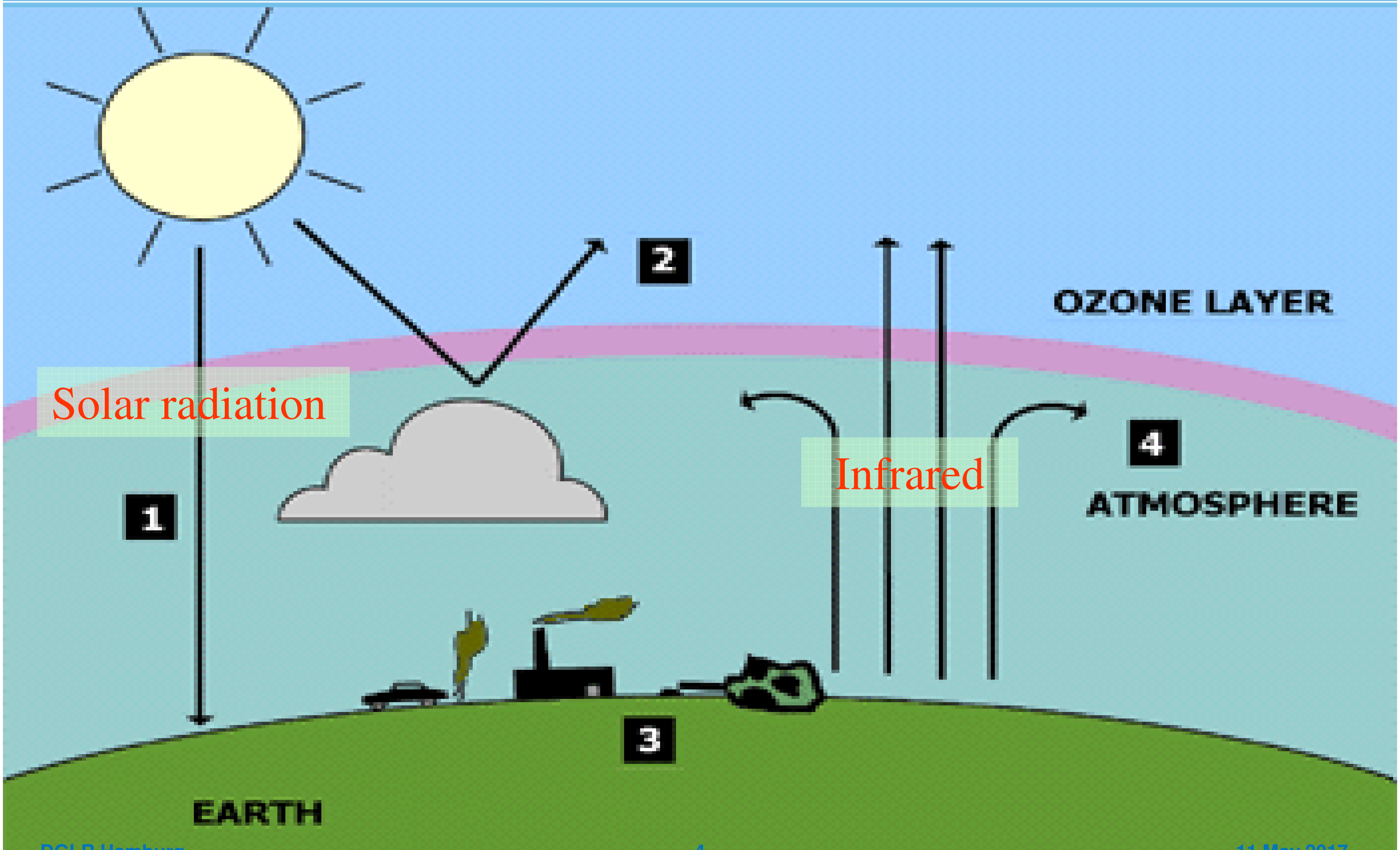
https://doi.org/10.5281/zenodo.7396634

Overview

- Aviation and climate change
- Fuel-efficient aircraft technologies
- Sustainable aviation fuels
- Global market-based measure
- Local air quality
- Noise
- Aircraft decommissioning and recycling

Aviation and climate change

Global warming



Source: WRI

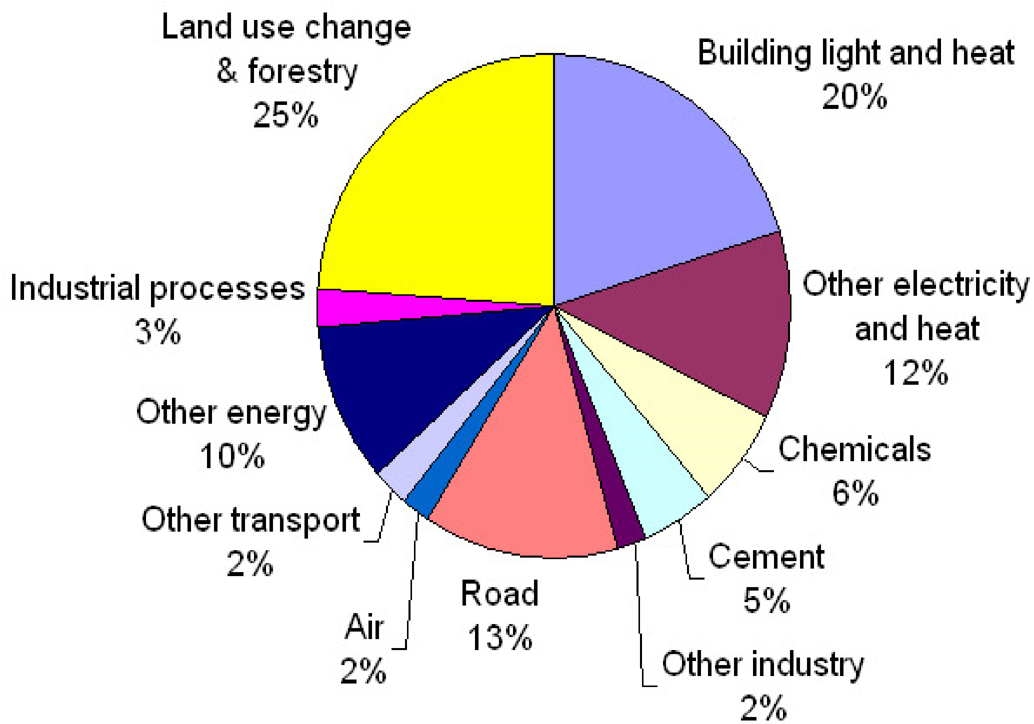
Aviation climate impact

How much of man-made CO_2 emissions comes from aviation?

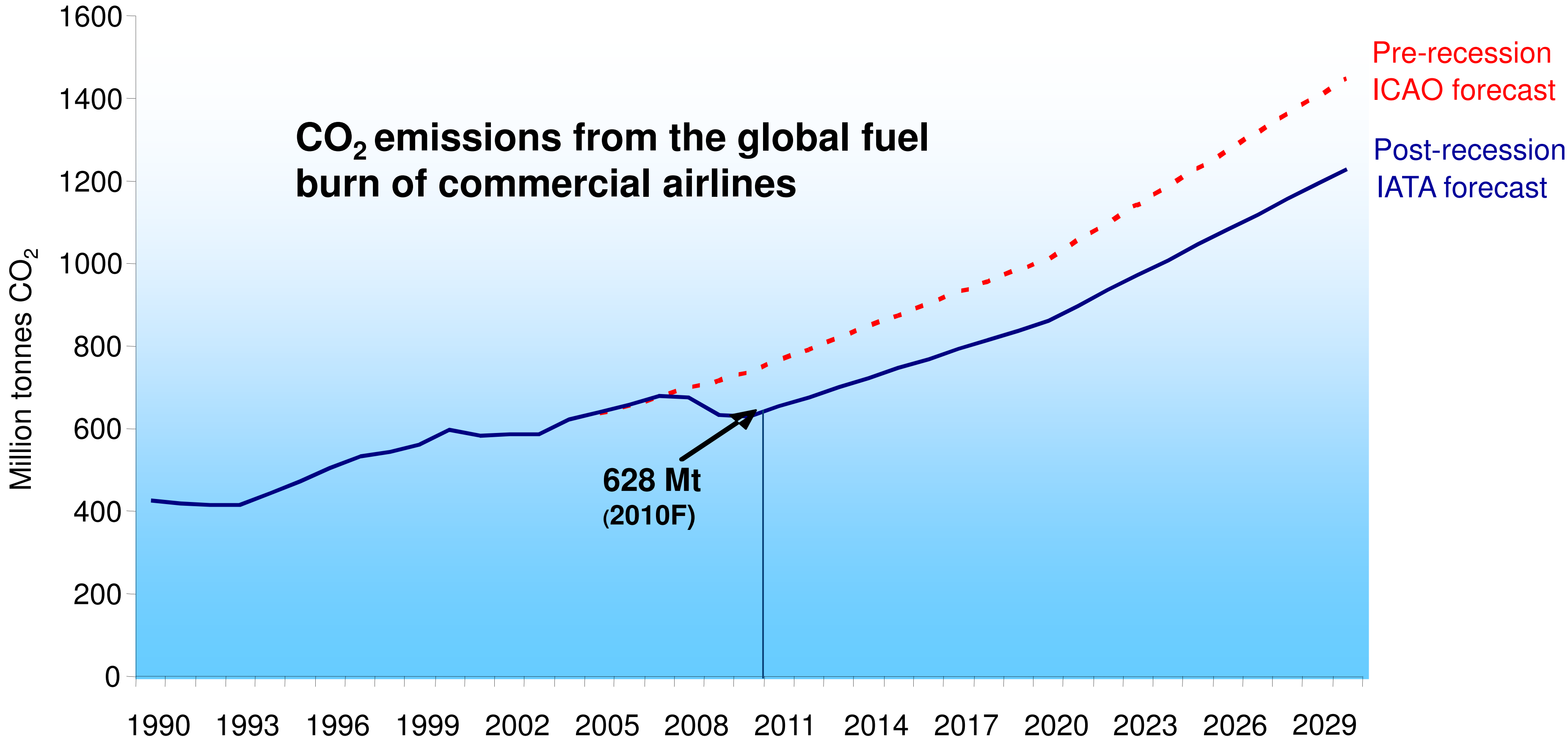
Air transport climate change contribution

Our carbon footprint is small but growing

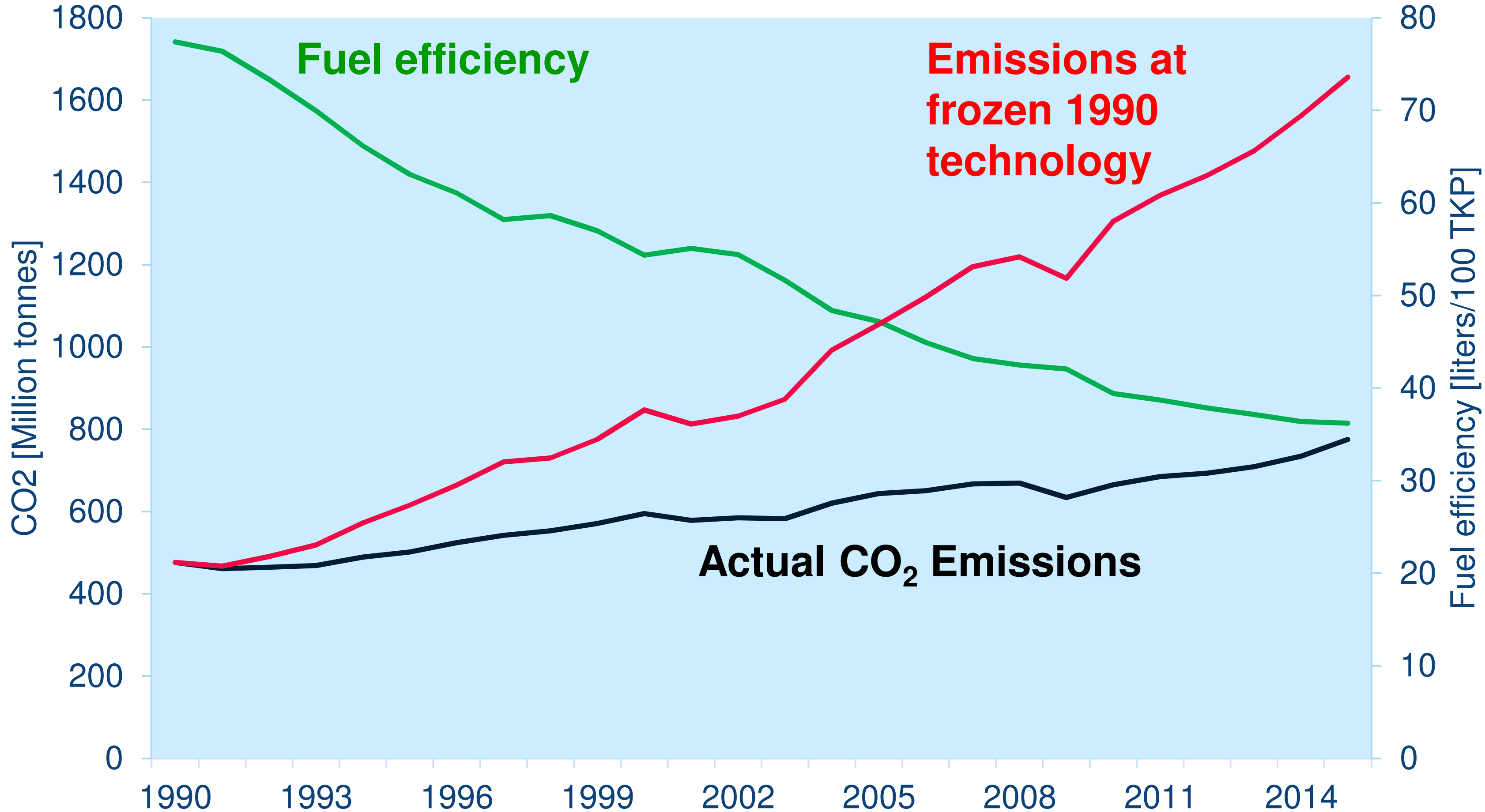
- From 2% today to 3% in 2050 (IPCC)



Aviation faces emissions challenge...



…..but our track record is strong



Industry Commitment on Climate Change

Geneva 2008


Aviation Industry Commitment to Action on Climate Change

We strongly encourage others to join us in this endeavour.

Four pillars of climate action

- **T** TECHNOLOGY
- **O** OPERATIONS
- **I** INFRASTRUCTURE
- **M** MARKET-BASED MEASURE

Three goals…

(commitment by all aviation industry sectors in 2009)

GOAL 1

PRE-2020 AMBITION

1.5% ANNUAL AVERAGE FUEL EFFICIENCY IMPROVEMENT FROM 2009 TO 2020.

T O I

GOAL 2

IN LINE WITH THE NEXT UNFCCC COMMITMENT PERIOD

STABILISE NET AVIATION CO_2 EMISSIONS AT 2020 LEVELS WITH CARBON-NEUTRAL GROWTH.

T O I +M

GOAL 3

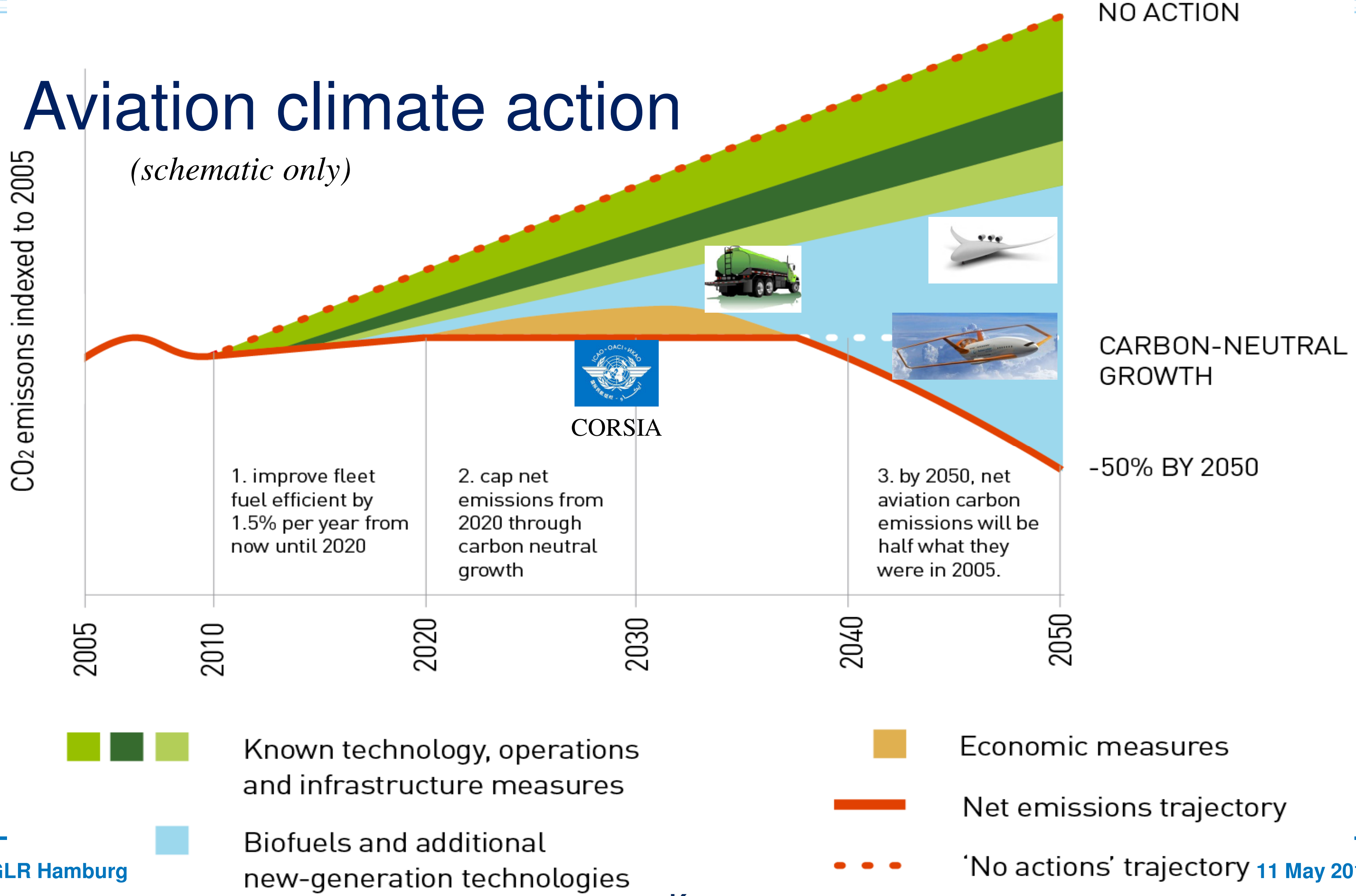
ON THE 2°C PATHWAY

REDUCE AVIATION'S NET CO_2 EMISSIONS TO 50% OF WHAT THEY WERE IN 2005, BY 2050.

T O I

Aviation climate action

(schematic only)



ICAO and Environment

ICAO Assembly (191 States)

ICAO Council (36 Members)

Committee on Aviation Environmental Protection (CAEP)
24 Members (States)
15 Observers (States, Intergovernmental organisations, Industry and NGOs)

WG1	WG2	WG3	FESG	MDG	GMTF	AFTF	ACCS	ISG
Noise technical	Airports & Operations	Emissions Technical	Forecasting & Economic Support	Modeling & Databases	Global MBM Technical	Alt Fuels	Aviation Carbon Calculator	Impact & Science

ICAO Environmental Goals

- Limit or reduce the impact of aviation **GHG emissions** on global climate
- Limit or reduce the impact of aviation emissions on **local air quality**
- Limit or reduce the number of people affected by significant **aircraft noise**

ICAO Basket of measures for climate action

- CO_2 Standard
- Operational measures
- Market-based measures (CORSIA)
- Alternative fuels for aviation

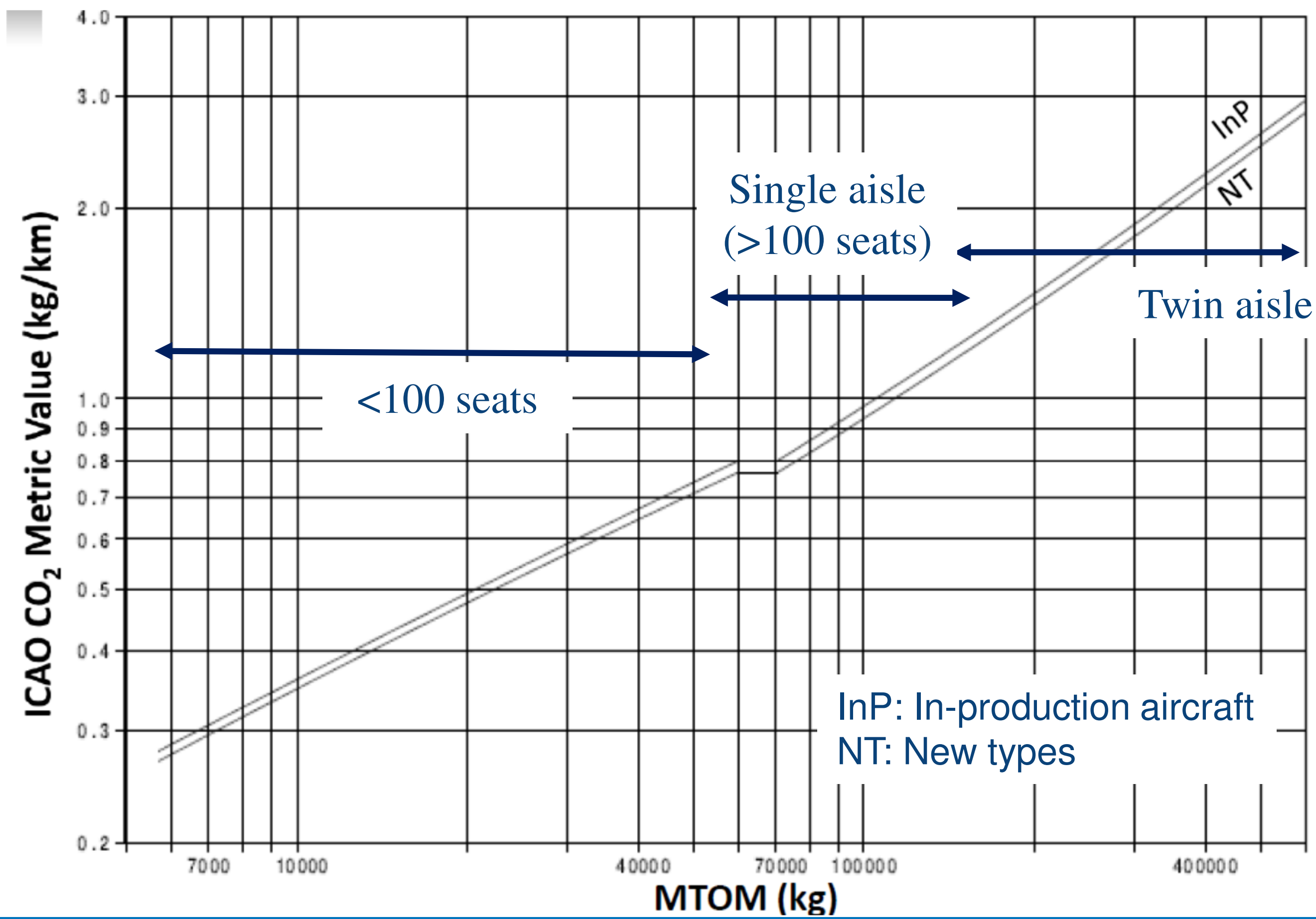
CO_2 Standard – definition

- CO_2 standard adopted in 2016 after 6 years of development and negotiations
- Metric value:

$$MV = \frac{1/SAR}{RGF^{0.24}}$$ as a function of MTOW

- SAR: Specific air range [km/kg]
  - (1/SAR: “fuel consumption” [kg/km])
- RGF: Reference geometric factor (similar to cabin area)

CO_2 Standard – certification limit



CO_2 Standard – applicability

2020	2021	2022	2023	2024	2025	2026	2027	2028

New types — Applications for new type certification

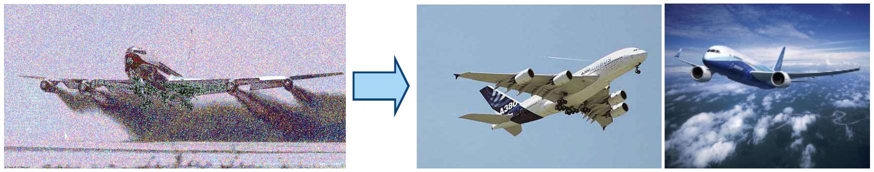
In-production types — All modified versions
By 2028 all InP types

In-service aircraft — ***(not applicable)***

Not designed to serve as a basis for operating restrictions or emissions levies

Fuel-efficient aircraft technologies

Strong track record



- Over the last 50 years
  - Hydrocarbons: -90%
  - Soot: eliminated
  - Noise: -75%
  - Fuel burn: -70%
- Well on track with our target:
  - 2.2% p.a. in average between 2008 and 2015
- New aircraft help
  - A380, B787, A350 consuming less than 3 l / 100 pax km

Research & Technology Goals

ACARE Environmental Goals

	Noise	CO_2	Other emissions	Green life cycle	Alternative fuels
Vision 2020 objectives (ref 2000)	• Halve perceived noise = **- 10 dB per operation** • 65 LDEN at airport boundaries (no-one impacted outside airport boundaries)	• **Decrease CO_2 by 50%** per pass.km	• **Decrease NO_X by 80%** (eq. -60%/CAEP6)	• Progress in reducing the environmental impact of the lifecycle of aircraft	None
Flightpath 2050 objectives (ref 2000)	• Reduce by 65% perceived noise = **- 15 dB per operation**	• **Decrease CO_2 by 75%** per pass.km	• **Decrease NO_X by 90%** • Europe at the forefront of atmospheric research • Emission-free taxiing	• Air vehicles are recyclable	• Europe centre of excellence on sustainable alternative fuels

ERA System Level Goal – Multi-Objective In Nature
Subsonic Transport System Level Metrics

NASA Subsonic Transport Metrics

v2013.1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

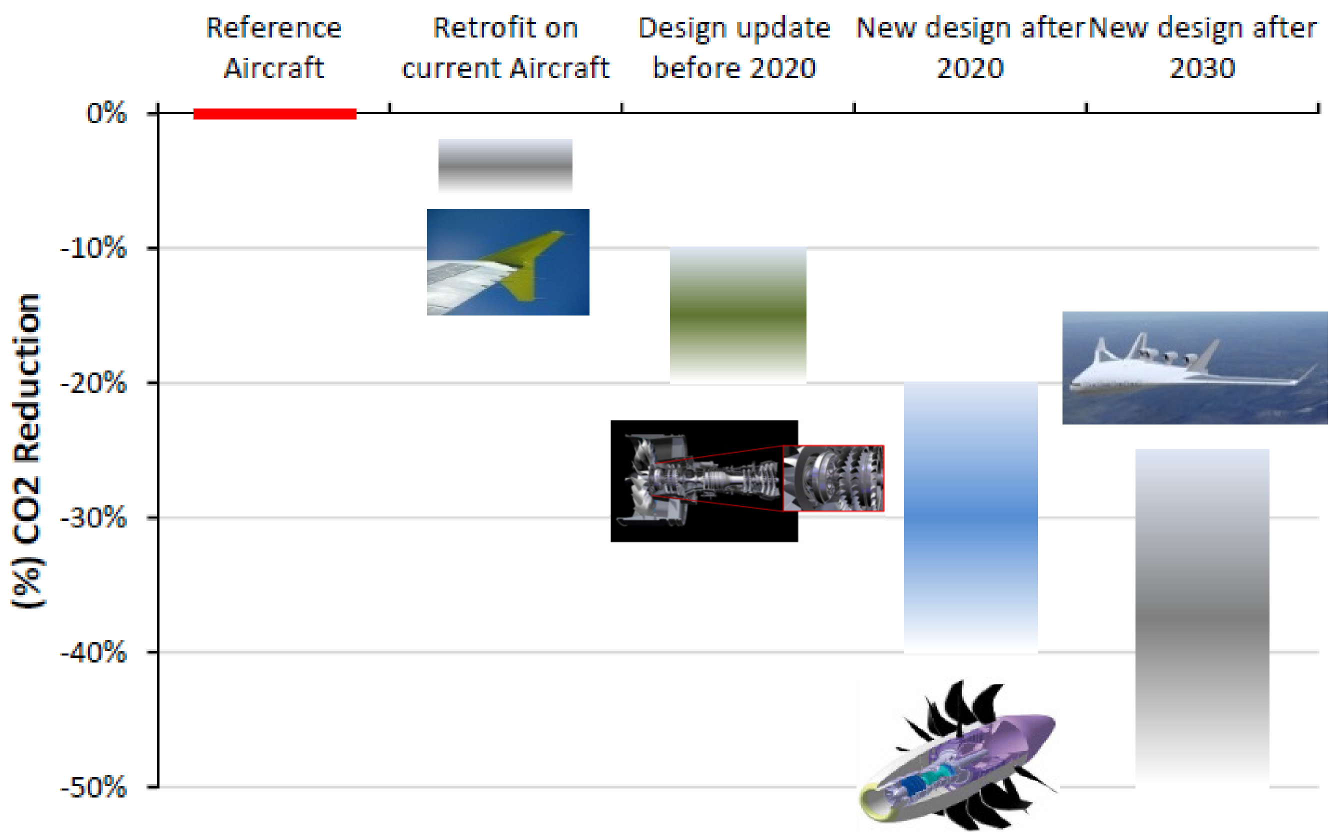
** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_2e per MJ for fuel and/or energy source used

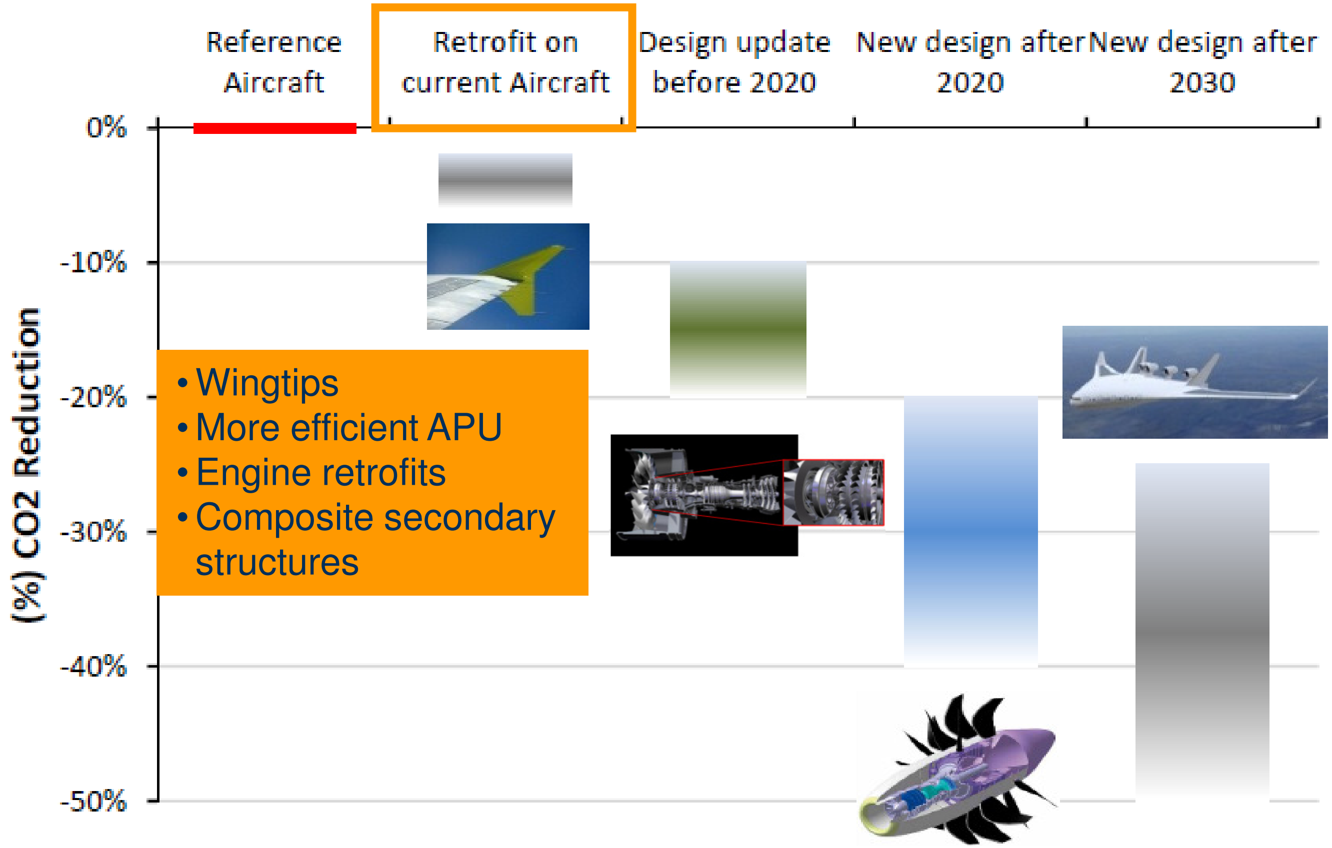
The ERA Project's goal is to identify and mature technologies and advanced configurations that, when integrated, can simultaneously meet the N+2 noise, LTO NOx, and fuel burn reduction metrics

Technology – Fuel saving potential

(IATA Technology Roadmap – TERESA project with DLR Hamburg)



Technology – Fuel saving potential



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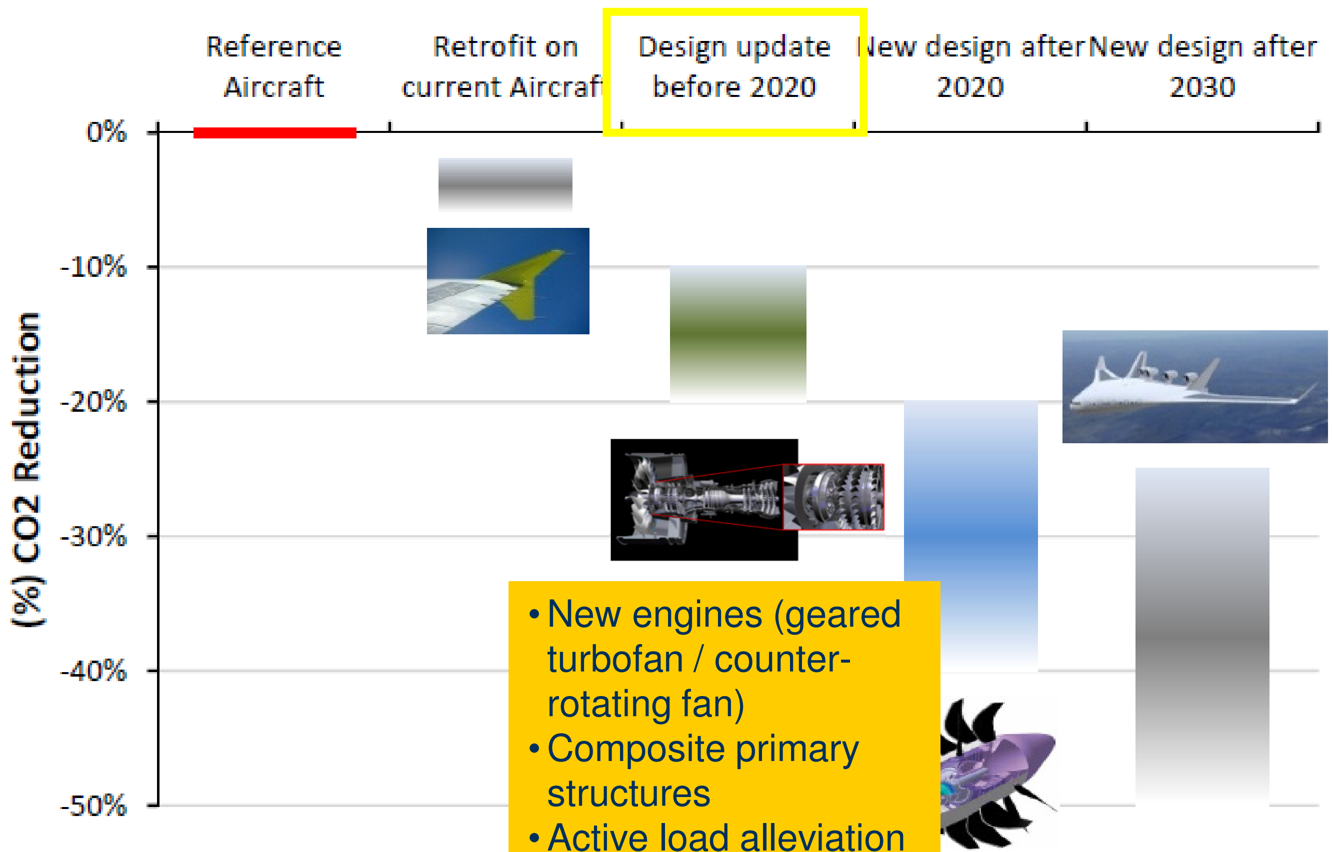
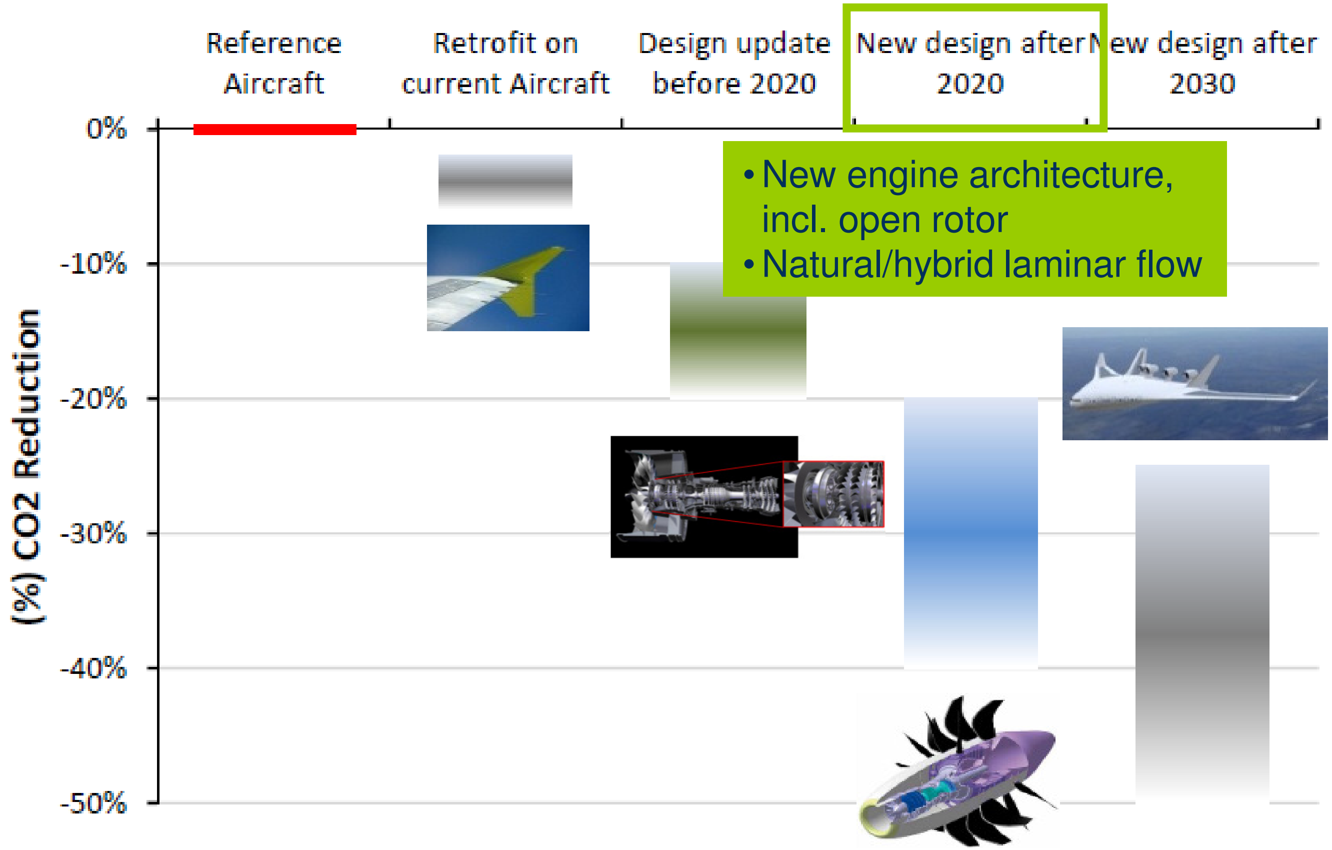
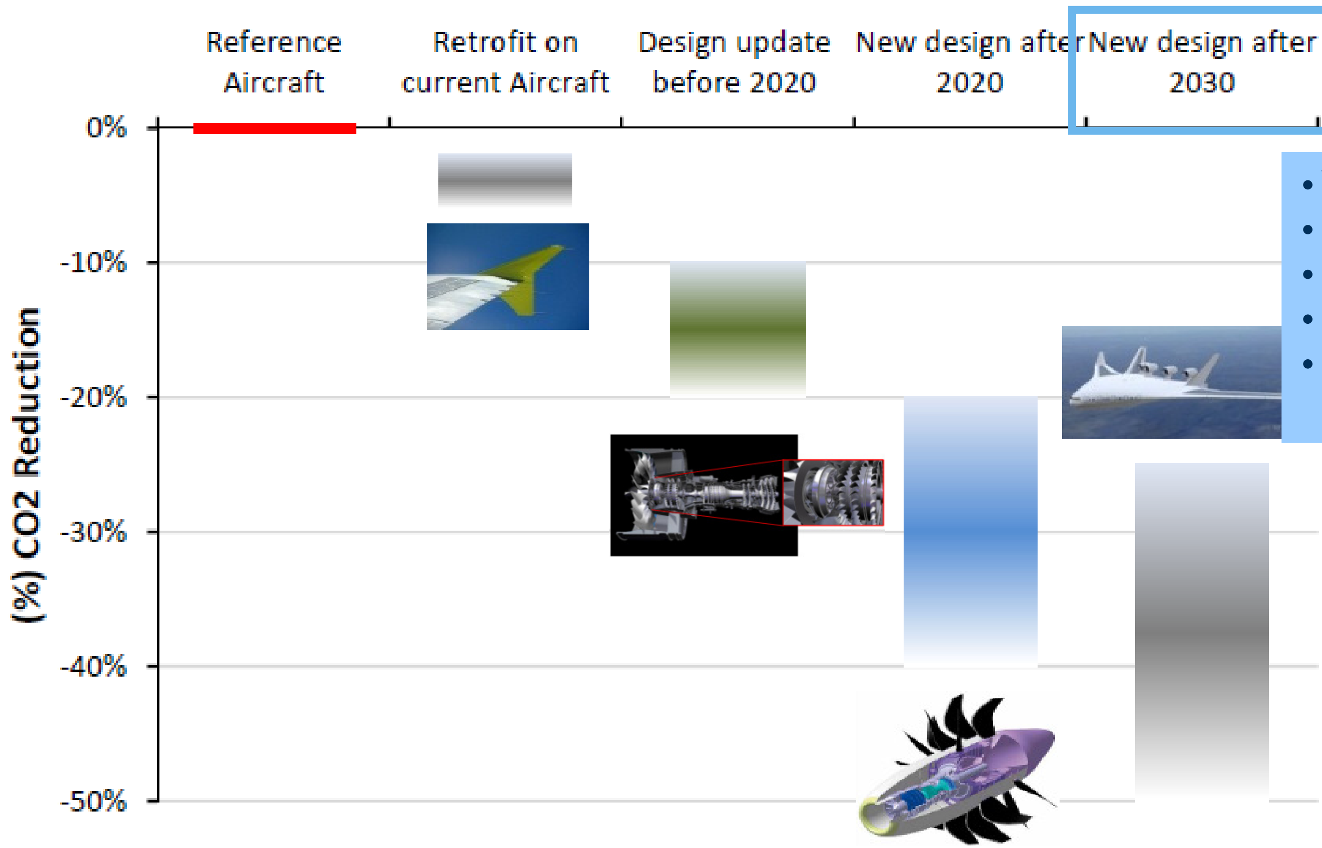


- New engines (geared turbofan / counter-rotating fan)
- Composite primary structures
- Active load alleviation

Technology – Fuel saving potential

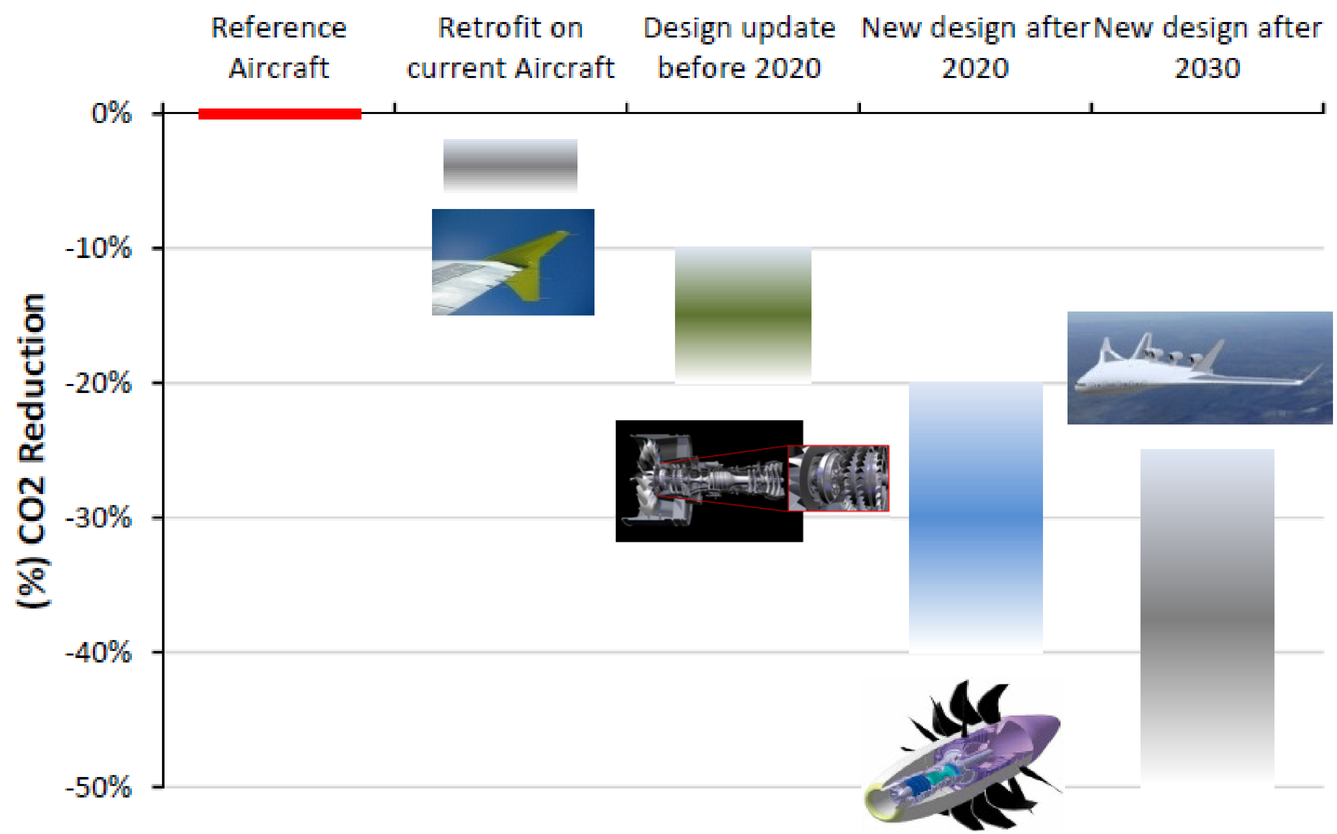


Technology – Fuel saving potential



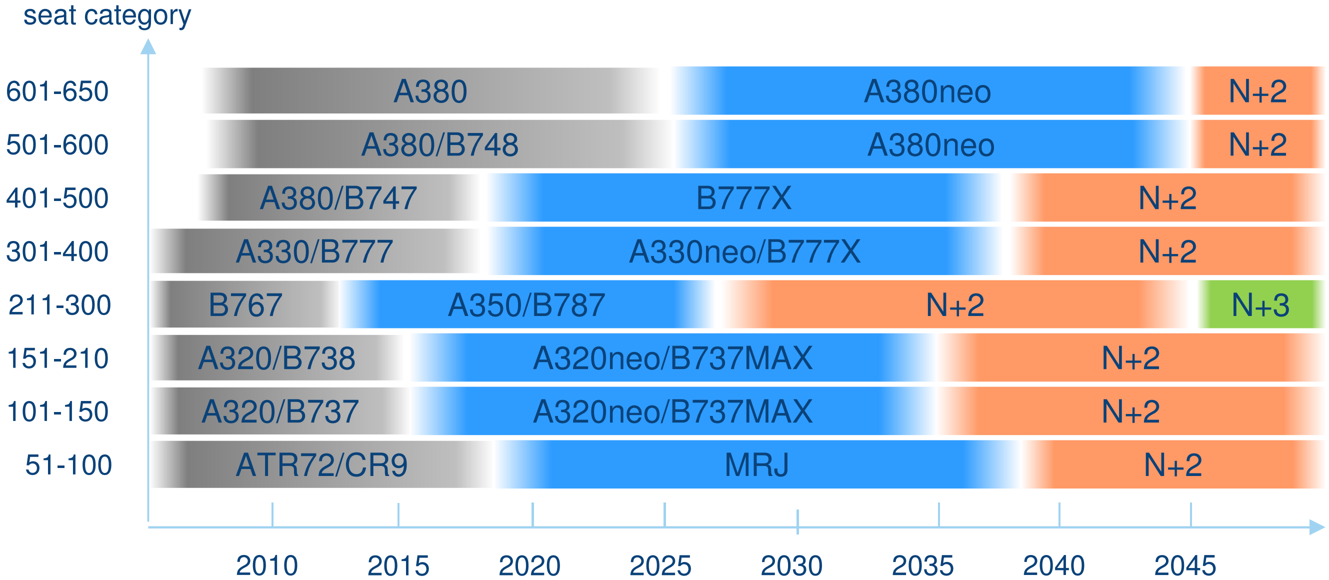
- Variable cycle
- Hybrid wing body
- Strut-braced wing
- Fuel cell
- Battery-powered aircraft

Technology – Fuel saving potential



34000 new aircraft over next 20 years (20000 growth, 14000 replacement)
Investment $4.5 trillion

Stepwise fleet renewal



Future fuel efficiency improvement occurs stepwise,
depending on introduction timescale of new aircraft generations
(every 15 to 20 years in each seat category)

Radically new aircraft configurations

(AIRCAT project with DLR Hamburg(

- Evolutionary aircraft configurations: Limited improvement potential
- Driven by environmental goals →

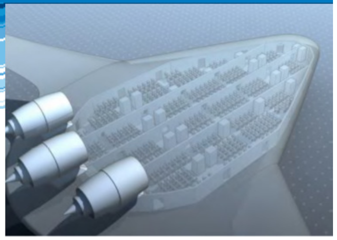
  Many new projects on radically new configurations over the last few years:
  - Other than tube-and-wing (e.g. blended wing body)
  - New propulsion (e.g. open rotor)
  - New structural configurations (e.g. double-bubble, strut-braced wing, box wing)
  - New energy sources (e.g. battery-powered)
  - etc.





Operational impacts

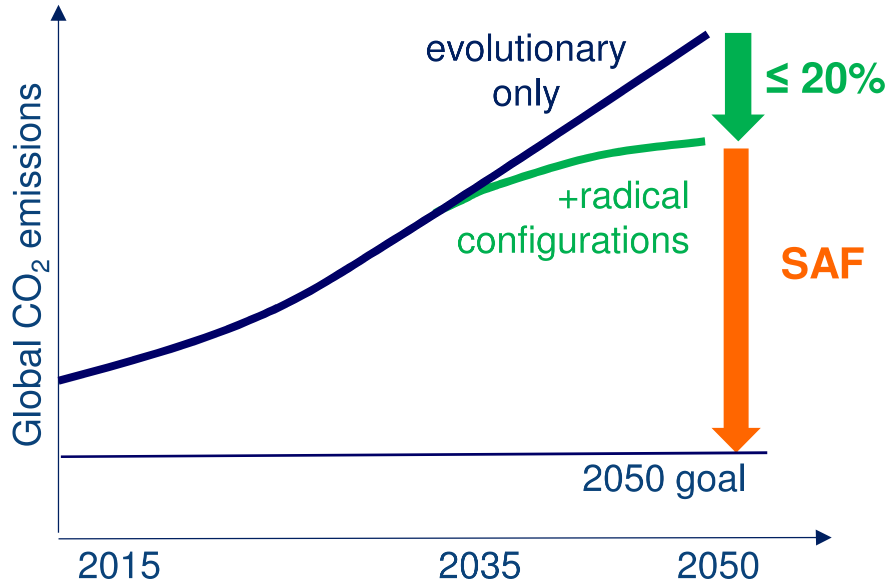
- Non-tube & wing configurations – blended wing body:
  - Passenger experience, Evacuation, Airport compatibility
- Slower flight speed – open rotor, battery aircraft:
  - Flight time, ATM integration
- New energies – electric, LNG etc.:
  - Connect airport to supply network
  - Adapt aircraft engines and fuel/power systems
- Radically new operational schemes could further contribute to fuel/CO_2 efficiency, e.g. formation flight





Impact on global fuel efficiency

- Radically new configurations:
  - Slow market penetration due to fleet renewal cycles
  - Could play a larger role beyond 2050
- Sustainable fuels
  - Will have to contribute largest part to 2050 CO_2 reduction goal
  - Fast uptake of drop-in fuels once available



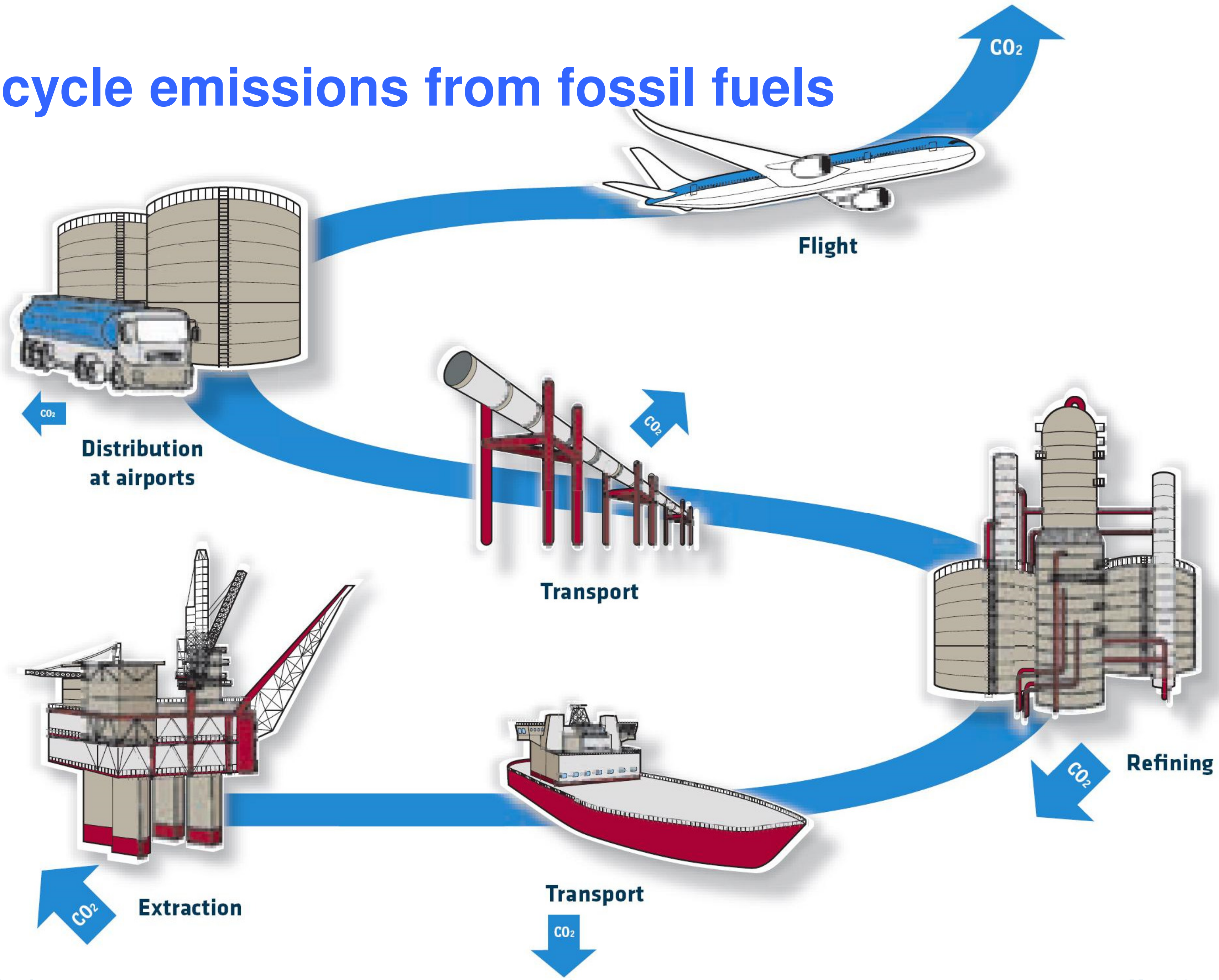
Source: IATA/DLR AIRCAT study

Outlook

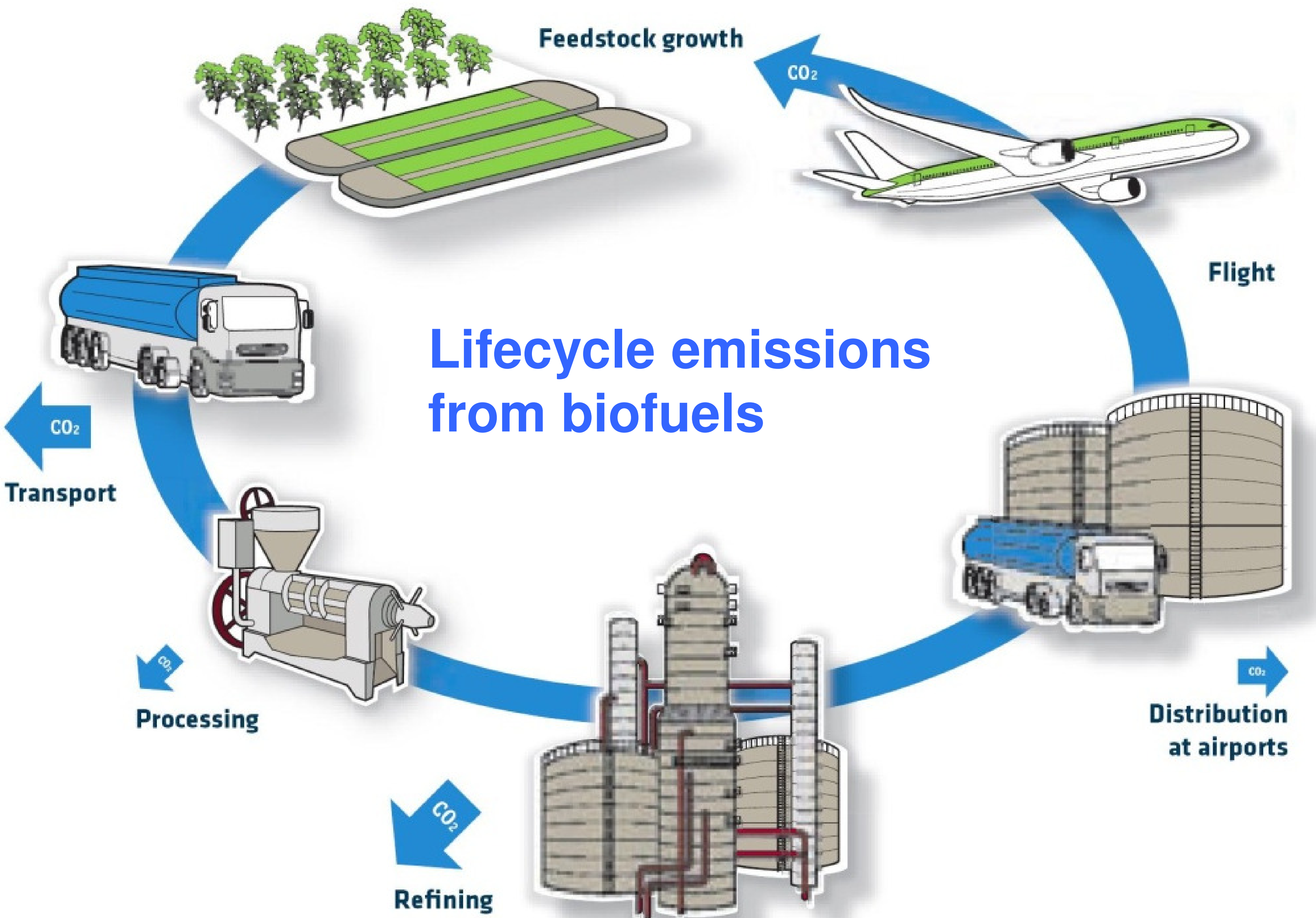
- Radically new concepts and technologies will likely be needed in the long term to meet the aviation climate goals
- Need to secure globally:
  - Reliable continuous energy supply
  - Airport compatibility
  - Passenger acceptance
- Way forward for implementation
  - Start low-level technology development early
  - Plan infrastructure and operational adaptation early
  - Plan long lead times and high investments
  - Accelerate market penetration

Sustainable aviation fuels

Lifecycle emissions from fossil fuels



Lifecycle emissions from biofuels



Airlines supporting sustainable jet fuel commercialisation

Commercial Readiness

R&D/Proof of Concept

- 1st technical certifications
- Test/demo flights

virgin atlantic

etc.

Operational Feasiblity

Over 2000 commercial flights (single or limited series):

Lufthansa	1,100+ flights
GOL	360+ flights
KLM	260+ flights

and 20 other airlines

Commercial-Scale Deals

- **Airline/Supplier offtake agreements,** e.g.

UNITED, AltAir Fuels

- **Bioports**

OSL OSLO AIRPORT, LAX Los Angeles World Airports

in preparation:

BioPort Holland, LEIPZIG-HALLE AIRPORT, AÉROPORTS DE MONTRÉAL

etc.

~2008 - 2011 | 2011 - 2015 | 2016+

Reaching Commercial Scale

Airline/supplier offtake agreements

UNITED
Southwest
FedEx
CATHAY PACIFIC
KLM
Lufthansa
SAS
jetBlue

AltAir Fuels
Fulcrum BIOENERGY
RED ROCK BIOFUELS
SG Preston
gevo
NESTE
SkyNRG FUTURE FRIENDLY FLYING

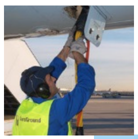
- First bioport with regular operations: Oslo Airport started 22 Jan 2016
- United/AltAir operations started 11 March 2016
- Largest agreement (United/ Fulcrum) over 270’000 t/year
- In addition, strong investments by US government (incl. military)

Requirements for sustainable aviation fuels (SAF)

- Drop-in
  - Can be blended with existing jet fuel
  - No need for adaptation of aircraft / engines nor parallel infrastructure
  - Technically certified as equivalent to conventional jet fuel
- Sustainability
  - Essential requirement for majority of airline customers
  - Working with ICAO on globally harmonized criteria

- Economic viability
  - Bridge the cost gap with Jet A-1 fuel
  - Ensure a level policy play field between road and air
  - Effective political support needed for sustainable jet fuel deployment
- Cooperation
  - Engagement of producers, suppliers, aviation industry and governments, EC and ICAO is essential

Sustainable aviation fuels – Timescale



First test flights

2008

Biofuels from vegetable oils and animal fats

First passenger flights

2011

First regular airline and airport supply

2016

5 production pathways certified

Biofuel production ramp-up to 1 – 6 Mt*

2020

Potential strong increase of SAF use

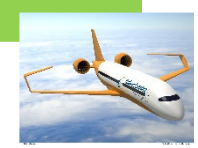
2030-35

First non-biomass drop-in fuels (PtL, solar)

With suitable political support: up to 100% SAF*

2050

Radically new drop-in and non-drop-in fuels and energies



*IATA/MIT/ICAO study

Sustainable aviation fuels – Way forward

- Sustainable aviation fuels can be a major instrument to meeting aviation's long-term emissions reduction goals
- Since early 2016, continuous supply starting:
  - Airline/supplier offtake agreements (mostly US)
  - Bioports
- Today's barriers are economic rather than technical
- Sustainability is key requirement for most aviation customers
- Positive political and legislative framework needed
- In the mid-to-long term, non-biological SAF solutions (from industrial waste gases, Power-to-Liquid, Solar jet fuel)

Global market-based measure

Aviation's global market-based measure

CORSIA
CARBON OFFSETTING AND REDUCTION SCHEME FOR INTERNATIONAL AVIATION

- Paris Agreement provided momentum to ICAO discussions
  - Aviation and shipping to be progressed through ICAO and IMO
- Historic decision at ICAO Assembly
  - Nearly all 191 ICAO States supported 'CORSIA'
- Industry was instrumental in agreement
  - Seven years since industry set goals and started pushing for a global MBM

How does CORSIA work?

- Addresses increase in CO_2 emissions from international civil aviation above 2020 levels

	PILOT PHASE	FIRST PHASE	SECOND PHASE
	VOLUNTARY		**MANDATORY**

68 States have volunteered to be part of the scheme from 2021 (more States are encouraged to volunteer).

Exemptions for: Small Islands, Least Developed Countries, Land-locked Developing Countries and States which have less than 0.5% of air traffic (although they can still volunteer).

MONITORING, REPORTING & VERIFICATION TO SET THE **BASELINE** (2019–2020)

Operators in the States included will offset emissions based on the average CO_2 growth of the aviation sector. (2021–2026)

Operators will offset based on average CO_2 growth of the sector. (2027–2029)

Offset obligations shift to include over 20% of individual operator growth. (2030–2032)

Offset obligations shift to be over 70% based on individual operator growth. (2033–2035)

2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035

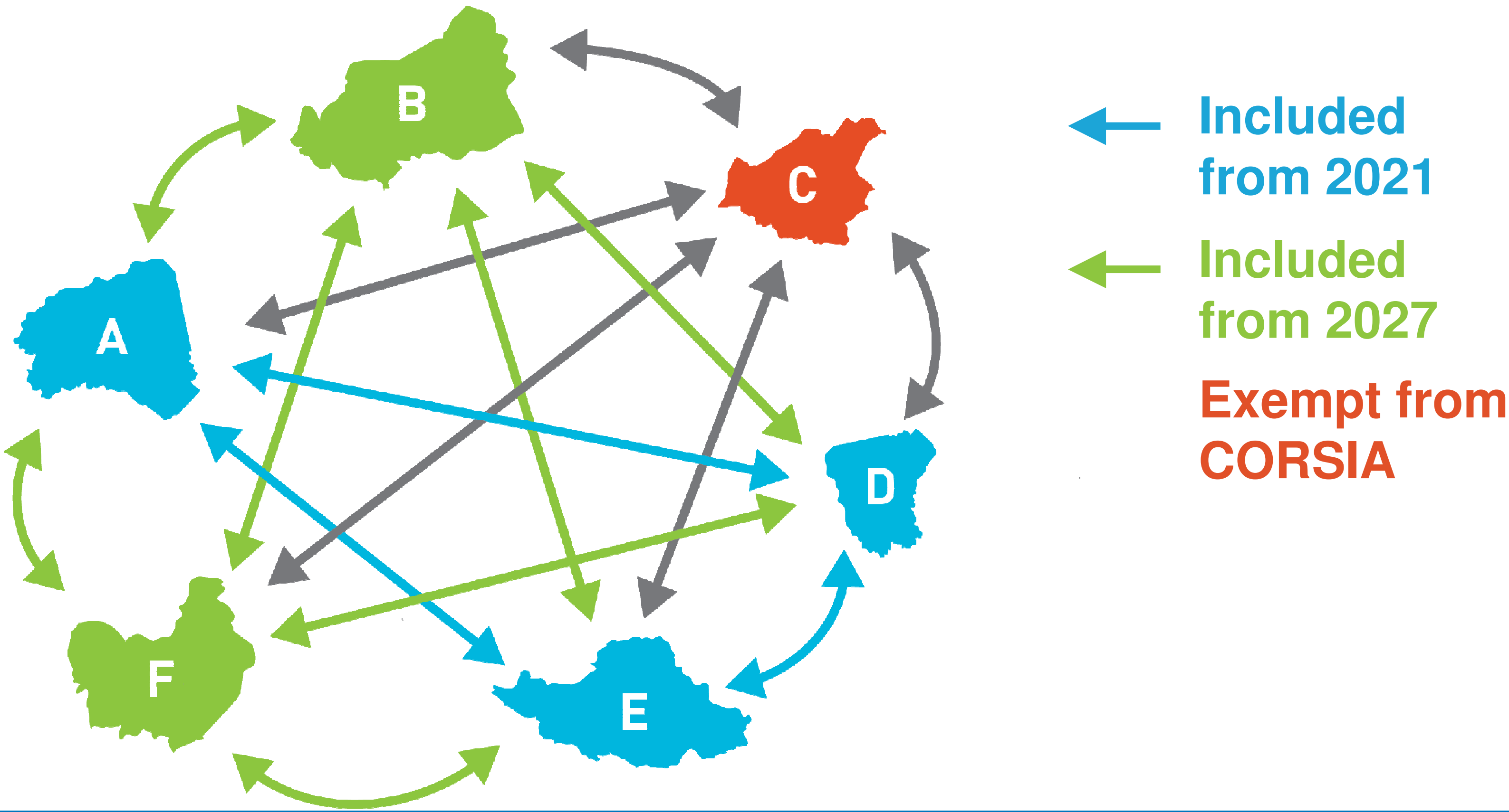
OVER **80%** OF THE GROWTH IN AIR TRAFFIC CO_2 AFTER 2020 WILL BE OFFSET

States included in the first (voluntary) phases

AS OF 12 OCTOBER 2016, **66 STATES** HAVE VOLUNTEERED TO BE PART OF CORSIA FROM THE START.

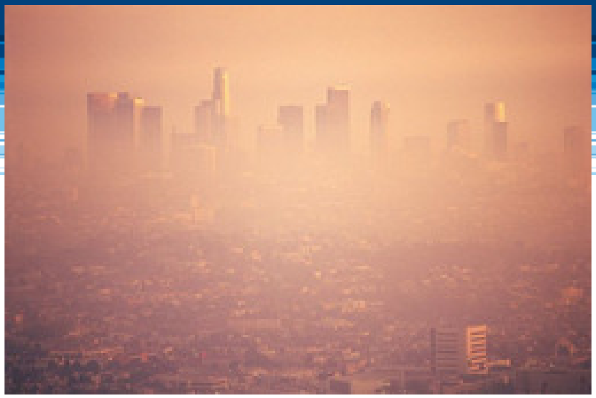
Route-based approach

→ limited market distortion



How will offsetting work for aviation?

Local air quality



Local air quality

- Focus on airport surroundings, usually close to urban and residential areas
- Aircraft emissions contributing to local air quality (LAQ) concerns:
  - Nitrogen oxides (NO_x)
  - Unburnt hydrocarbons (UHC)
  - Carbon monoxide (CO)

  Regulated in ICAO certification standard (Annex 16, Vol. II)
  - Particulate Matter (PM)
    - New ICAO standard under development (to replace "smoke number")
    - New standard will consider PM mass <u>and</u> number (important for ultrafine particles)
  - Sulphur oxides (SO_x) – depend on fuel composition only

Local air quality

Multitude of emissions in airport areas:

- Aircraft operations
  - Landing, takeoff, taxiing, turnaround
- Ground service equipment (GSE)
  - Fuel & catering trucks, tugs etc.
  - Can be run electric, with hydrogen, etc.
- Other airside and landside vehicles
  - Cars, taxis, buses, trains, etc.
- Stationary power generation plants
- Maintenance and handling activities
  - Fuel storage, de-icing, etc.

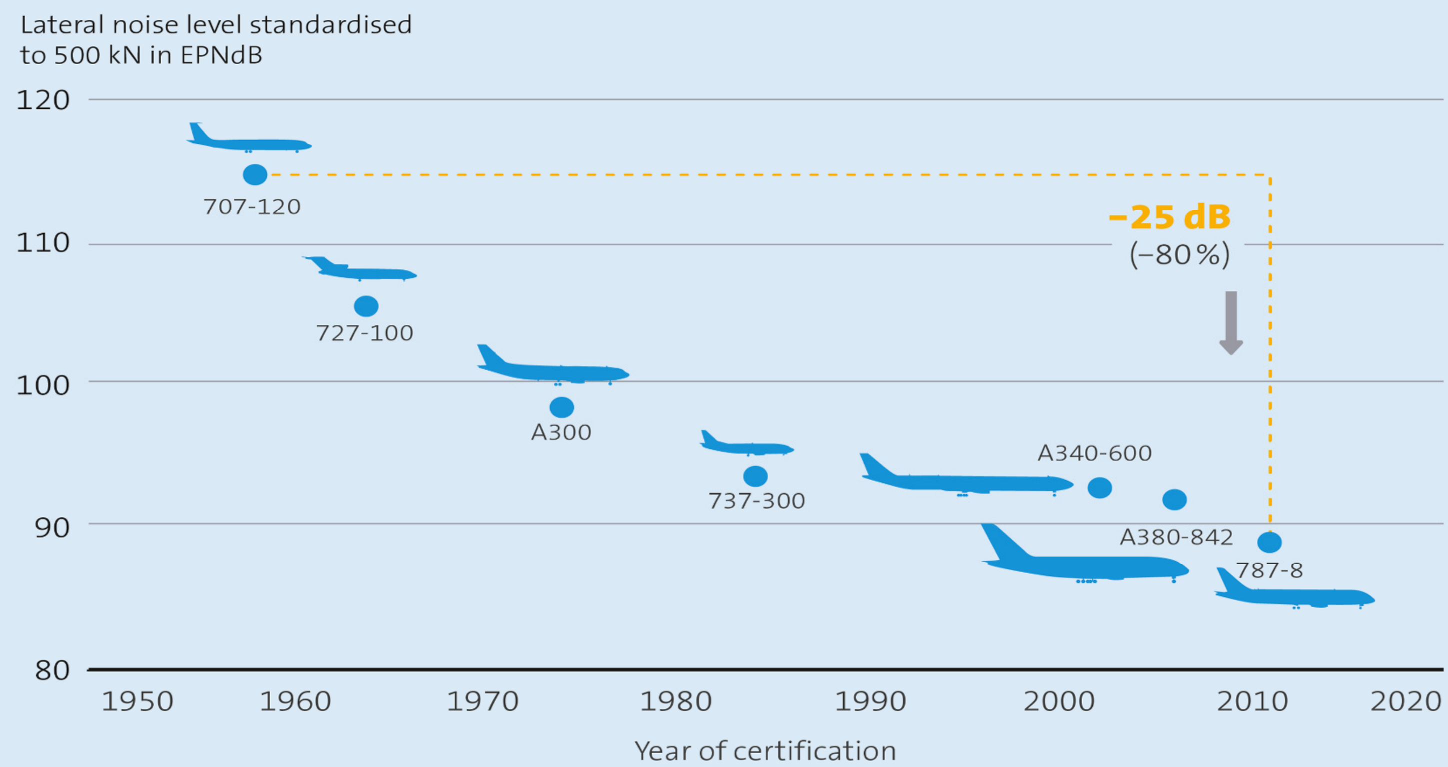
- LAQ measurements do not distinguish origin of pollutants
- Alternative fuels reduce LAQ impact

Noise

Noise

- Aircraft noise reduction at source:
  - - 75% over the past 50 years (minus 20 dB)
  - - 50% expected from 2000 to 2020 (minus 10 dB)
- Noise stabilized in spite of traffic growth
  - Remains, the main obstacle to airport development
  - Annoyance is the problem, not noise
  - Growing pressure, especially in Europe, to put traffic limits, ban night operations, etc.

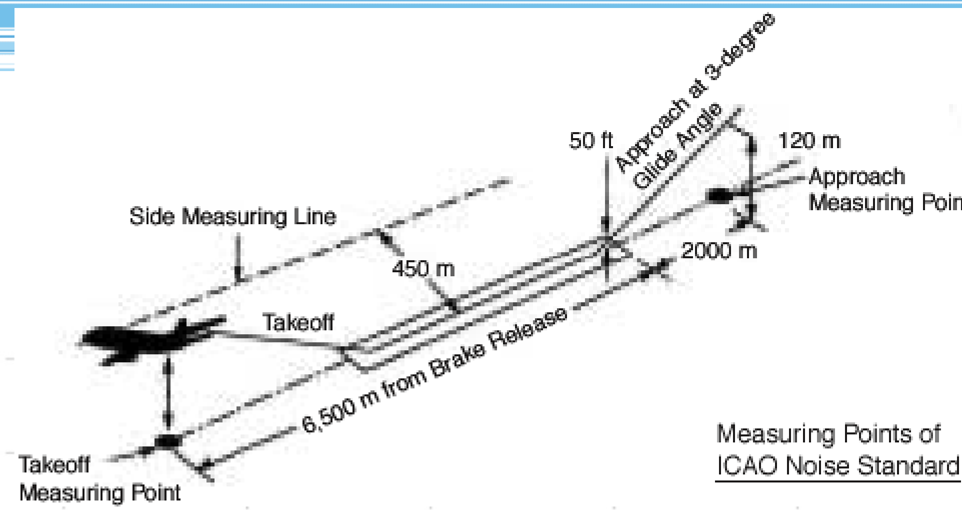
Development of aircraft noise emissions

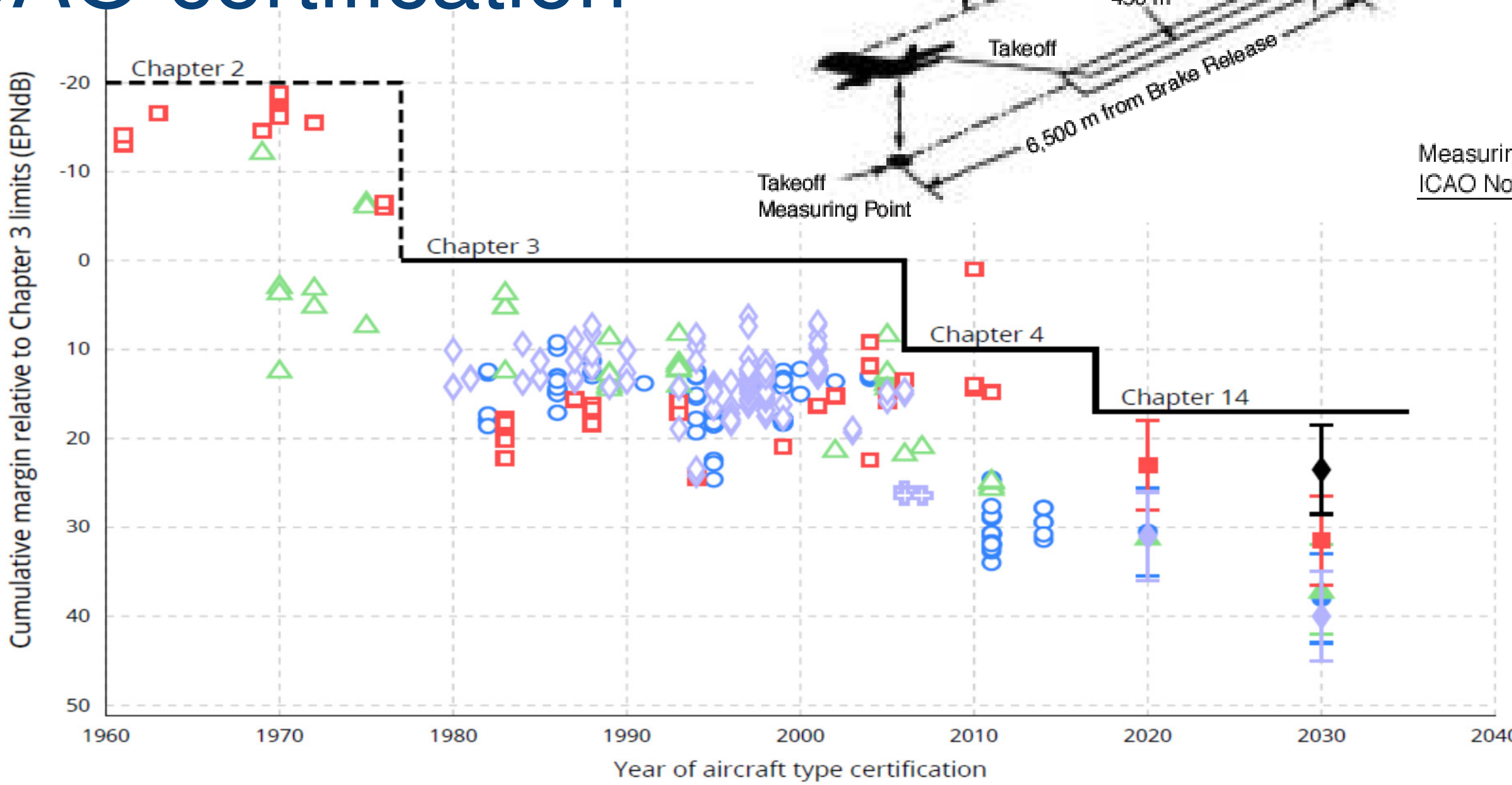


*EPNdB: Effective Perceived Noise in Decibels
Source: CFD-Software E+F GmbH Berlin

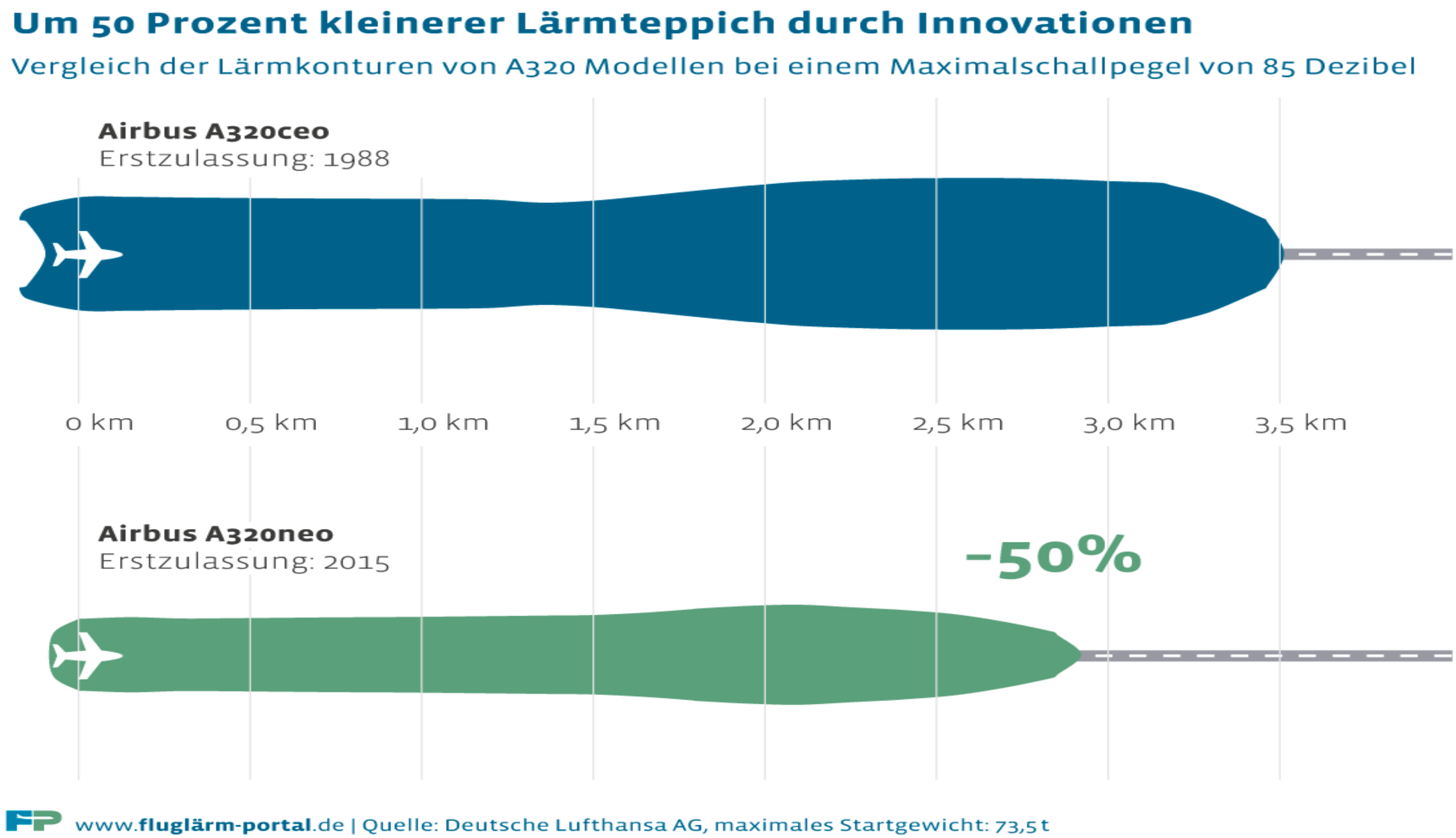
www.bdl.aero

Noise reduction and ICAO certification

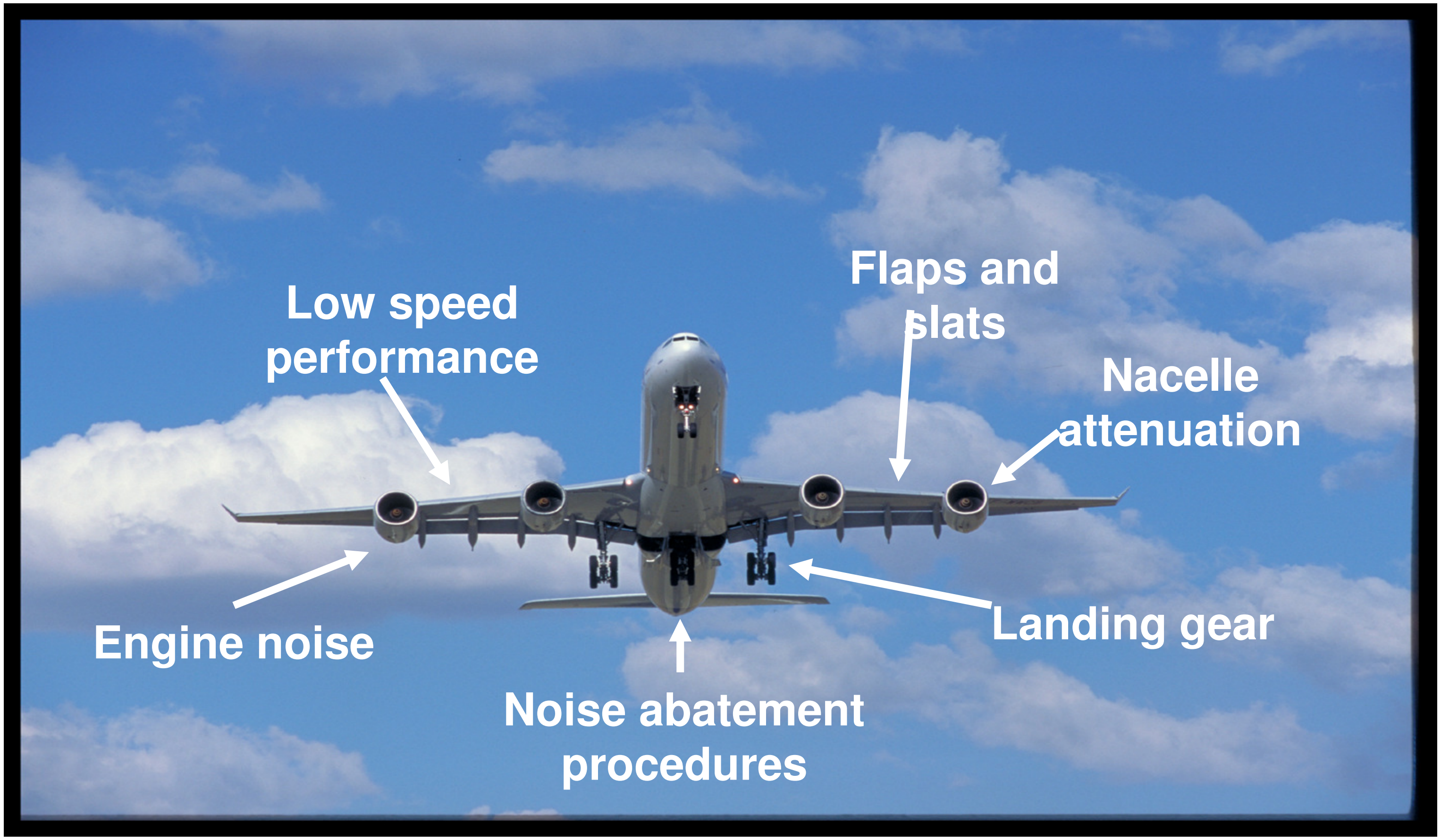




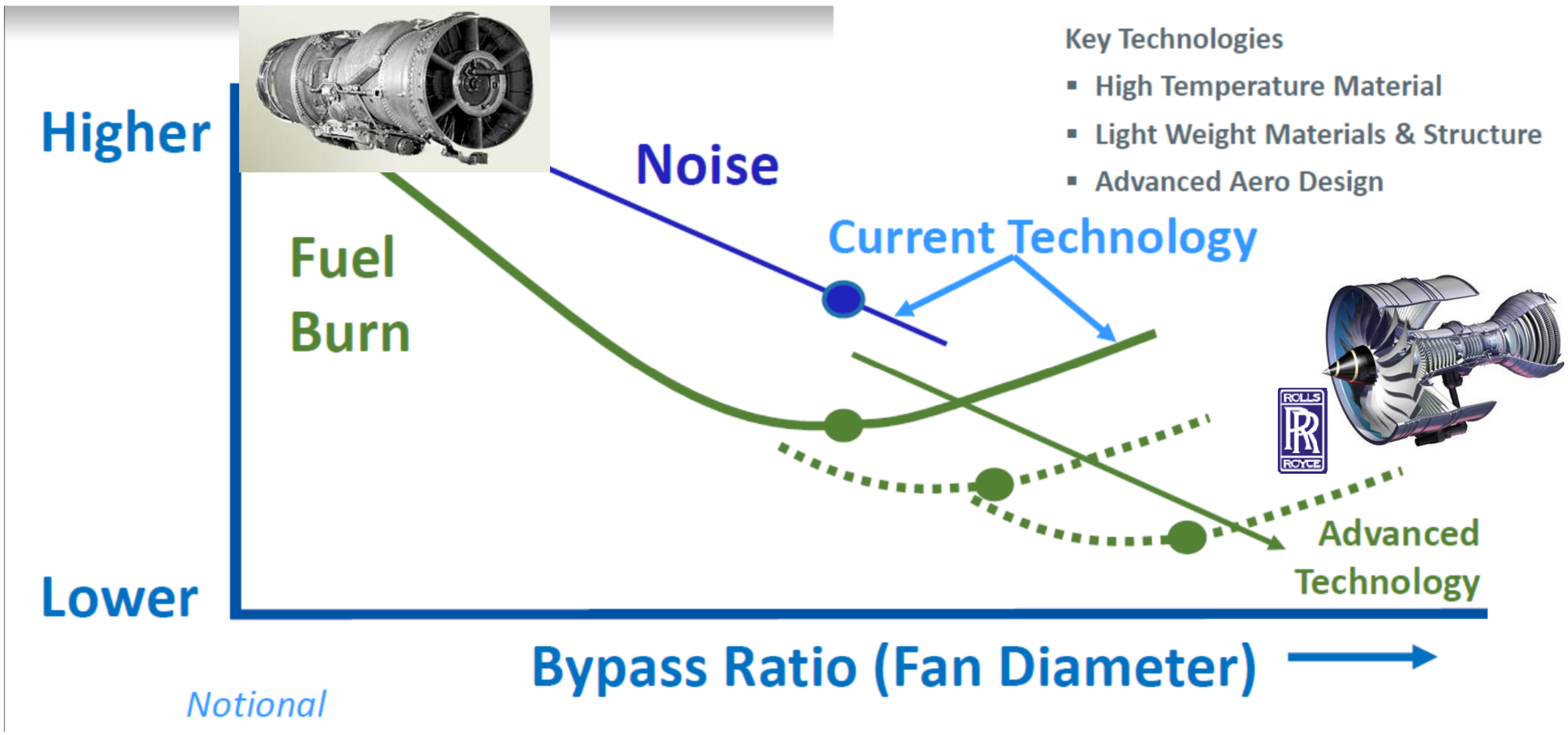
Noise footprint reduction



Engine and airframe noise



Engine bypass ratio



Aircraft decommissioning and recycling

Aging aircraft world fleet

- Steeply rising number of aircraft to be decommissioned
  - More than 3000 commercial aircraft over 25 years old and still in service
  - Average service time of an aircraft 25+ years
    - Significant variability – depending on business model
    - Recent trend to decommission aircraft at lower age
    - Many large airlines sell aircraft well prior to decommissioning
    - Specific target group of carriers with old aircraft (including numerous cargo airlines) – financial capacity usually low
  - 12000 aircraft expected to be decommissioned in the next 20 years

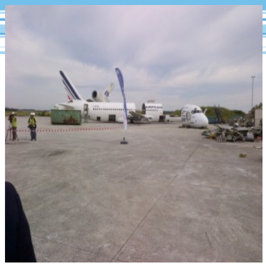
Needs for decommissioning

Decommissioning process	Aircraft	Dismantling facility	Estimated number
Controlled  (including storage, e.g. Mojave desert)	Flyable	Fixed	> 3000
	Immobilised	Mobile only	
Uncontrolled  (at airfield edges)	Immobilised	Mobile only	Unknown

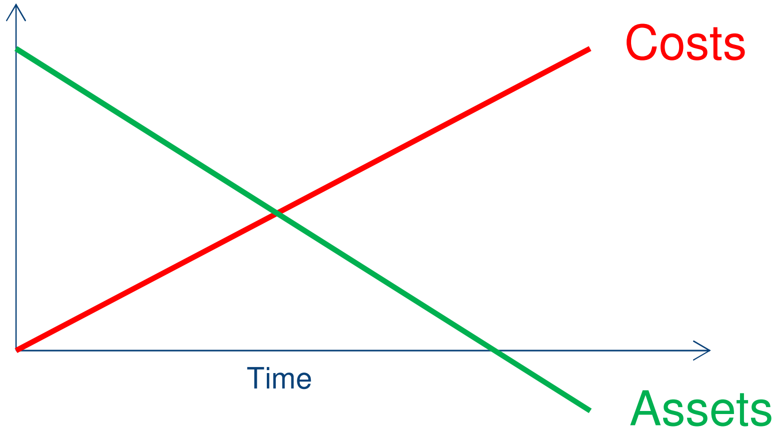
Aircraft end-of-life issues

- Safety
  - Re-use of parts/equipment that have lost certification (black market)
  - Aircraft cut up in questionable safety conditions
- Environment
  - Hazardous substances (e.g. hydraulic fluids, asbestos, depleted uranium ballast)
  - Soil and water contamination
  - Waste management regulations
- Operations
  - Obstruction of airport areas
  - Airport expansion inhibited

Economic aspects



- Airlines should be encouraged to do controlled decommissioning
  - Avoid disincentivising costs (target group is financially weak)
  - Optimised re-use / recycling should allow maximal benefit from components' residual value



Maintenance
Waste
Parking
Forgone airport utilisation

Residual value:
- Metal
- Equipment? not if certification lost
minus Liabilities

Re-use and recycling

- Many pieces of equipment (engines, avionics, …) can be re-used
  - Represents much higher value than metal structure
  - Rigorous safety control needed → new identification systems (RFID) can help
  - Avoid equipment losing certification
- Various metallic alloys, mainly Al
  - Separated by type?
    → Higher value, but higher separation costs
- Carbon-fibre composites (e.g. tailplanes)
  - Recycling methods under development
- For the future:
  - Increased use of recyclable materials in new aircraft
  - "Design for deconstruction"

Way forward

- Develop best practices for controlled aircraft decommissioning
  - Best use of residual value
  - Minimize environmental and safety risks
  - IATA-led industry group working on best practices manual
- Make mobile decommissioning services accessible all over the world
- Earlier decommissioning accelerates fleet renewal
  - Enhances implementation of new technologies

Conclusions

- Environment is a major challenge for aviation
- Aviation represents 2% of man-made CO_2 emissions, but growing
- Aviation is the first global industry sector committing to ambitious climate goals
- ICAO supports these goals with a basket of measures
  - Global market-based measure, CO_2 standard etc.
- Technology goals have led to an impressive number of innovation activities
  - Sustainable aviation fuels
  - Radically new aircraft configurations and propulsion energies
- New standards drive reduction of noise and pollutant emissions
- Emerging topic: Aircraft decommissioning and recycling

Thank you!

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