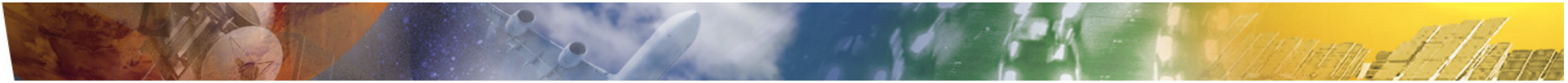


MEASURING THE LONG-TERM SUSTAINABILITY OF AIR TRANSPORT – AN ASSESSMENT OF THE GLOBAL AIRLINE FLEET AND ITS CO₂-EMISSIONS UP TO THE YEAR 2050

**G.A.R.S. Workshop “Aviation and the Environment”
Bad Honnef, 26th November 2008**

**Wolfgang Grimme
German Aerospace Center (DLR)**

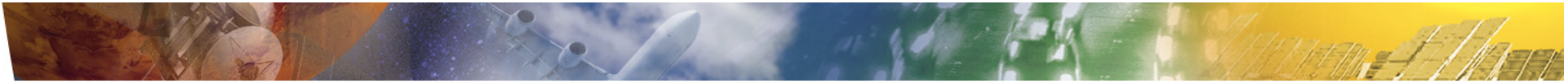


“Prediction is very difficult, especially about the future”

- Niels Bohr

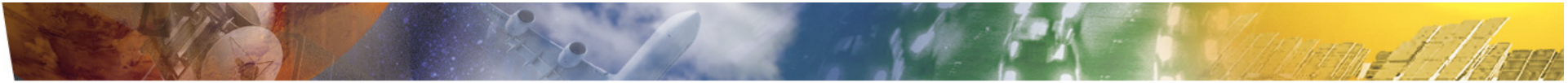


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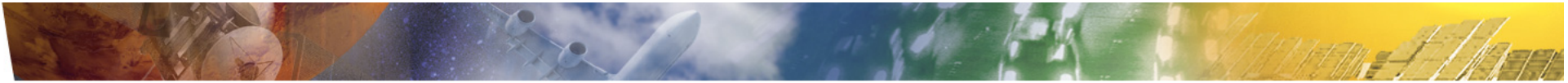
Outline

1. CO₂-Emissions of Aviation and Stakeholders' Reduction Targets
2. Elements Contributing to Emissions Reductions
3. Modelling Approach
4. Quantification of Current and Future CO₂-Emissions
5. Discussion of Results
6. Conclusions



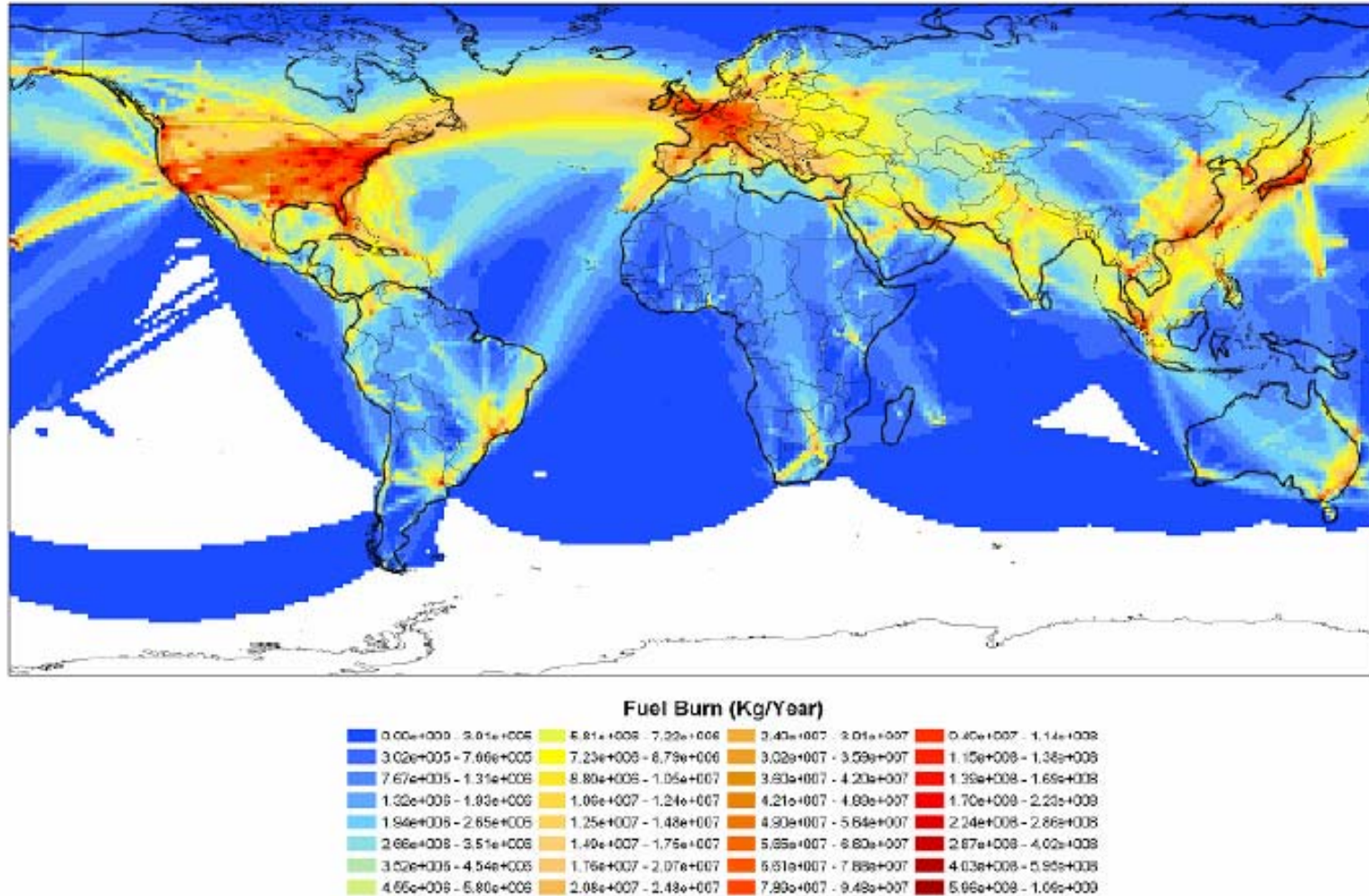
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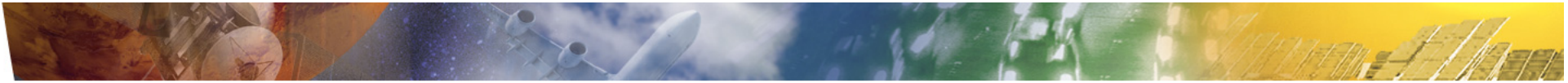
1. CO₂-Emissions of Aviation and Stakeholders' Reduction Targets

Geographical Distribution of Aviation Emissions



Source: AERO2k, cited in: Methodologies for Aviation Emission Calculation – A comparison of alternative approaches towards 4D global inventories by Martin Schaefer, 2006



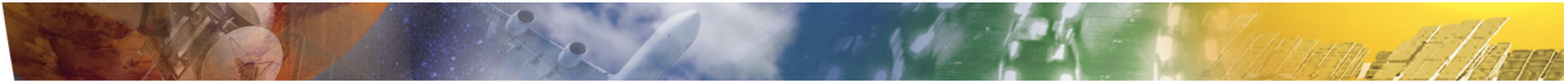


1. CO₂-Emissions of Aviation and Stakeholders' Reduction Targets

- Total CO₂ emitted in 2004 by commercial air transport:

630,000,000 t

- Comparison of global fuel consumption in different transport modes:
 - Air Transport: 200,000,000 t
 - Maritime Transport: 280,000,000 t
 - Road Transport: 1,320,000,000 t



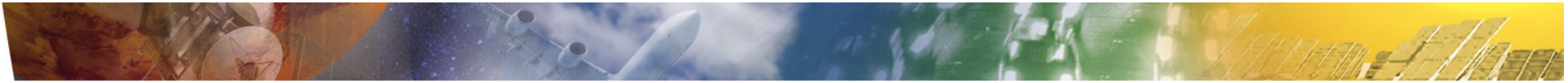
1. CO₂-Emissions of Aviation and Stakeholders' Reduction Targets

➤ Among the most prominent CO₂-reduction objectives are the following:

- ACARE: -40% to -45% specific emissions of aircraft entering service in 2020 compared to 2000
- IATA: Carbon-free air transport industry by 2050
- Joint Industry Commitment (ACI, ATAG, CANSO, IATA, ICCAIA and manufacturers):

Carbon-neutral growth / Aspiration of a carbon-free future

- Individual objectives by airlines/airports:
 - carbon-free airport operations in Sweden and the Netherlands
 - 7% improvement in specific CO₂ emissions until 2012 (Air France)
 - 17% improvement in specific CO₂ emissions until 2020 (KLM)



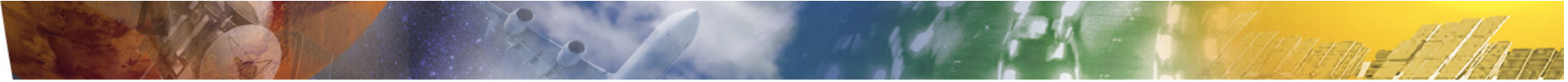
1. CO₂-Emissions of Aviation and Stakeholders' Reduction Targets

Key research question:

- How will CO₂ emissions from aviation develop until 2050, considering expected innovations in technology and operations?

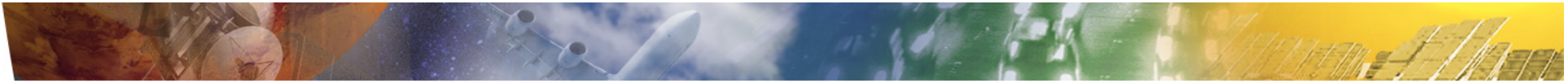
Modelling approach:

- Assumptions on technology parameters, derived from desk research of areas of innovation and their contribution to efficiency increases
- Analysis of air transport forecasts and deduction of a traffic growth scenario
- Modelling of individual aircraft emissions, annual transport performance, production and retirement rates



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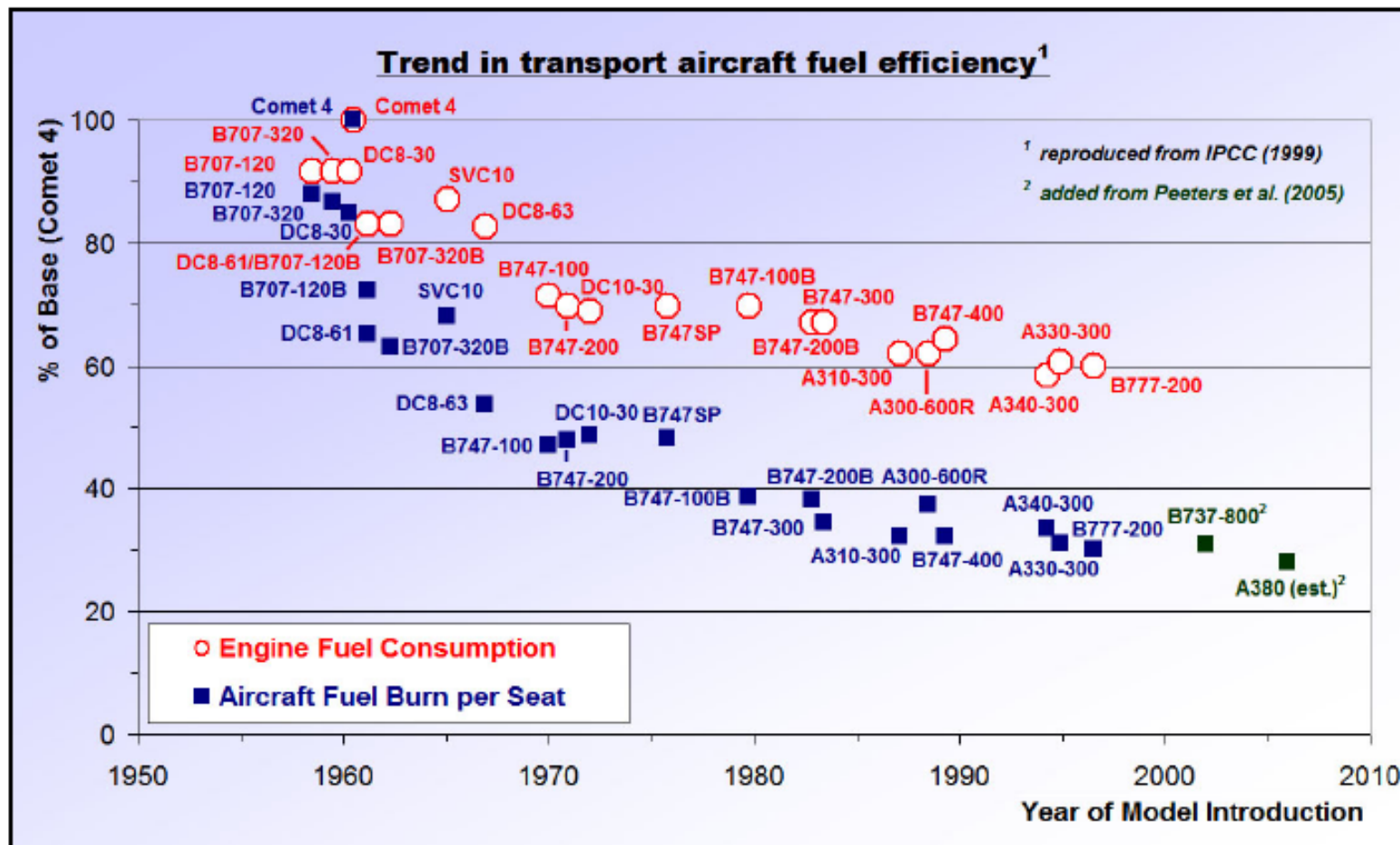


2. Elements Contributing to Emissions Reductions

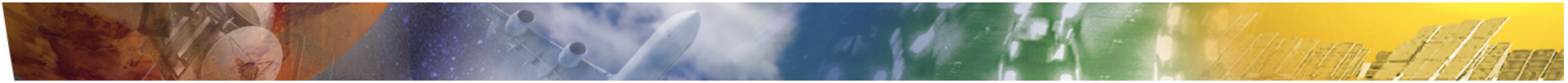
- Four main elements can be identified that contribute to the emissions reduction objectives:
 - Technology (Airframe, Engines, Fuel)
 - Air Traffic Management
 - Operational Procedures
 - Economic Instruments

2. Elements Contributing to Emissions Reductions

Aircraft and Engine Technology and their Impacts on Fuel Consumption

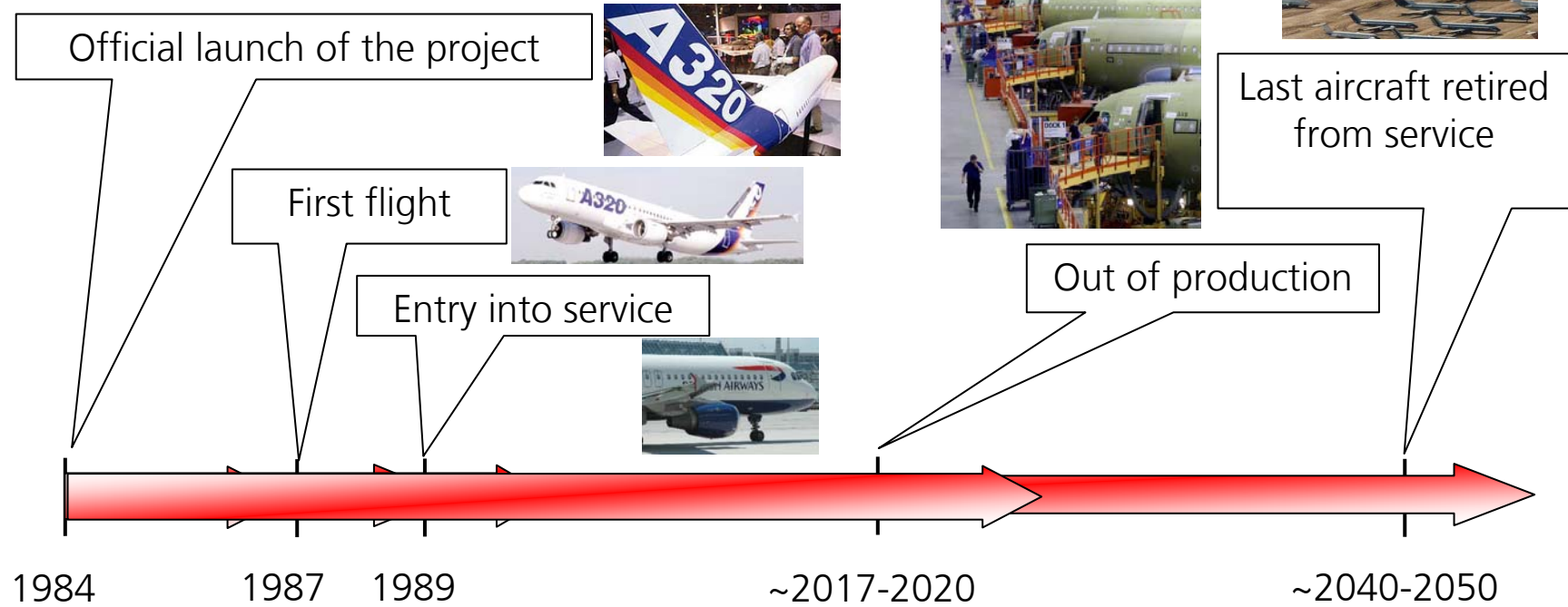


Source: Methodologies for Aviation Emission Calculation – A comparison of alternative approaches towards 4D global inventories by Martin Schaefer, 2006



2. Elements Contributing to Emissions Reductions

- Example of long service life – A320:



Total product life-cycle: 56-66 years!!!



2. Elements Contributing to Emissions Reductions

➤ Technology:

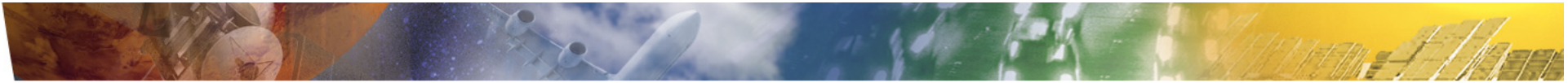
- It becomes increasingly difficult to reduce emissions further
- Characteristics of the air transport system: Long product life cycles, long service life of aircraft
- Time span of product life cycles has increased, as it gets increasingly expensive to develop aircraft, which have a significant advantage over their predecessors – particularly for short-haul aircraft
- Tradeoffs have to be considered:
 - Propfan/Open Rotor could reduce CO₂-emissions considerably (by 20%), but would result in noiser and slower aircraft
 - Higher engine temperatures could increase fuel efficiency but may lead to high NO_x emissions



2. Elements Contributing to Emissions Reductions

➤ Fuel

- Built-in efficiency driver to reduce CO₂-emissions: fuel price
- High prices of fossil fuel are an incentive for the development of alternatives
- Biomass-to-Liquid (BtL) fuels are under development, based on wood or algae
- Life Cycle Emissions of BtL-fuel can be 90% lower than with fossil fuel
- Challenges: Technological and economic availability (~ 200 Mt would be needed to meet current demand)
- Alternative technology: Hydrogen – needs new aircraft and ground infrastructure – economic viability highly questionable

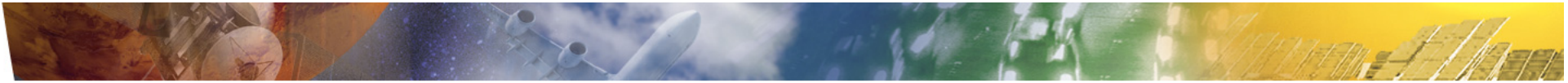


2. Elements Contributing to Emissions Reductions

➤ Air Traffic Management

- Global contribution of ATM to CO₂ emissions of aviation: 7-11% (Source EUROCONTROL)
- Projects: Single European Sky, FAA NextGen, more direct intercontinental routes

→ CO₂ emissions reduction potential in the area of ATM is significant, but limited in comparison to aircraft technology



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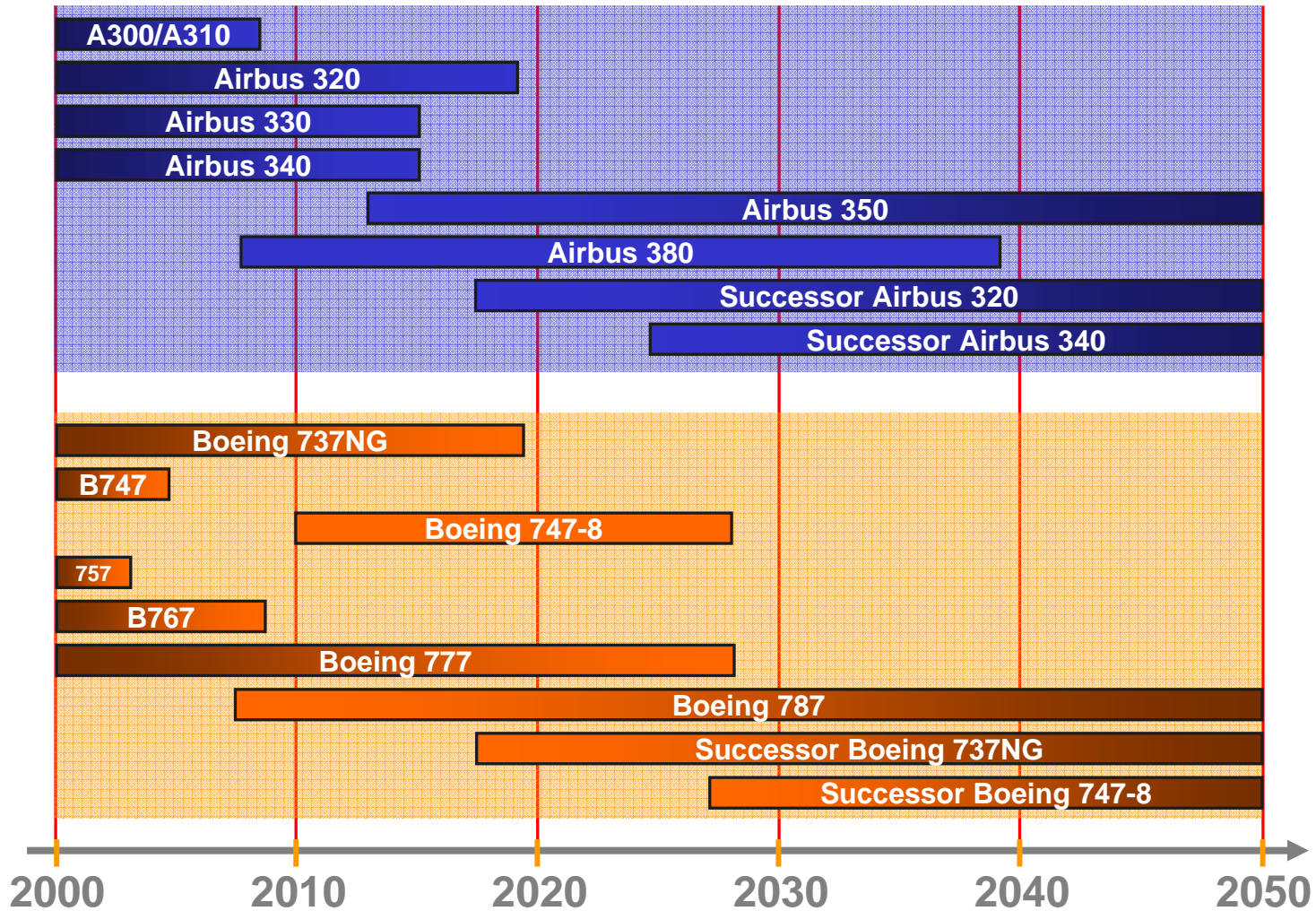
3. Modelling Approach

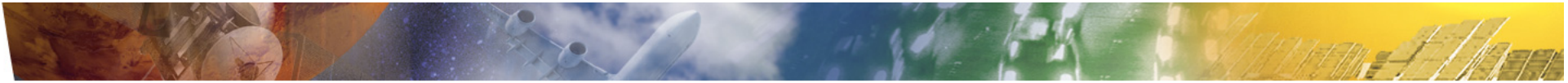
- Assumptions concerning traffic growth scenario
 - Passenger air transport growth
 - 2006-2026: CAGR 4.8% (oriented at Airbus GMF)
 - 2027-2050: CAGR 2.6% (final RPK value oriented at CONSAVE 2050)
 - Each individual aircraft will be able to “produce” annual revenue passenger kilometres based on annual utilisation, speed, seat load factor and no. of seats:

$$\text{Annual Transport Performance (in RPK)} = \sum_{i=1}^n U_i \times S_i \times LF_i \times SC_i$$

3. Modelling Approach

Aircraft in production 2000-2050





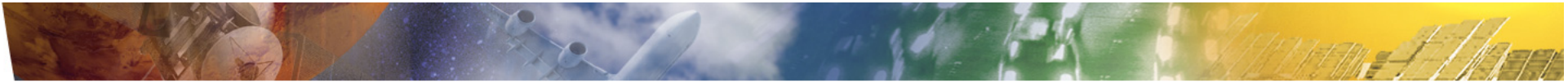
3. Modelling Approach

Further assumptions:

- Efficiency of new aircraft:
 - New single aisle jets will be 15% more efficient than their predecessors
 - New twin aisle jets will be 25% more efficient than their predecessors

- Global ATM Efficiency will increase by a total of 10% between 2012 and 2025

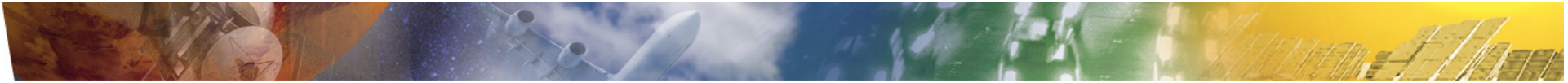
- Biofuels will be added between 2010 and 2050, up to a total of 25% of fuel needed in air transport, life-cycle CO₂-emissions of BtL-fuels are 90% smaller than fossil fuels



3. Modelling Approach

Modelling the annual fuel consumption of each aircraft:

- Annual block hour statistics, derived from ASCEND Online Fleets
- Avg. fuel consumption per block hour derived from EUROCONTROL Base of Aircraft Data (BADA)
- Service life of aircraft: 25 years for single aisle aircraft / 30 years for twin aisle aircraft



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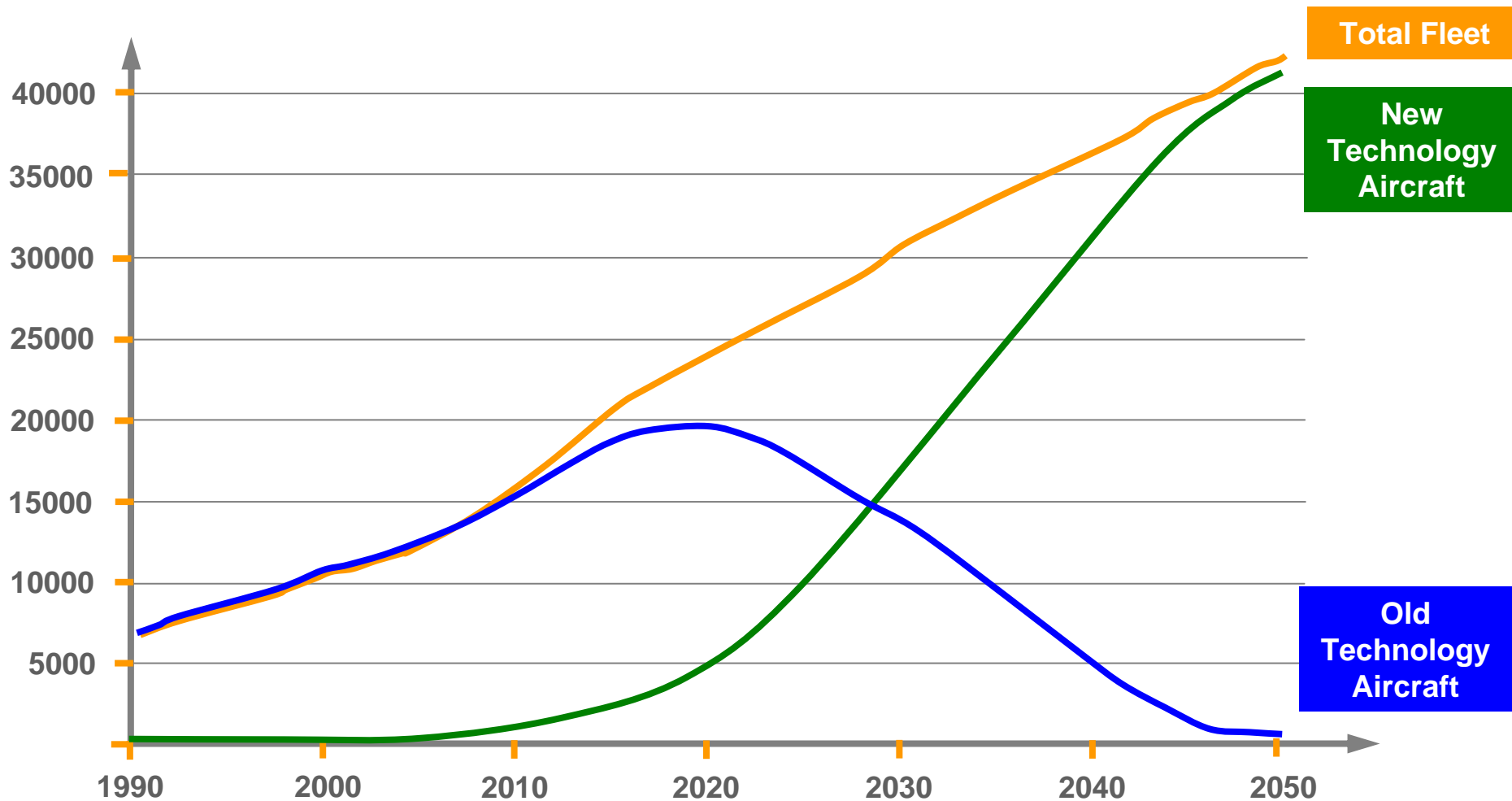
4. Quantification of Current and Future CO₂-Emissions

Current Situation – CO₂ Emissions of the World Fleet in 2005

Aircraft Type	Total CO ₂ -Emissions in 2005 (in thousand tons)	Tendency compared to previous Year
Boeing 747-400	67,330	↘
Airbus A320-Family	62,419	↗
Boeing 767	45,393	→
Boeing 777	44,297	↗
Boeing 737NG	42,875	↗
Boeing 737-300/400/500	39,901	↘
Boeing 757	32,415	↗
Airbus A340	28,693	↗
Airbus A330	24,250	↗
McDonnell Douglas MD80-Series	23,248	↘

4. Quantification of Current and Future CO₂-Emissions

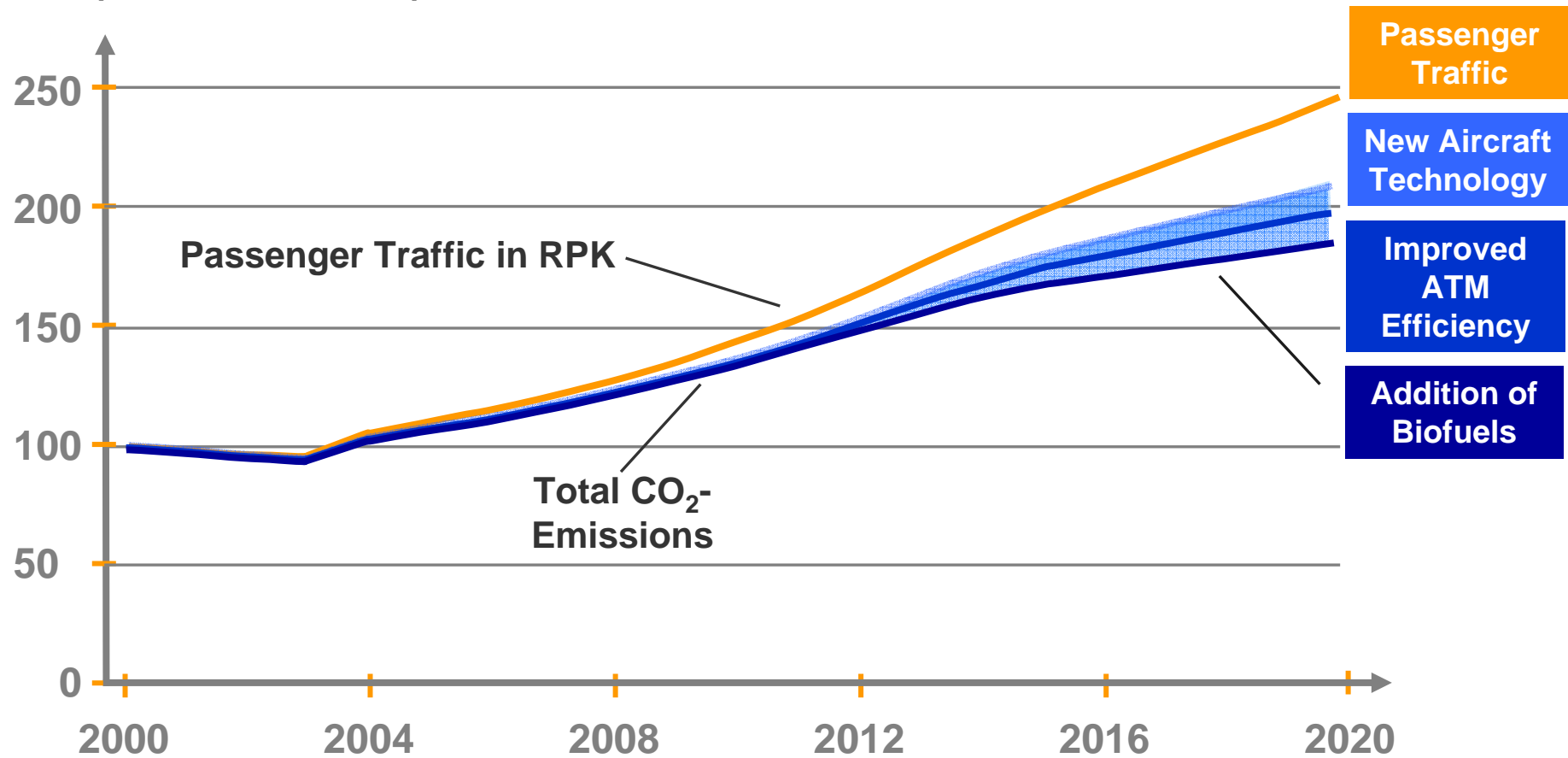
Global Passenger Aircraft Fleet Development until 2050



4. Quantification of Current and Future CO₂-Emissions

Effects of Technology I - Extrapolation until 2020

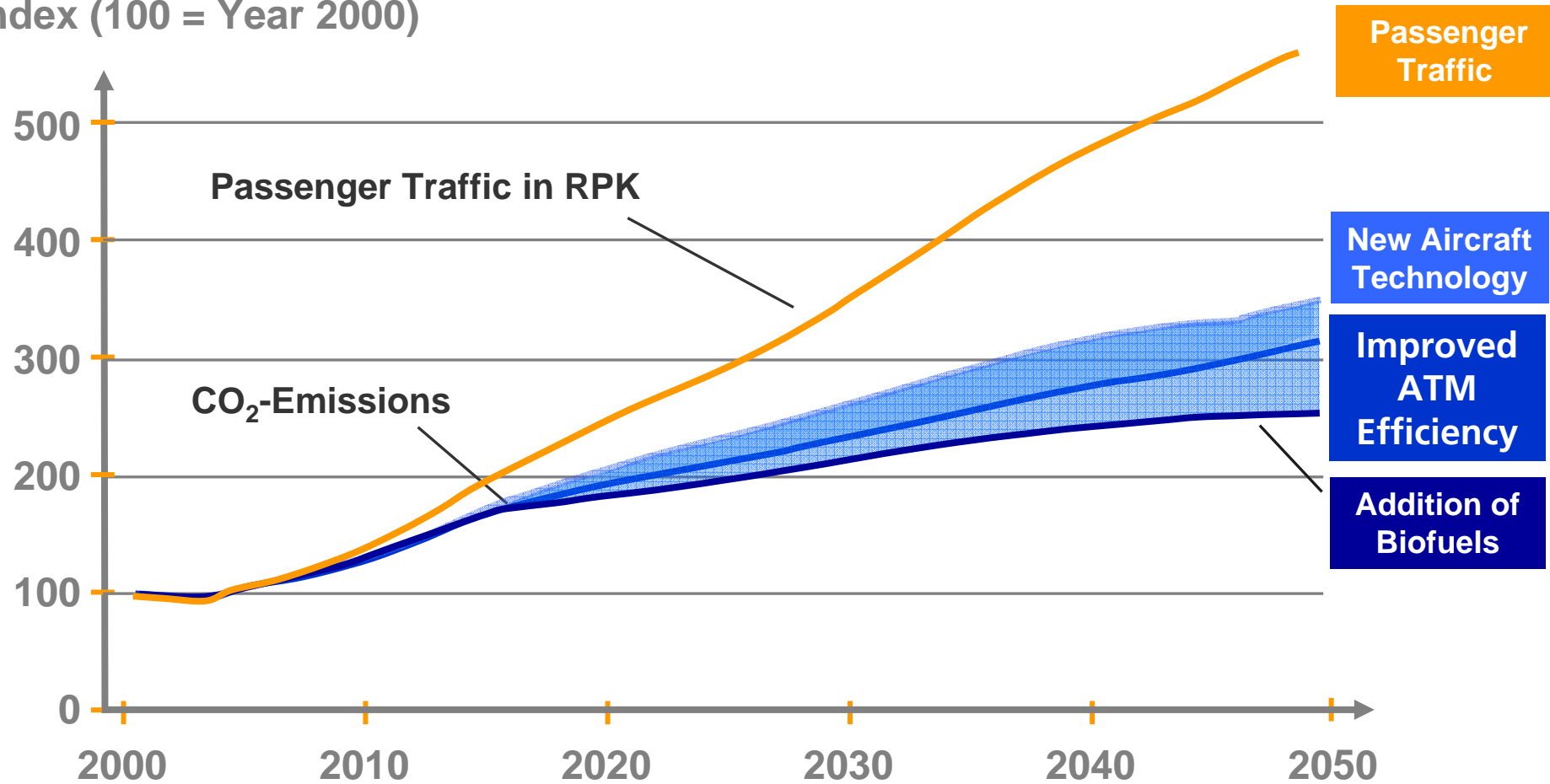
Index (100 = Year 2000)



4. Quantification of Current and Future CO₂-Emissions

Effects of Technology I - Extrapolation until 2050

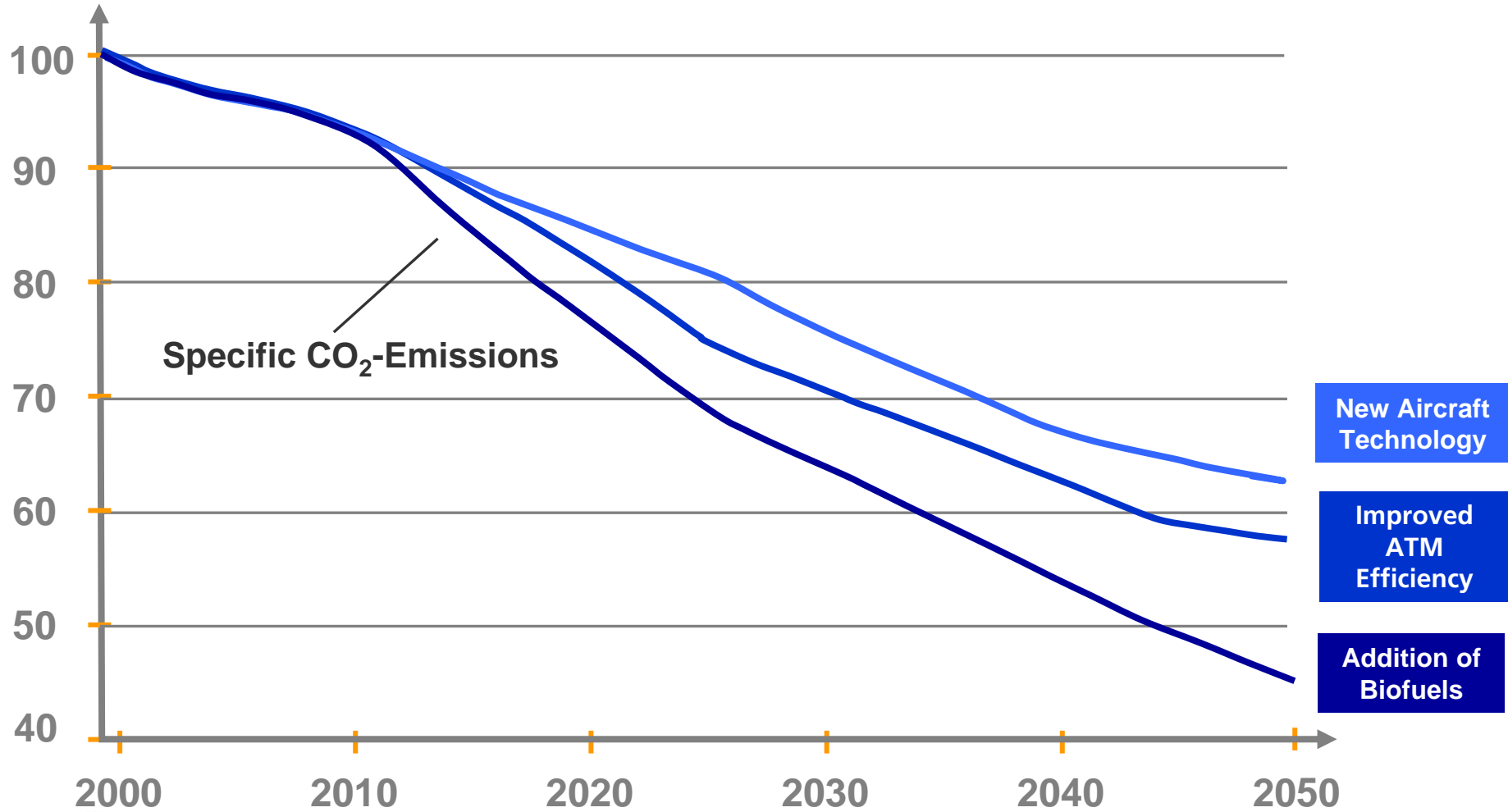
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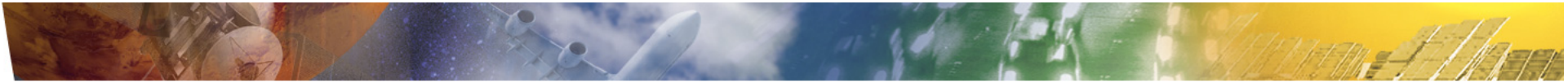


4. Quantification of Current and Future CO₂-Emissions

Specific CO₂-Emissions - Extrapolation until 2050

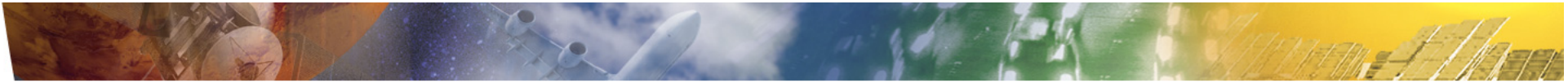
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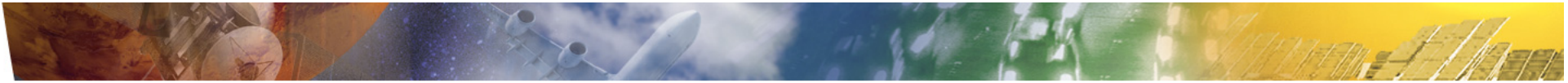
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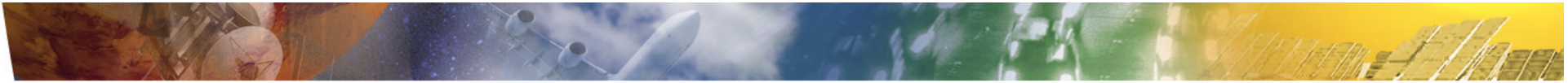
5. Discussion of Results

- Even if new technology becomes available, a considerable time span is needed between the point of entry into service and large-scale use in the global fleet
- Given the expected entry-into-service dates of new aircraft and production capacities, it will take until 2029 that new technology aircraft will make up the majority of the world fleet
- The contribution of ATM efficiency improvements is limited – even with a globally optimised ATM structure, emissions can be reduced by 7-11%, this is equivalent to only four to five years of growth
- Aircraft and engine technology can contribute significantly, but it is increasingly difficult/expensive to realise reductions in this area with conventional technology
- Biofuels can also have a significant contribution to emissions reduction and may also be particularly interesting from a cost-benefit perspective



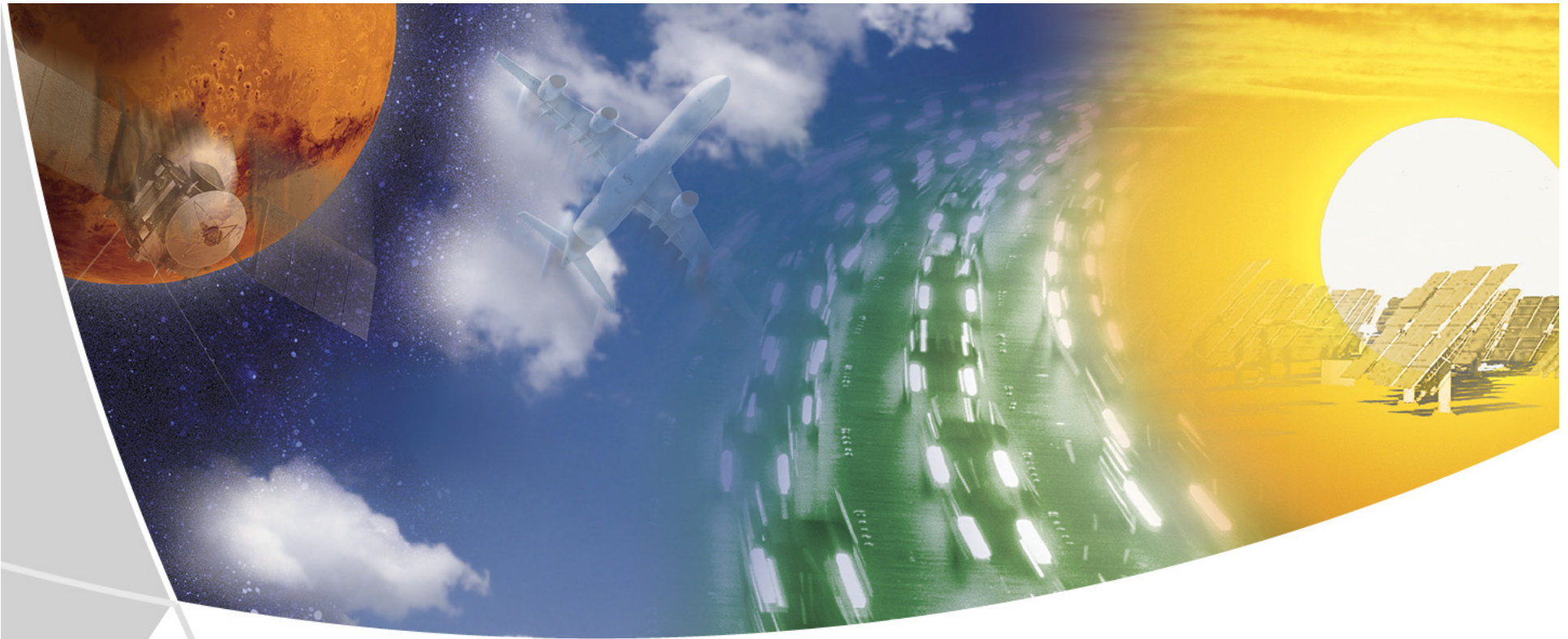
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6. Conclusions

- The presented model is capable estimating CO₂ emissions for different technological scenarios, without the extensive data needs of emissions inventories
- It may also be used for the quantification of scenarios including break-through technologies or other radical changes
- Also normative scenarios (e.g. “what needs to be done to achieve a predefined emissions level?”) may be quantified



Thank you for
your attention!



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1. Fuel Consumption, Emissions and Ecological Impacts of Aviation

Aircraft Technology and Fuel Consumption



Aircraft type: McDonnell Douglas DC-9-41
Introduction into service: 1968
Typical seating: 125
Fuel consumption FRA-BCN (1167 km): 6165 kg
Fuel consumption per passenger: 49.32 kg

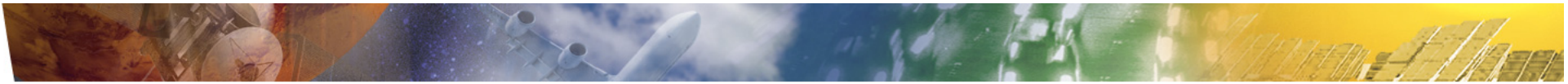


Aircraft type: Boeing 737-300
Introduction into service: 1984
Typical seating: 128
Fuel consumption FRA-BCN (1167 km): 4183 kg
Fuel consumption per passenger: 32.68 kg

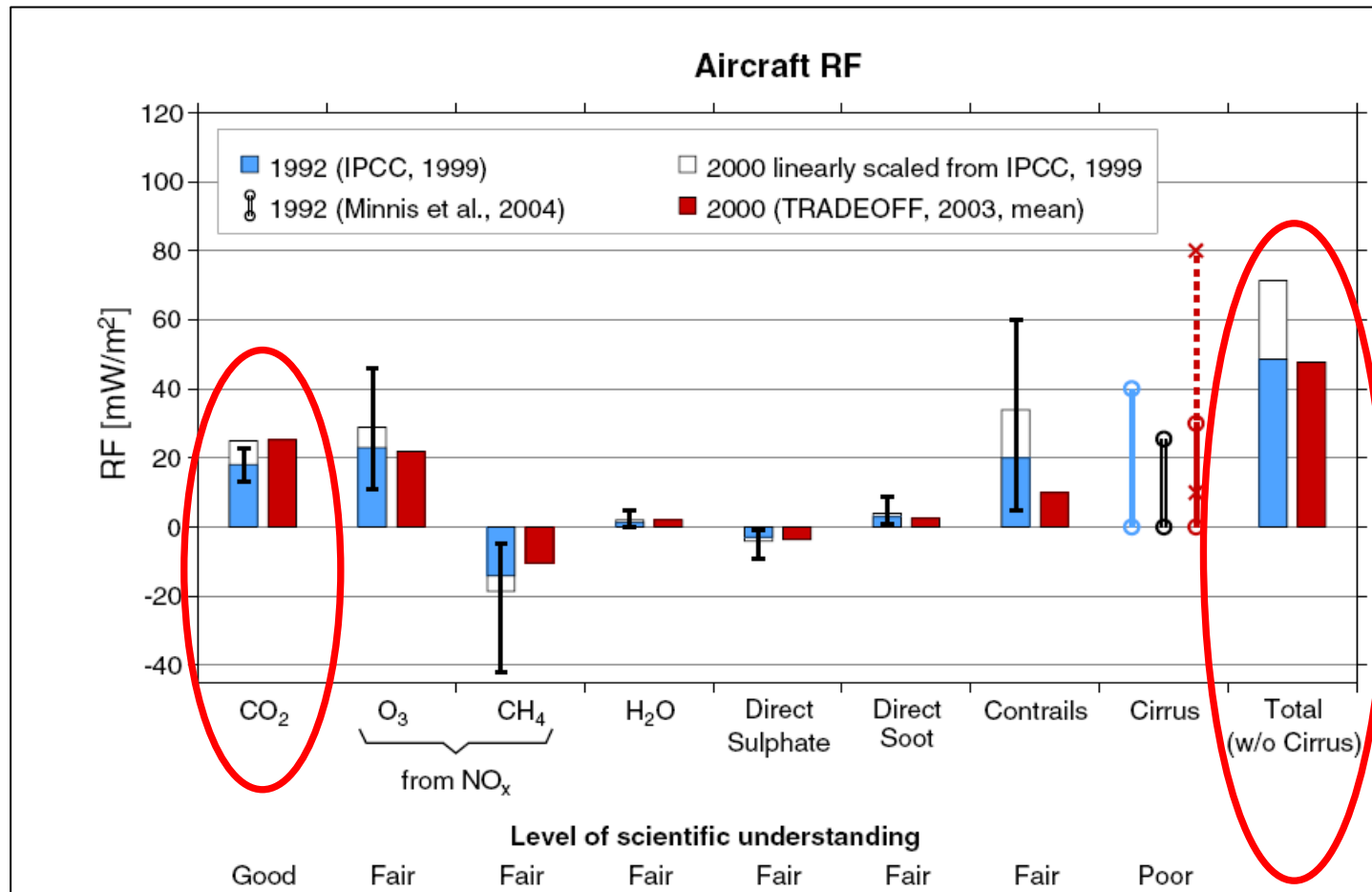


Aircraft type: Airbus A319-100
Introduction into service: 1996
Typical seating: 124
Fuel consumption FRA-BCN (1167 km): 3980 kg
Fuel consumption per passenger: 32.10 kg





1. Emissions and Ecological Impacts of Aviation (II)



Source: Sausen et al., 2005.

