

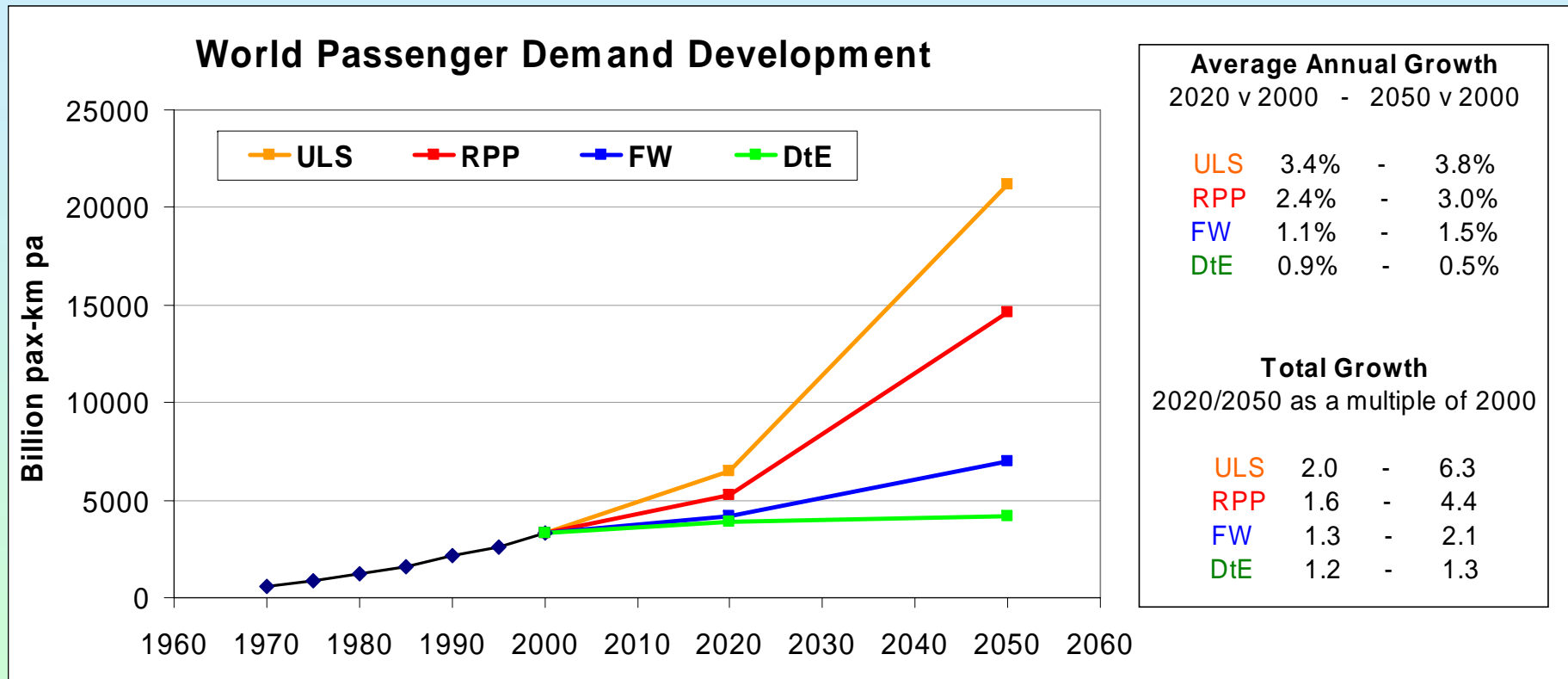
Results (Excerpt)

- **Transport Key Indicators**
 - Global Transport Volume
 - Saturation effects
 - Trips/Capita per region
 - Flights, Fleet and Runways
 - Unit costs comparison
 - Airlines profitability

- **Emissions**

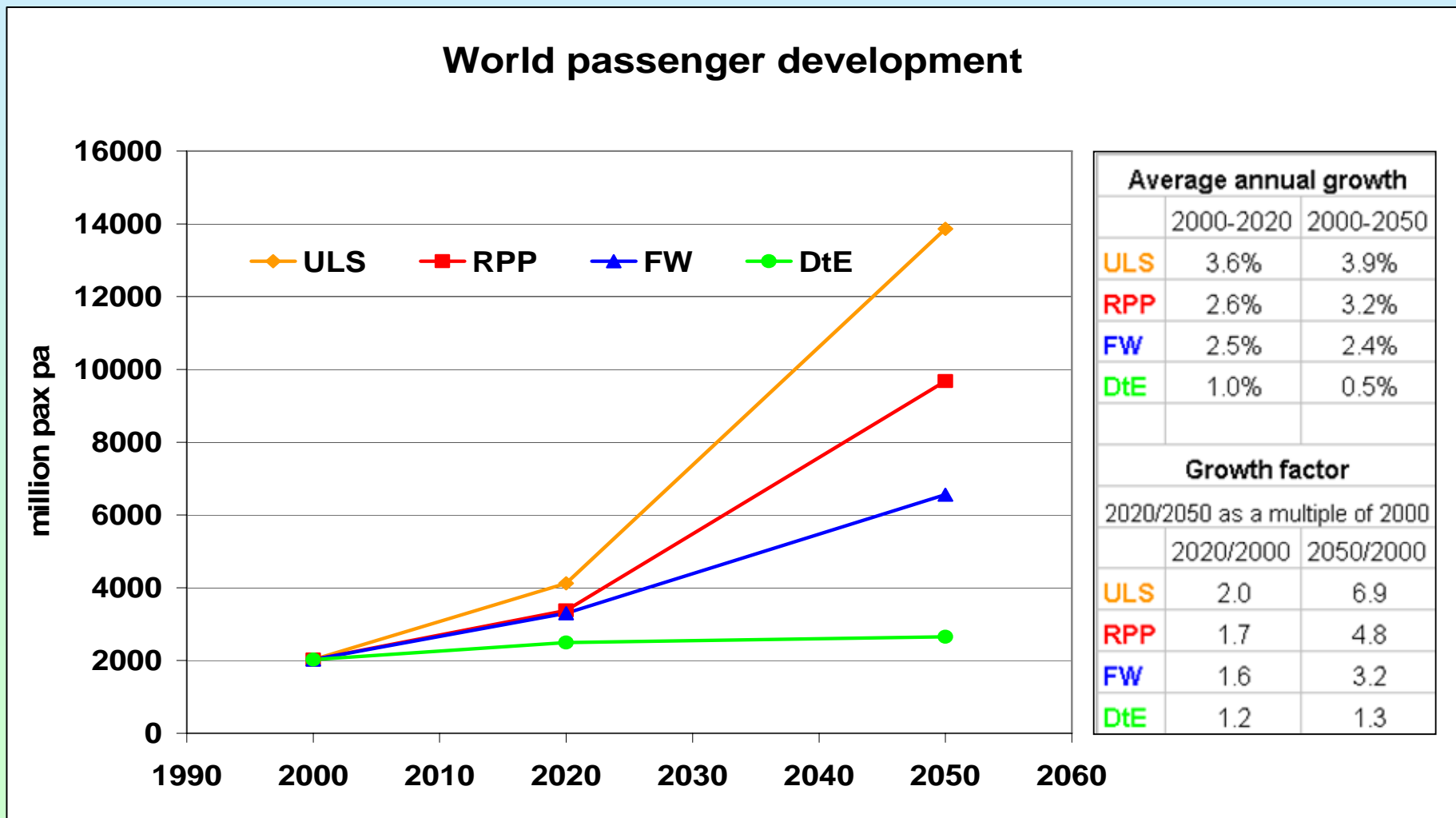
- **Sub-scenarios, measures and sensibility checks**

Comparison of the total passenger demand in billion pax-km p.a.

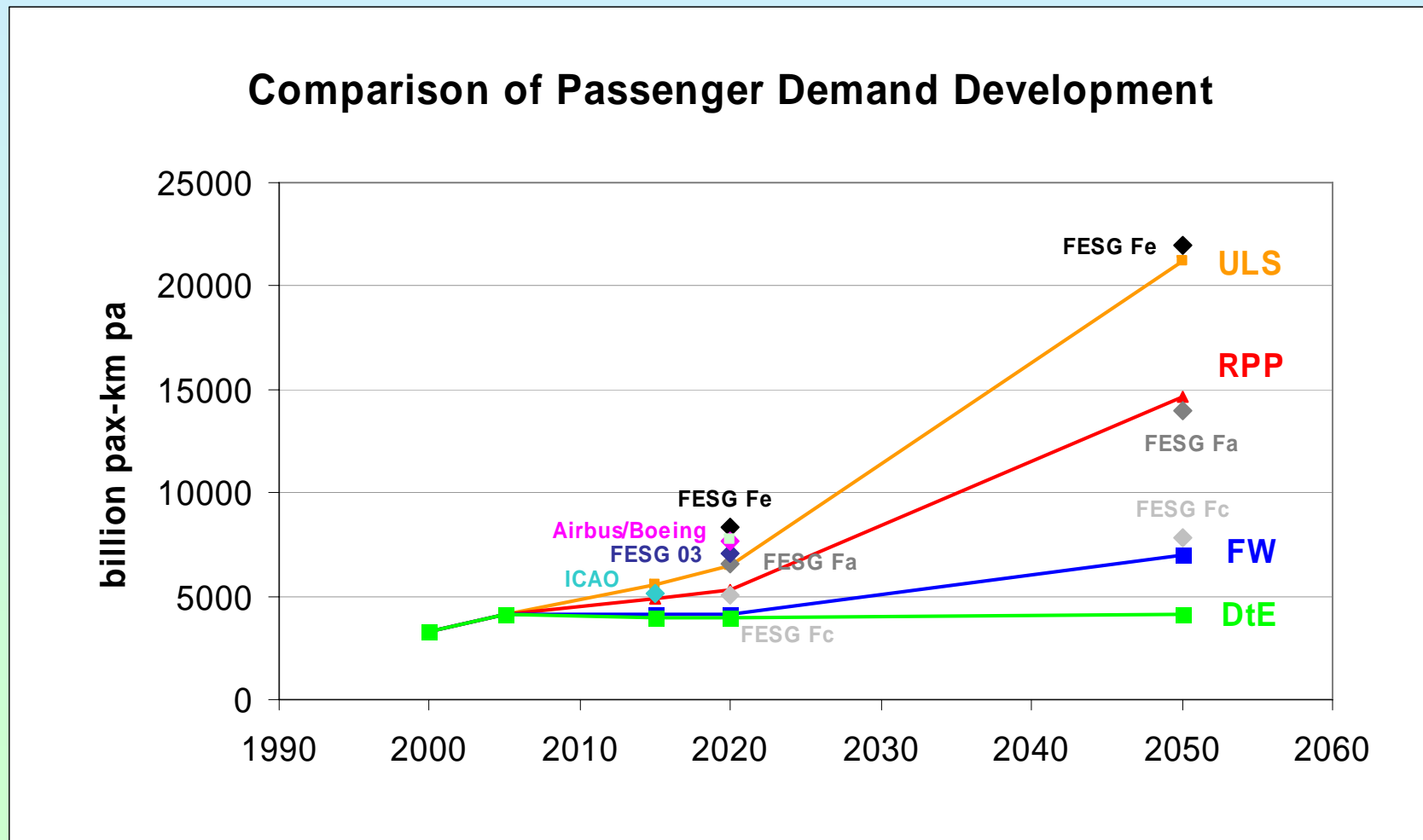


Highest growth in Scenario **ULS** with 6505 billion pax-km p.a. in 2020 and 21185 billion pax-km p.a. in 2050 - Corresponding growth rate p.a. 3.4% (2020) and 3.8 % (2050) - Scenario **RPP**: 2.4% (2020) and 3.0% (2050)

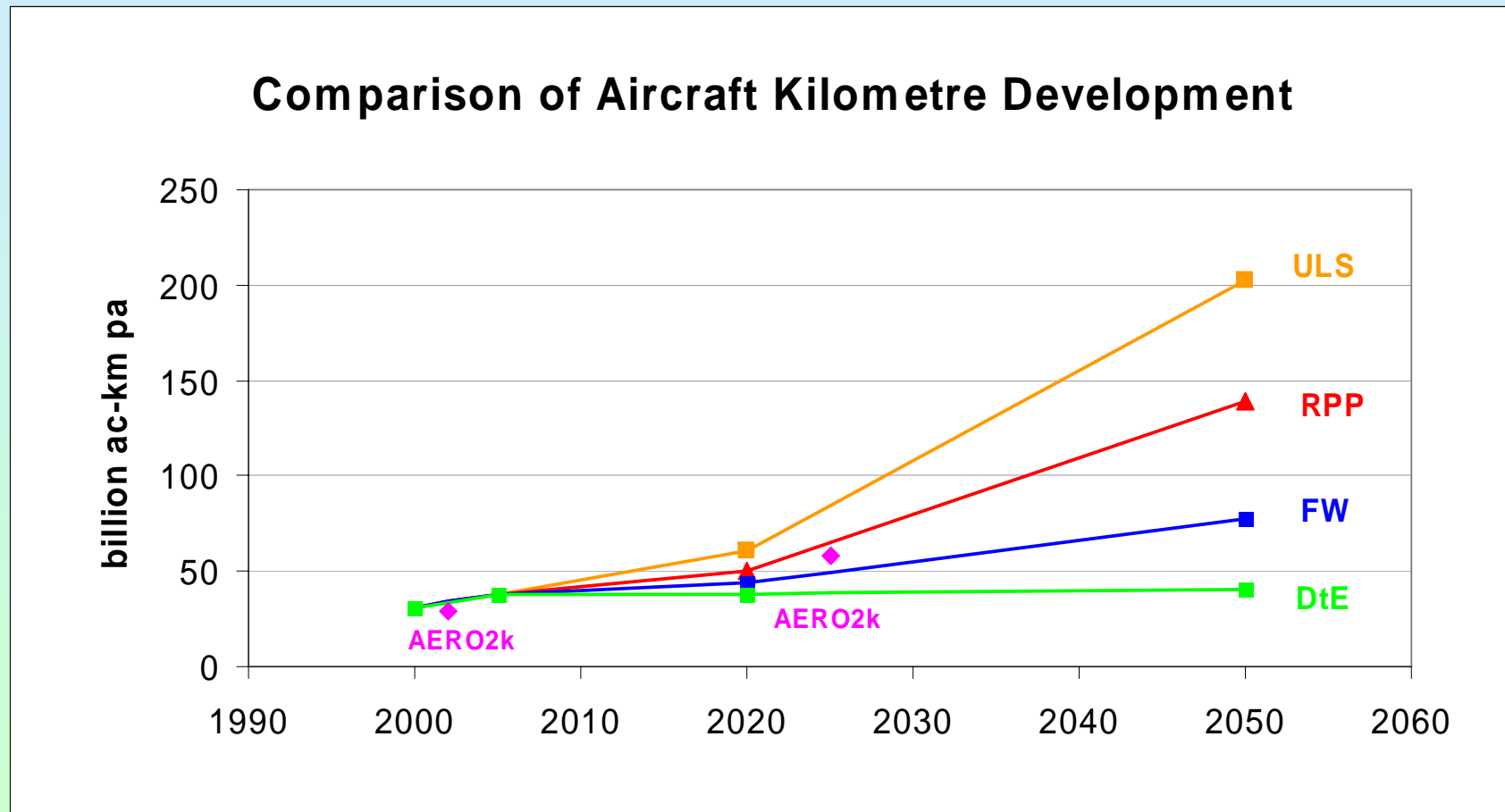
Comparison of the total passenger demand in million pax p.a.



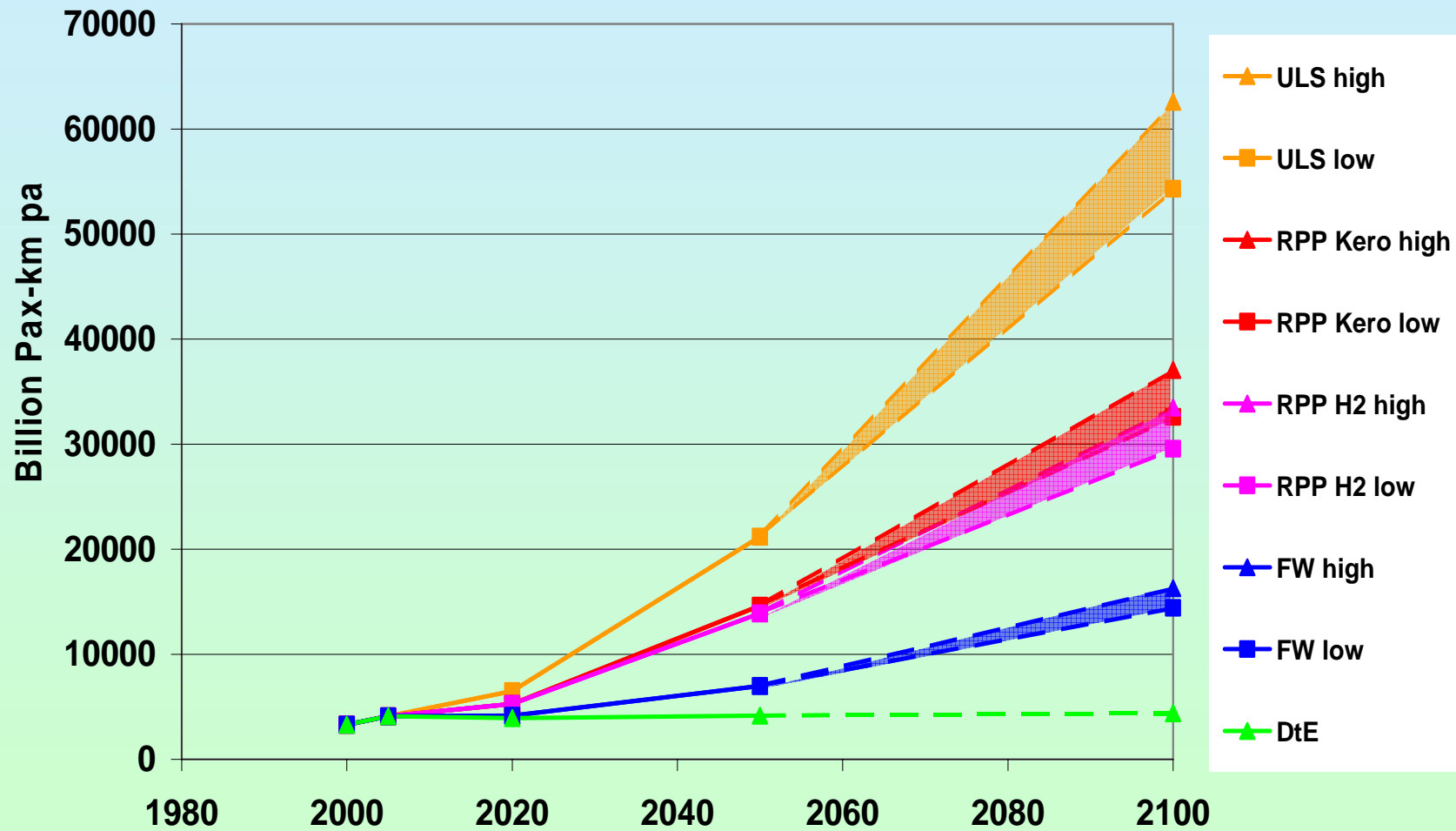
Comparison of passenger demand with results from ICAO, Airbus, Boeing and FESG



Comparison of passenger demand with results from AERO2k

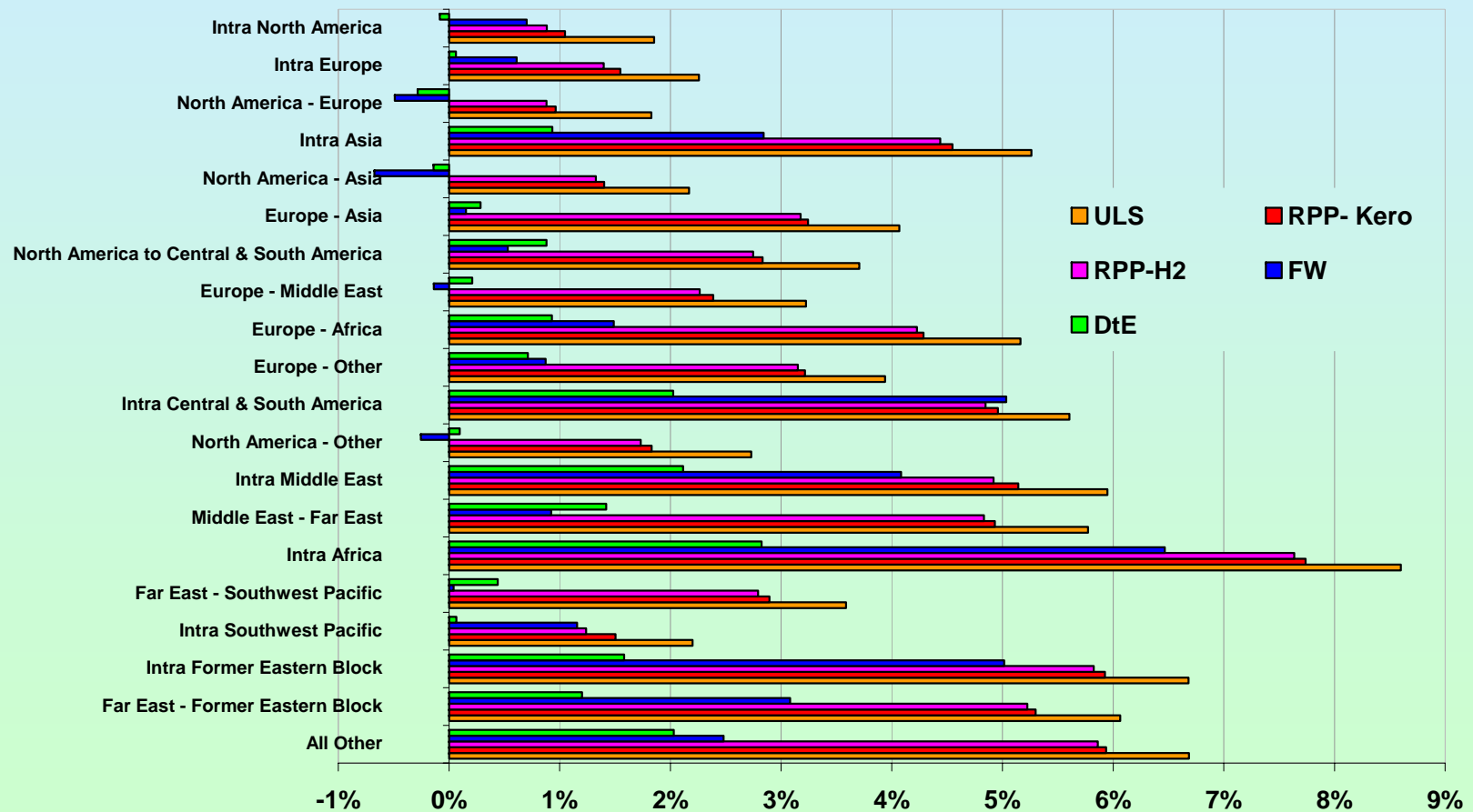


World Passenger Demand - Outlook to 2100



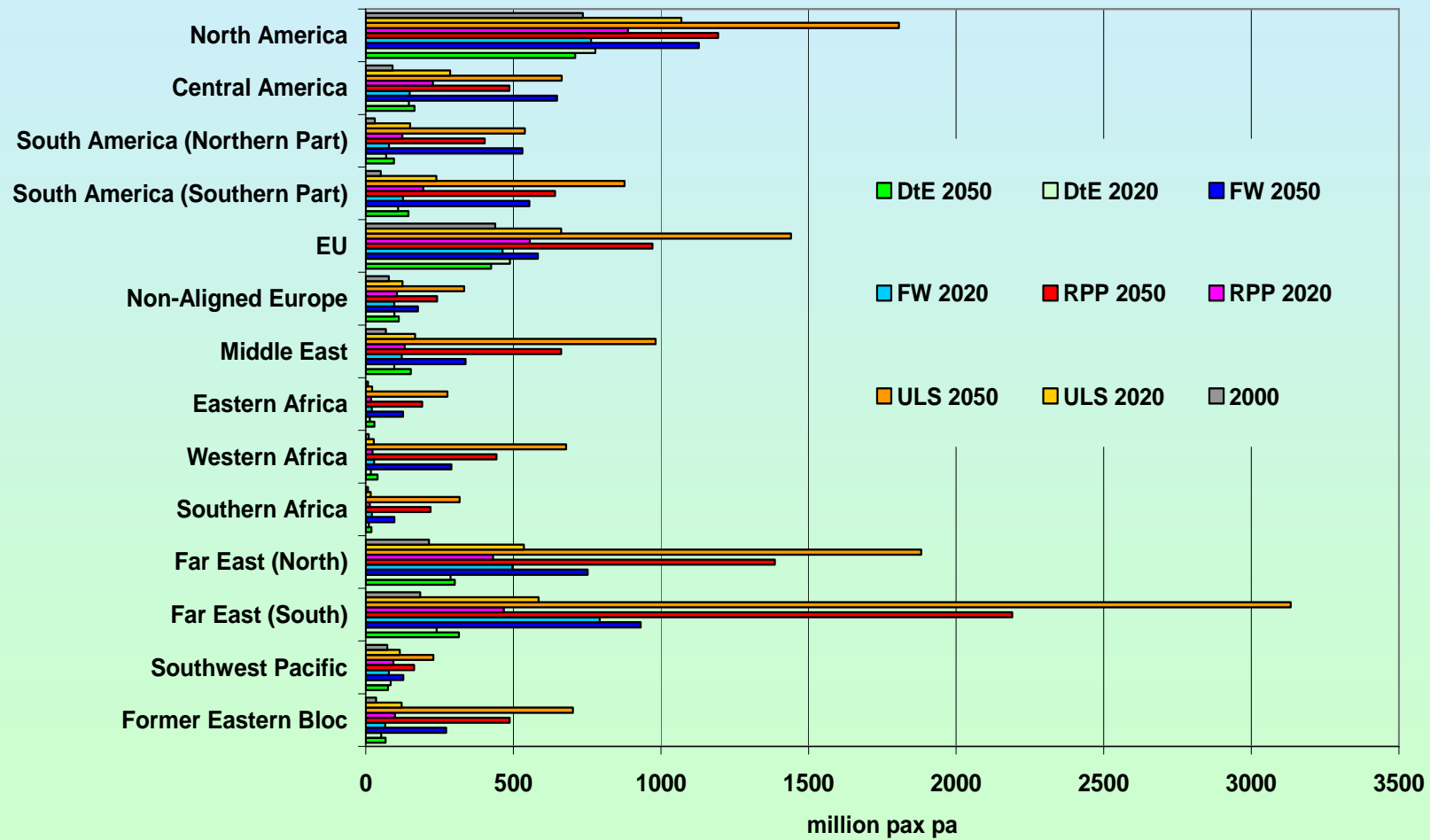
Regional results – traffic flow annual growth rates

Annual growth rates of major traffic flow for route groups between 2000 and 2050

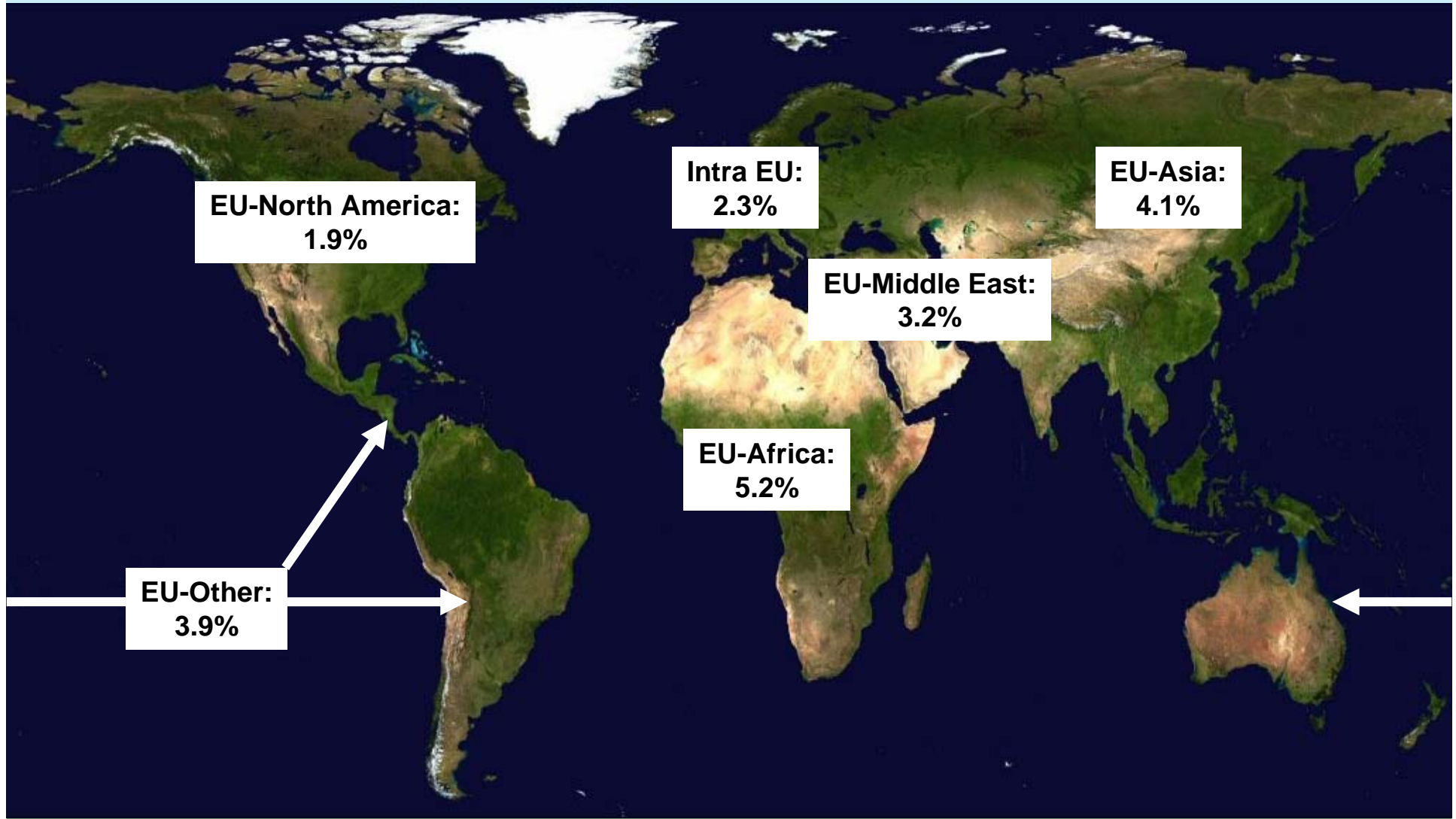


Regional results – passenger demand between 2000 and 2050

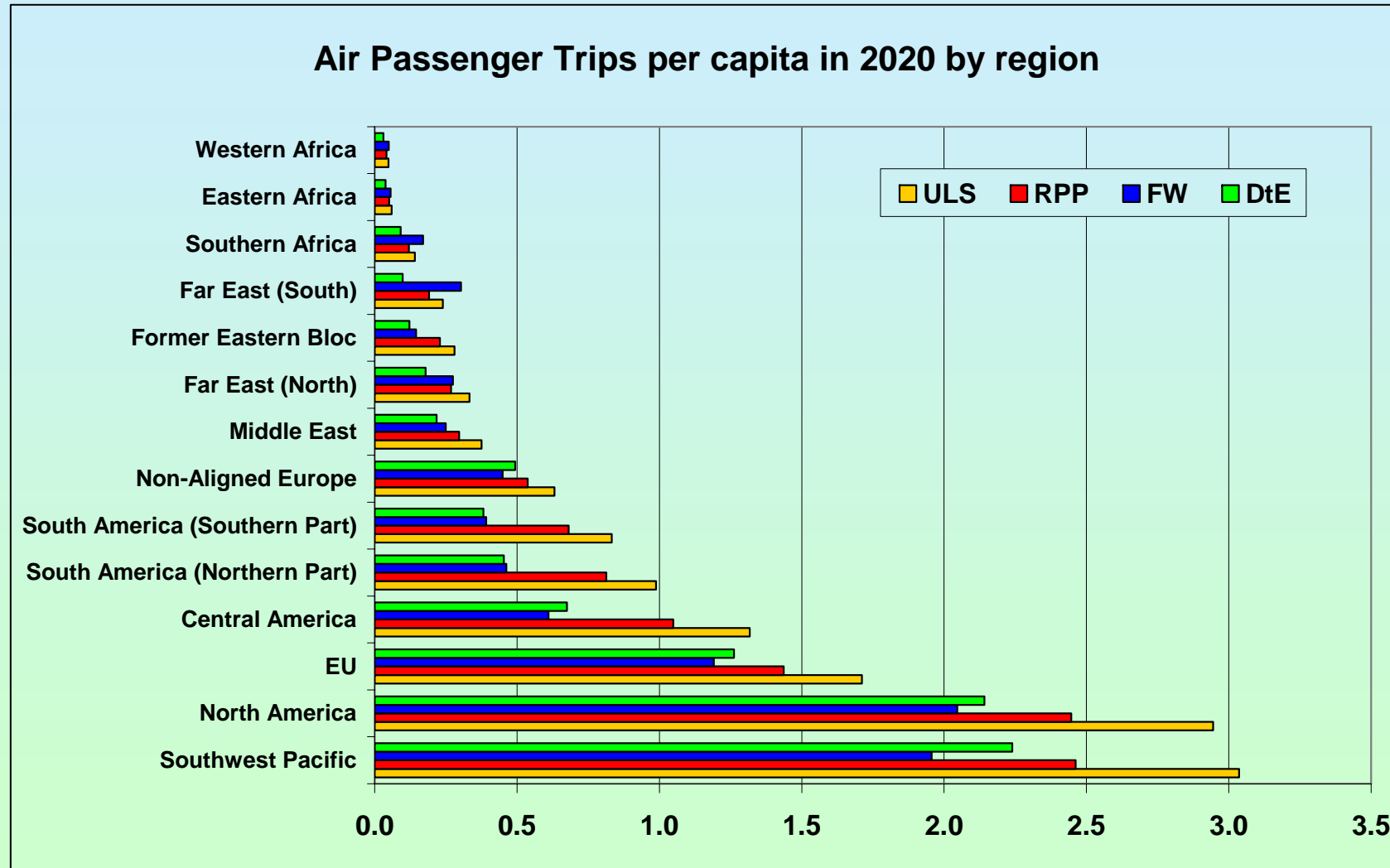
Passenger demand development in the IATA regions



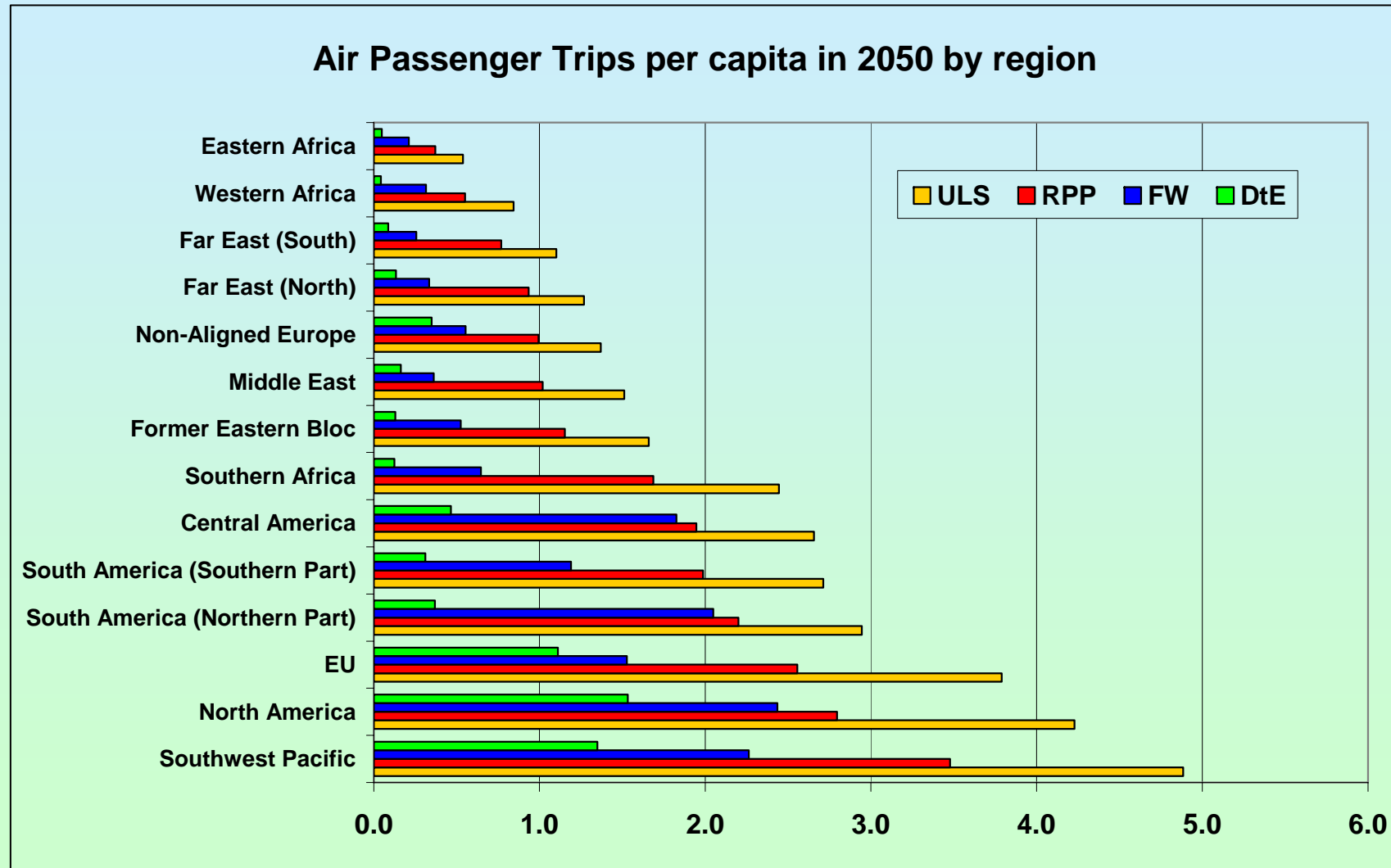
Annual average growth rates for Europe between 2000 and 2050 (ULS)



Trips per capita in 2020 for IATA regions



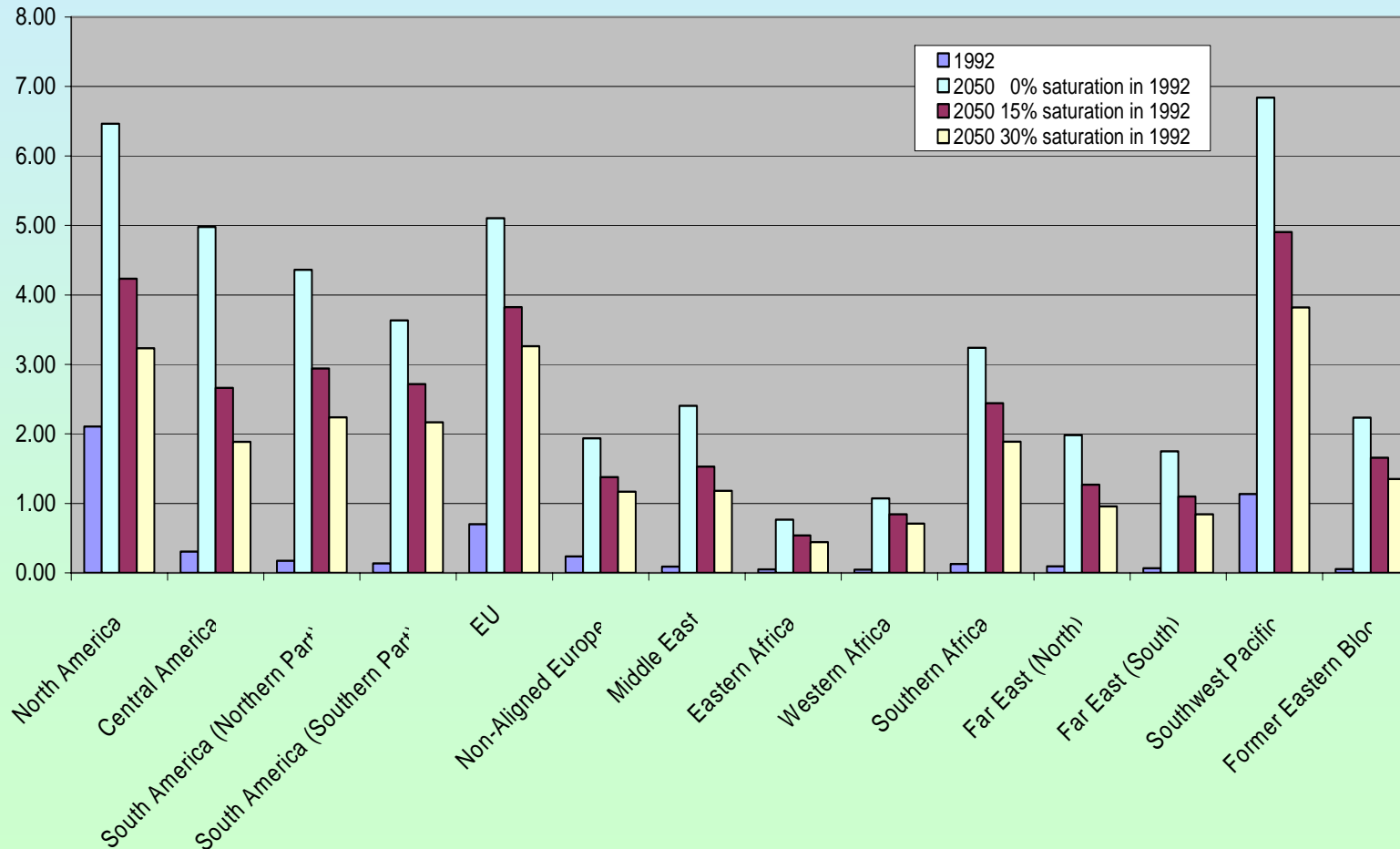
Trips per capita in 2050 for IATA regions



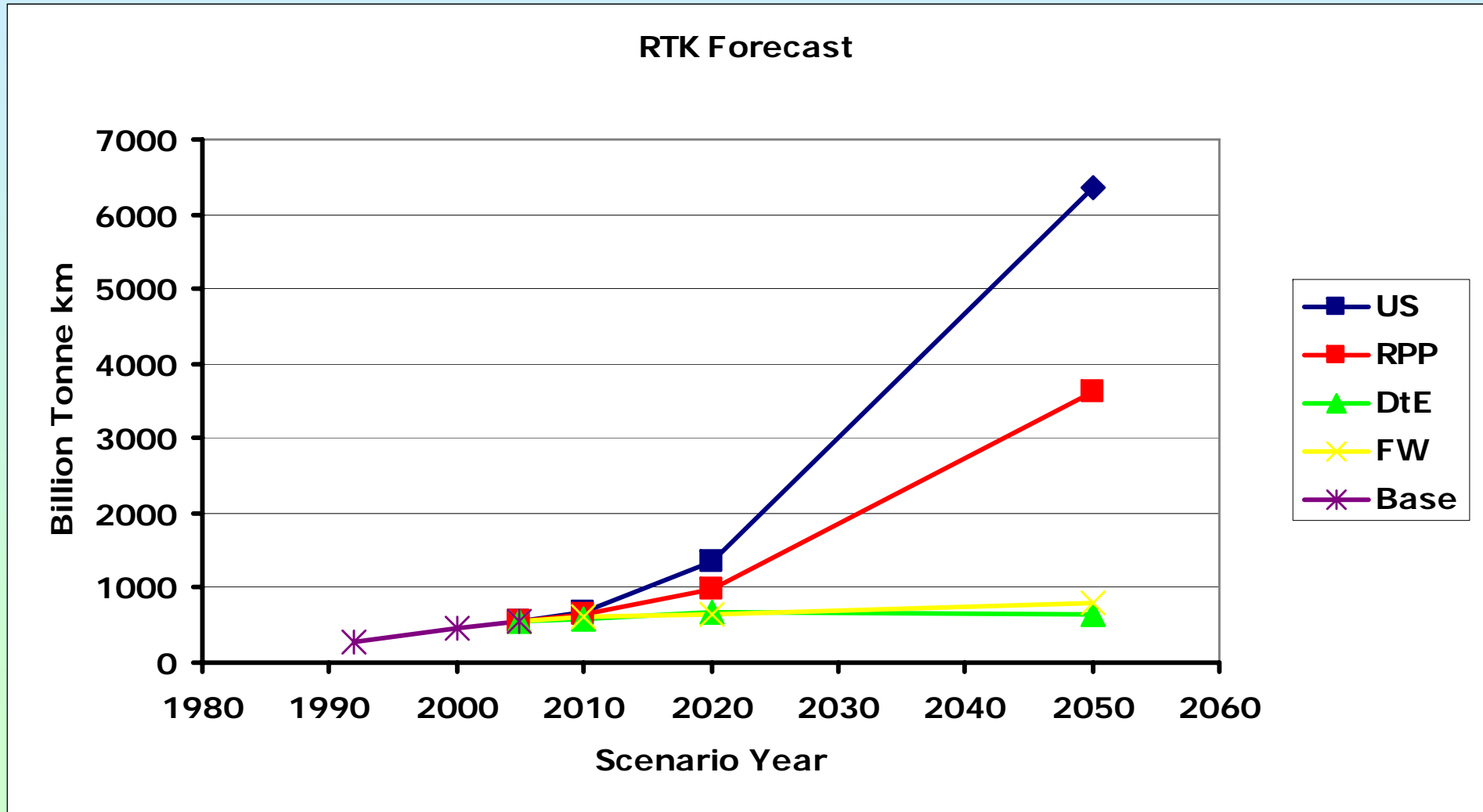
Trips per capita in 2050 for IATA regions

for scenario ULS and for various levels of saturation in 1992

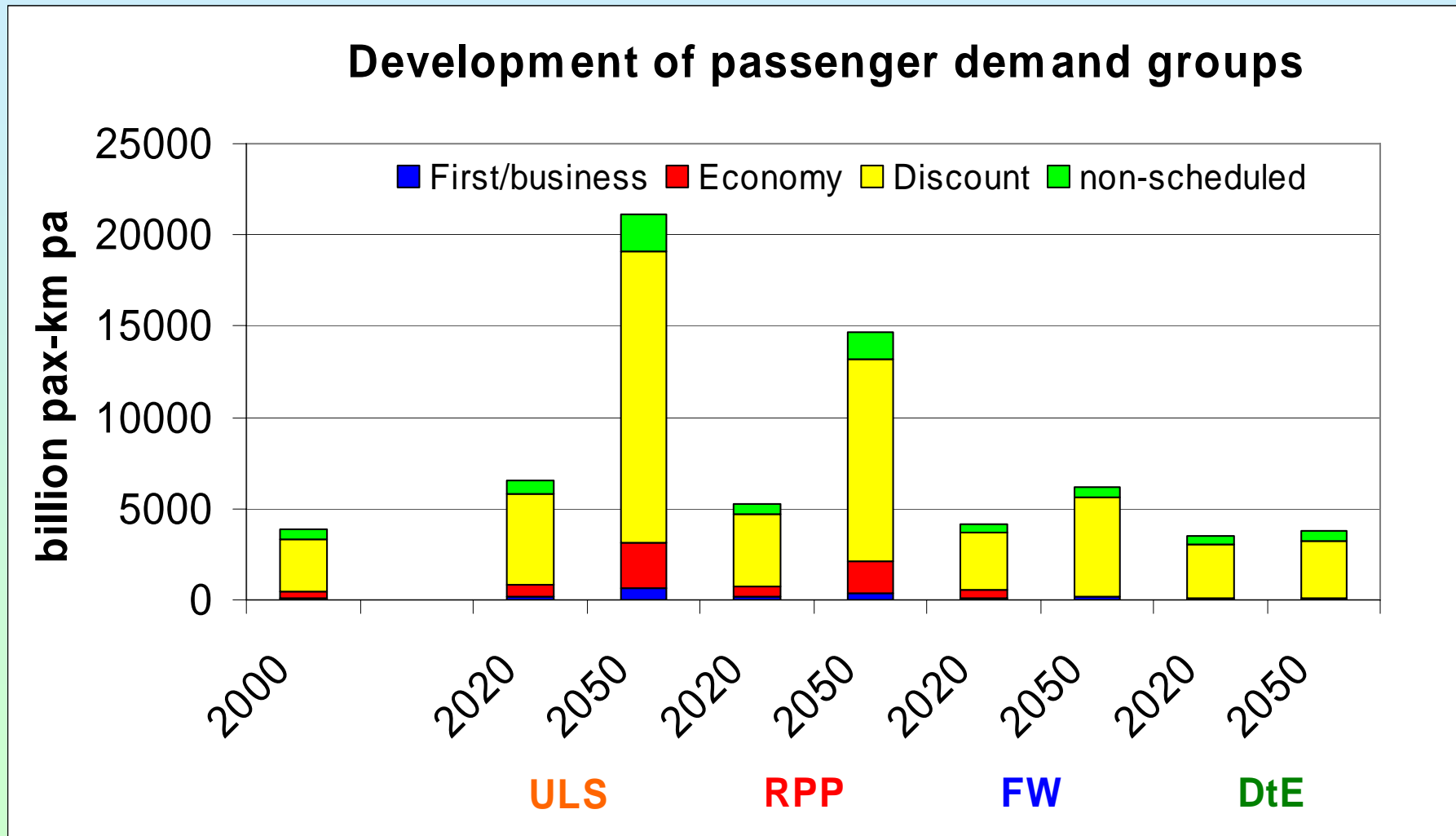
Air Passenger Trips per Capita in 2050 by Region for the **Unlimited Skies** Scenario for various levels of saturation in 1992



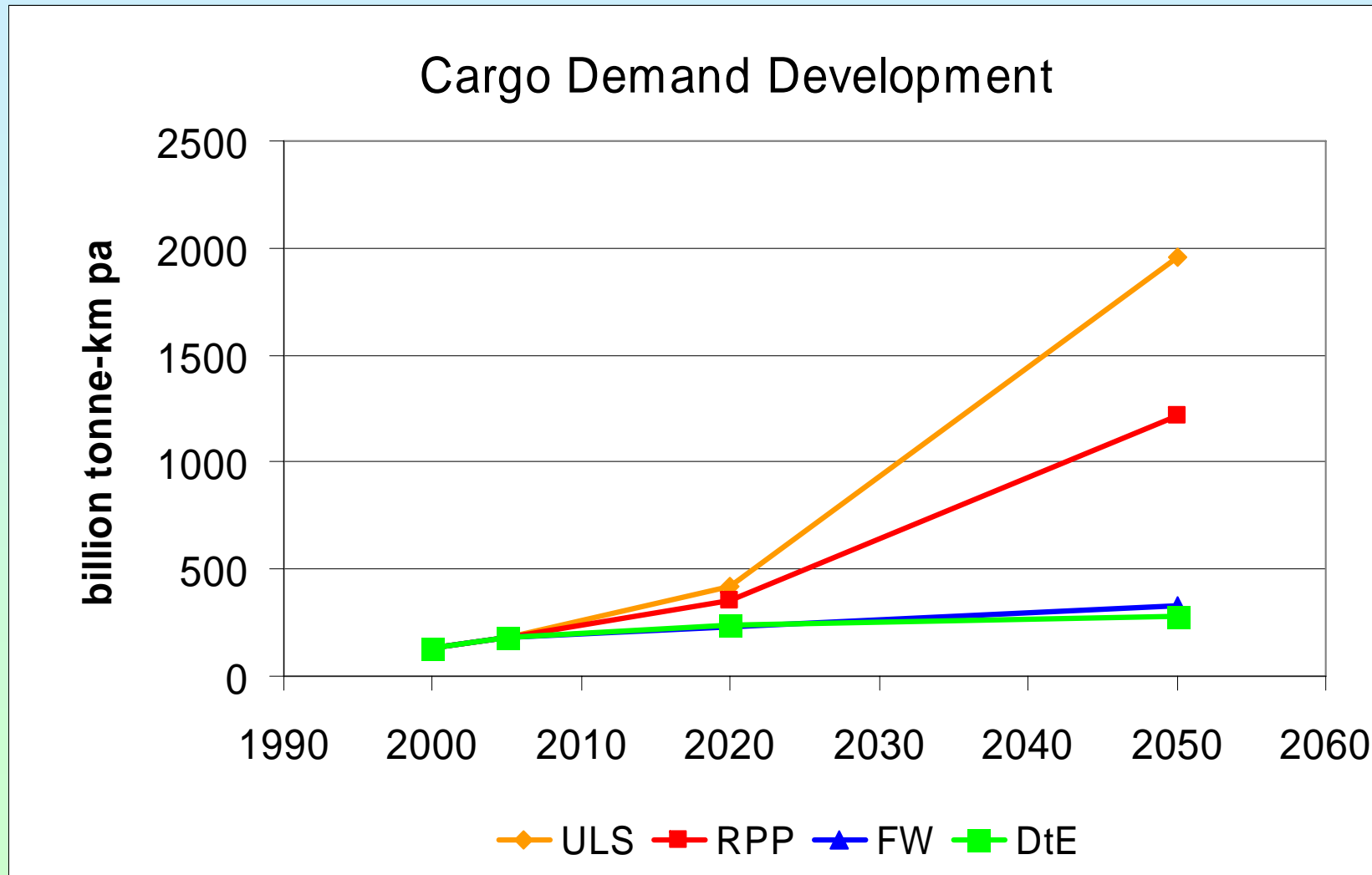
Overall growth comparison



Development of passenger demand groups



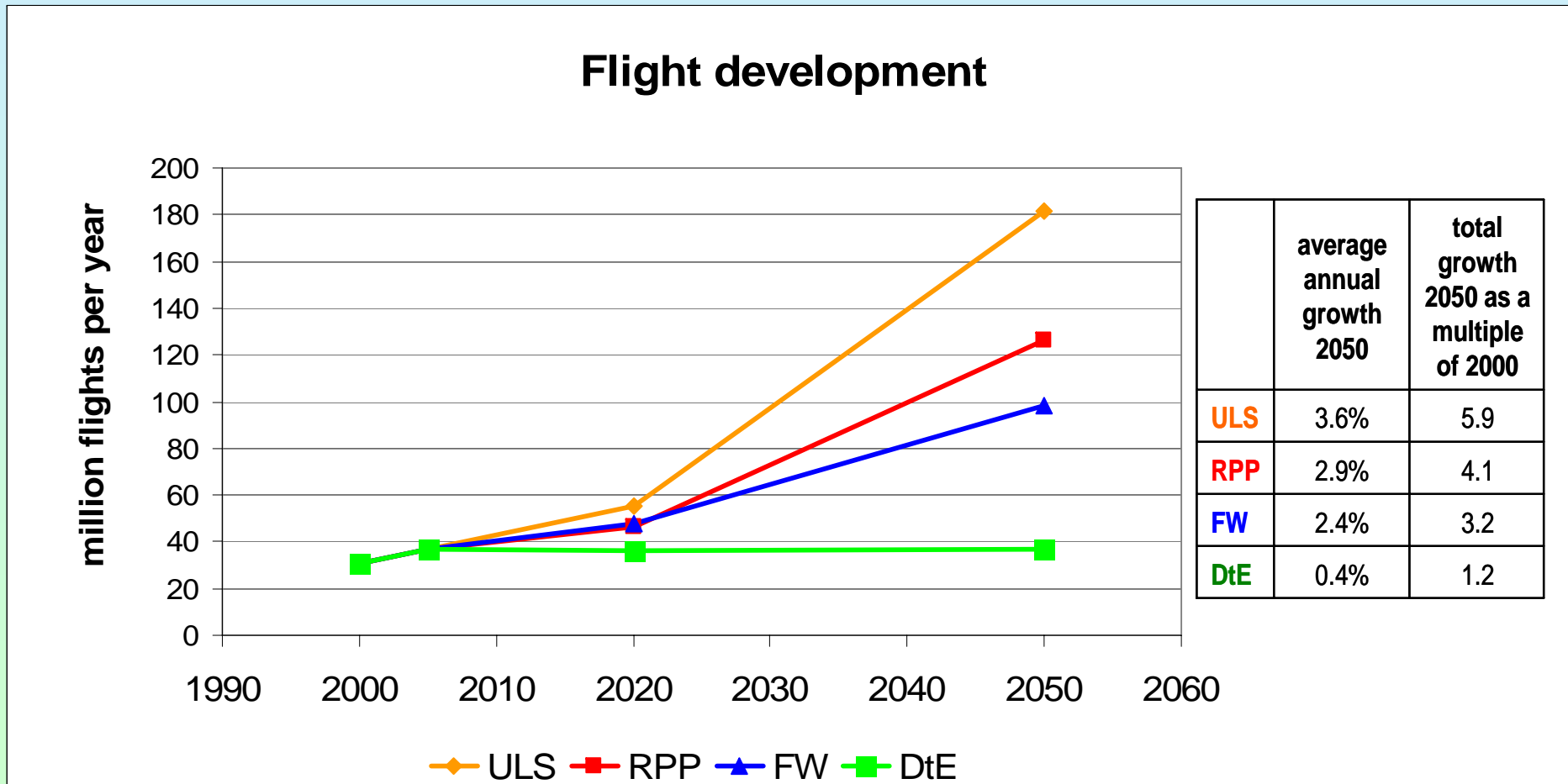
Cargo demand in billion tonne-km p.a.



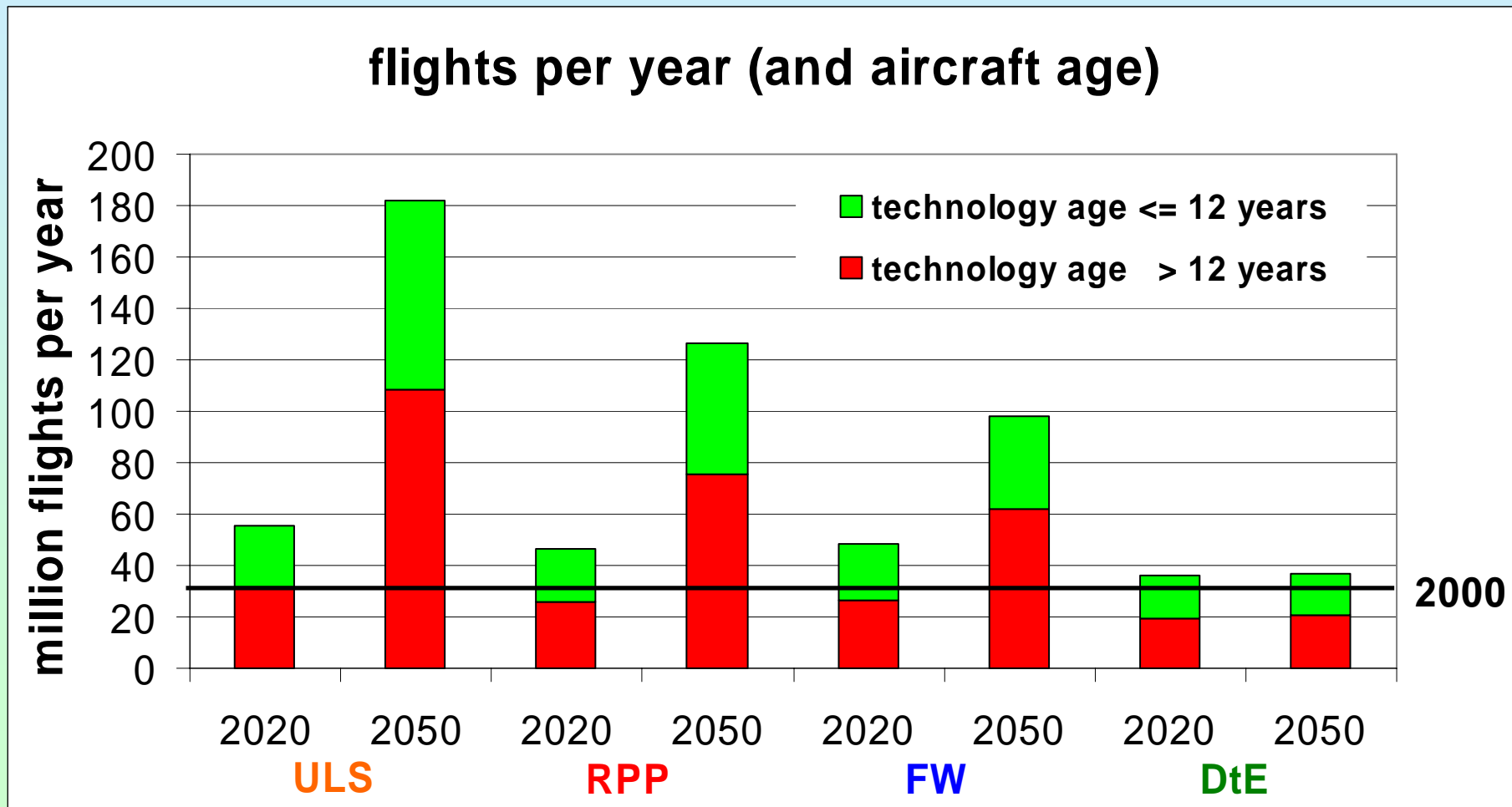
Conclusions related to demand

- Different scenario assumptions result in a wide range of imaginable long term developments in travel demand until 2050.
- The “Unlimited Skies” scenario yields a high increase in air trips per capita all over the world – providing aviation with sufficient infrastructure is a big challenge (primarily in the EU & US).
- The “Regulatory Push & Pull” scenario corresponds with high demand growth, too; according to assumptions aviation needs to be more sustainable.
- In the scenario “Fractured World” travel demand will only increase within the various world regions and “friendly” blocks (with acceptable profitability).
- In “Down to Earth” regional travel will be preferred by customers, mainly by train/cars, in consequence of life style changes - aviation is low profitable business.

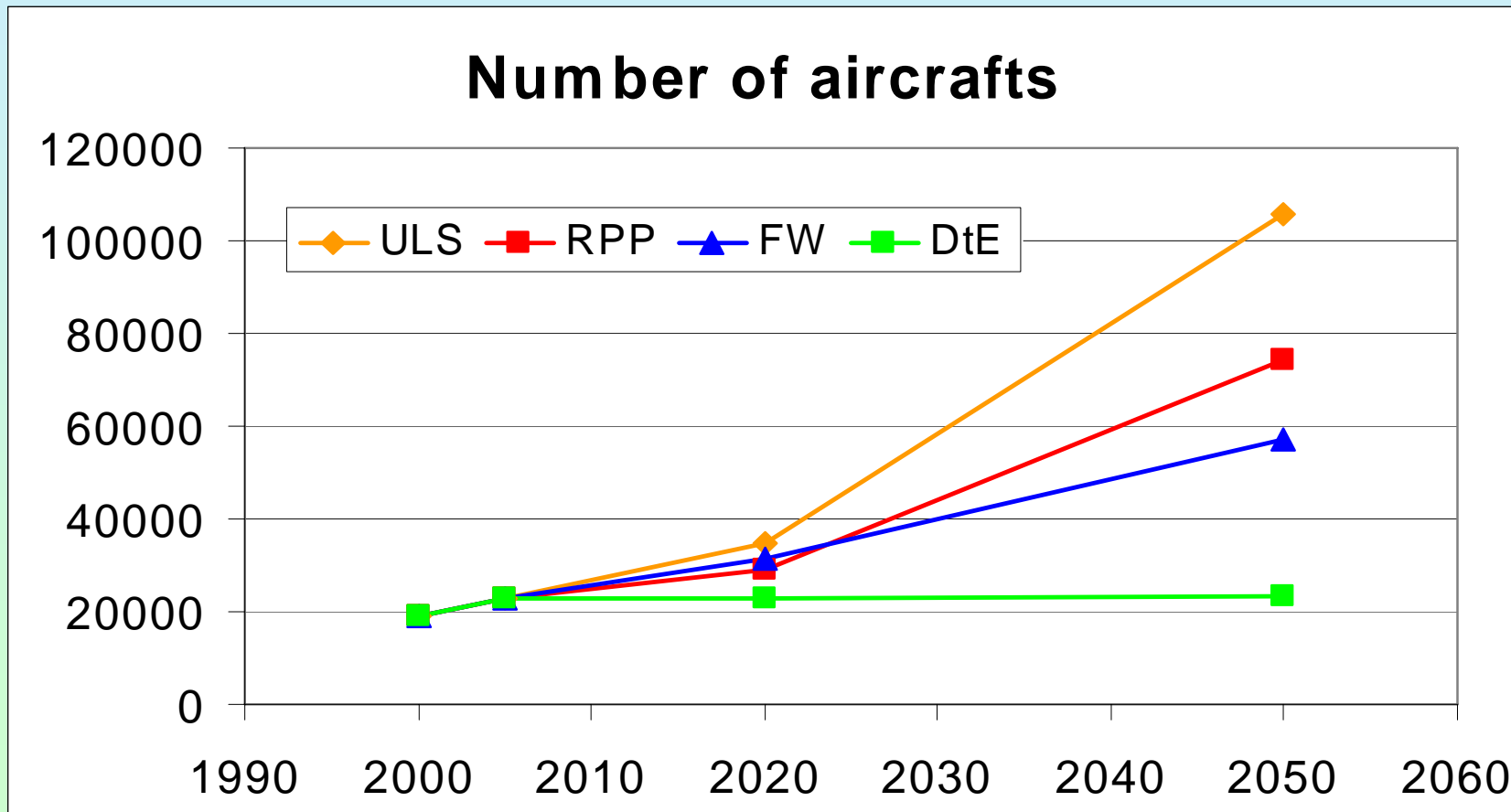
Flight development in million flights p.a. plus total & annual growth rates



Flights by aircraft technology age

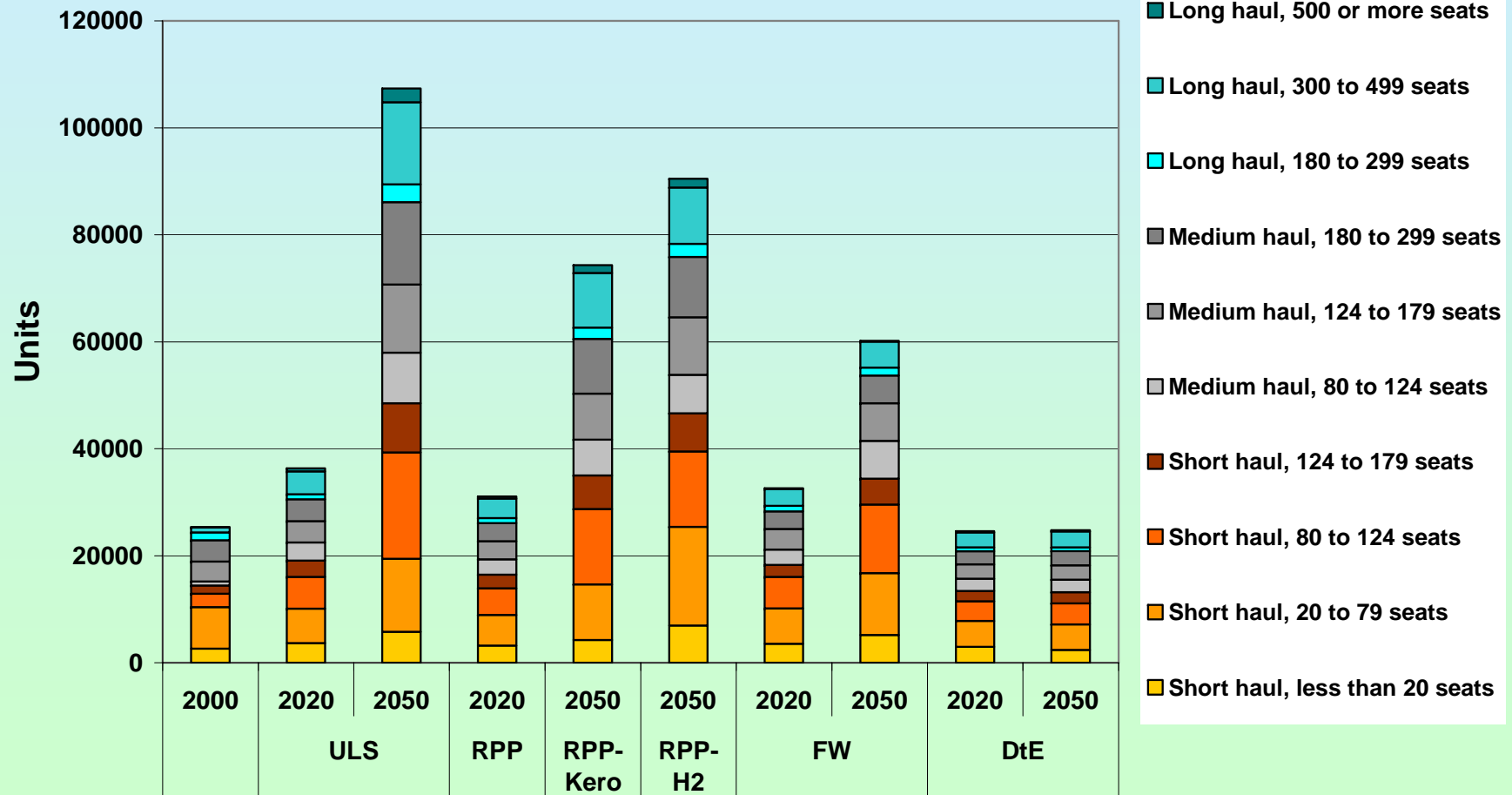


Number of aircraft



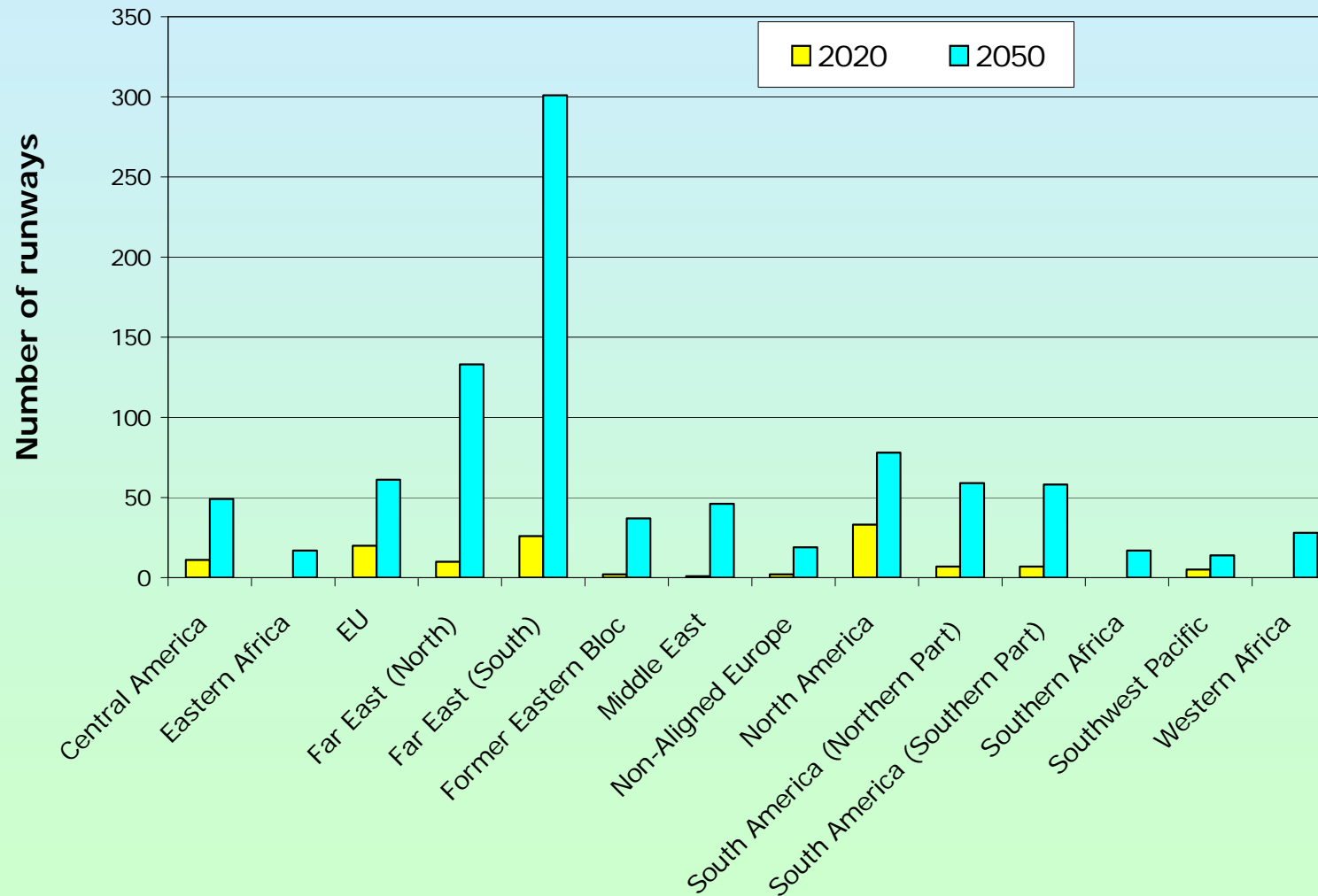
Fleet mix until 2050

Fleet mix until 2050



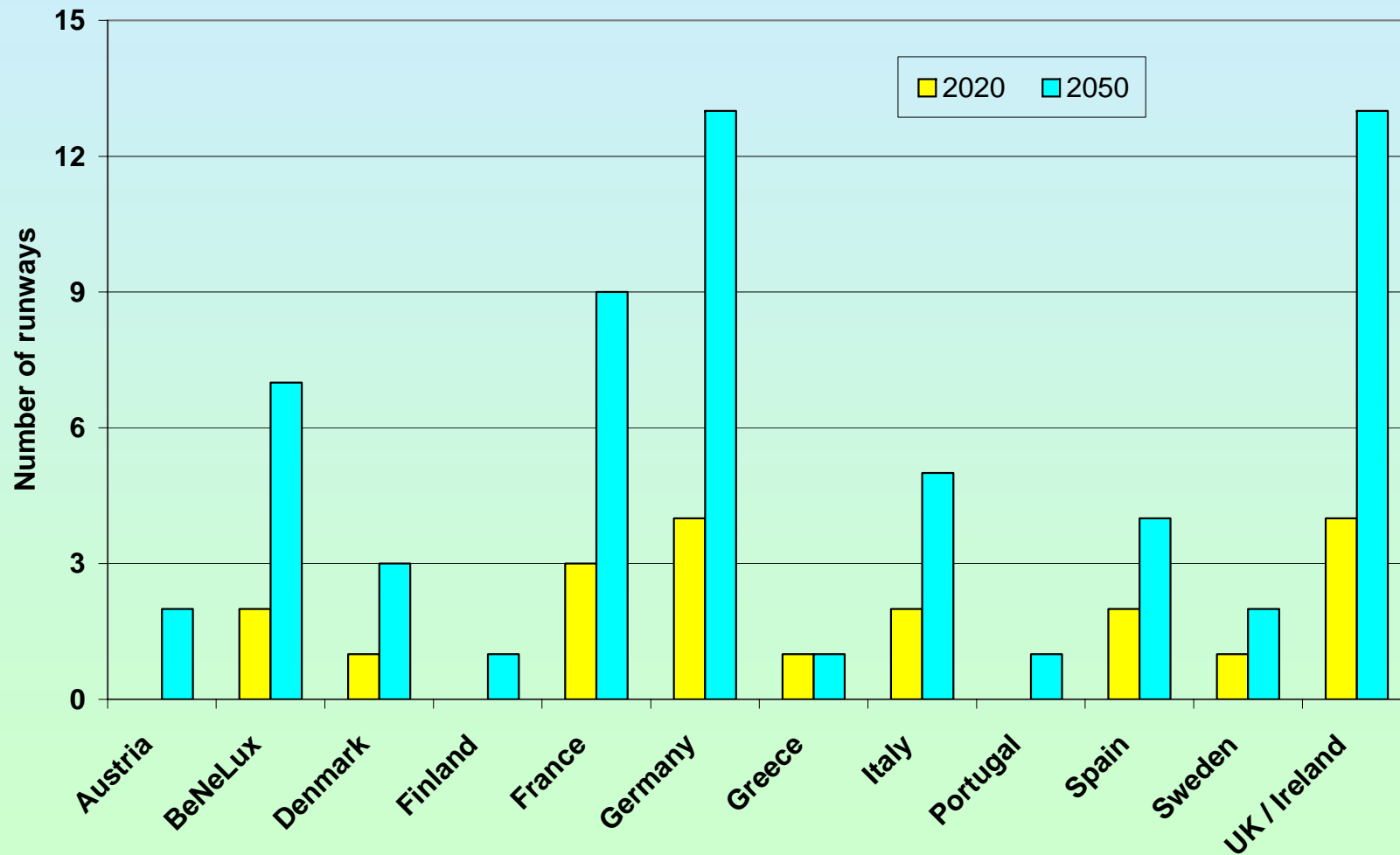
Unlimited Skies - Additional Global Runway Requirements

Additional Runway Requirements Worldwide (ULS)



Unlimited Skies - Additional Runway Requirements in Europe

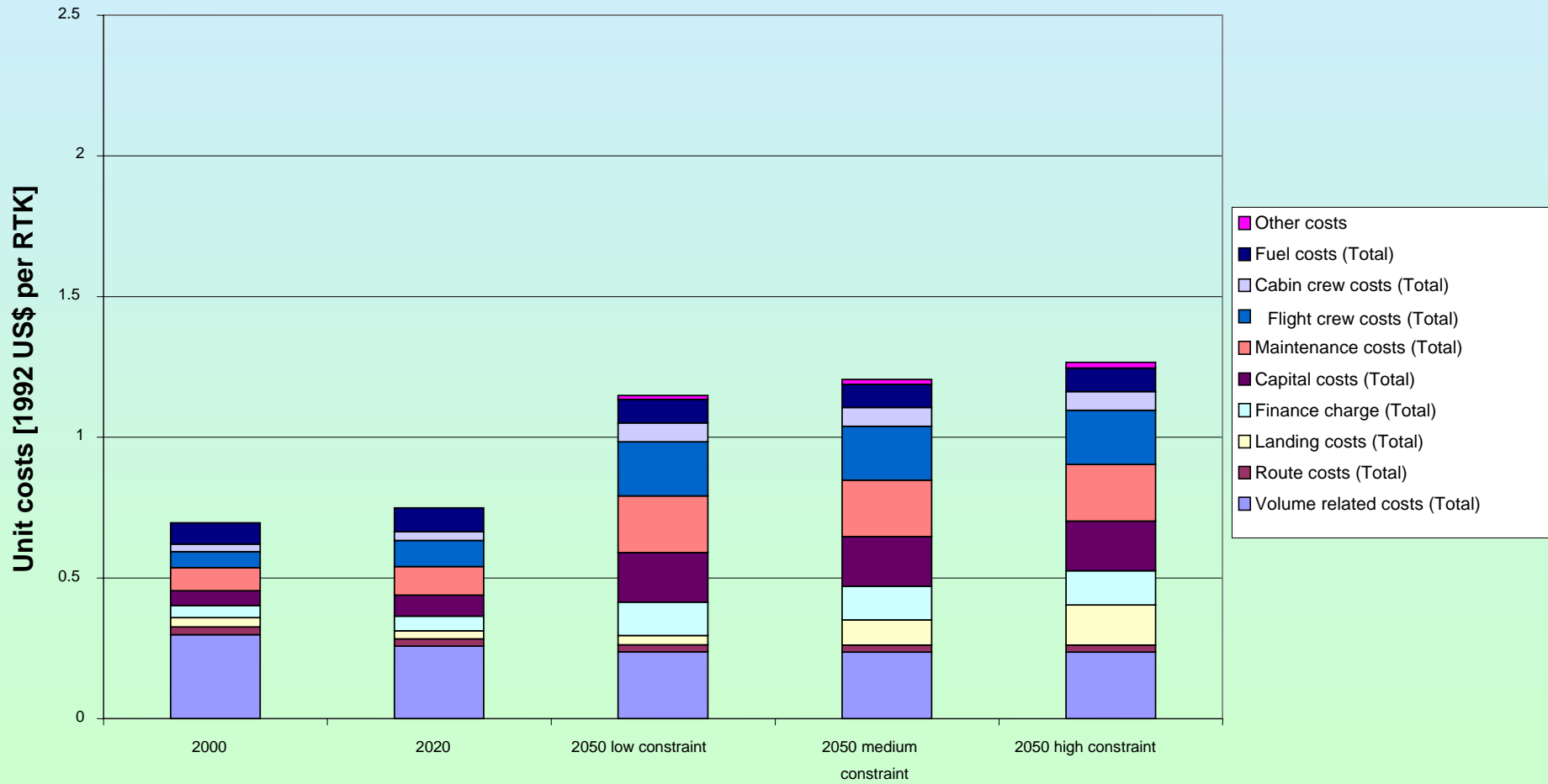
Additional Runway Requirements in Europe (ULS)



Unit costs (1/5)

Unlimited Skies

Unit Costs

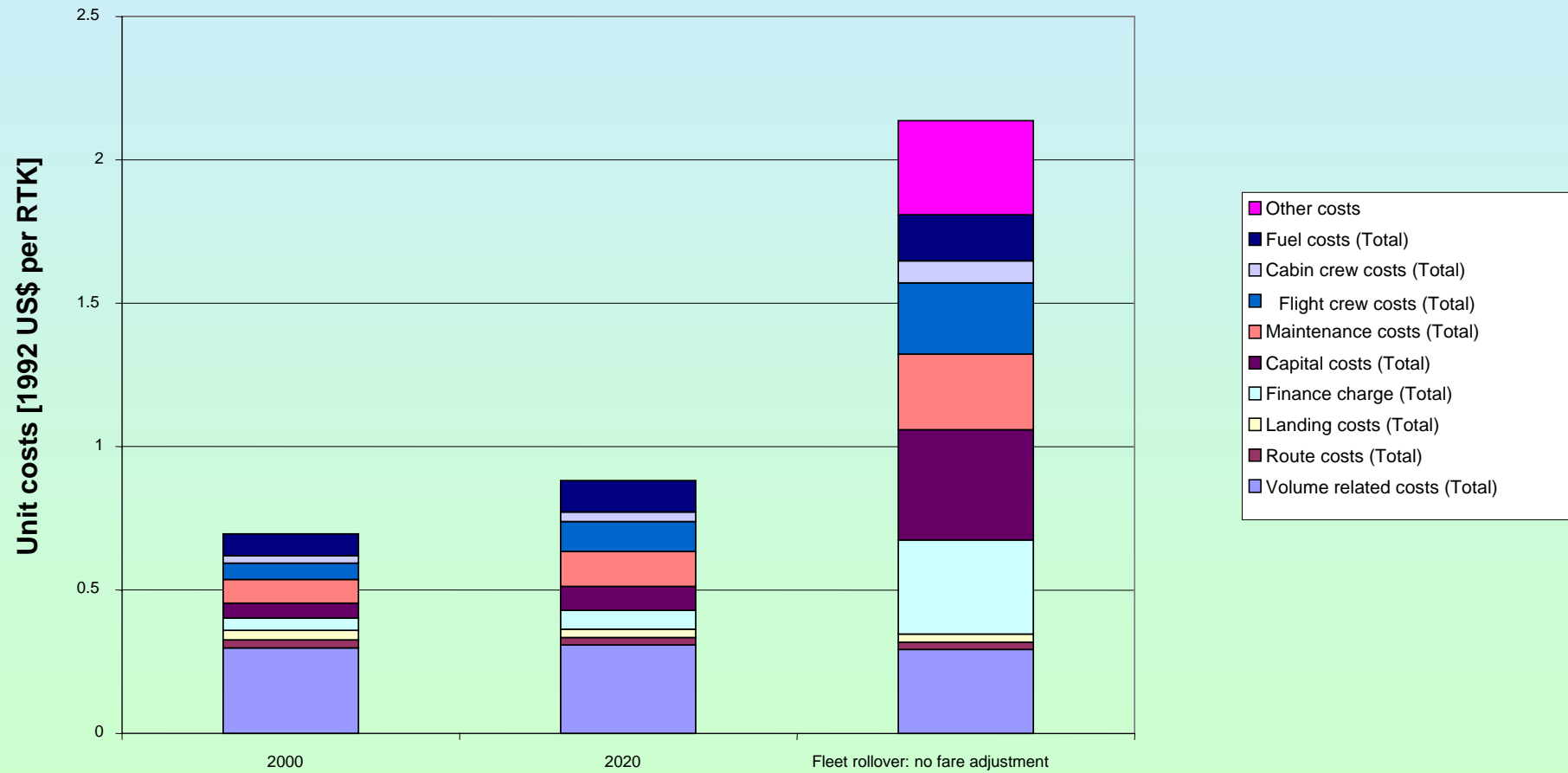


Unit costs (2/5)

Regulatory Push & Pull

with kerosene - hydrogen fleet rollover

Unit Costs

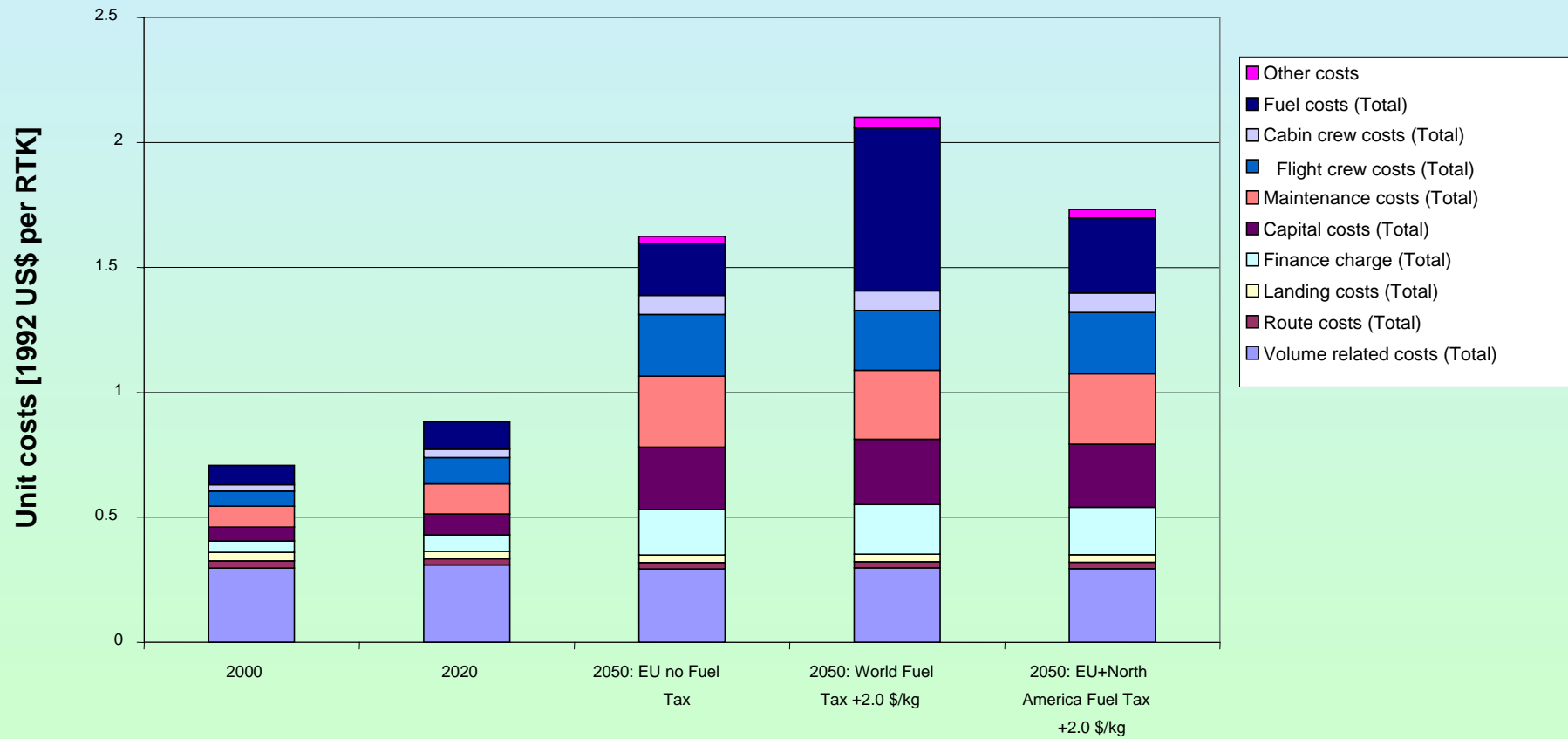


Unit costs (3/5)

Regulatory Push & Pull

kerosene fleet

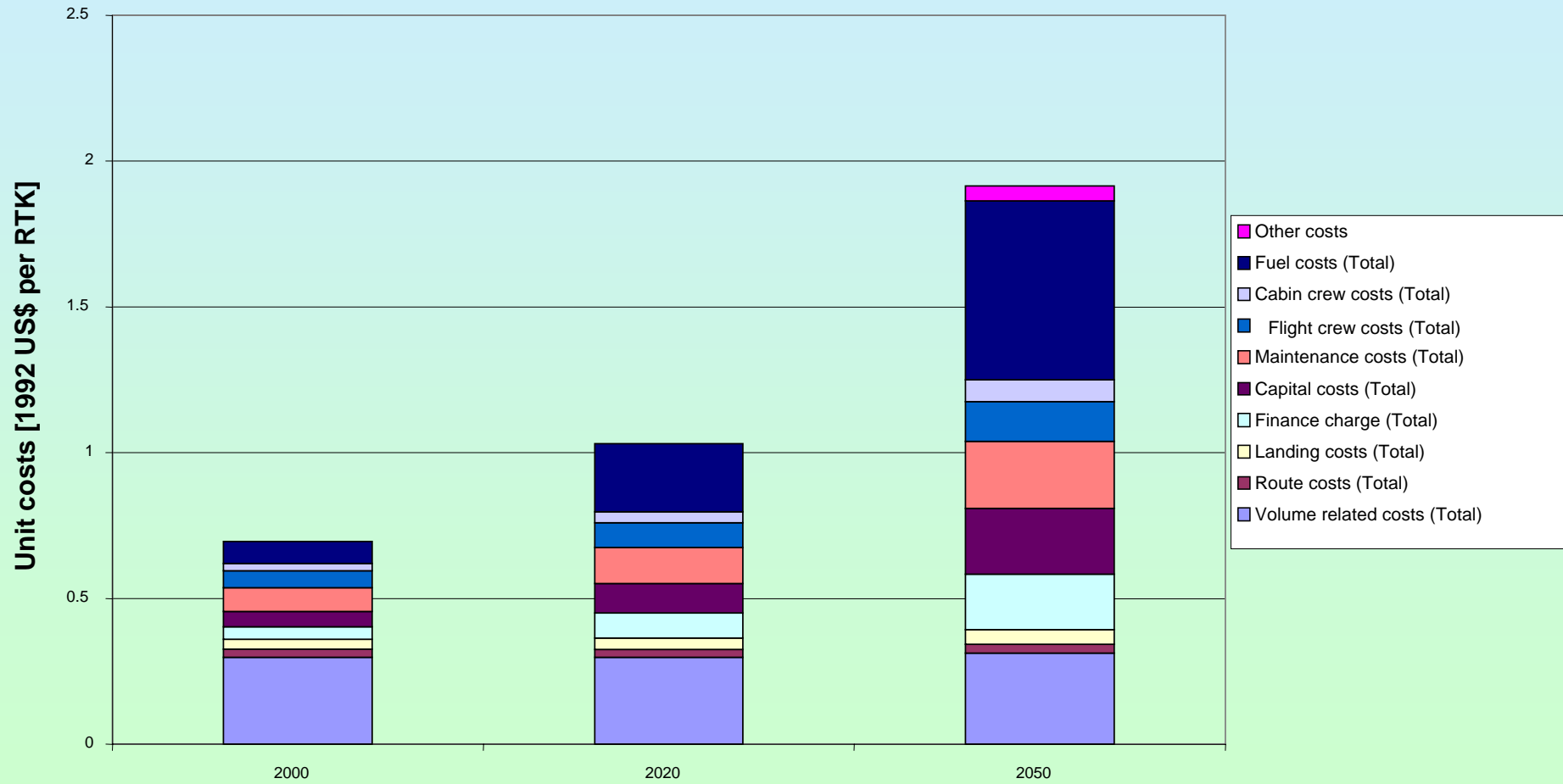
Unit Costs



Unit costs (4/5)

Fractured World

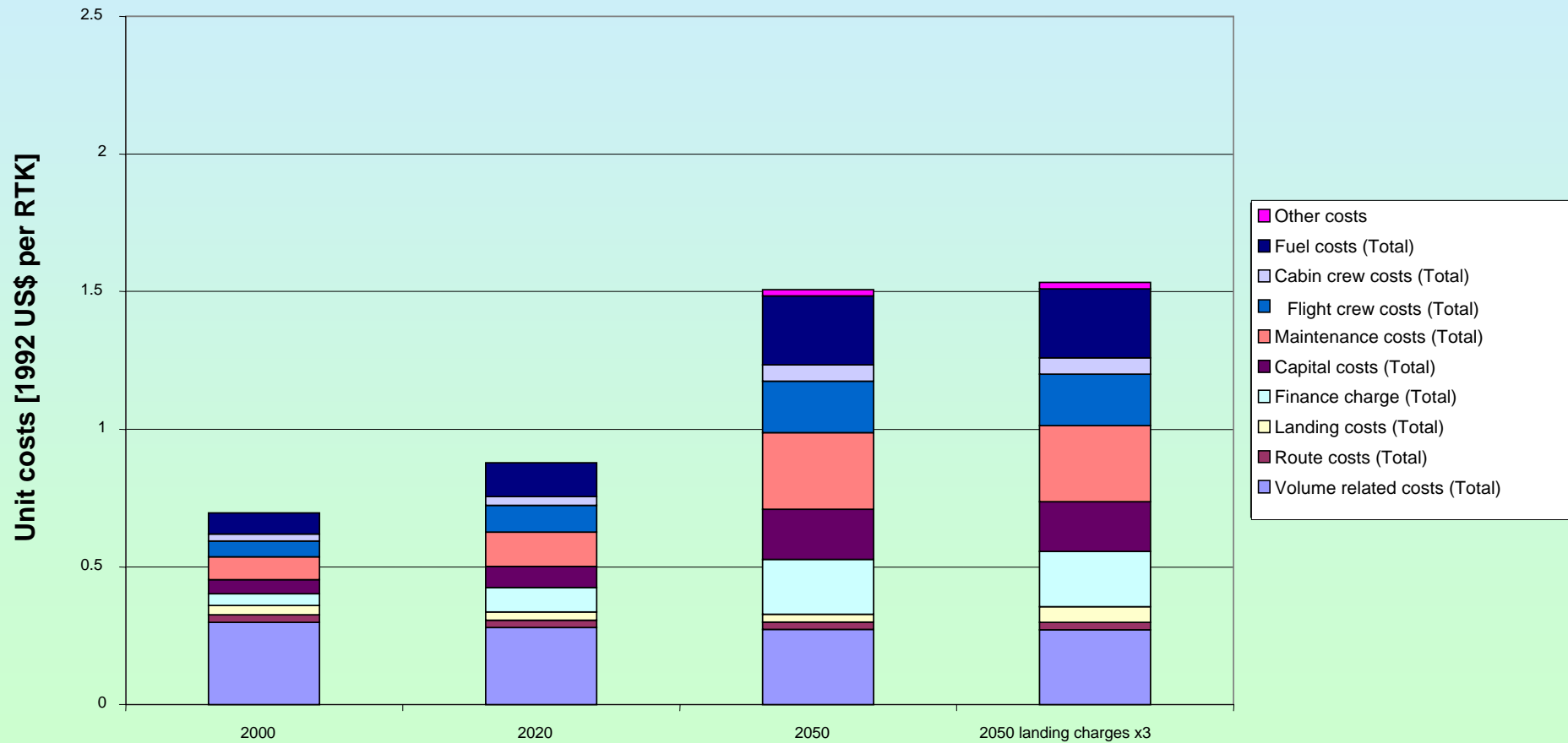
Unit Costs



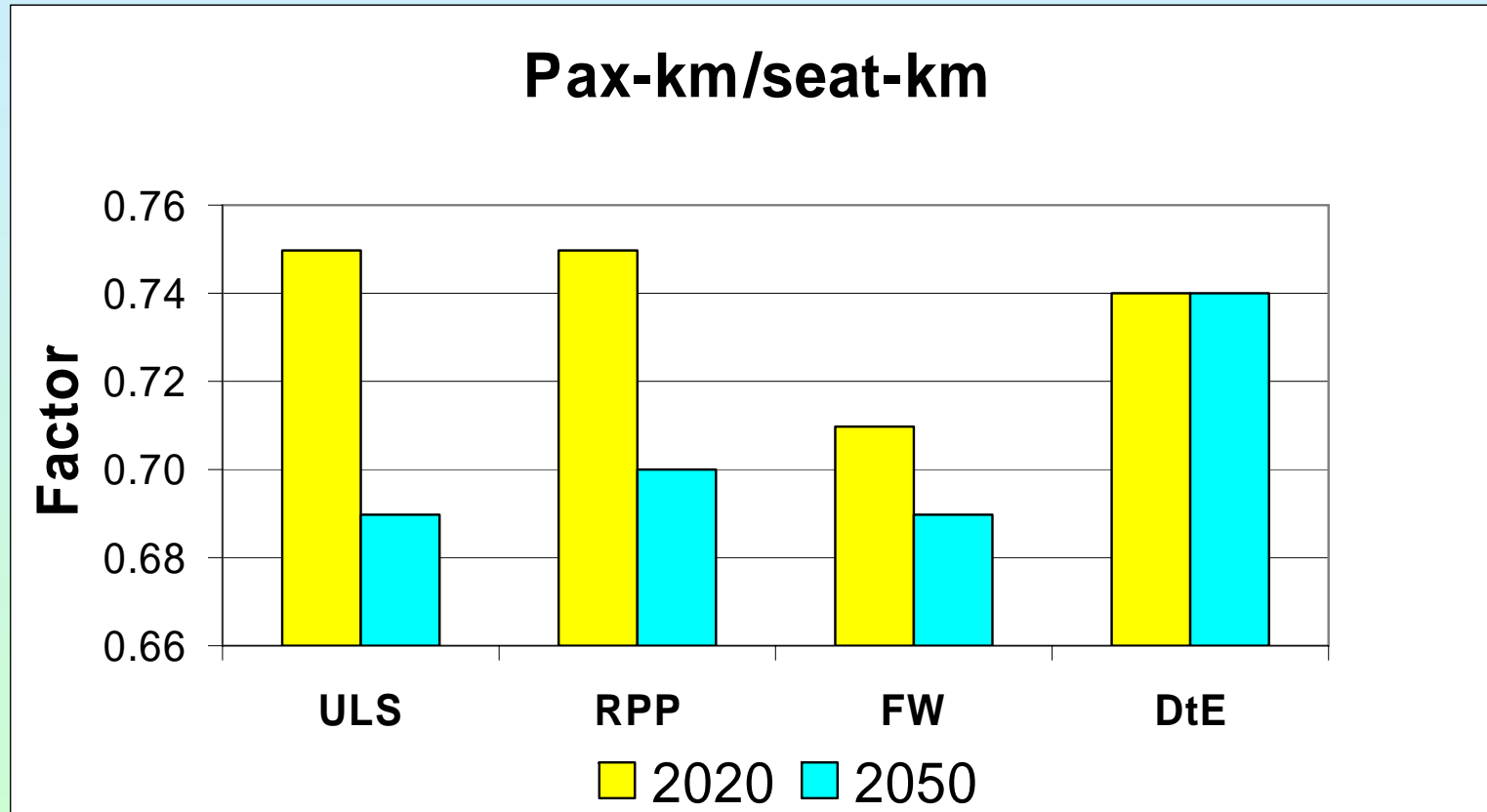
Unit costs (5/5)

Down to Earth

Unit costs

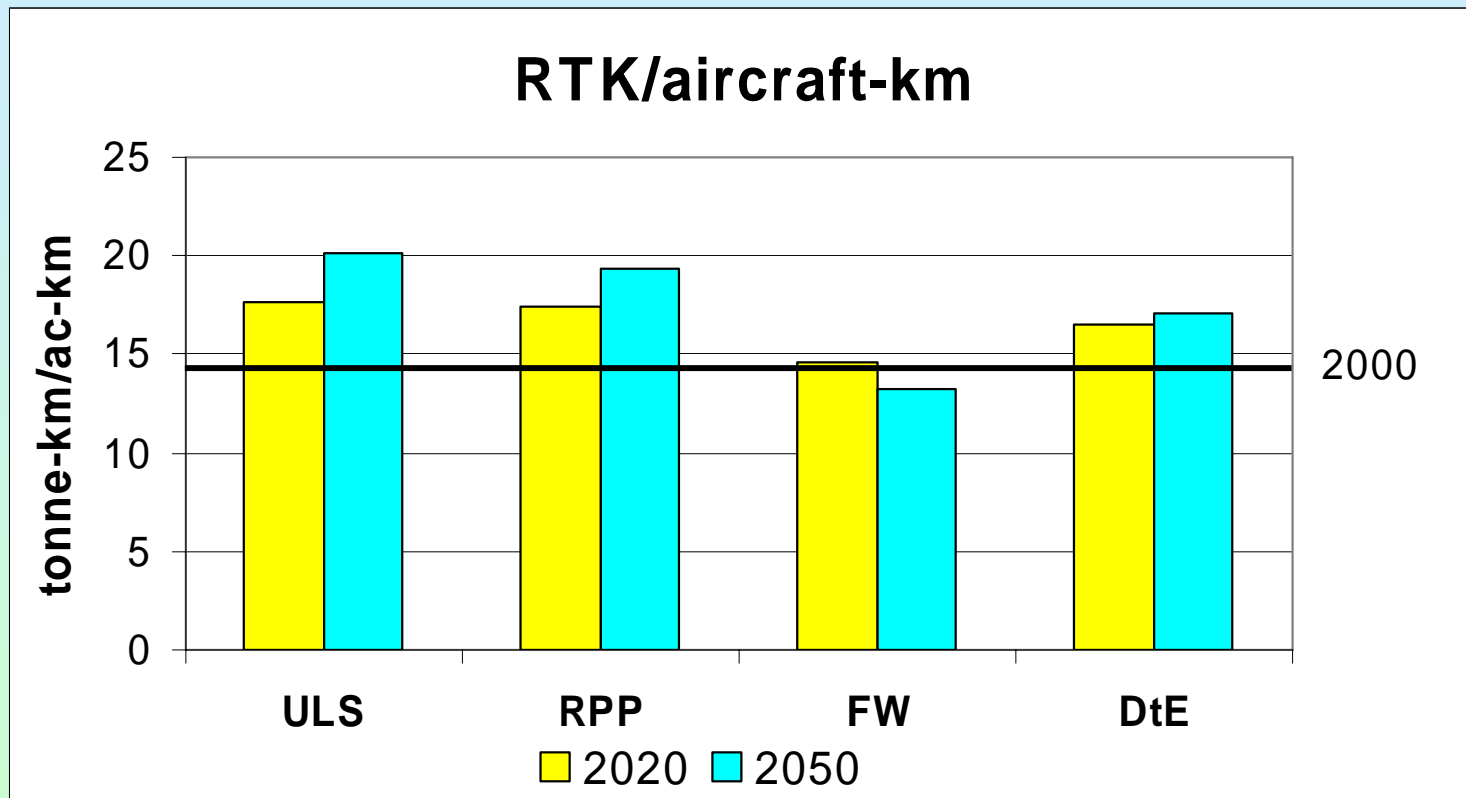


Pax-km/seat-km relative to 2000



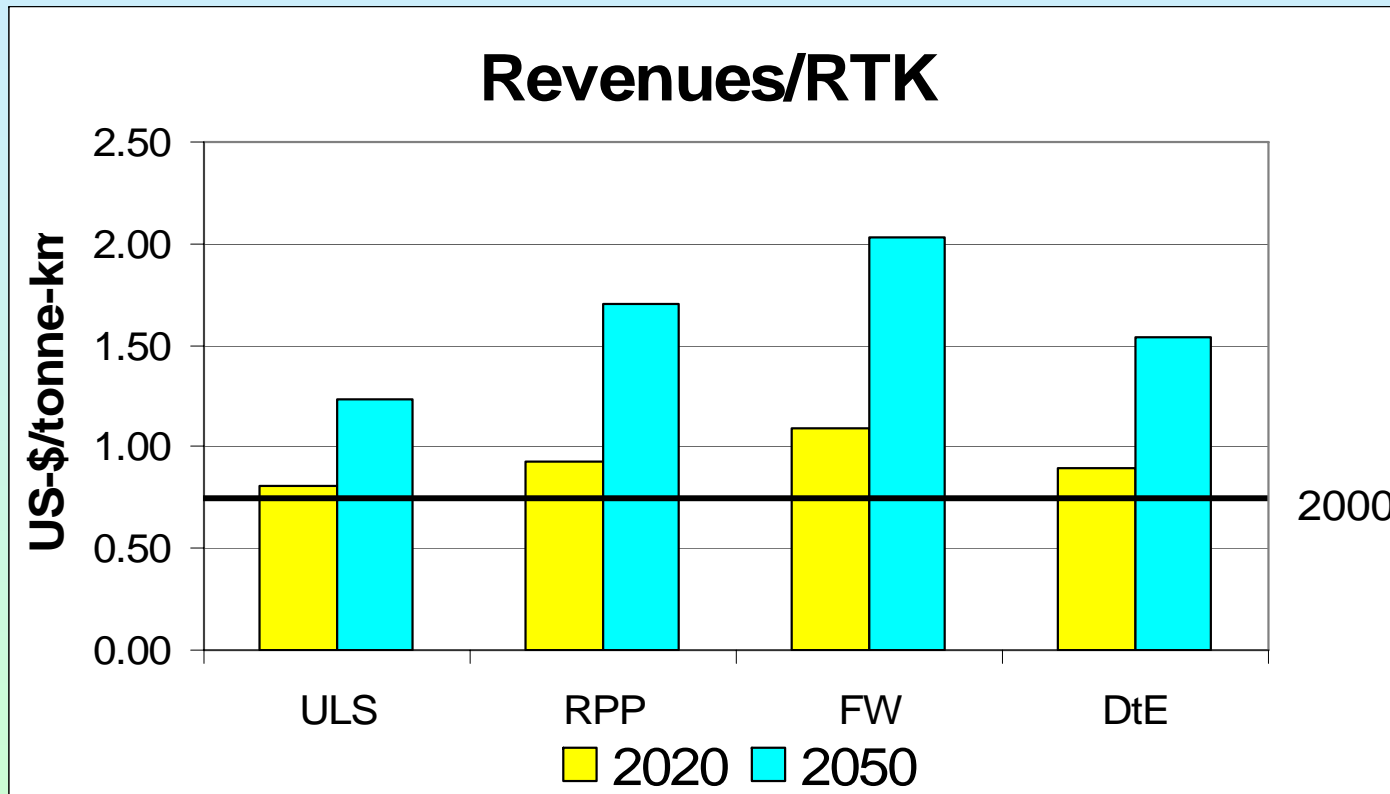
This ratio represents the average load factor of the global fleet. As a consequence of a change to larger aircraft especially beyond 2020 (to 2050) in all scenarios, this factor will - in the long-term - reduce in value.

RTK/aircraft-km in tonne-km/ac-km



This revenue tonne kilometer/aircraft kilometer in tonne-km/ac-km are indicating for all scenarios except FW an increase in efficiency and technology compared to 2000.

Revenues/RTK in 1992 US \$/tonne-km



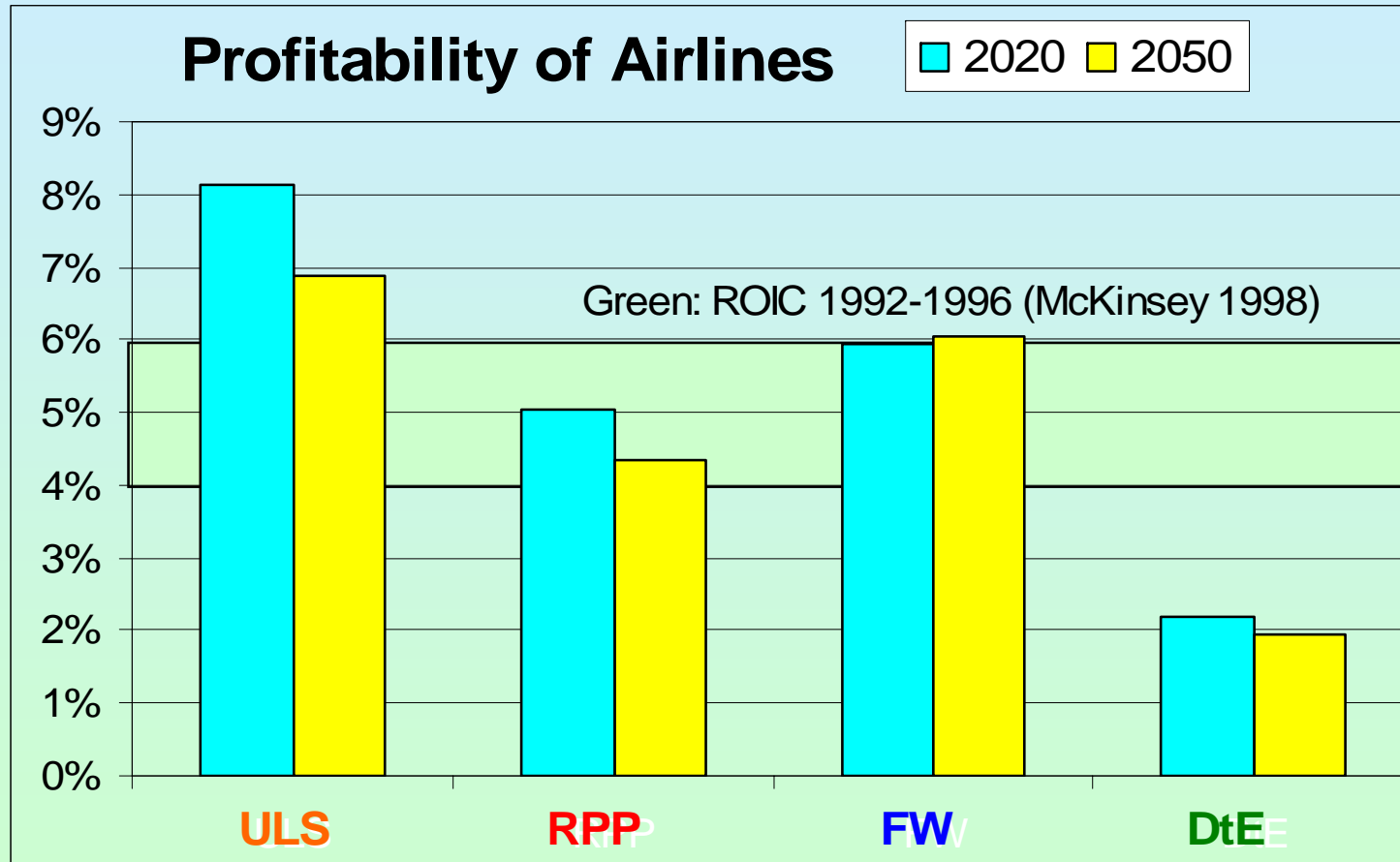
Highest revenues per RTK are to expect in FW (caused by a larger proportion of short-distance trips) while lowest revenues per RTK are in ULS (caused by large costs to realise the high traffic volume). ULS has high competition and high traffic volumes.

Costs & Revenues and Profitability of Airlines

Airlines Profitability	Unlimited Skies	Regulatory Push & Pull	Fractured World	Down to Earth
2020	8,14%	5,05%	5,93%	2,19%
2050	6,88%	4,35%	6,05%	1,95%
Operating costs and revenues in billion US\$ (1992)				
Costs 2020	803	776	665	552
Revenues 2020	869	815	705	564
Costs 2050	4678	4351	1961	1049
Revenues 2050	5000	4540	2079	1070

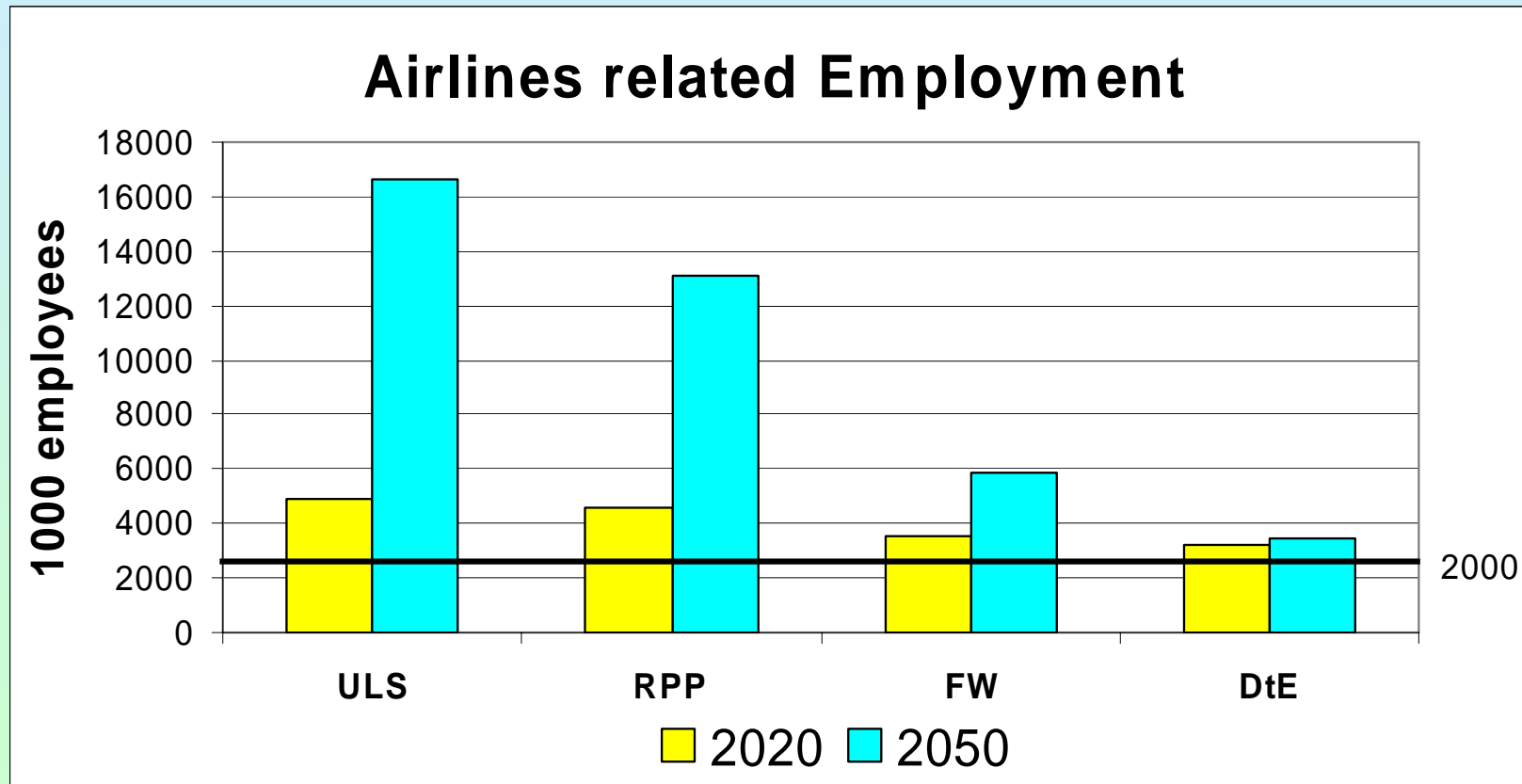
The comparably good profitability in FW is to explain by differences in the regional development – some regions; especially North America and Eurasia seem to be able to adjust to the assumed fragmentation in the long run, dividing the world into winners and losers of a fractured world. One has to keep in mind, that this conclusion is only valid for the estimated time horizon and under the assumption, that the potential for conflicts and security problems – typically very high in this scenario – does not reach a “wild card” level such as another world war.

Profitability of airlines (revenues in percentage of invested capital)



Remark: Profitability in this graph considers only activities from flight business and no other sources, actually visible in new business models!

Airlines related employment



Key features for emissions and airport air quality

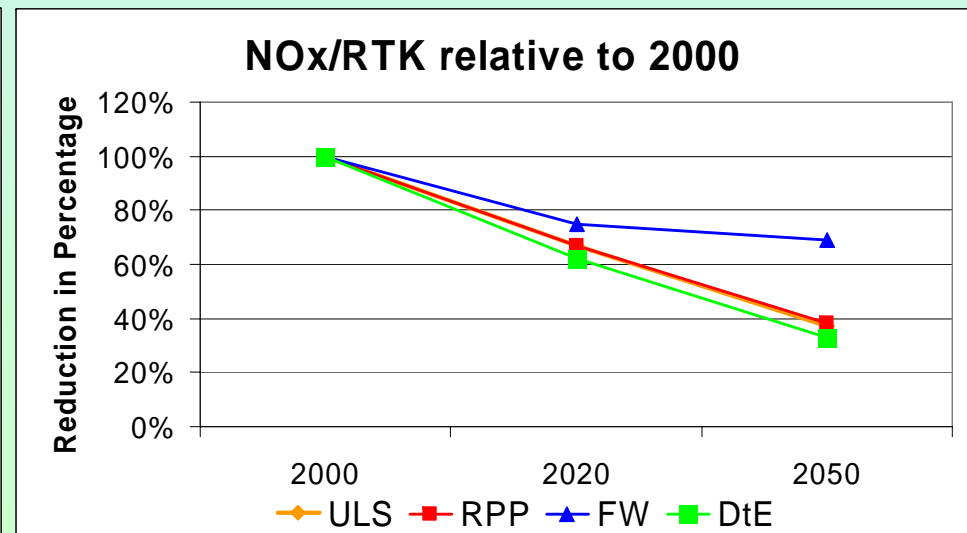
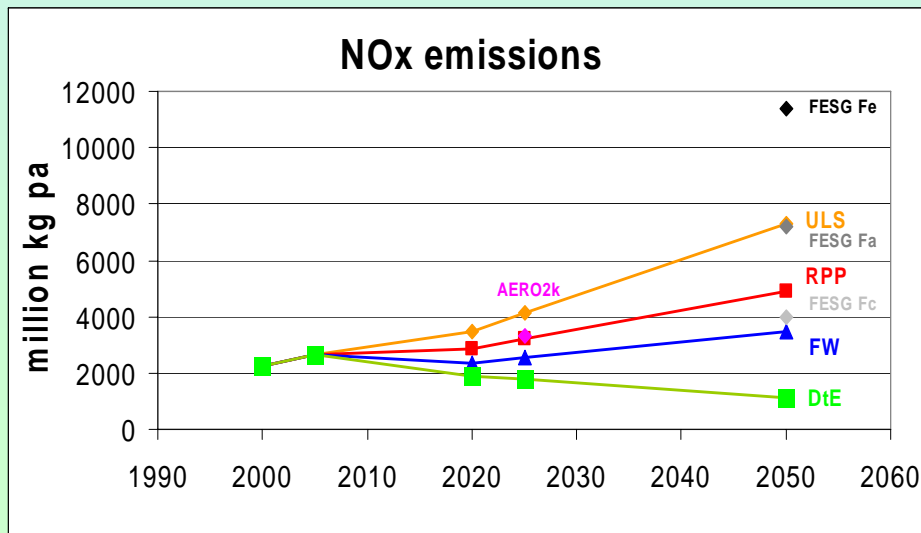
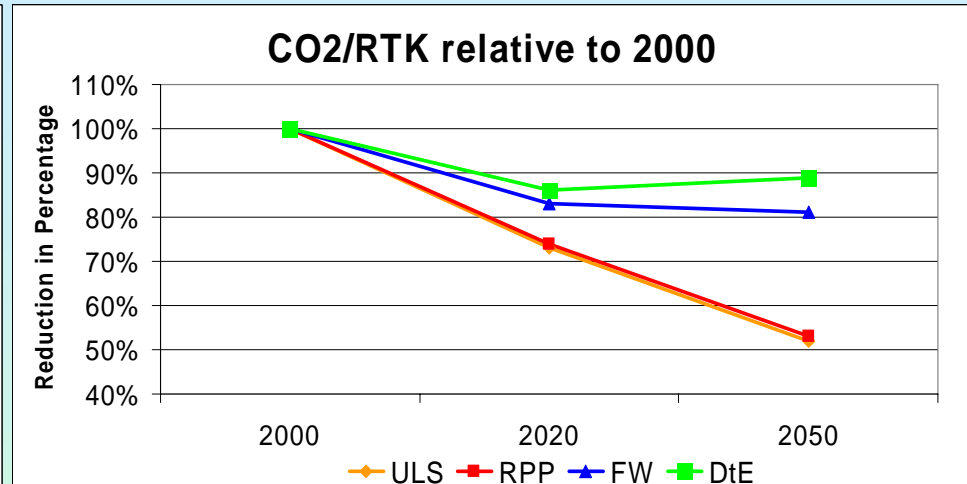
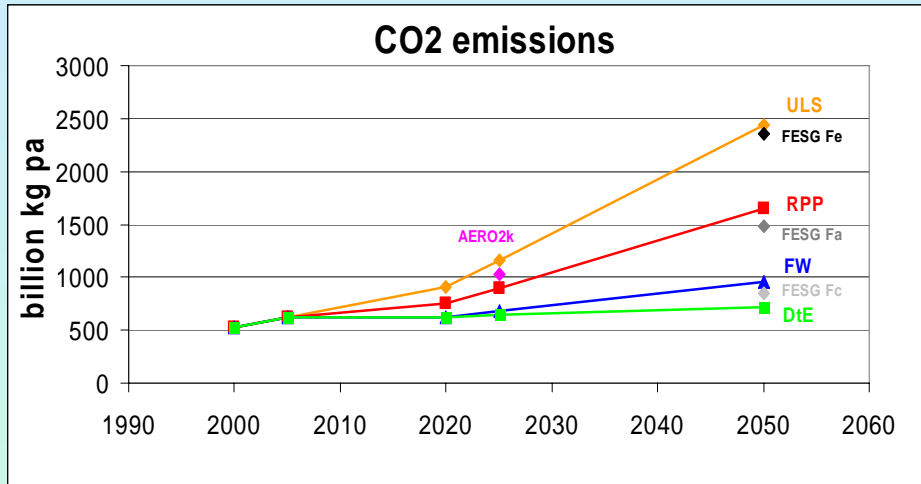
Scenario	Year	AC-km [Billion km]	Fuel [Tg]	CO ₂ [Tg]	H ₂ O [Tg]	NO _x [Tg]	CO* [Tg]	C _x H _y * [Tg]	SO ₂ * [Tg]
History	2000	31.0	168.1	530.7	207.9	2.228	0.86	0.260	0.155
ULS	2020	60.6	287.1	906.5	355.1	3.495	1.28	0.321	0.264
	2050	202.1	773.4	2441.6	956.7	7.313	3.46	0.774	0.712
RPP Kerosene	2020	50.5	237.2	748.9	293.4	2.871	1.07	0.273	0.218
	2050	138.8	523.9	1653.8	648.1	4.914	2.40	0.560	0.481
RPP H ₂	2050	127.6	210.7**	75.8	1757.3	1.382	n.c.	n.c.	n.c.
FW	2020	44.2	197.2	622.6	243.9	2.361	1.04	0.265	0.181
	2050	77.2	302.5	955.0	374.2	3.459	1.75	0.425	0.278
DtE	2020	38.0	198.0	624.9	244.9	1.898	0.91	0.245	0.182
	2050	40.7	227.9	719.4	281.9	1.113	1.06	0.3	0.206

n.c. = not calculated

* For CO, C_xH_y, SO₂ the current level of emission regulations is assumed for all scenarios

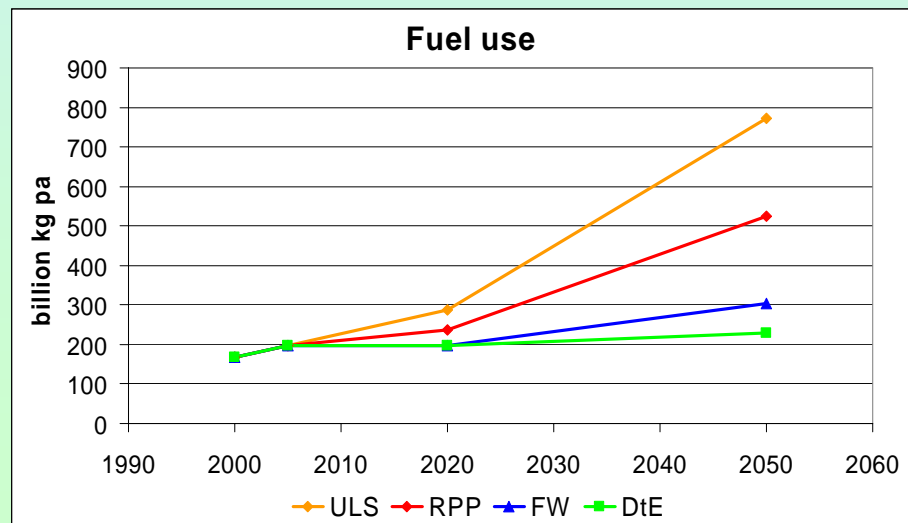
** Fuel consumption in predominantly hydrogen, but with 8.5% kerosene powered aircraft remaining

CO2 and NOx Emissions – absolute and relative to 2000



Fuel consumption and emissions

Scenario	Year	Fuel (in billion kg p.a.)	CO2 (in billion kg p.a.)	NOx (in million kg p.a.)	Annual global aircraft kilometres (in Billion ac-km p.a.)
ULS	2020	287	907	3495	61
	2050	773	2442	7313	202
RPP	2020	237	749	2871	51
	2050	524	1654	4914	139
FW	2020	197	623	2361	44
	2050	303	955	3459	77
DtE	2020	198	625	1898	38
	2050	228	719	1113	41



Emissions – share of global aviation

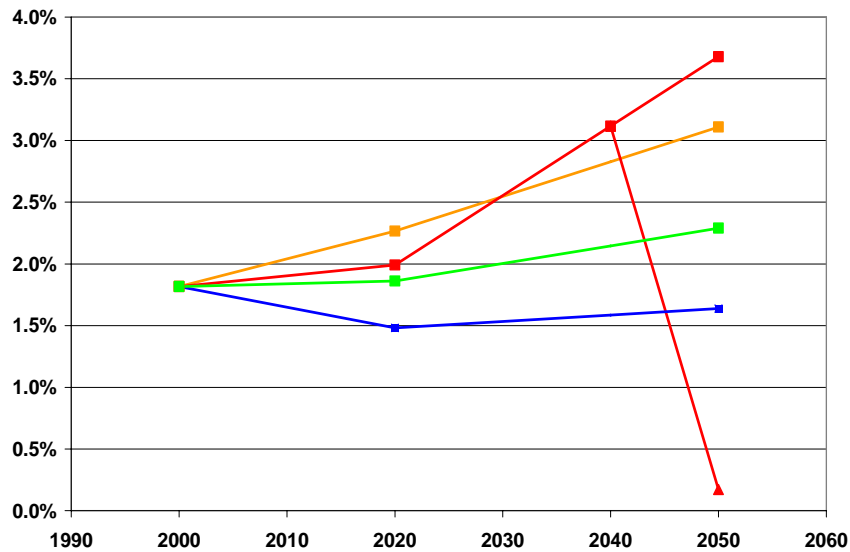
CO2 emissions: Share of civil aviation	2000	2020	2050
ULS	1.82%	2.27%	3.11%
RPP – kerosene	1.82%	1.99%	3.68%
RPP – cryoplane	1.82%	1.99%	0.17%
FW	1.82%	1.48%	1.64%
DtE	1.82%	1.86%	2.23%

NOx emissions: Share Of civil aviation	2000	2020	2050
ULS	2.12%	2.31%	2.50%
RPP – kerosene	2.12%	1.90%	2.45%
RPP – cryoplane	2.12%	1.90%	0.42%
FW	2.12%	1.53%	1.60%
DtE	2.12%	1.31%	0.85%

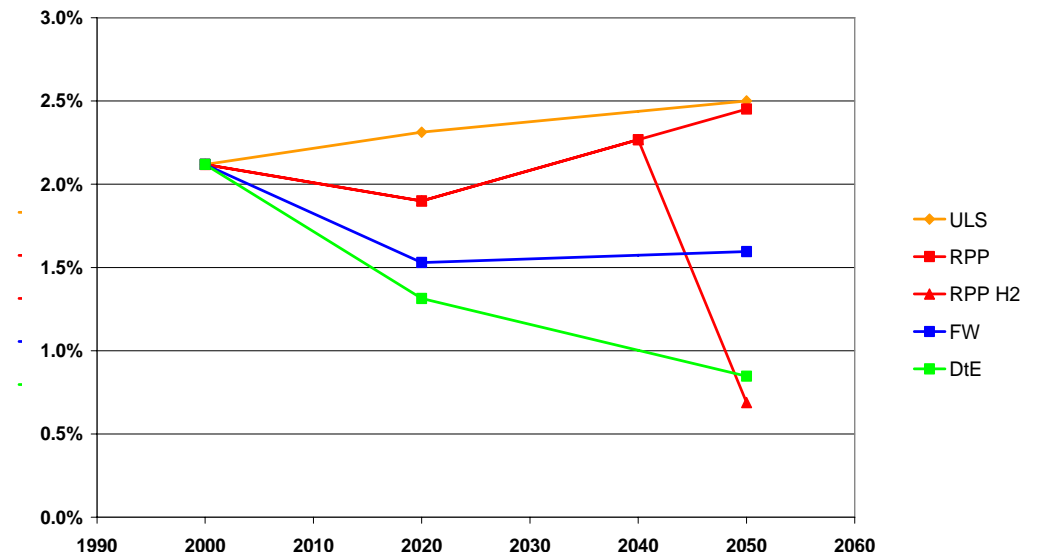
Remark: some uncertainties in these figures result from the fact that the scenario assumptions from IPCC/SRES are very close to those for the CONSAVE scenarios, but completely identical only in respect of the dominant aspects GDP and population.

Emissions – CO2 and NOx share of global aviation

Contribution from aviation to global CO2-emissions



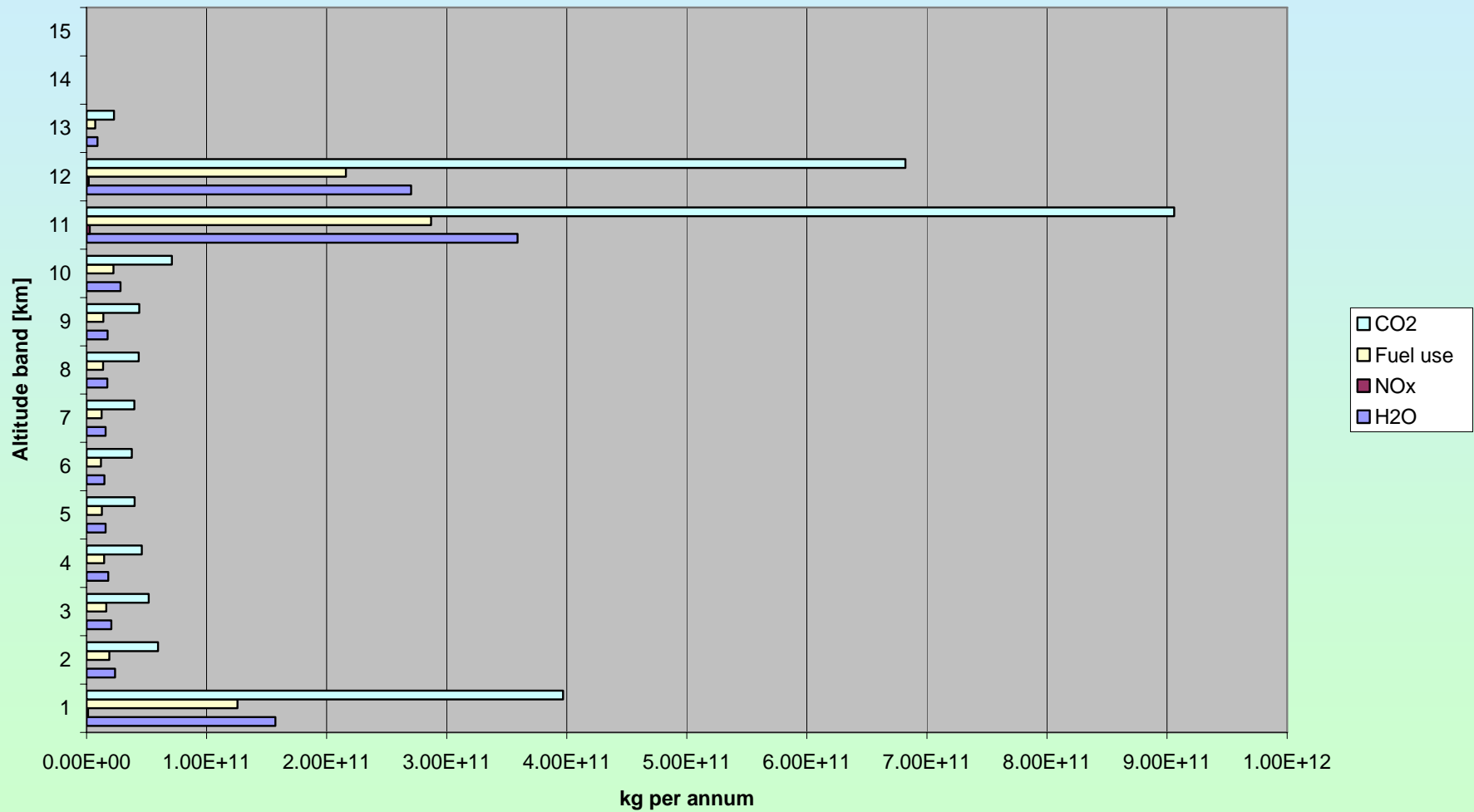
Contribution from aviation to global NOx-emissions



Remark: some uncertainties in these figures result from the fact that the scenario assumptions from IPCC/SRES are very close to those for the CONSAVE scenarios, but completely identical only in respect of the dominant aspects GDP and population.

Emission by altitude band for 2050 in scenario ULS

Emission by altitude in 2050 for the Unlimited Skies

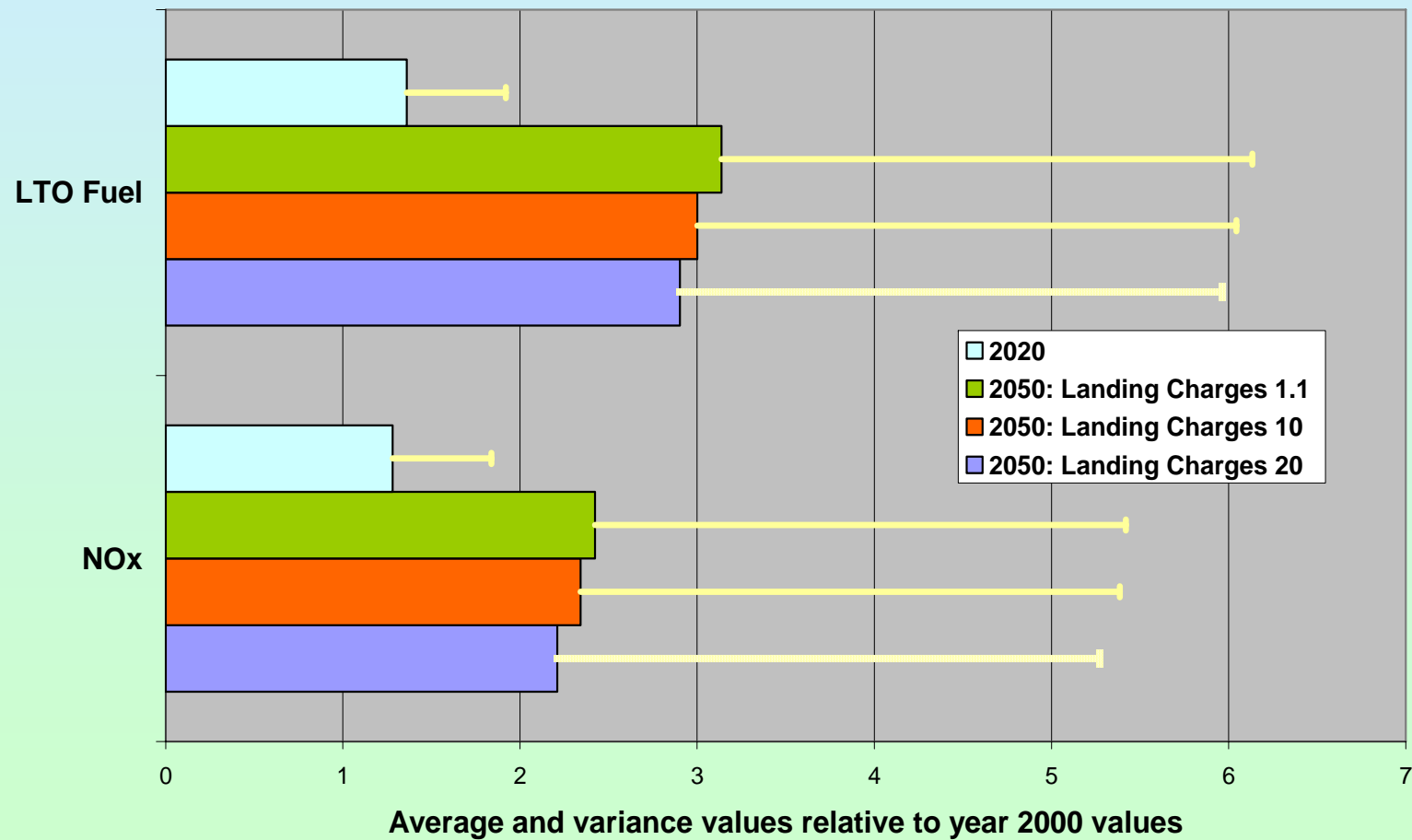


Local air quality – main results

- In **Unlimited Skies**, local air quality obviously worsens. Apparently, the increase in air traffic cannot be compensated by the technology advances as introduced in the fleet.
- In **Regulatory Push & Pull** with the all kerosene powered fleet scenario, local air quality obviously worsens, but at a lower pace than the **Unlimited Skies**. Also obvious, application of a kerosene tax (of the order of 10 % of the kerosene price) has only a small effect: Airlines and demand responses to taxes of this level are quite small.
- In the **Regulatory Push & Pull** with the kerosene to hydrogen fleet roll-over, shows a remarkably different situation, because the fleet is quite young, hence incorporating the latest technology. On the other hand, aviation is not financially sustainable. Even, if only the costs of new aircraft are born by the airlines (infrastructure costs are not taken into account), the aviation industry is faced with heavy losses, even if they have sought the best possible position in fare levels.

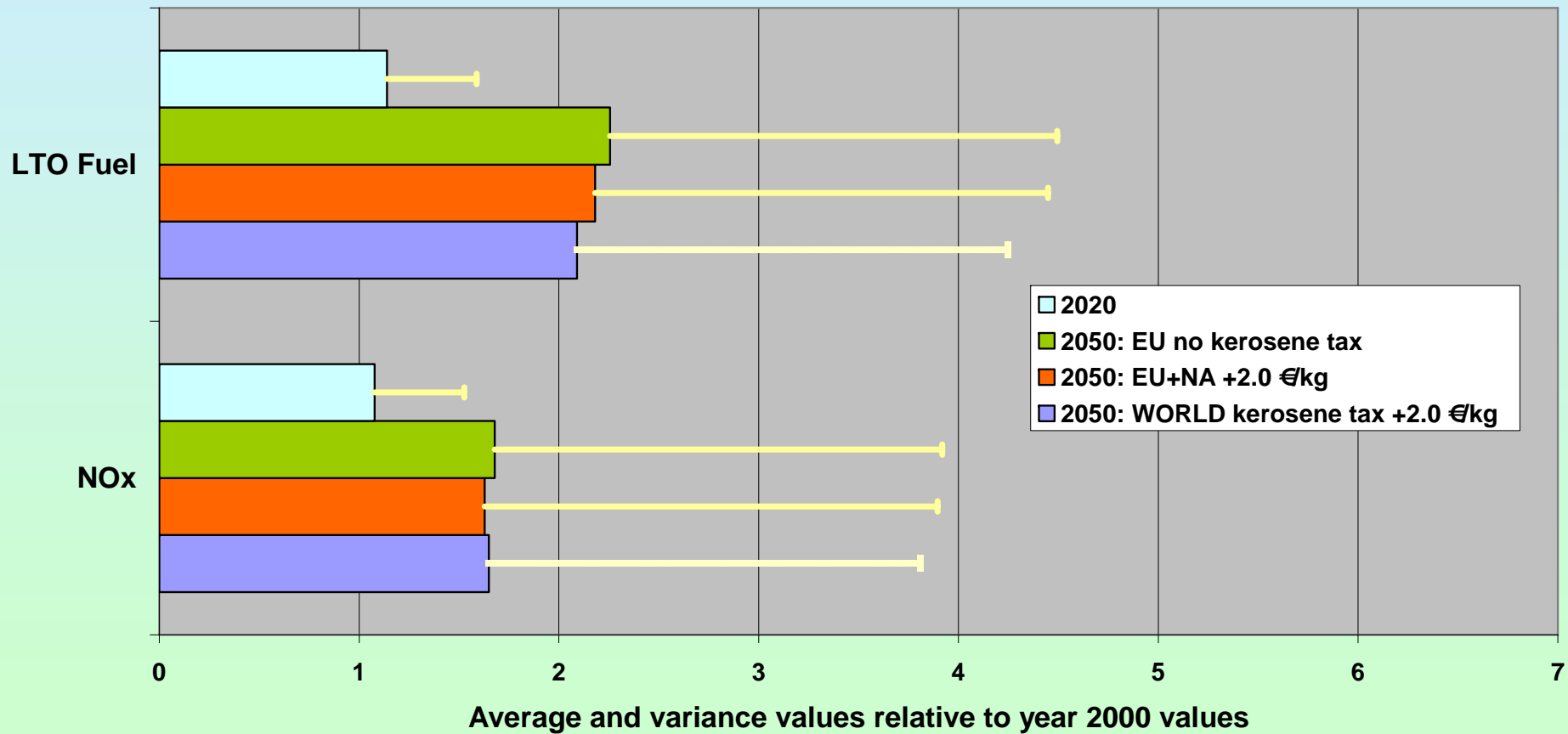
Local air quality – LTO results for Unlimited Skies

LTO results for Unlimited Skies Scenarios



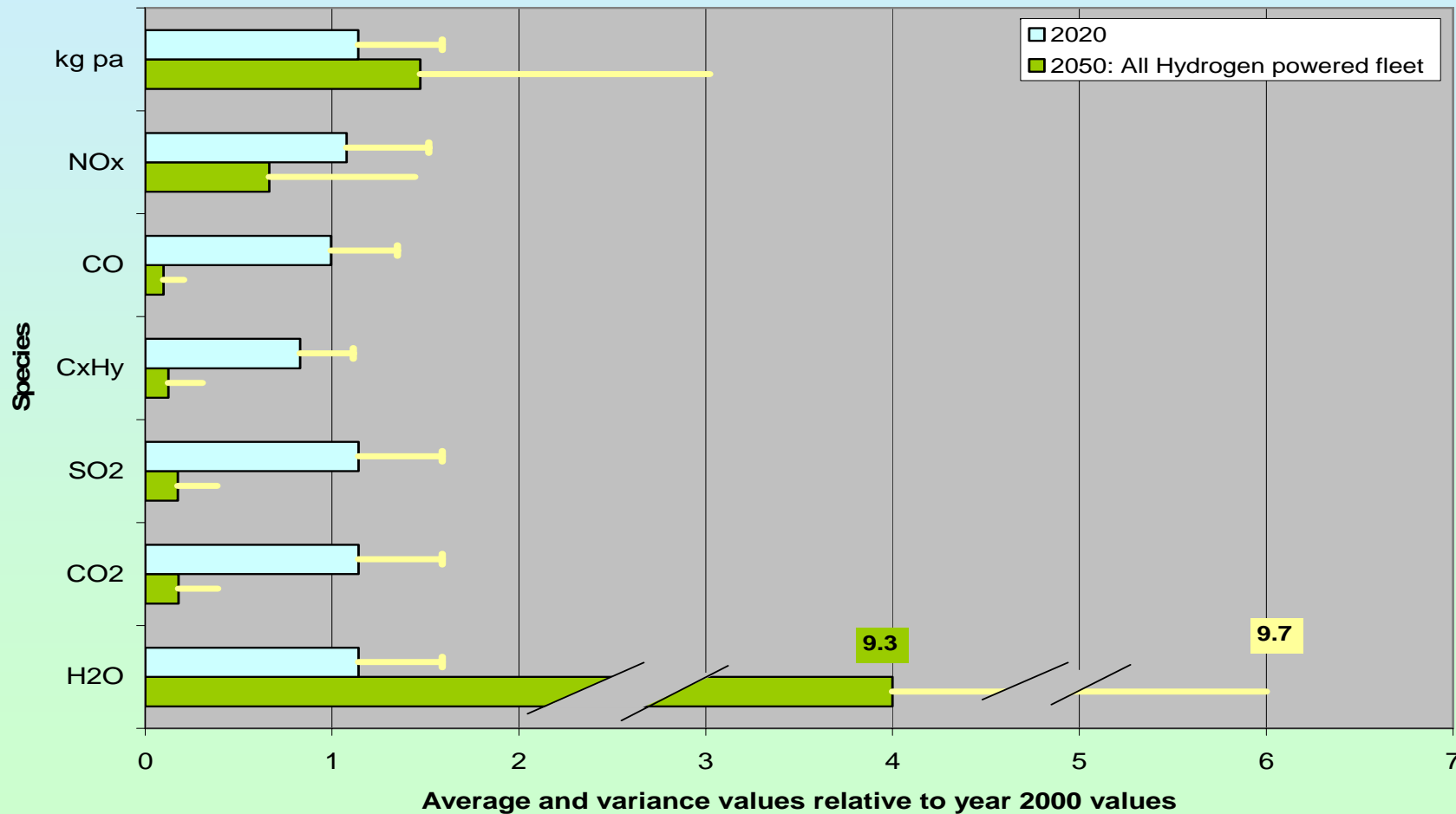
Local air quality – LTO results for Regulatory Push & Pull /Kerosene

LTO results for Regulatory Push & Pull Scenarios all kerosene-taxed fleet



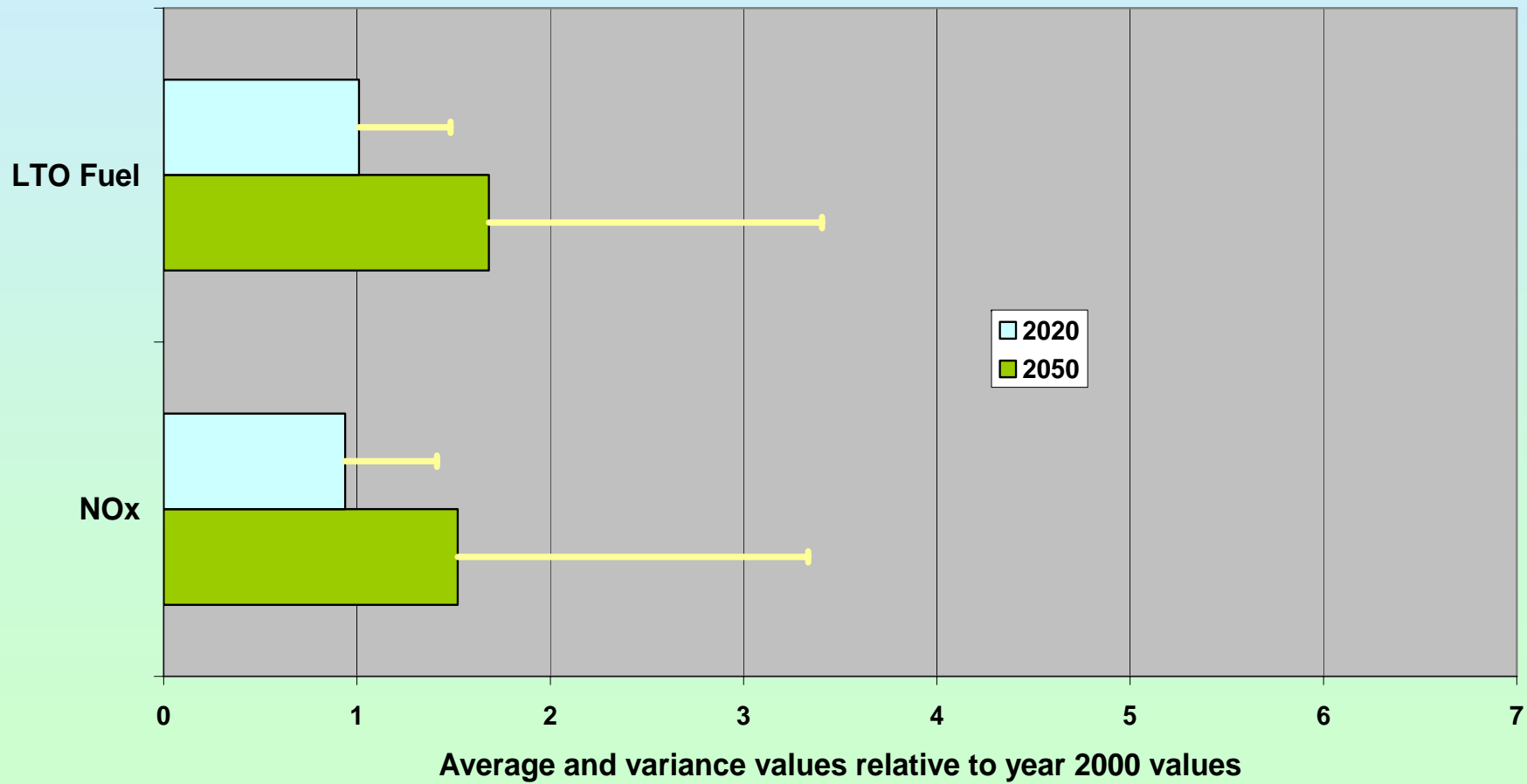
Local air quality – LTO results for Regulatory Push & Pull /Hydrogen

LTO results for **Regulatory Push & Pull Scenario with transition to Hydrogen**



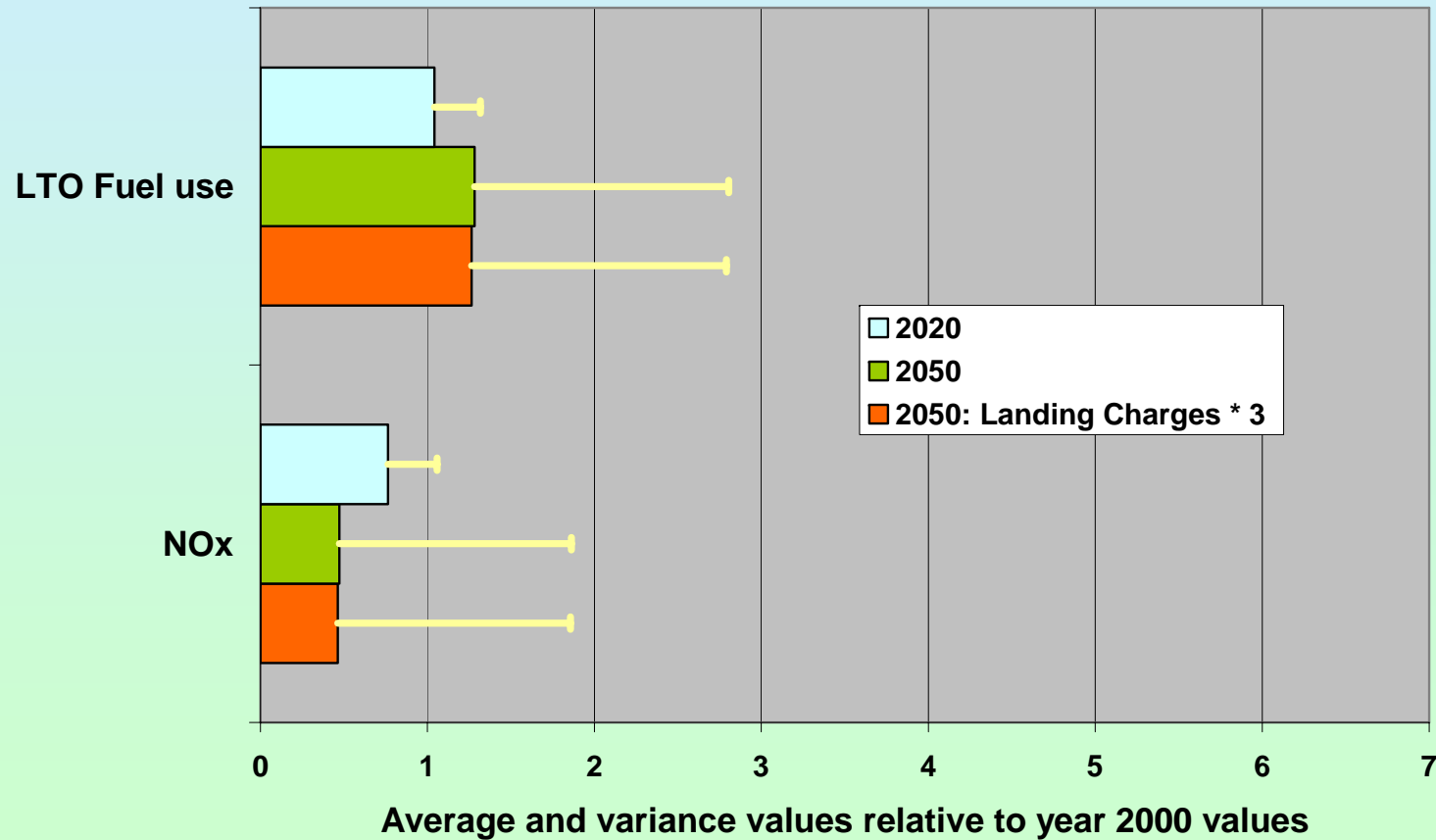
Local air quality – LTO results for Fractured World

LTO results for Fractured World Scenarios

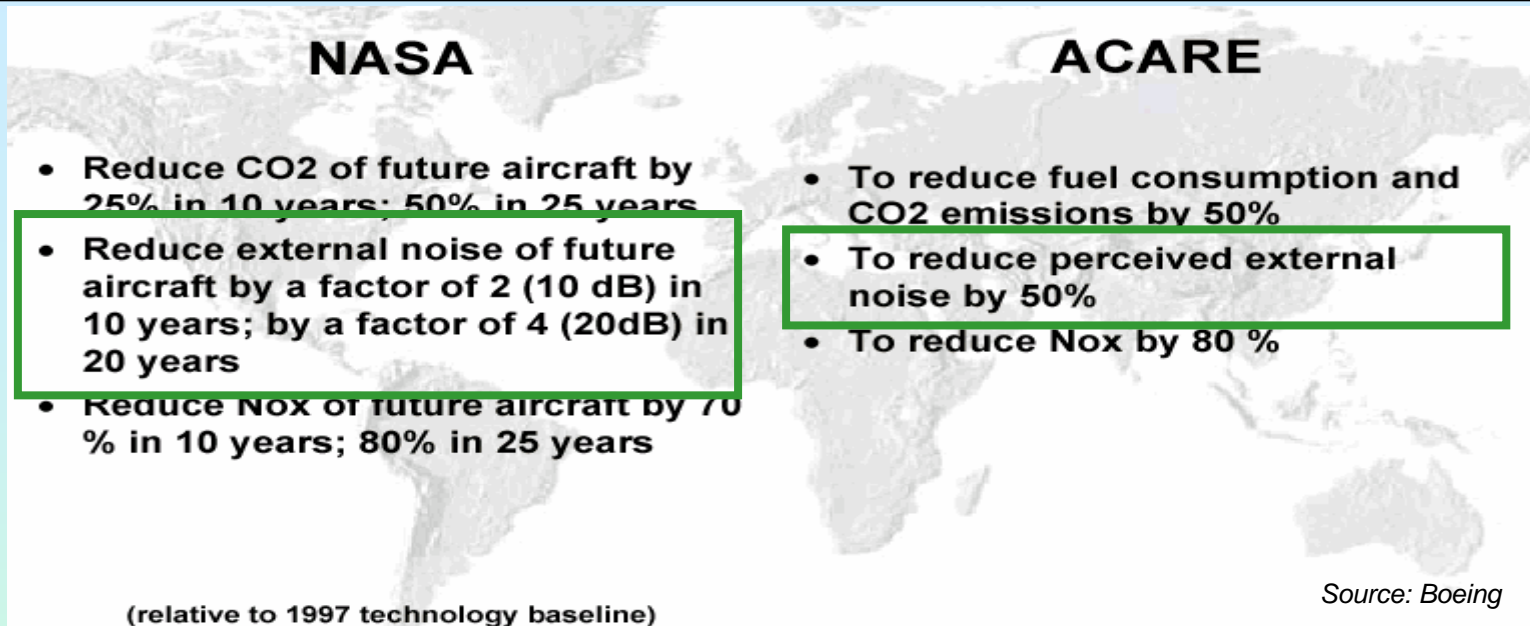


Local air quality – LTO results for Down-to-Earth

LTO results for Down to Earth Scenarios



Noise reduction in 2050



Scenario	ULS	RPP Hydrogen	RPP Kerosene	FW	FW	DtE
Region	EU	EU	EU	World	EU	EU
Source weighted reduction	-13,9	-15,8	-14,1	-12,5	-12,6	-15,3
Traffic volume factor	2,26	1,46	1,57	2,82	1,13	0,72
Traffic technology factor	0,9	0,95	0,95	0,95	0,95	0,95
Total noise reduction (Lden*)	-11	-14	-12	-8	-12	-17

*Lden = Noise measure for all kinds of noise during daytime, evening and night

Measure assessment for sub-scenarios - results:

➤ **Possible impact of measures on the development of the aviation system**

- **ULS**: Landing Charge for Financing Infrastructure (Start 2020)
- **RPP**: Fuel Tax for Reducing Emissions (Start 2020)
- **RPP**: Kerosene-to-Hydrogen fleet rollover (Start 2040)

❖ **Impacts of measures on:**

- Demand
- Number of Aircraft
- Emissions
- Airlines profitability

ULS-Measure Landing Charge for Financing Infrastructure (Start 2020)

Remark: A landing charge increase by a factor of 3 to 6 is required to accommodate all air traffic in the US and EU using additional infrastructure.

Data:

ULS Landing charge	Demand billion pax-km pa			Fleet number of aircrafts			Movements 1000 mov pa			NOx million kg pa		
	2000	2020	2050	2000	2020	2050	2000	2020	2050	2000	2020	2050
ULS (charge factor 1.1)	3308	6505	21185	18988	34790	105570	393.6	608.3	1607.6	2227.9	3494.5	7312.6
ULS (charge factor 10)	3308	6505	20874	18988	34790	102250	393.6	608.3	1383.2	2227.9	3494.5	7262.9
ULS (charge factor 20)	3308	6505	20554	18988	34790	100200	393.6	608.3	1226.5	2227.9	3494.5	7186.2

Assessment for Engineers:

ULS Landing charge	Reduction compared to "no measure"			
	Demand	Aircraft	Movements	NOx
ULS (charge factor 10)	1.5%	3.1%	14.0%	0.7%
ULS (charge factor 20)	3.0%	5.1%	23.7%	3.0%

Assessment for Regulators:

ULS Landing charge	Measure Efficiency				Profitability in	
	Demand	Aircraft	Movements	NOx	2020	2050
ULS (charge factor 1.1)						6.88%
ULS (charge factor 10)	2.1%	4.7%	22.5%	1.3%	8.14%	5.24%
ULS (charge factor 20)	4.3%	7.6%	38.1%	3.3%		4.20%

RPP-Measure Fuel Tax for Reducing Emissions (Start 2020) and
RPP-Measure Introduction of Hydrogen Fleet (Start 2040)

Data:

RPP Fuel Tax and Hydrogen	Demand billion pax-km pa			Fleet number of aircrafts			NOx million kg pa			CO2 billion kg pa		
	2000	2020	2050	2000	2020	2050	2000	2020	2050	2000	2020	2050
RPP (Kerosene/no tax)	3308	5284	14636	18988	29278	74346	2228	2871	4914	531	749	1654
RPP (1\$/kg)			14259			68114			4650			1563
RPP (2\$/kg)			13884			63575			4419			1485
RPP Hydrogen 2040			13886			67957			1382			76

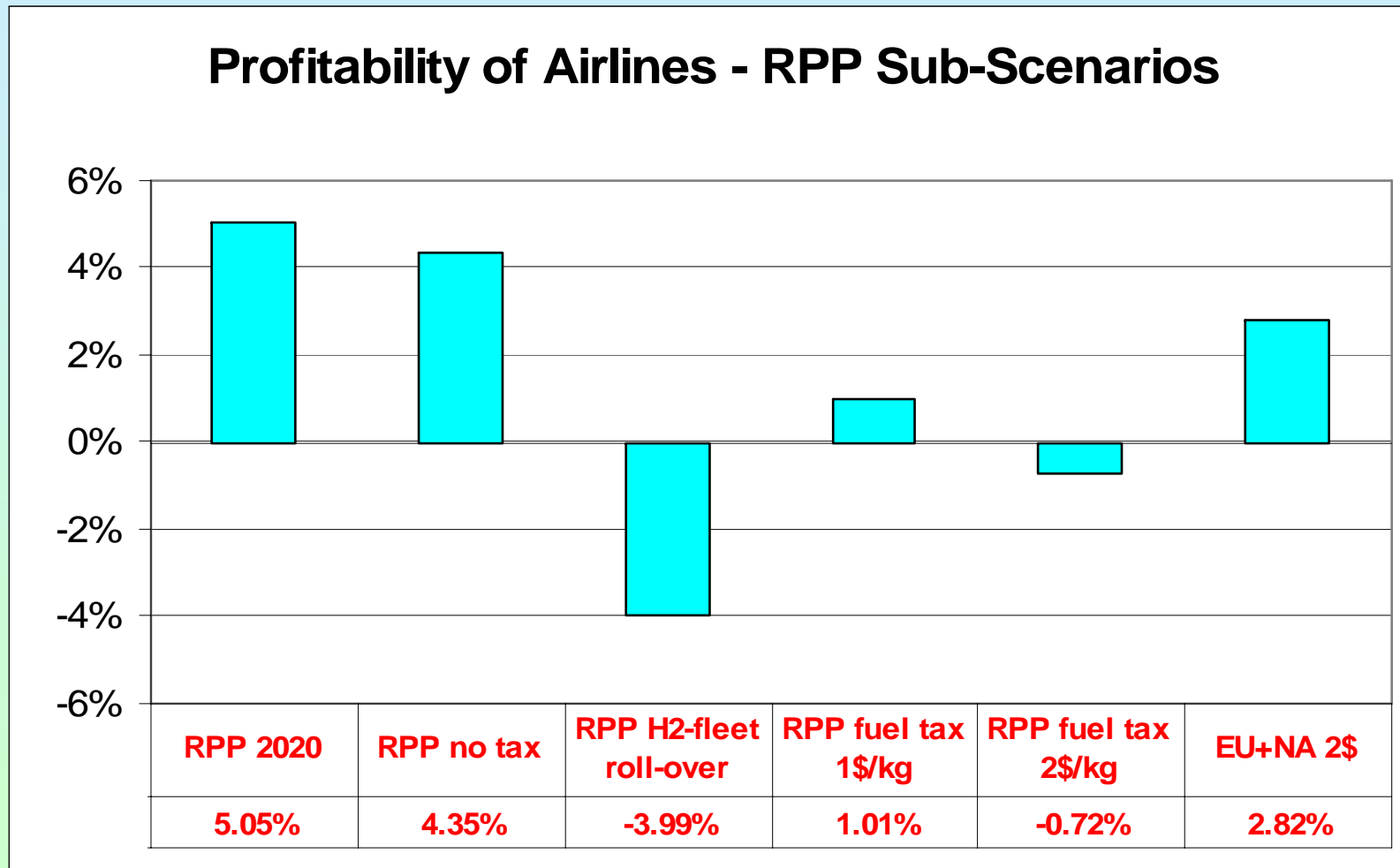
Assessment for Engineers:

RPP Fuel Tax	Reduction compared to "no measure"			
	Demand	Aircraft	CO2	NOx
RPP (1\$/kg)	2.6%	8.4%	5.5%	5.4%
RPP (2\$/kg)	5.1%	14.5%	10.2%	10.1%
RPP Hydrogen	5.1%	8.6%	95.4%	71.9%

Assessment for Regulators:

RPP Fuel Tax	Measure Efficiency				Profitability in	
	Demand	Aircraft	CO2	NOx	2020	2050
RPP (Kerosene/no tax)					5.05%	4.35%
RPP (1\$/kg)	4.0%	13.8%	10.0%	12.9%		1.01%
RPP (2\$/kg)	8.0%	23.9%	18.7%	24.2%		-0.72%
RPP Hydrogen	8.0%	14.2%	174.4%	172.9%		-3.99%

Profitability for different RPP sub-scenarios
 (revenues in percentage of invested capital)



Conclusions related to measures

Landing Charges (to finance infrastructure enhancements, causing higher ticket prices, slightly lower demand and reduced movements); might work with acceptable losses for aviation business - with positive effects on noise even that we assume technical innovations according to ACARE goals. *Market approach works in aviation*

Reduced emissions by fleet innovations will be overcompensated by demand growth in **ULS** and **RPP** - but significant emission reductions probably with hydrogen (not considering uncertainties with respect on possible effects on contrail and cirrus cloud formation).

But: A significant reduction of emissions via fuel tax or a quick introduction of hydrogen powered aircraft (rollover 8-10 years) reduces strongly the profitability of aviation business.

The CONSAVE outcomes/results

- are strictly scenario related, based on the assumptions made for the different development paths
- are in the range of respective main assumptions and results made in other recent scenario and forecast (especially demand and emissions) work
- are ideally complementary to other work (forecasts, scenarios)

For the set of aviation scenarios

- We are confident, that the underlying assumptions are in line with respective main assumptions and results made in other recent scenario and forecast (especially demand and emissions) work
- The intention is that they can serve as a European reference and as a future input for frame setting activities like ACARE and IPCC