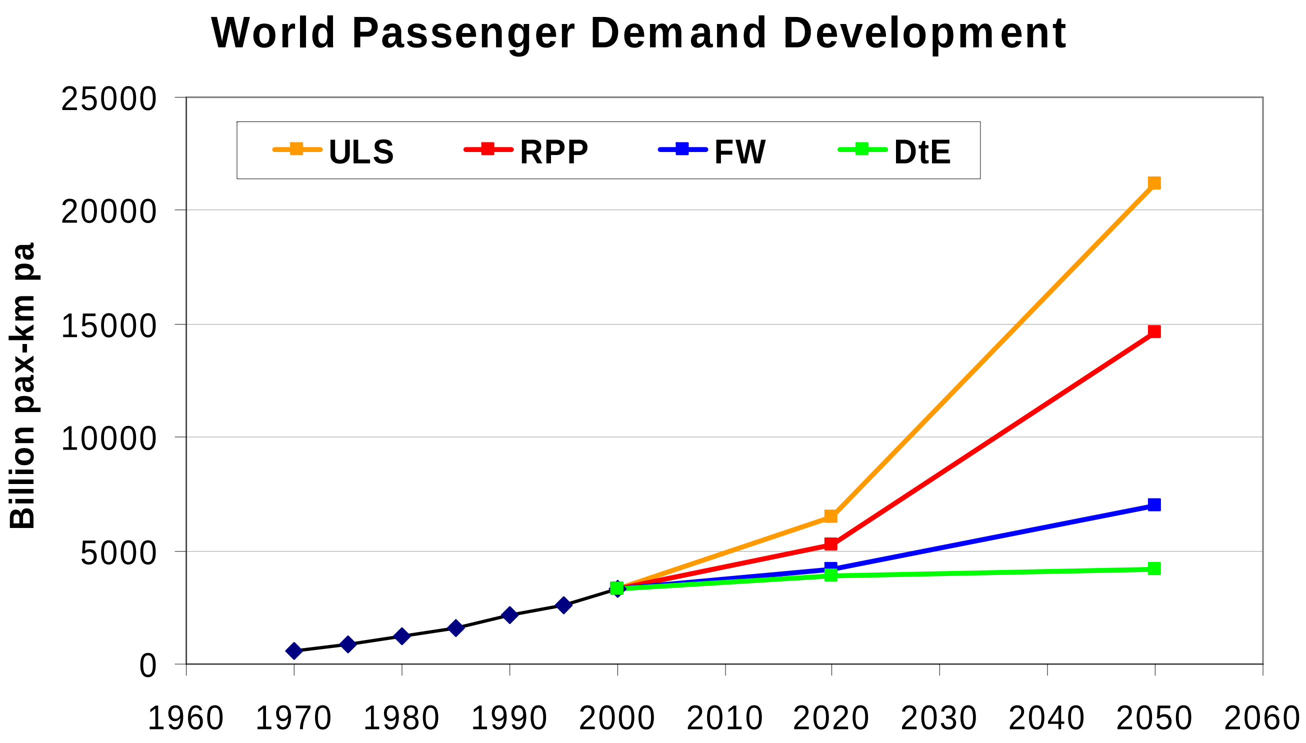
Results (Excerpt)

- **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.



Average Annual Growth

2020 v 2000 - 2050 v 2000

	2020 v 2000		2050 v 2000
ULS	3.4%	-	3.8%
RPP	2.4%	-	3.0%
FW	1.1%	-	1.5%
DtE	0.9%	-	0.5%

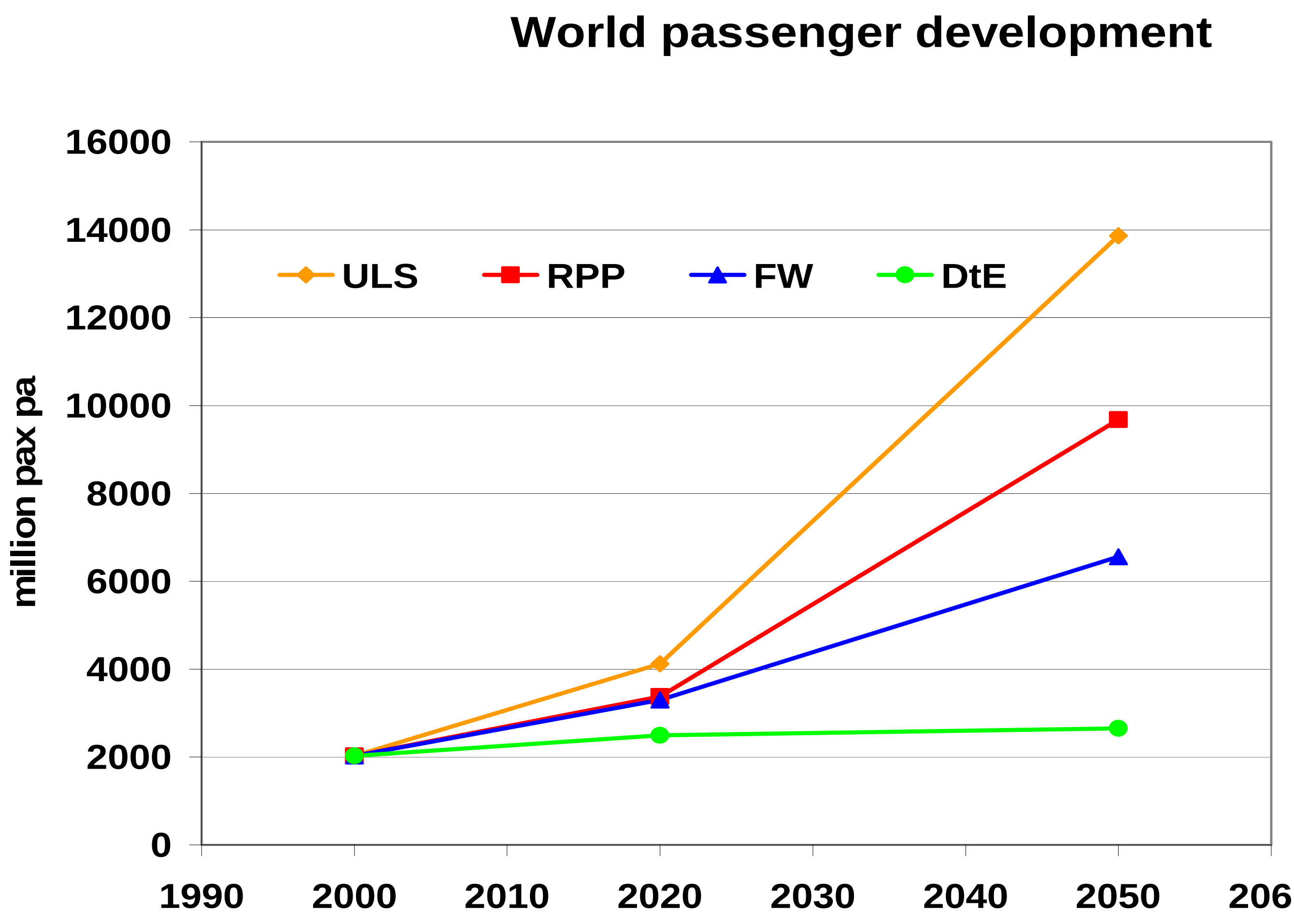
Total Growth

2020/2050 as a multiple of 2000

	2020		2050
ULS	2.0	-	6.3
RPP	1.6	-	4.4
FW	1.3	-	2.1
DtE	1.2	-	1.3

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.


World passenger development

Average annual growth

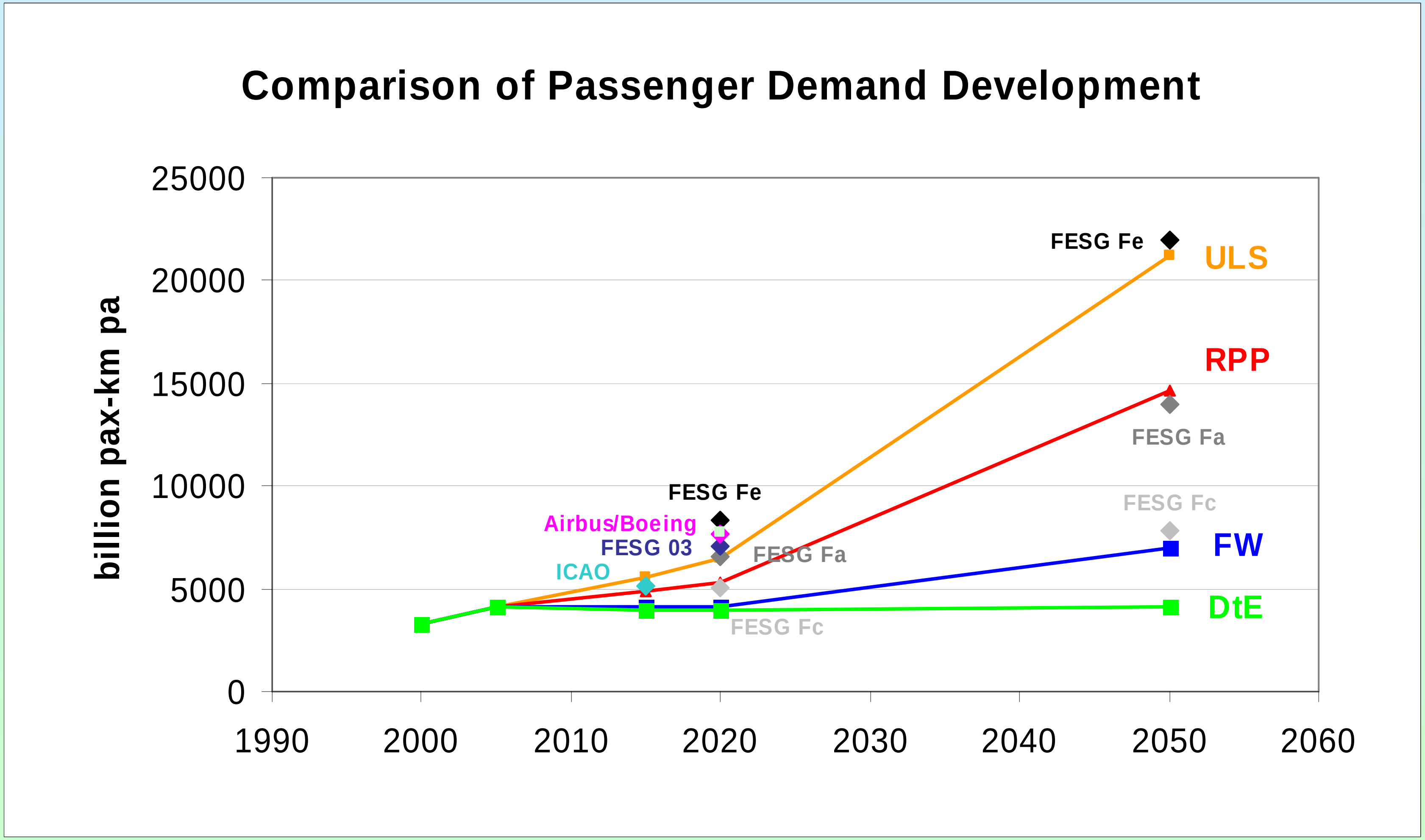
	2000-2020	2000-2050
ULS	3.6%	3.9%
RPP	2.6%	3.2%
FW	2.5%	2.4%
DtE	1.0%	0.5%

Growth factor

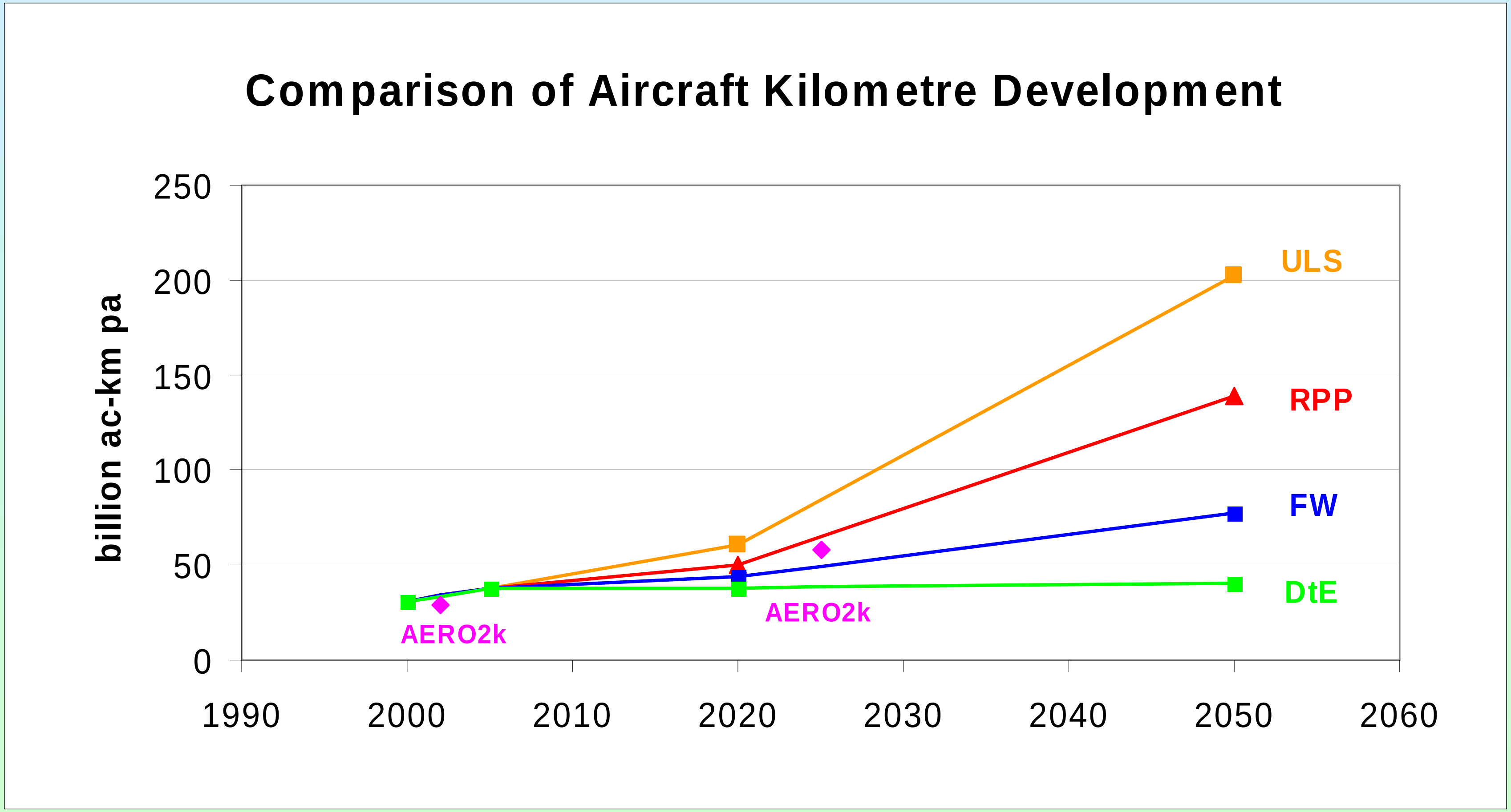
2020/2050 as a multiple of 2000

	2020/2000	2050/2000
ULS	2.0	6.9
RPP	1.7	4.8
FW	1.6	3.2
DtE	1.2	1.3

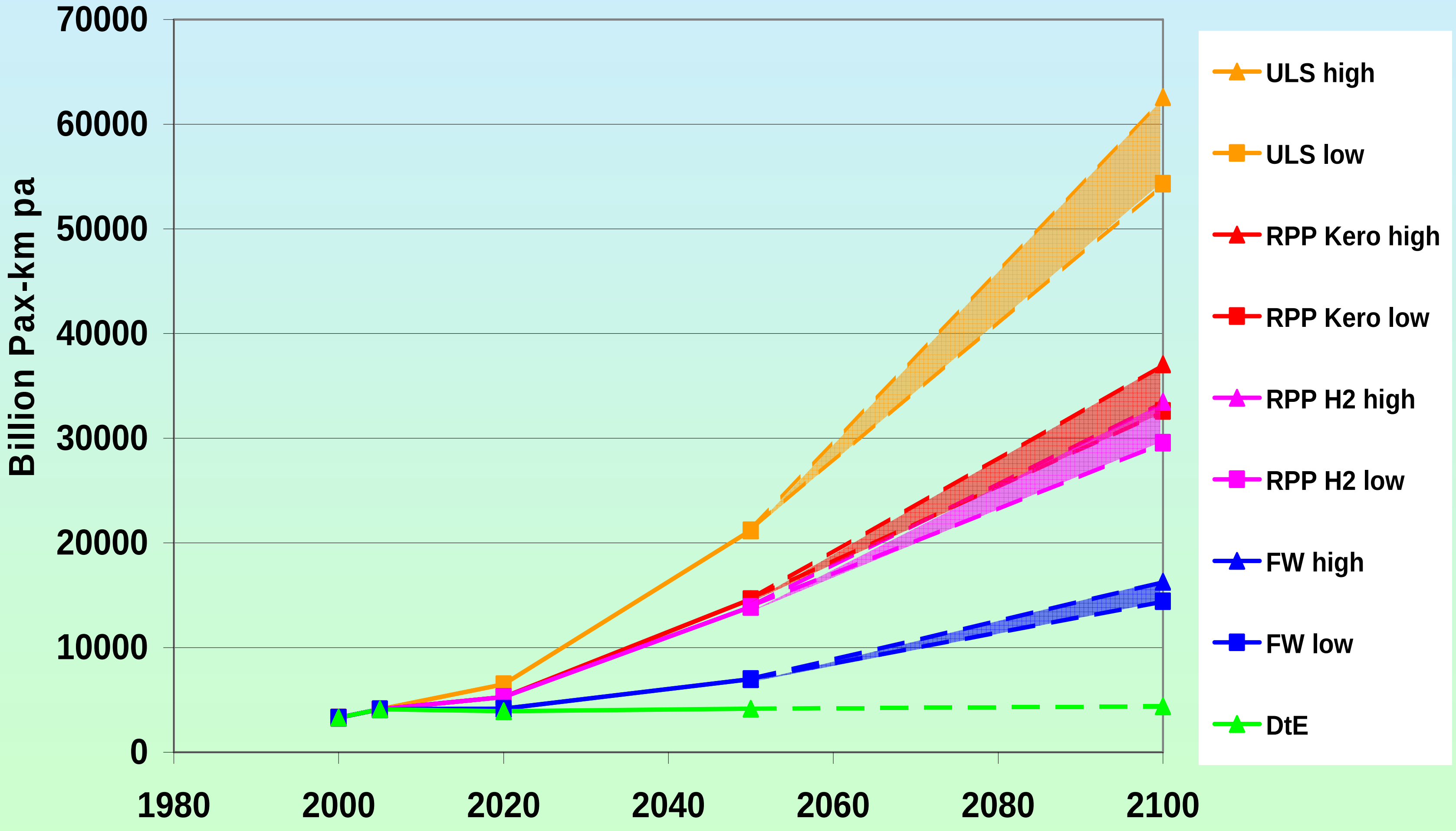
Comparison of passenger demand with results from ICAO, Airbus, Boeing and FESG



Comparison of passenger demand with results from AERO2k

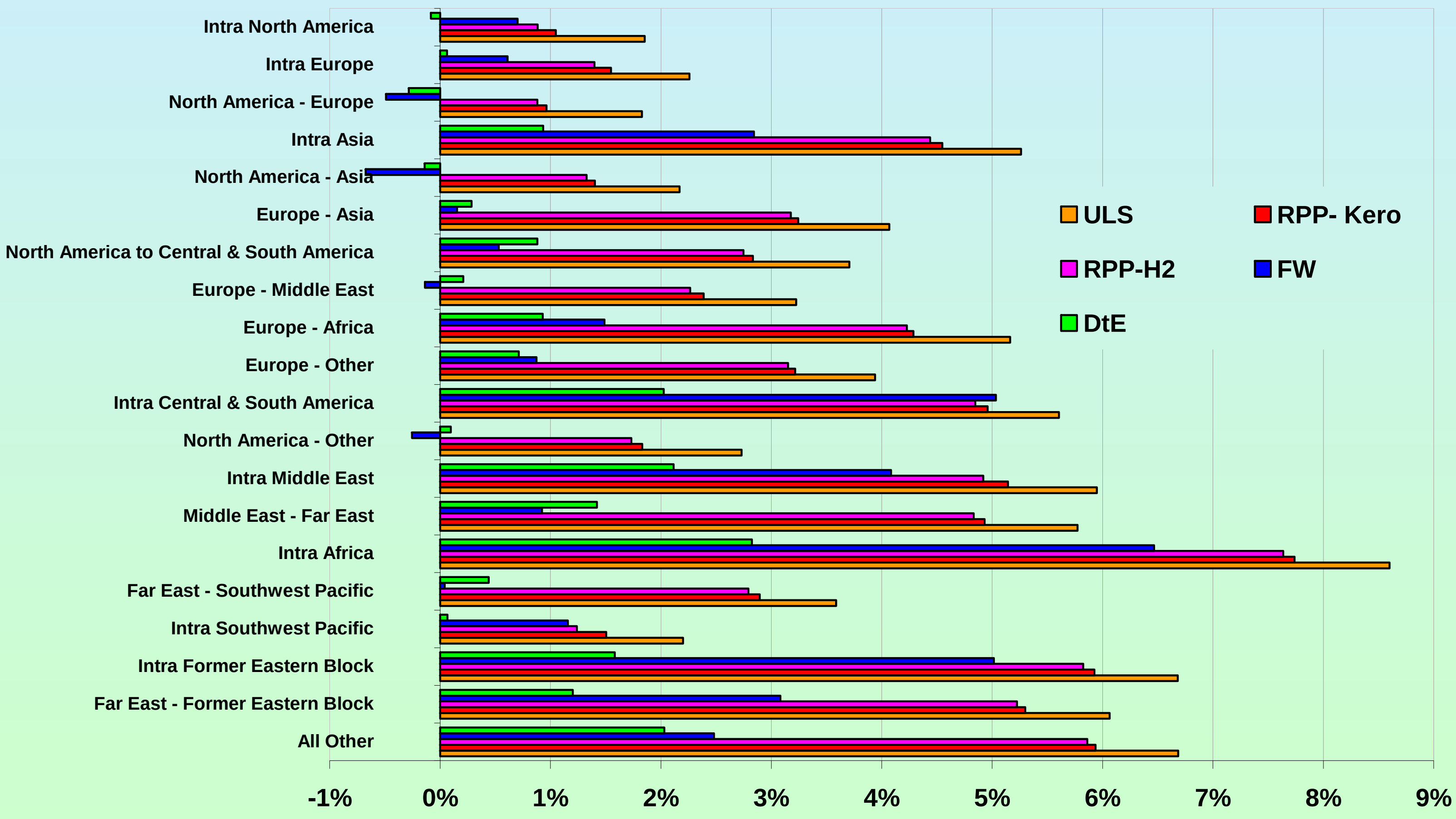


World Passenger Demand - Outlook to 2100

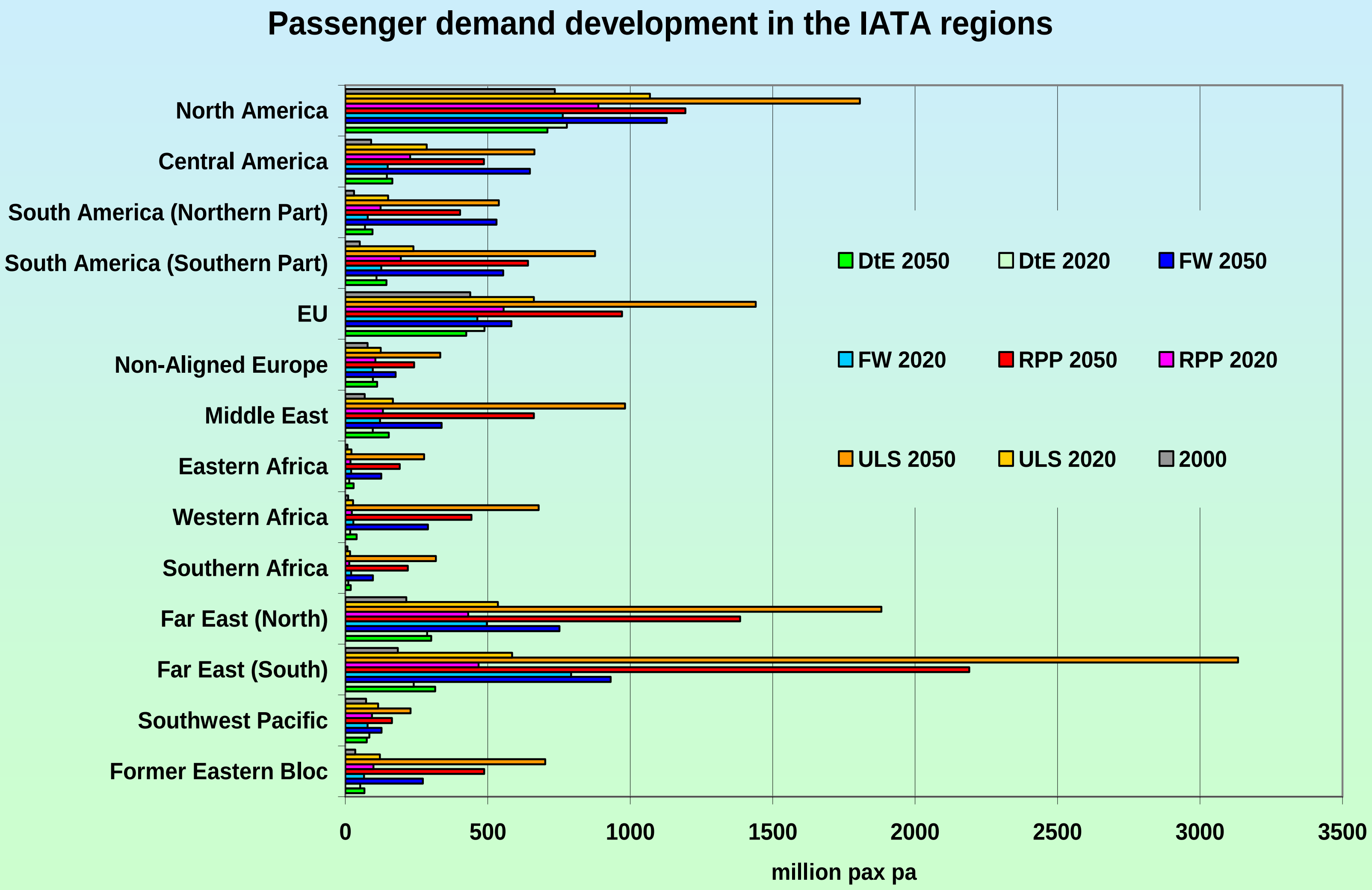


Regional results – traffic flow annual growth rates

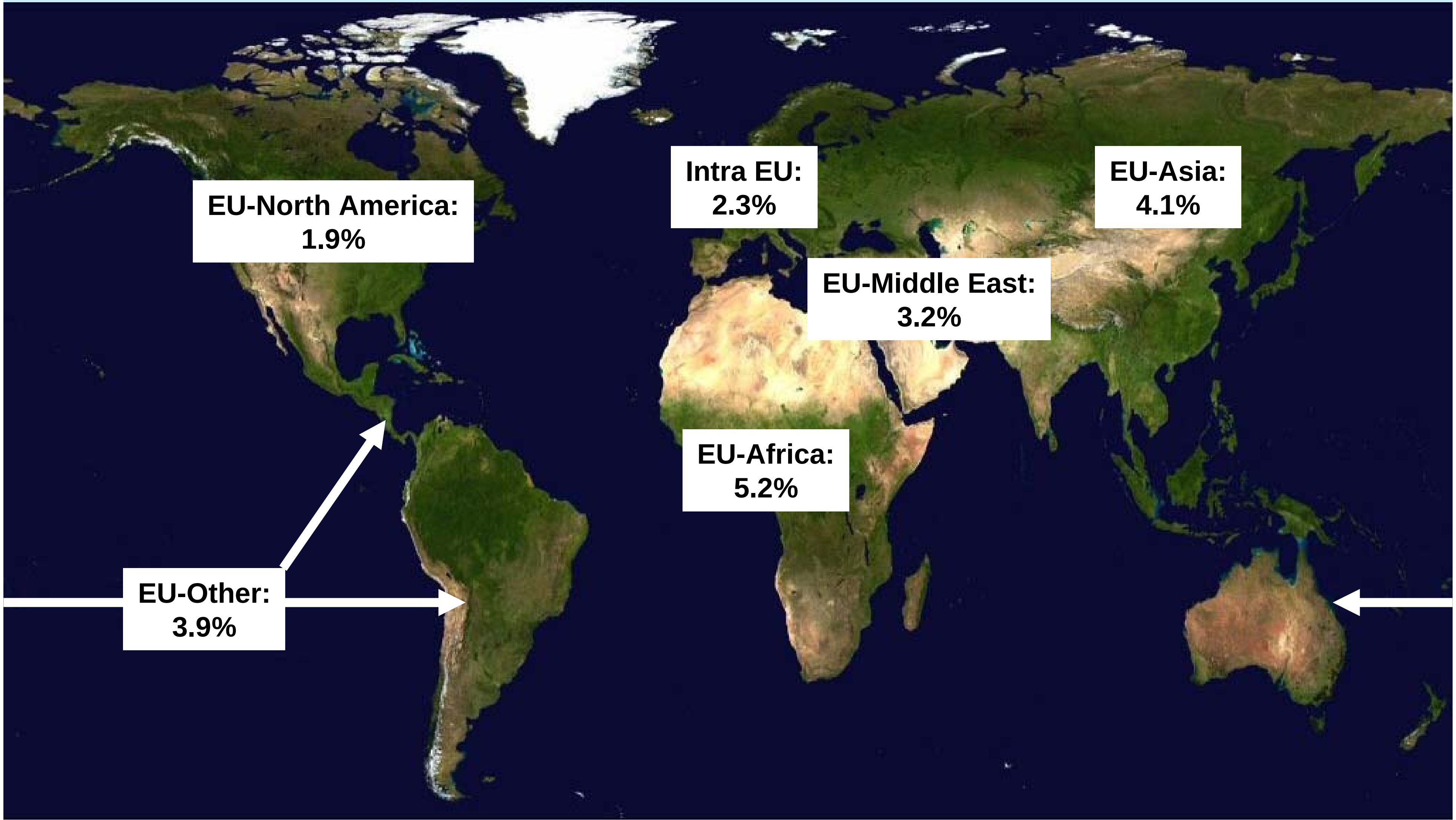
Annual growth rates of major traffic flow for route groups between 2000 and 2050



Regional results – passenger demand between 2000 and 2050



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



EU-North America: 1.9%

Intra EU: 2.3%

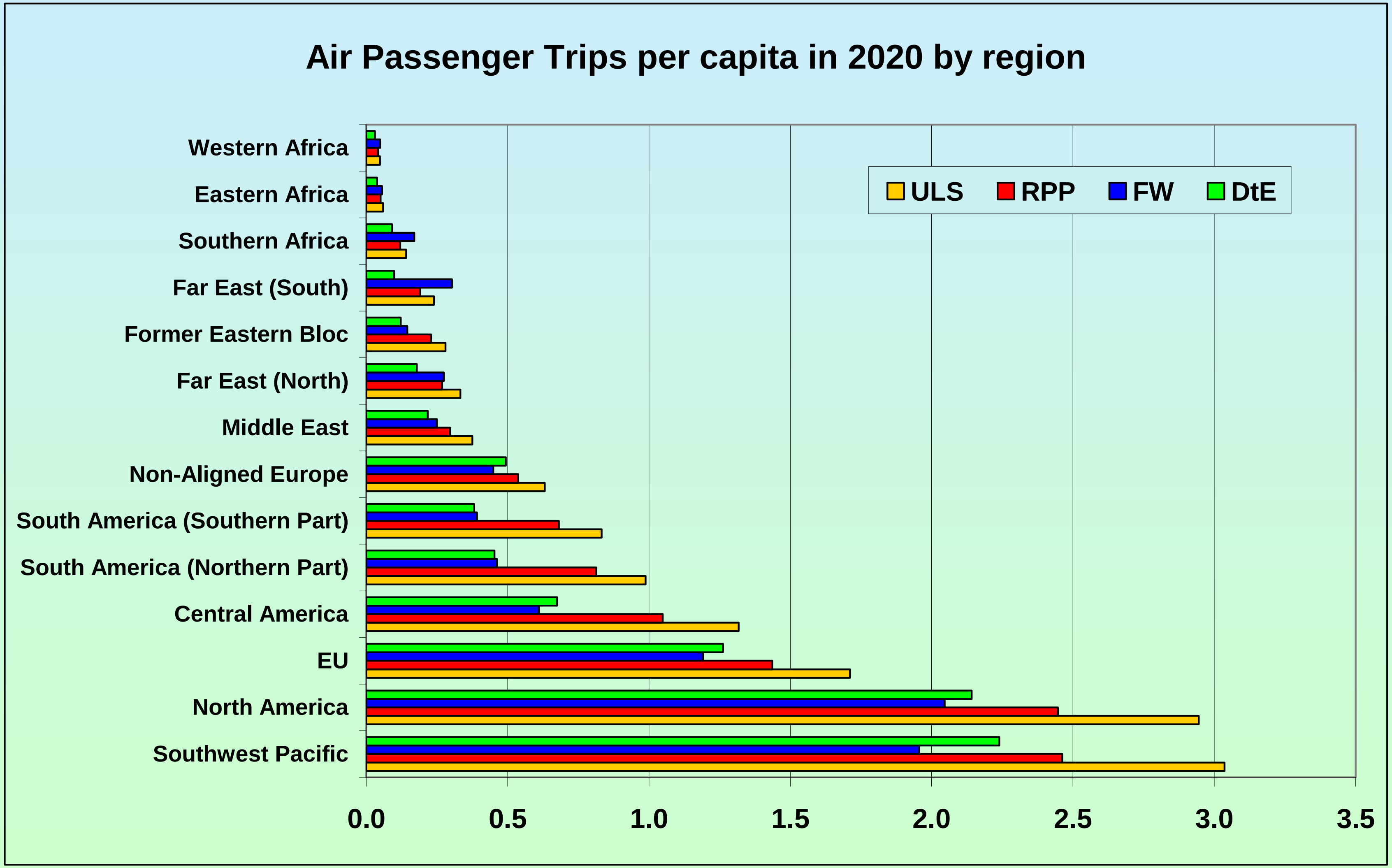
EU-Asia: 4.1%

EU-Middle East: 3.2%

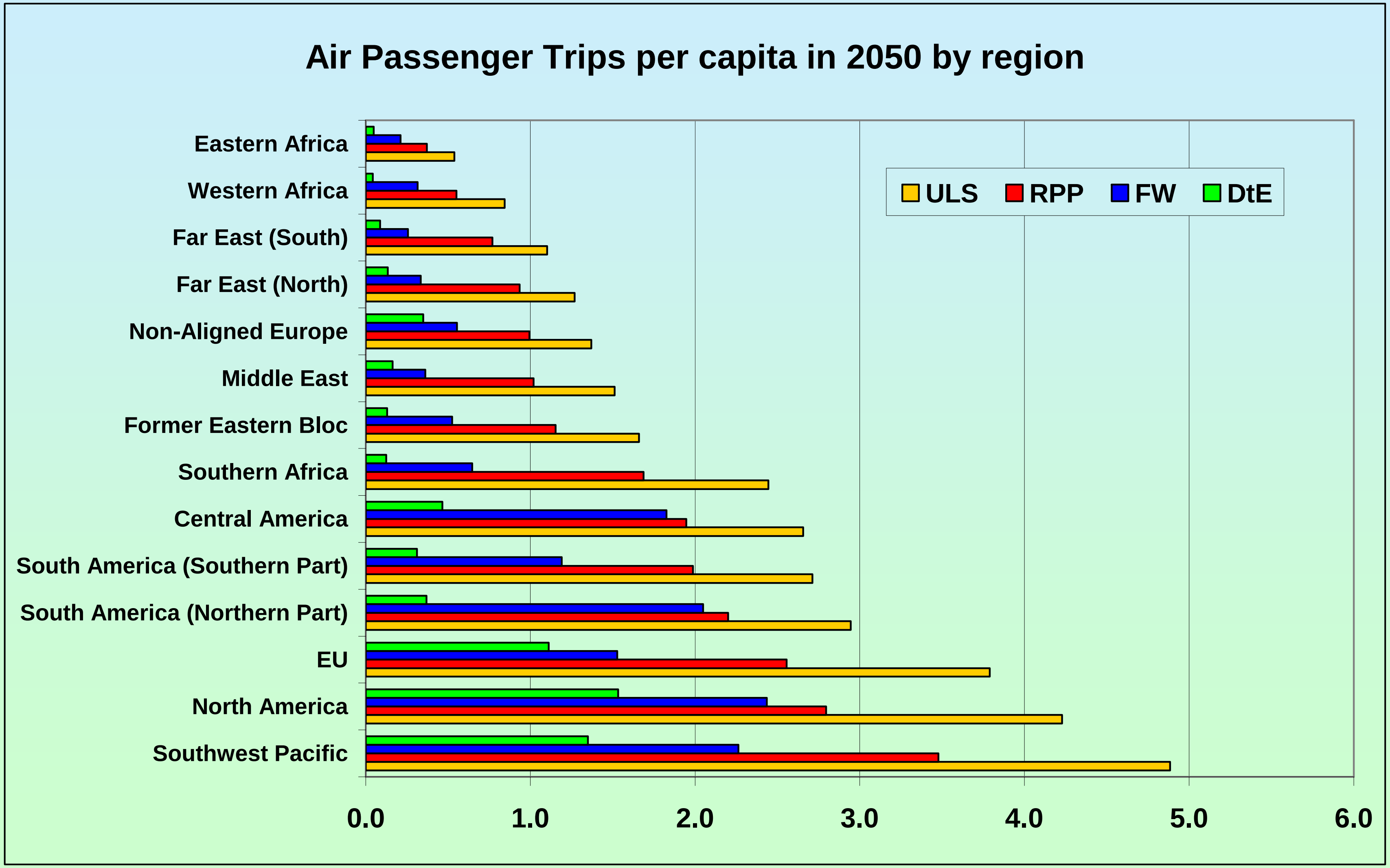
EU-Africa: 5.2%

EU-Other: 3.9%

Trips per capita in 2020 for IATA regions



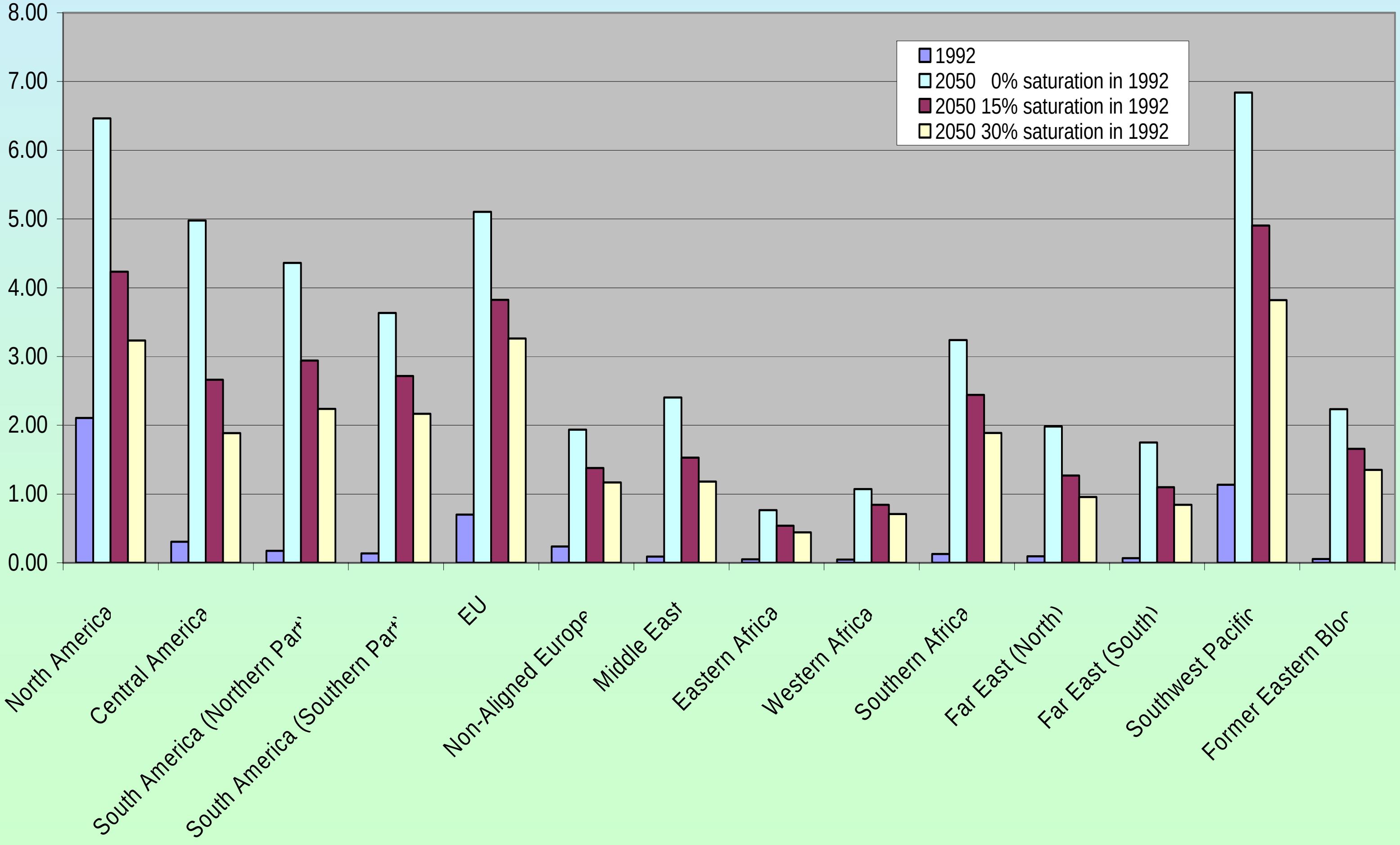
Trips per capita in 2050 for IATA regions



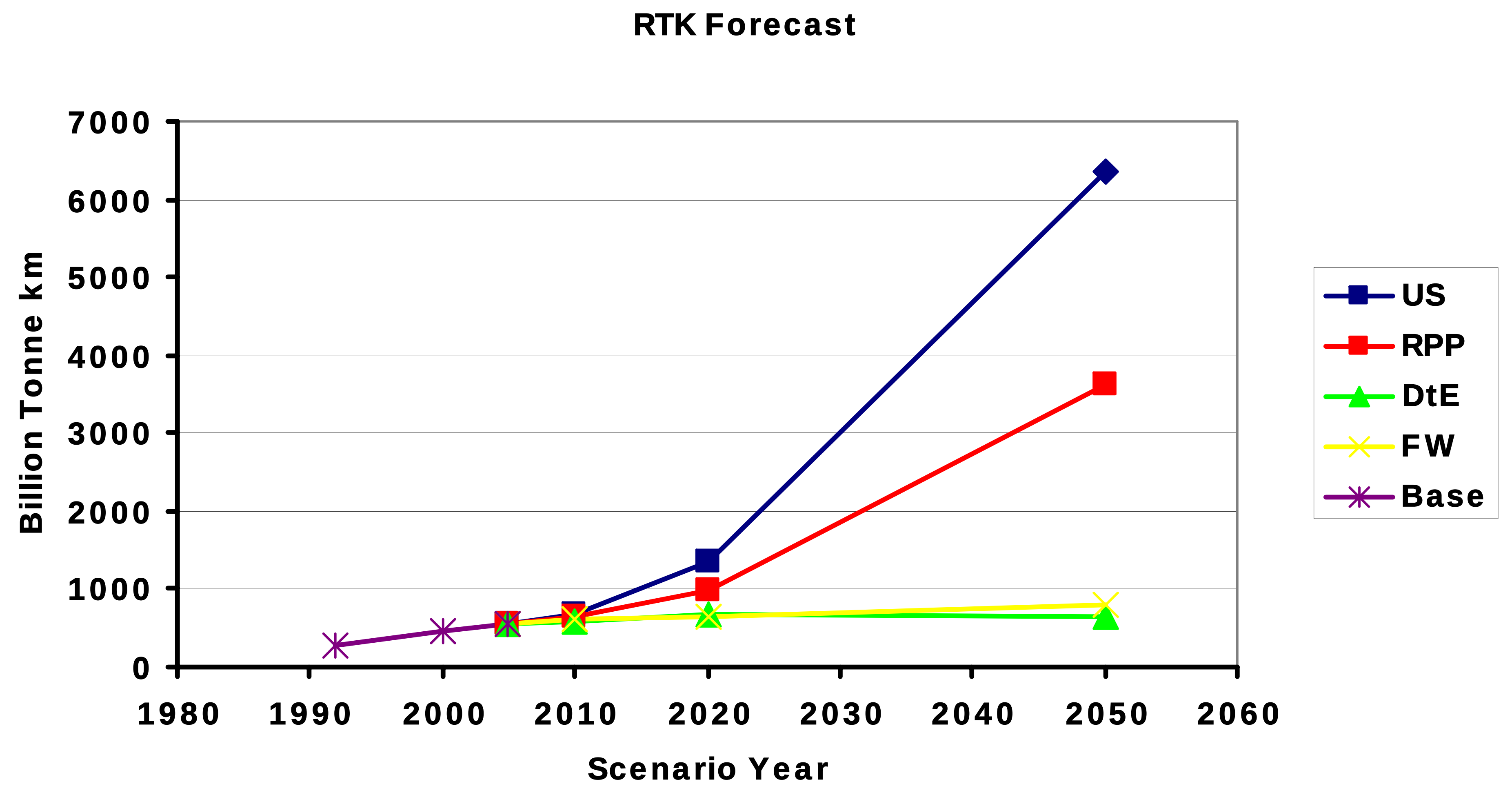
Trips per capita in 2050 for IATA regions

for scenario ULS and for various levels of saturation in 1992

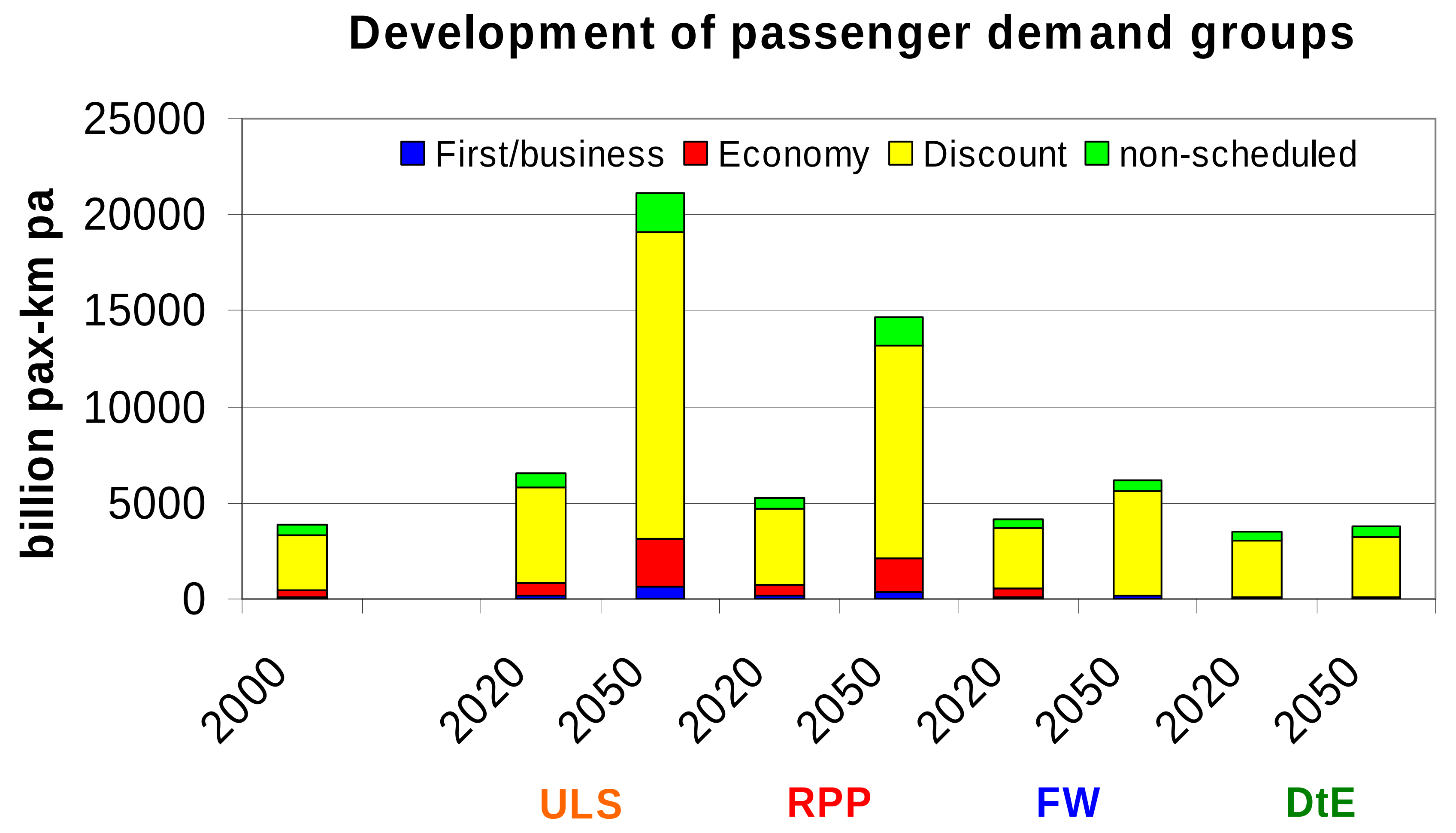
Air Passenger Trips per Capita in 2050 by Region for the Unlimited Skies Scenario
for various levels of saturation in 1992



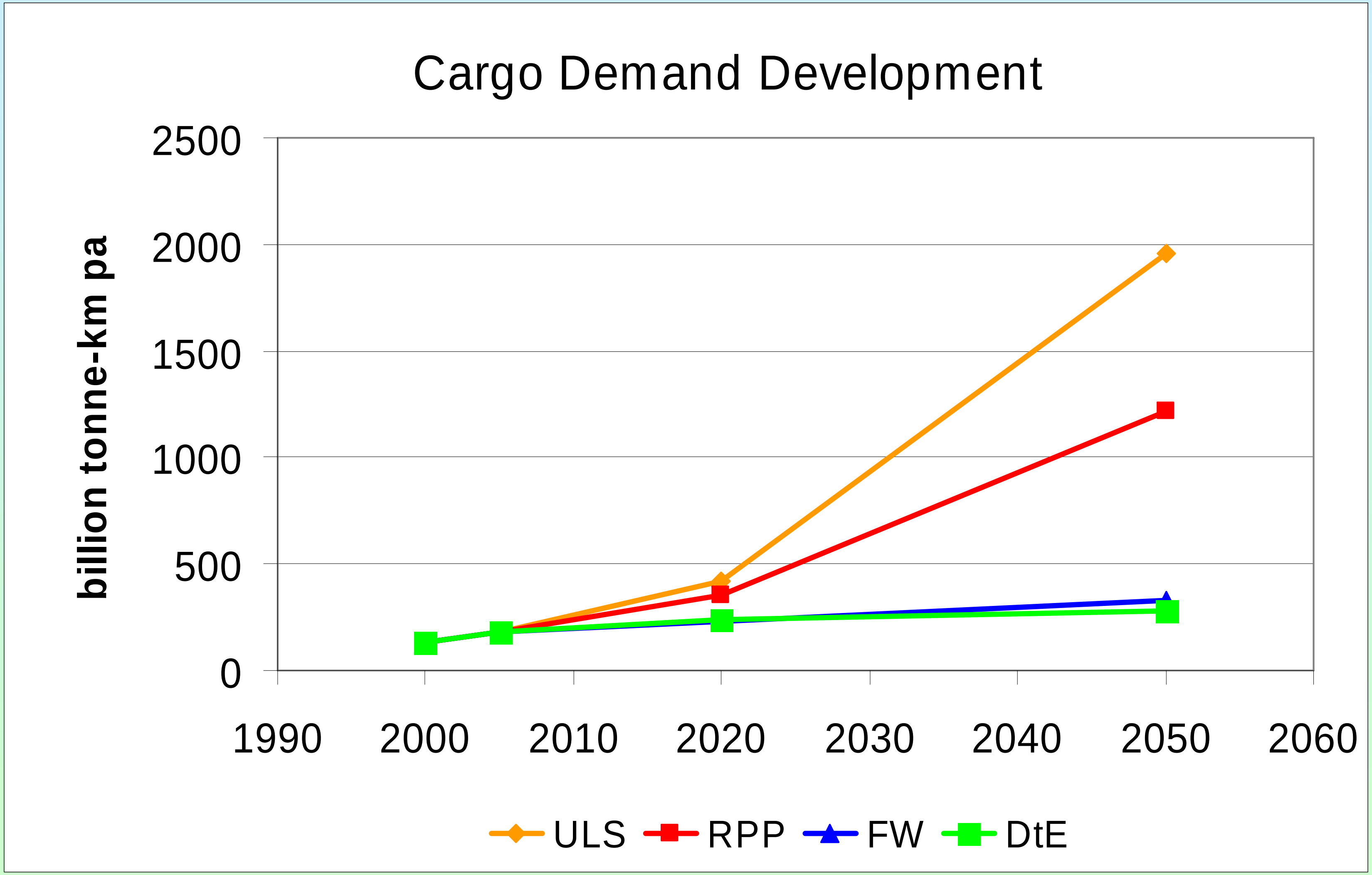
Overall growth comparison



Development pf passenger demand groups



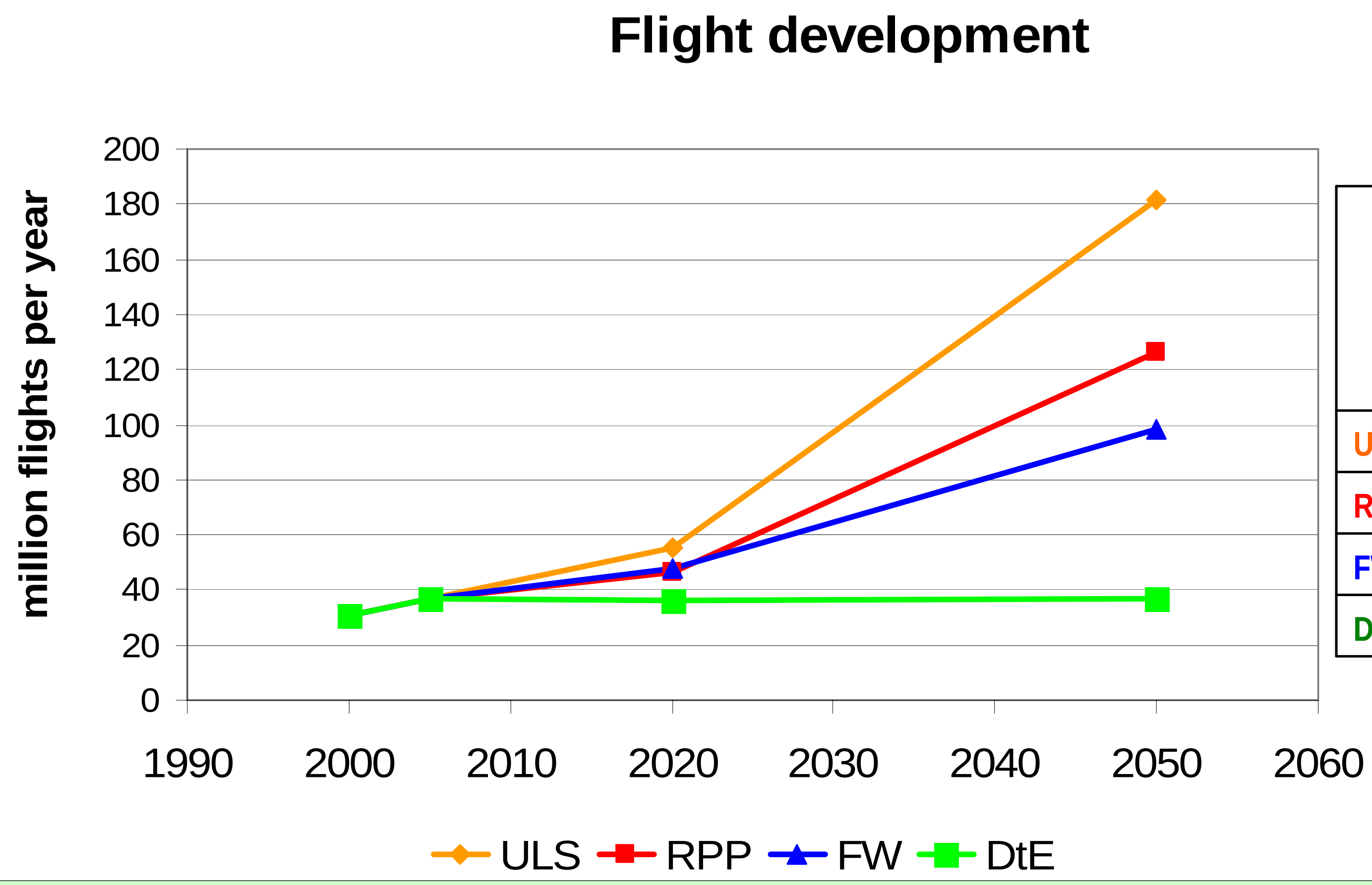
Cargo demand in billion tonne-km p.a.



Conclusions related to demand

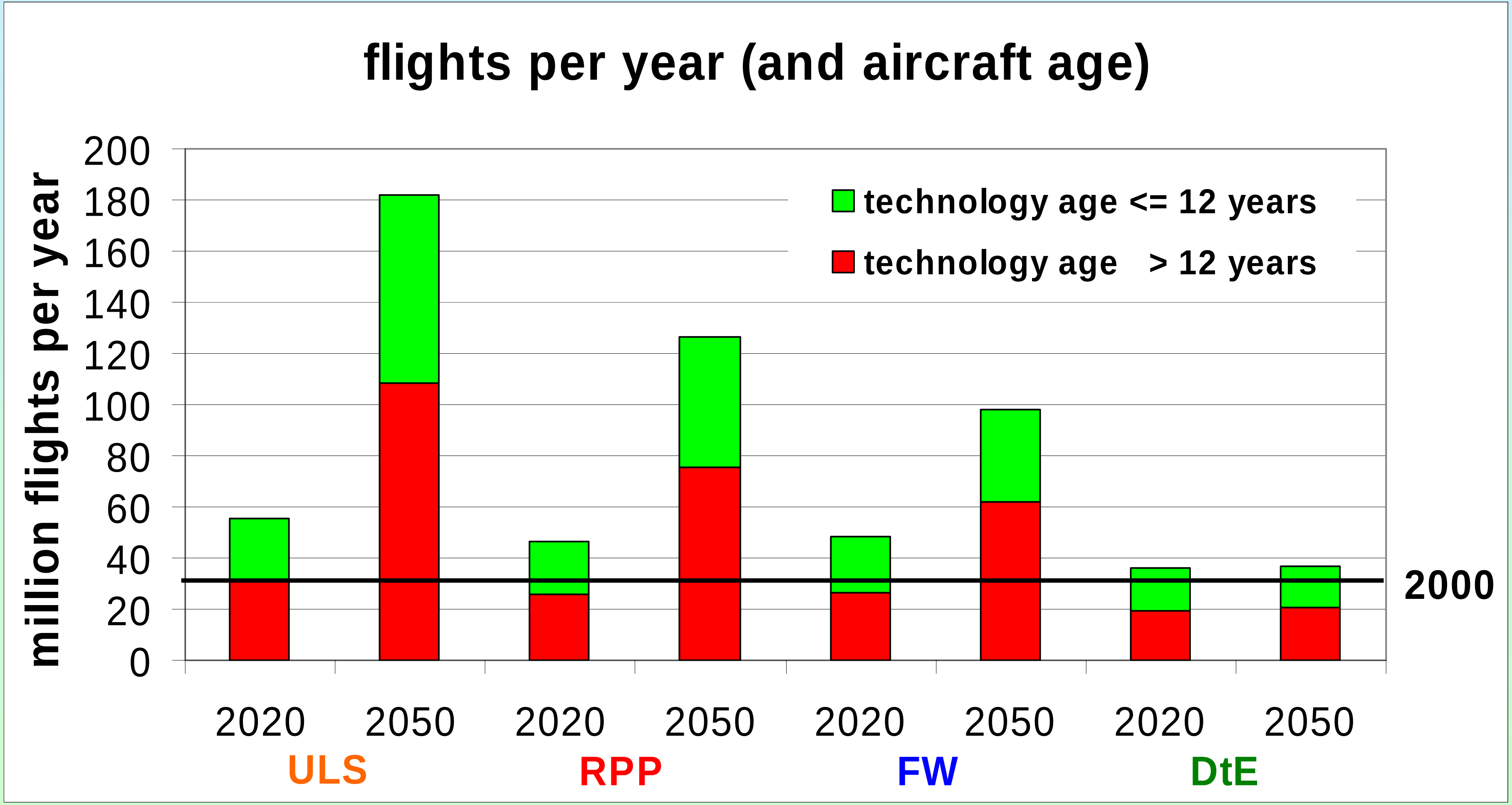
- Different scenario assumptions result in a wide range of imaginable long term developments in travel demand until 2050.
- The “Unlimited Skies” scenario yields a high increase in air trips per capita all over the world – providing aviation with sufficient infrastructure is a big challenge (primarily 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

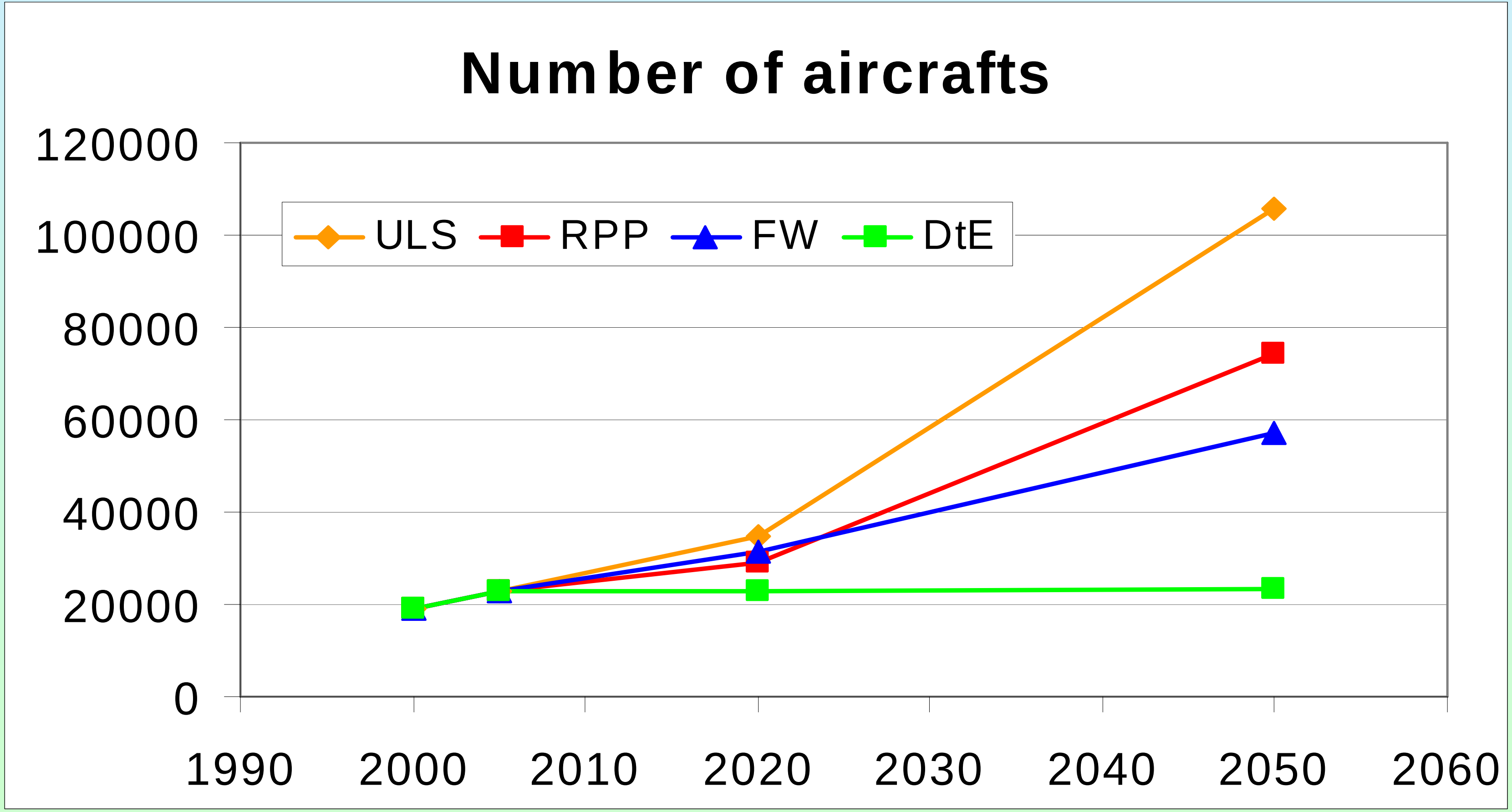


	average annual growth 2050	total growth 2050 as a multiple of 2000
ULS	3.6%	5.9
RPP	2.9%	4.1
FW	2.4%	3.2
DtE	0.4%	1.2

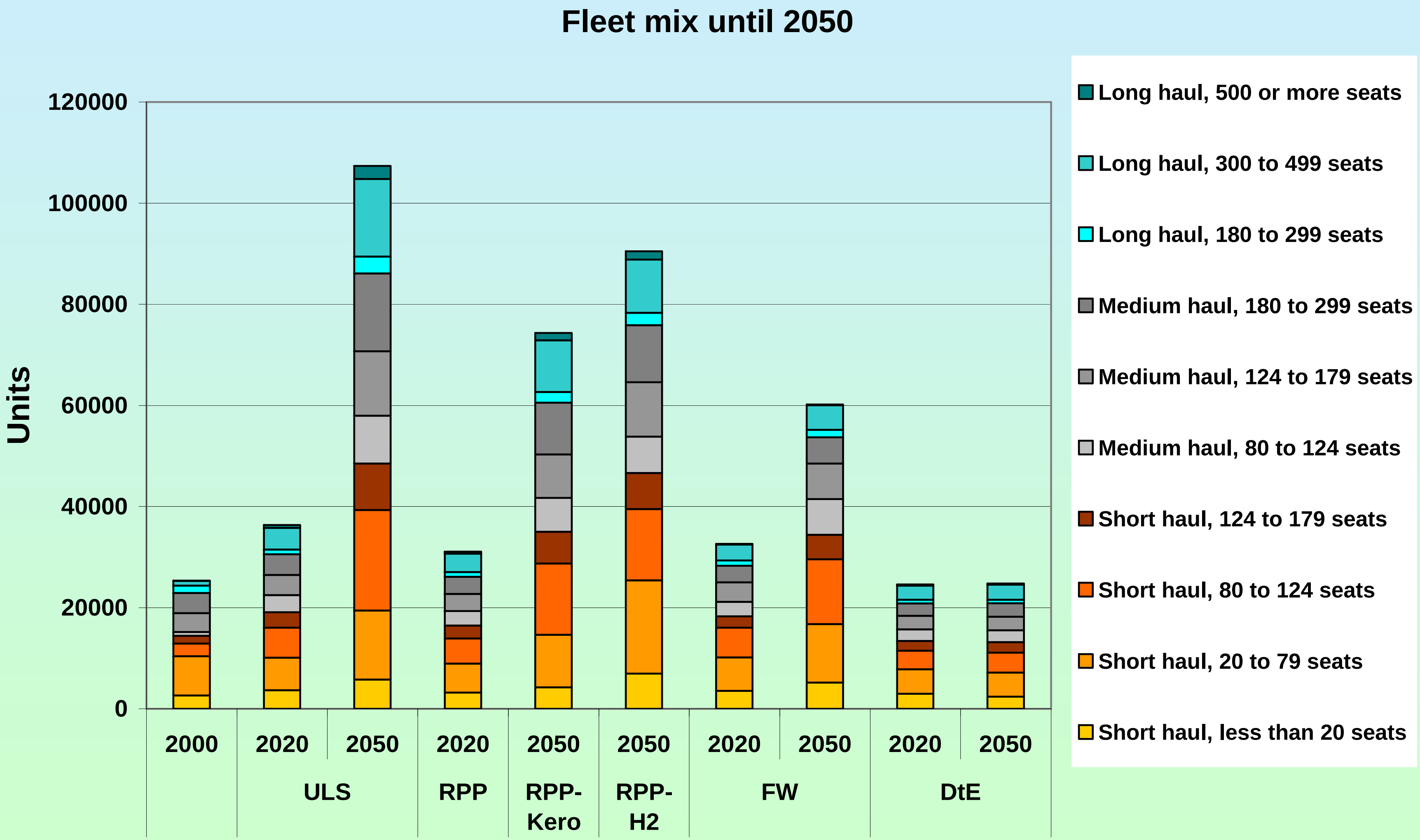
Flights by aircraft technology age



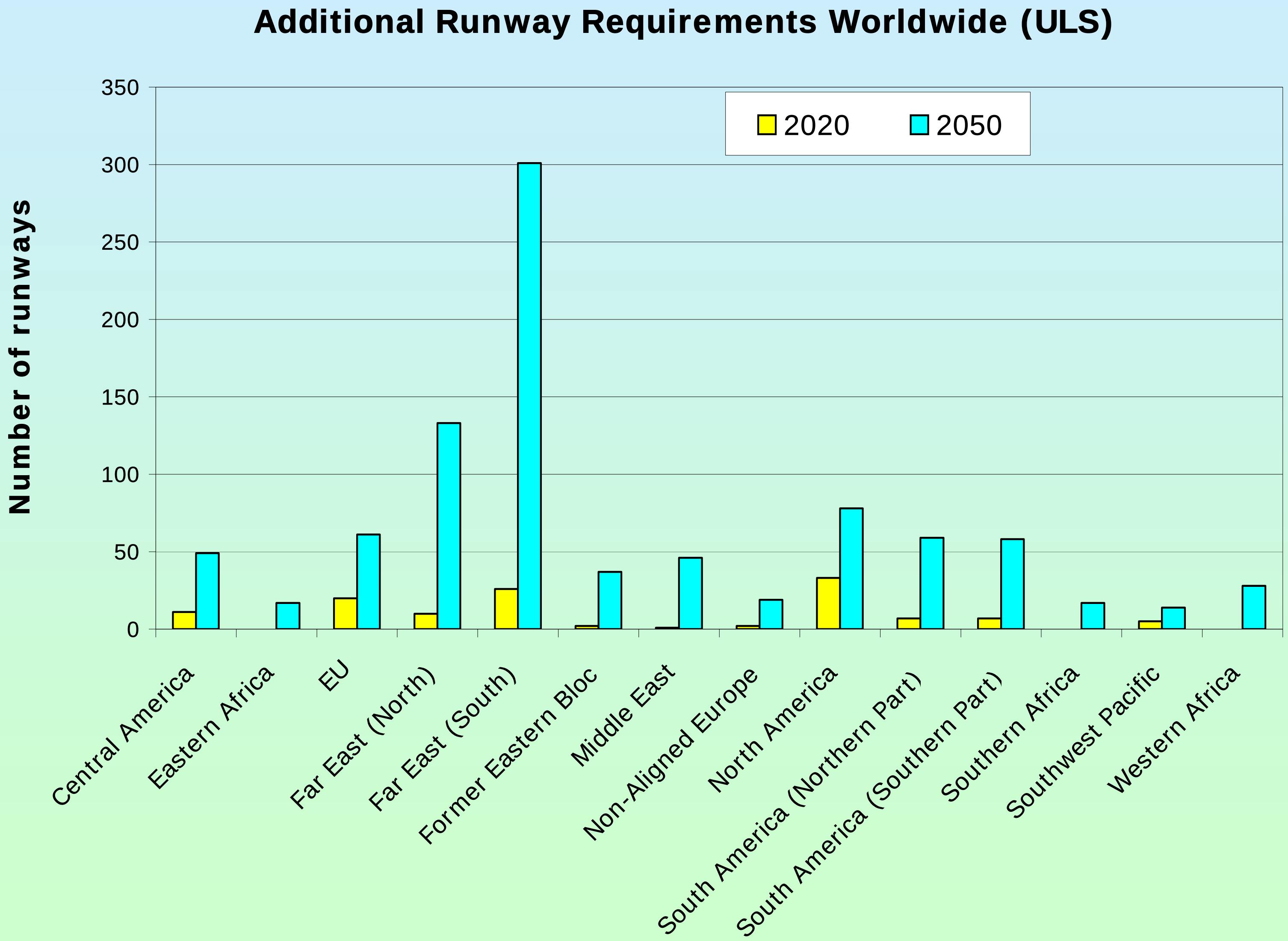
Number of aircraft



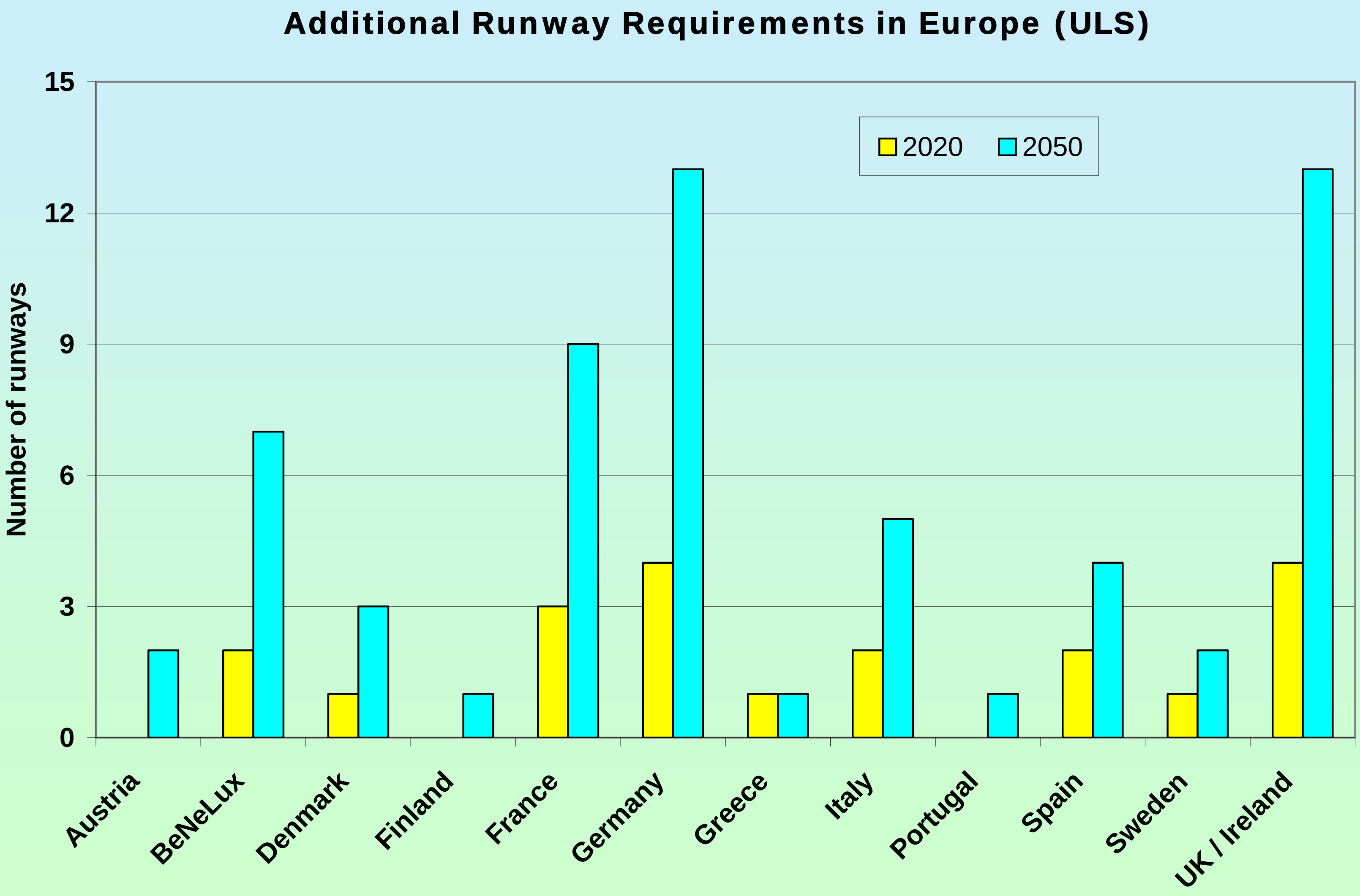
Fleet mix until 2050



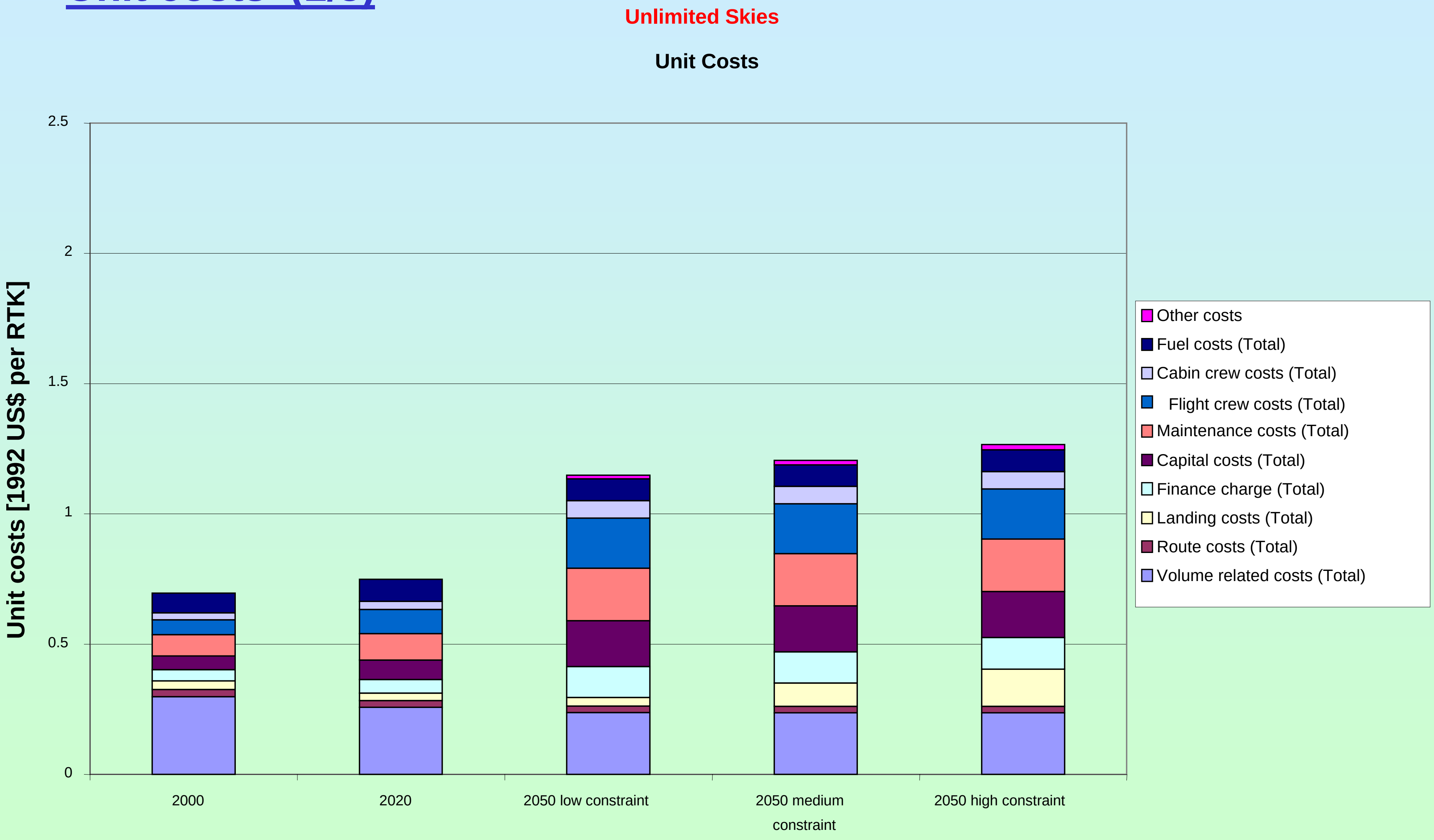
Unlimited Skies - Additional Global Runway Requirements



Unlimited Skies - Additional Runway Requirements in Europe

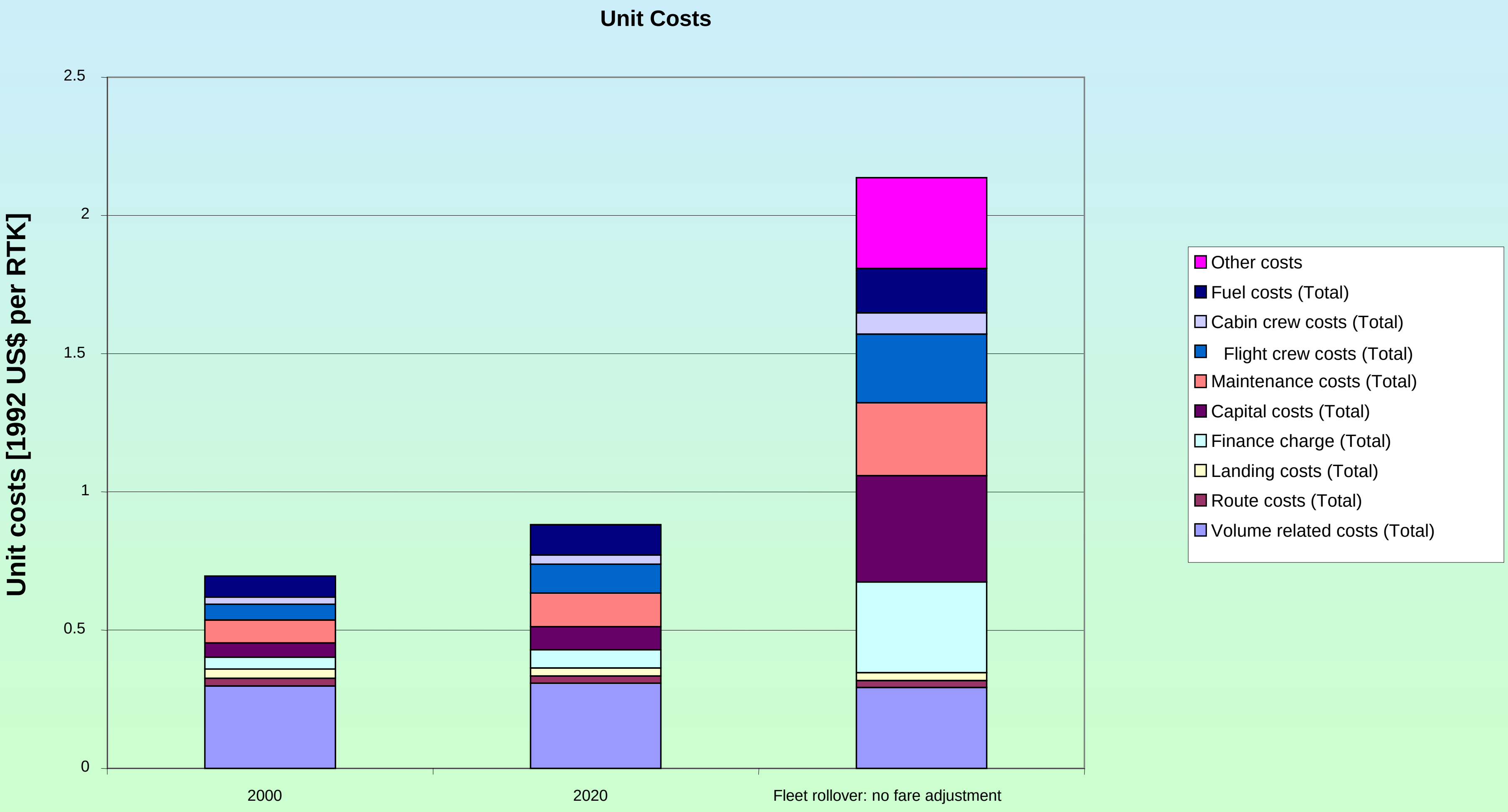


Unit costs (1/5)

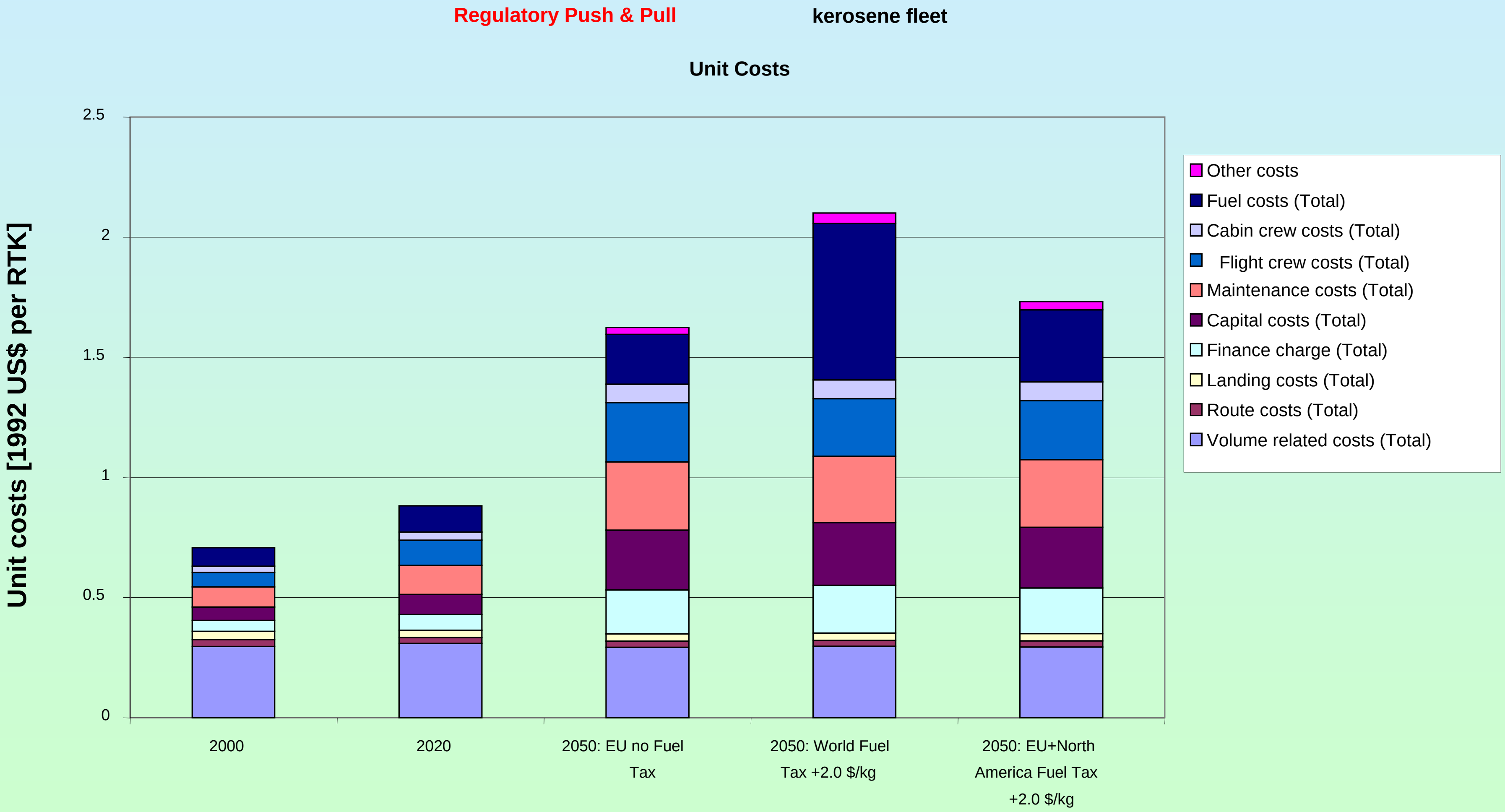


Unit costs (2/5)

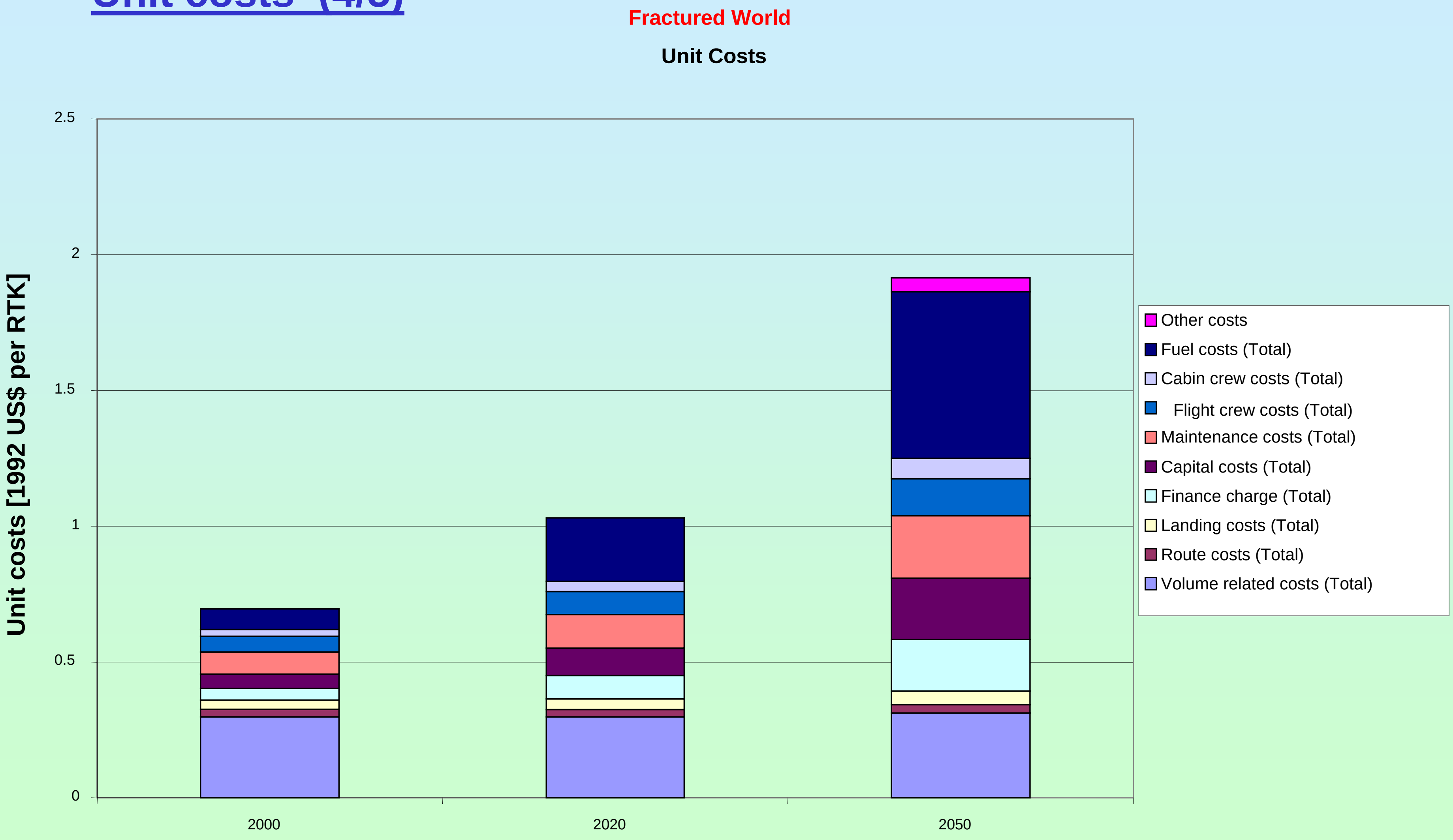
Regulatory Push & Pull **with kerosene - hydrogen fleet rollover**



Unit costs (3/5)

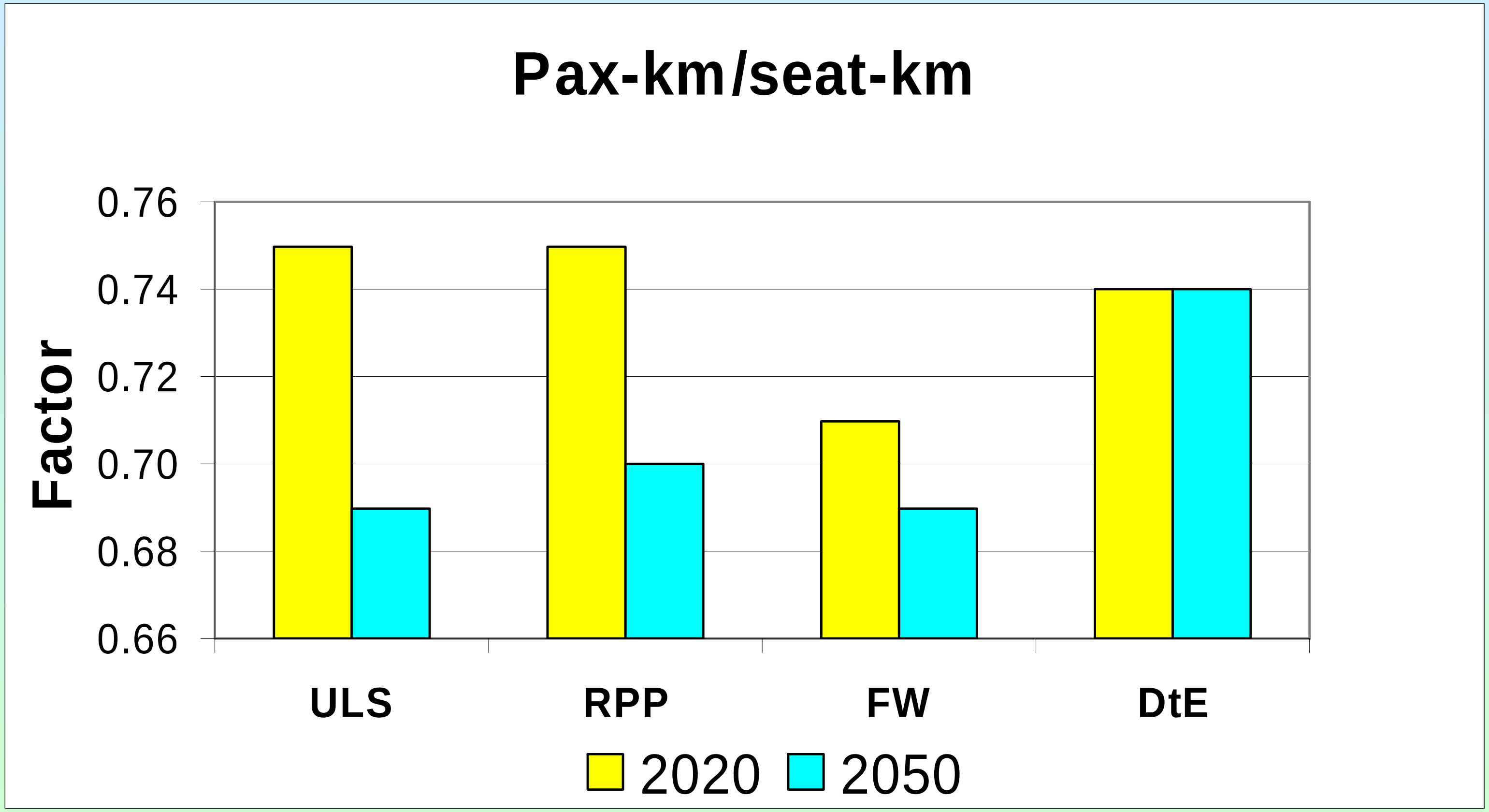


Unit costs (4/5)



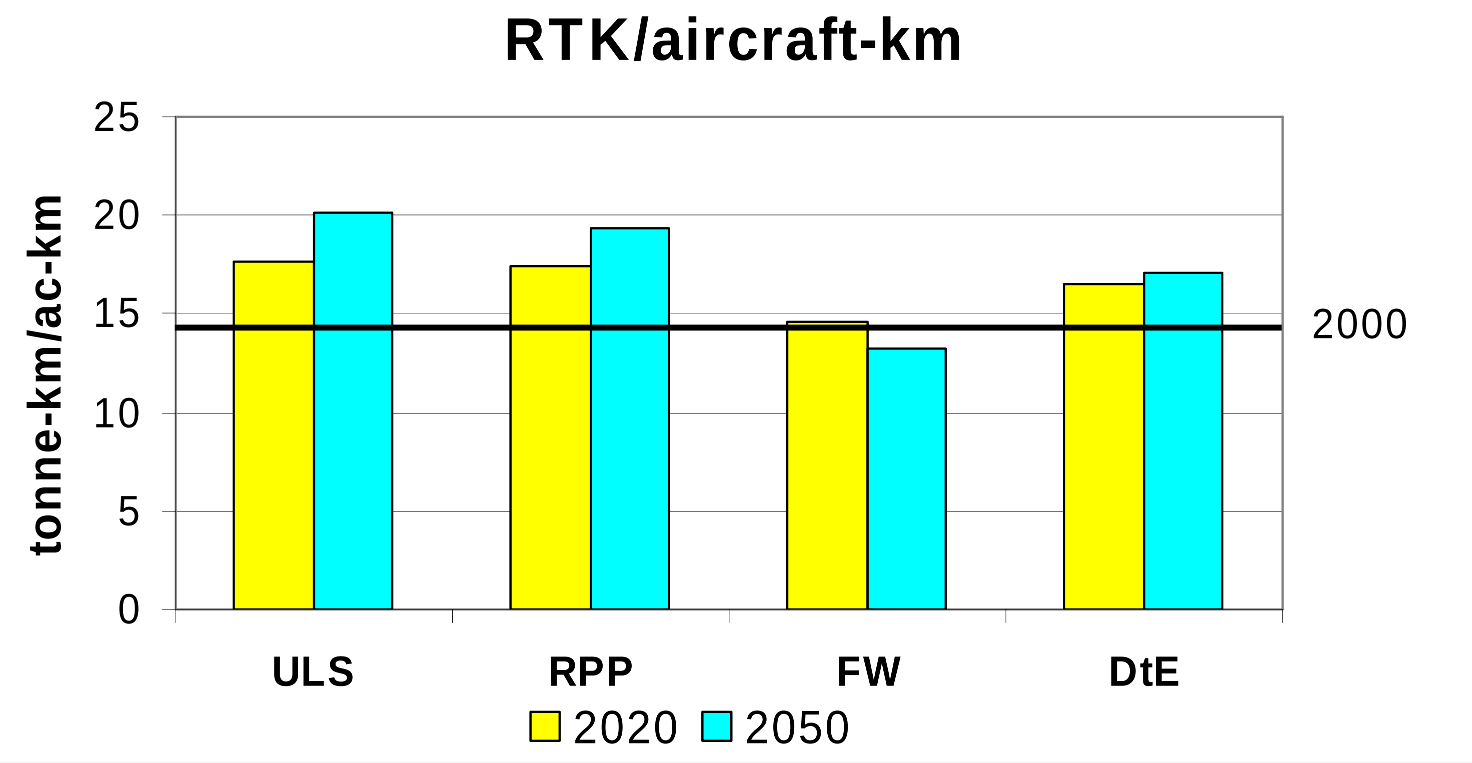
Unit costs (5/5)

Pax-km/seat-km relative to 2000



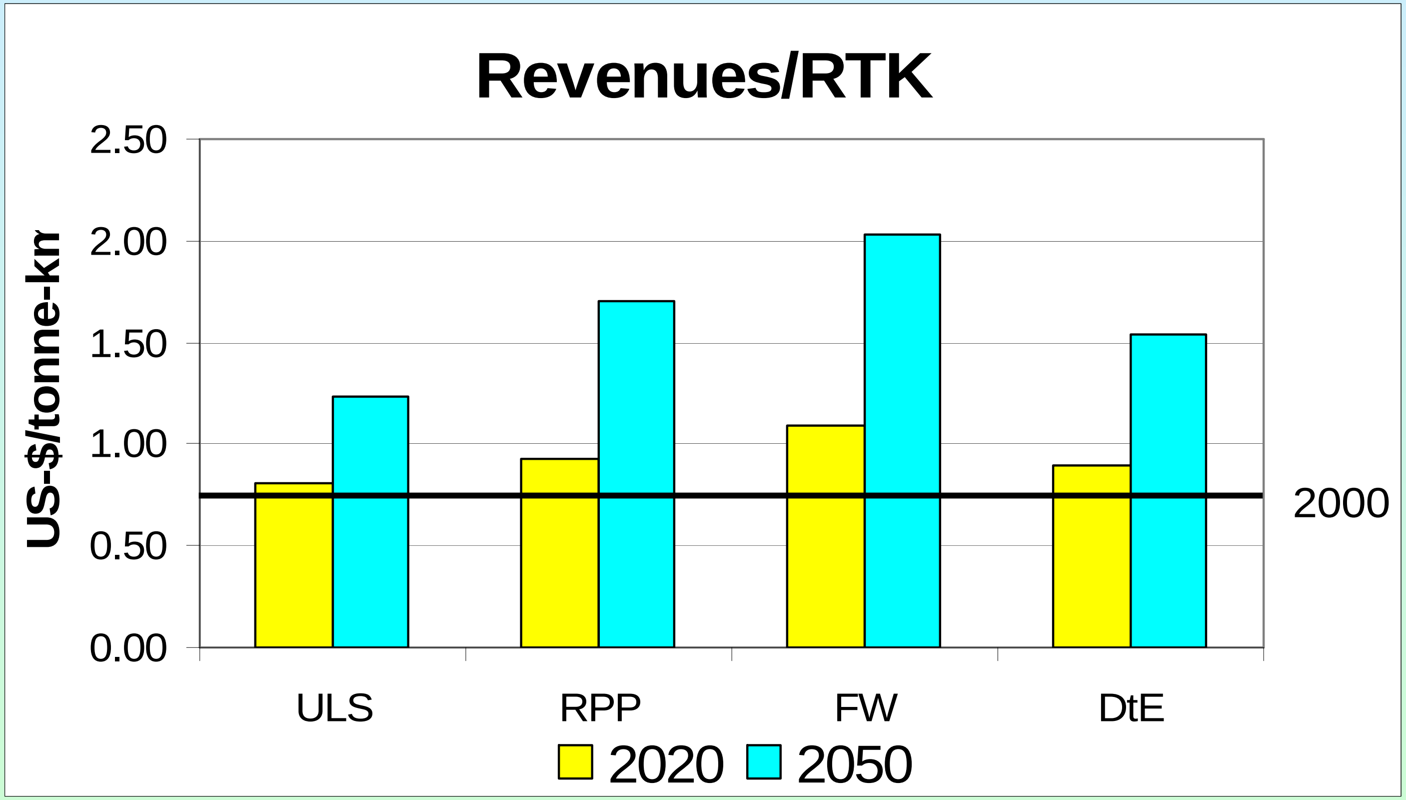
This ratio represents the average load factor of the global fleet. As a consequence of a change to larger aircraft especially beyond 2020 (to 2050) in all scenarios, this factor will - in the long-term - reduce in value.

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



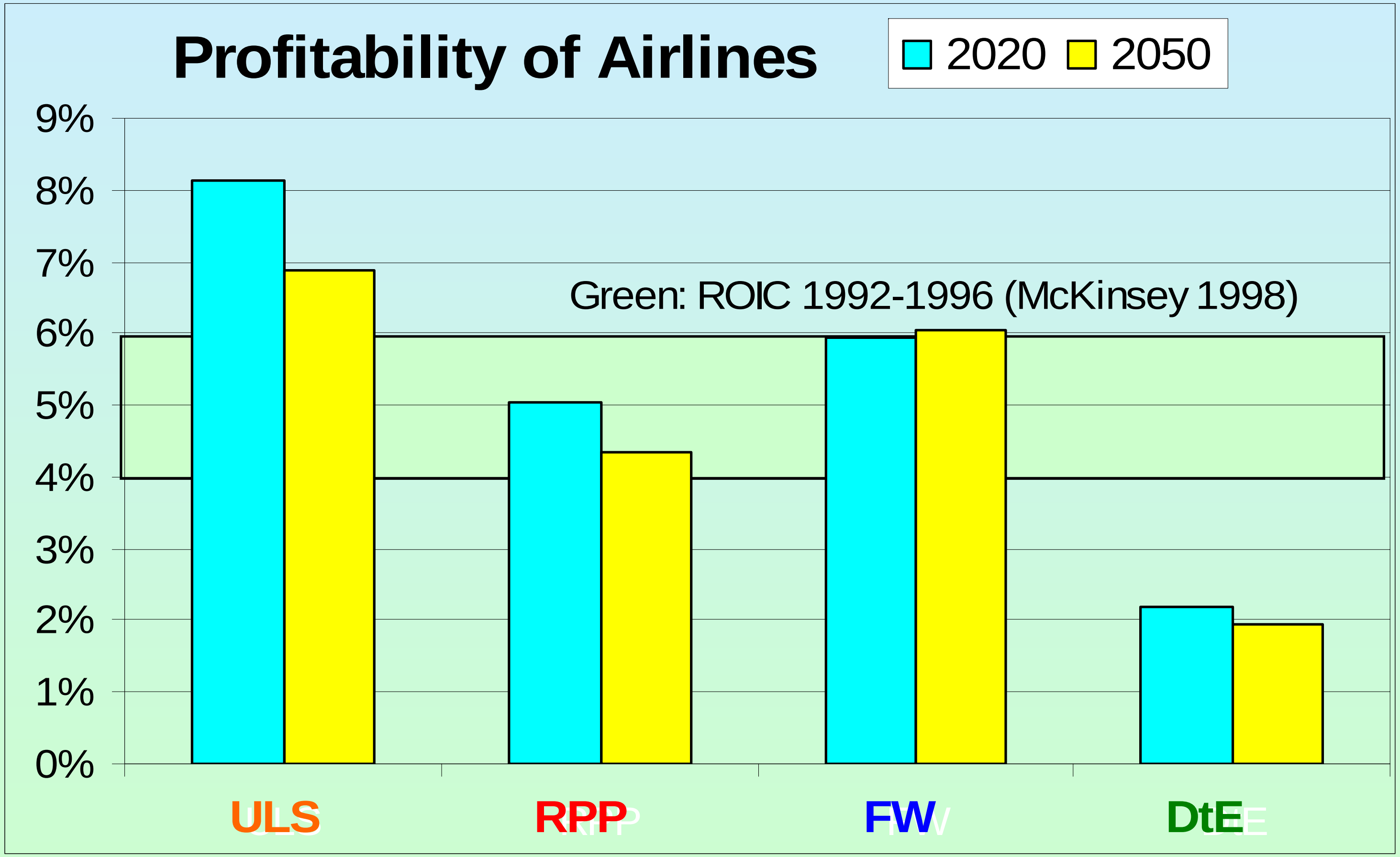
Highest revenues per RTK are to expect in FW (caused by a larger proportion of short-distance trips) while lowest revenues per RTK are in ULS (caused by large costs to realise the high traffic volume). ULS has high competition and high traffic volumes.

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

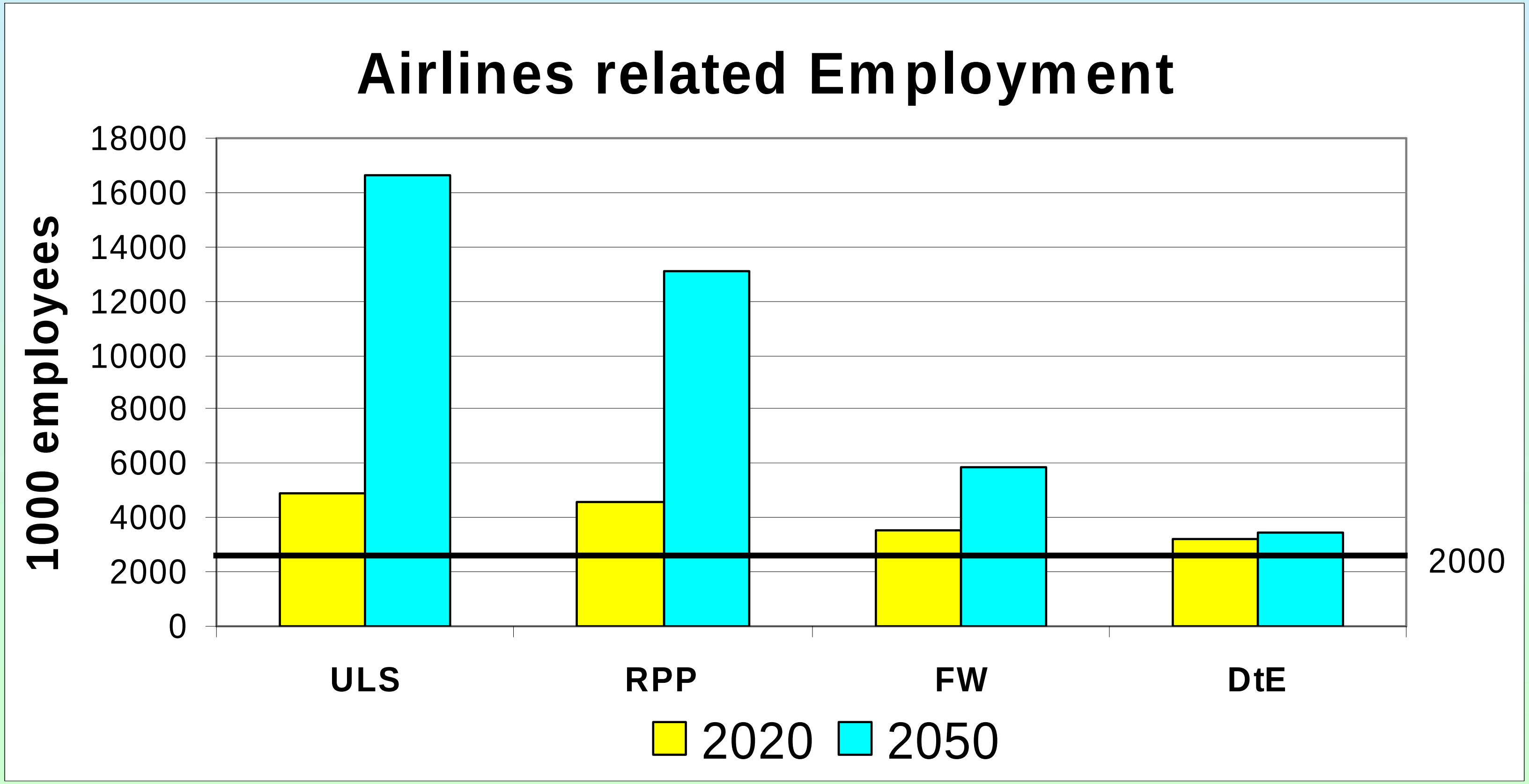
The comparably good profitability in FW is to explain by differences in the regional development – some regions; especially North America and Eurasia seem to be able to adjust to the assumed fragmentation in the long run, dividing the world into winners and losers of a fractured world. One has to keep 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

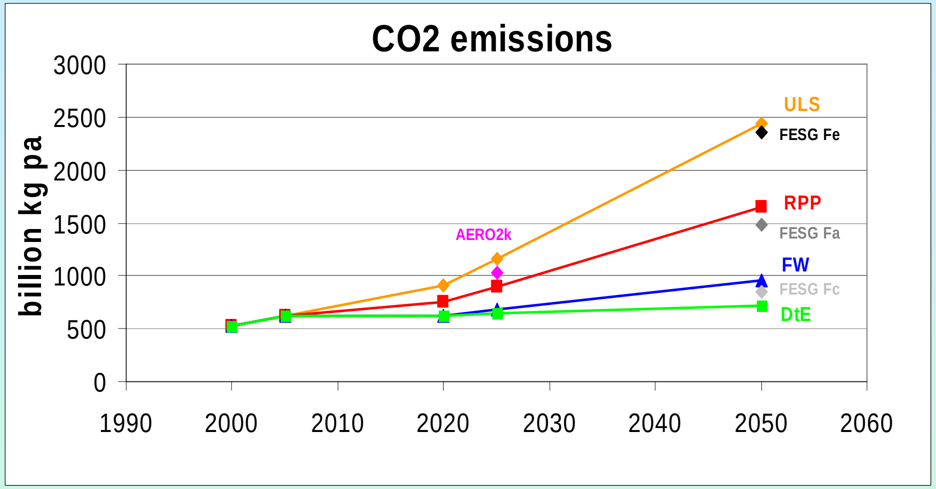
Scenario	Year	AC-km [Billion km]	Fuel [Tg]	CO2 [Tg]	H2O [Tg]	NOx [Tg]	CO* [Tg]	CxHy* [Tg]	SO2* [Tg]
History	2000	31.0	168.1	530.7	207.9	2.228	0.86	0.260	0.155
ULS	2020	60.6	287.1	906.5	355.1	3.495	1.28	0.321	0.264
	2050	202.1	773.4	2441.6	956.7	7.313	3.46	0.774	0.712
RPP Kerosene	2020	50.5	237.2	748.9	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 H2	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

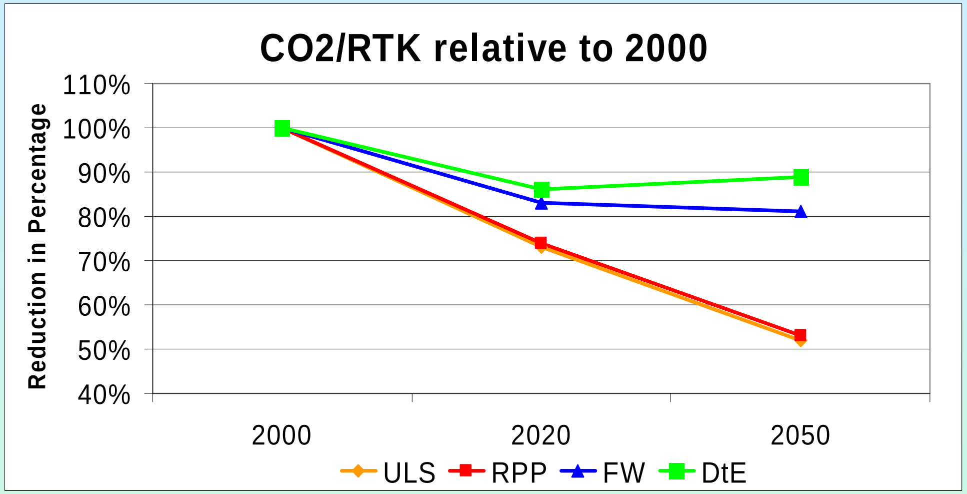
n.c. = not calculated

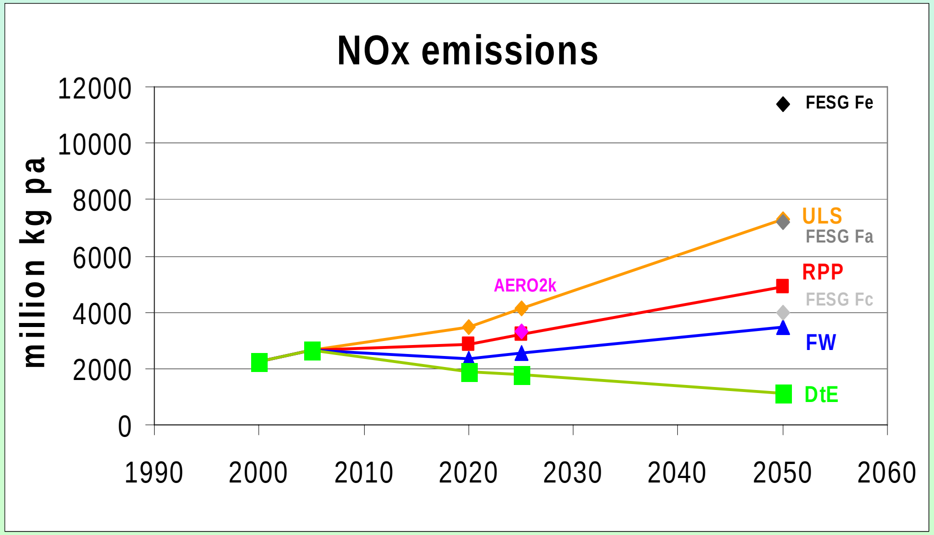
* For CO, CxHy, SO2 the current level of emission regulations is assumed for all scenarios

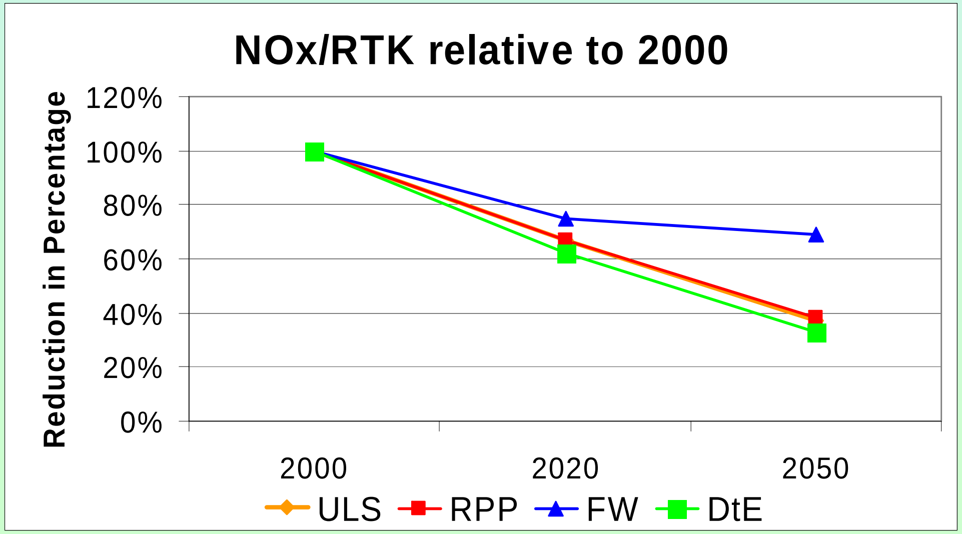
** Fuel consumption in predominantly hydrogen, but with 8.5% kerosene powered aircraft remaining

CO2 and NOx Emissions – absolute and relative to 2000



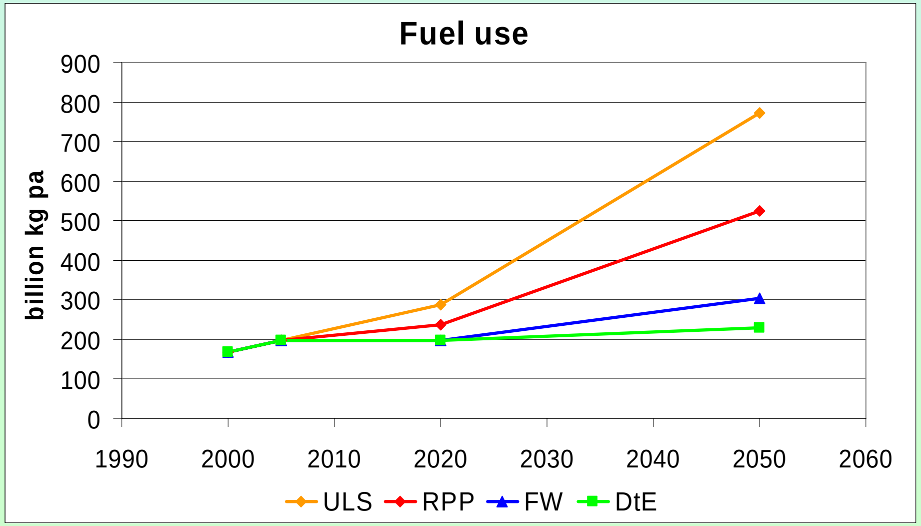






Fuel consumption and emissions

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



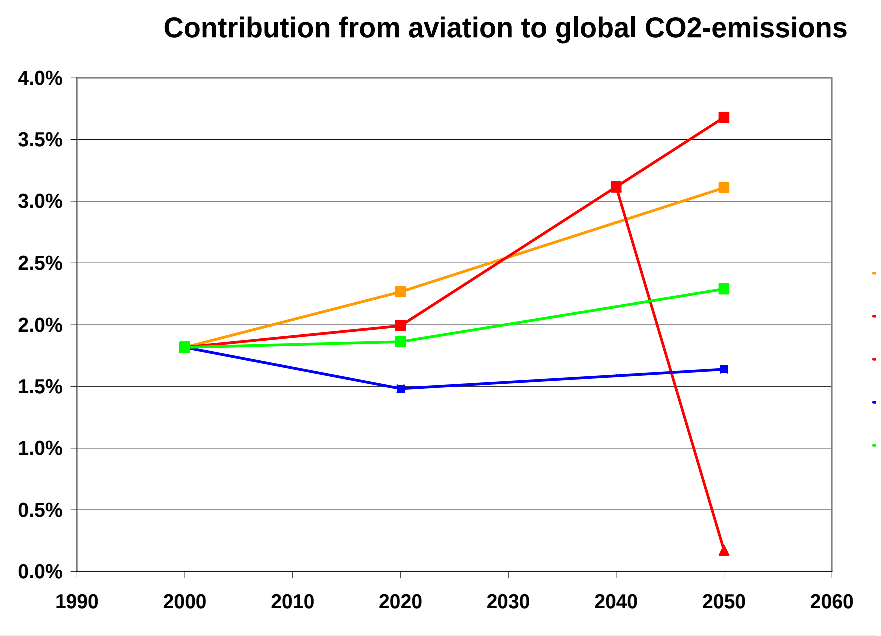
Emissions – share of global aviation

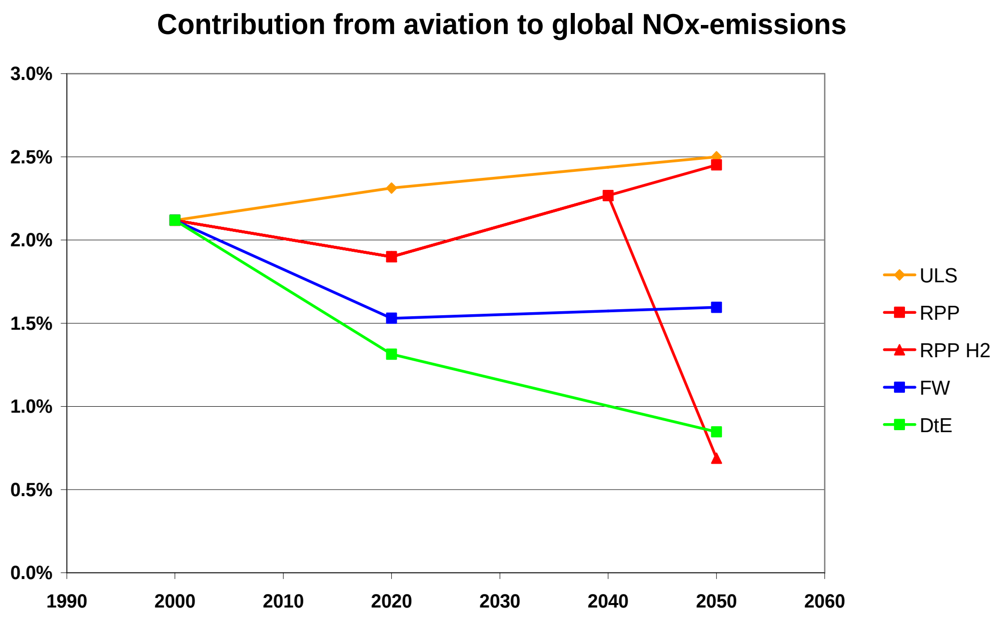
CO2 emissions: Share of civil aviation	2000	2020	2050
ULS	1.82%	2.27%	3.11%
RPP – kerosene	1.82%	1.99%	3.68%
RPP – cryoplane	1.82%	1.99%	0.17%
FW	1.82%	1.48%	1.64%
DtE	1.82%	1.86%	2.23%

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.

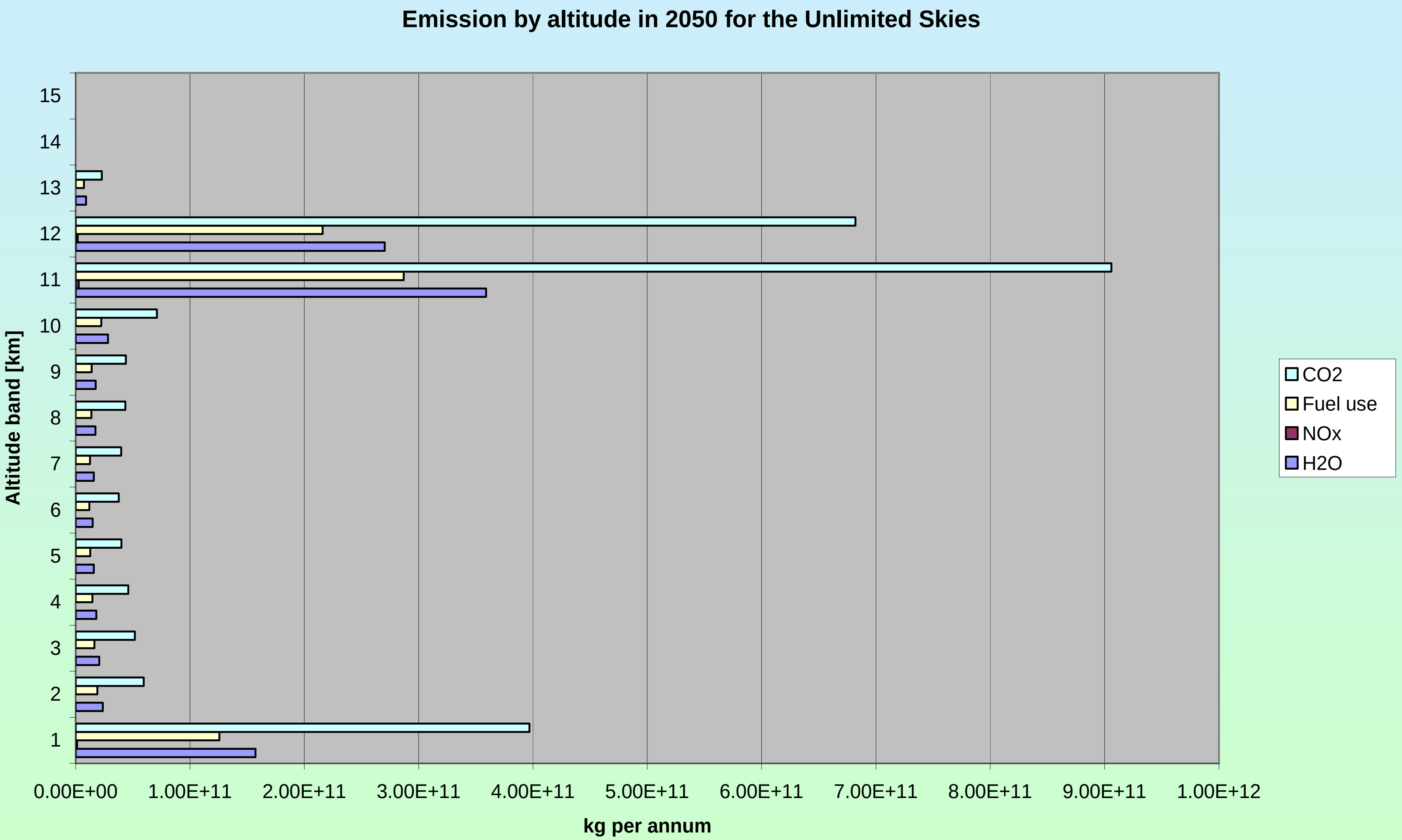
Emissions – CO2 and NOx share of global aviation


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



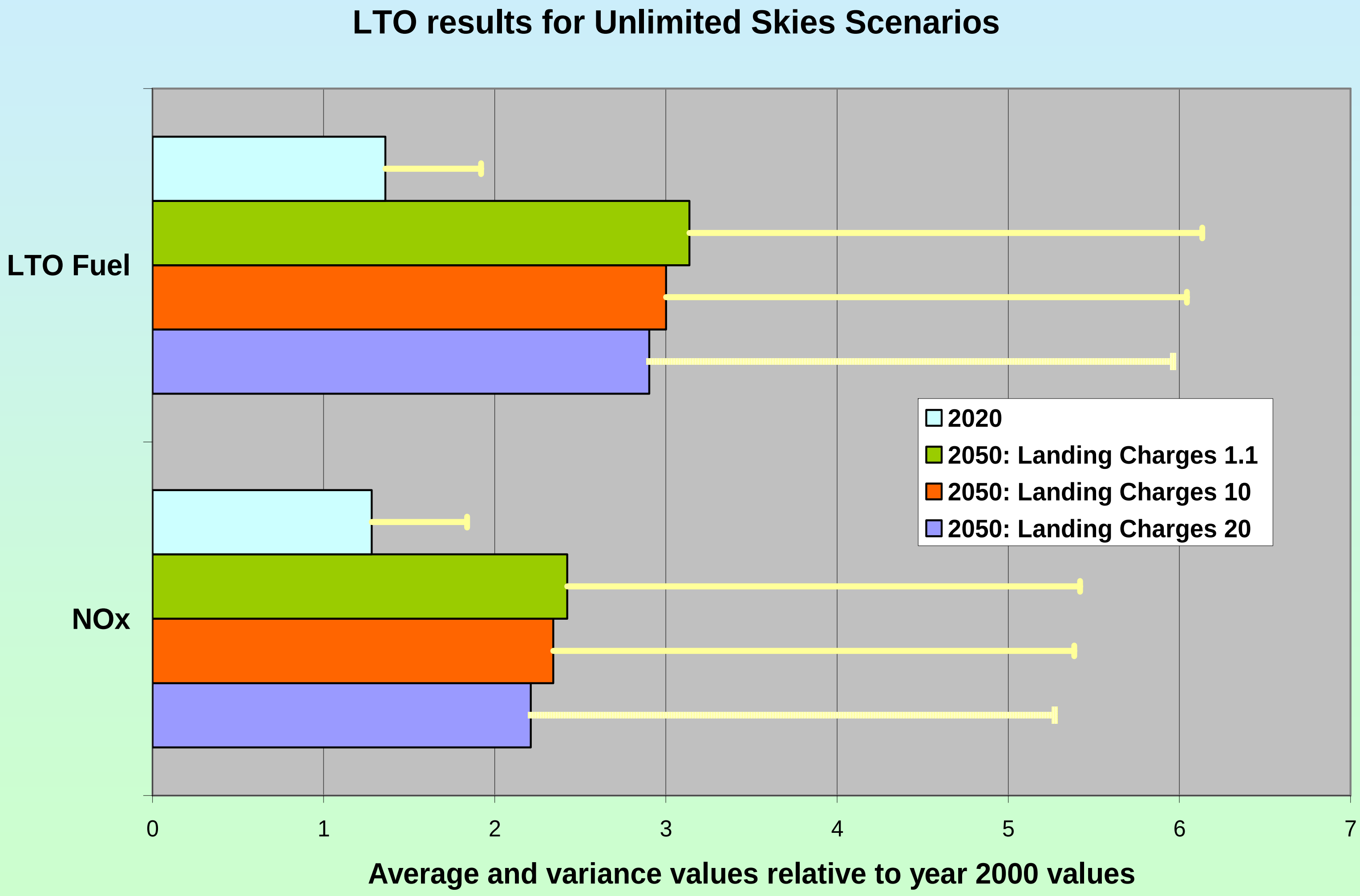
Local air quality – main results

- 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.

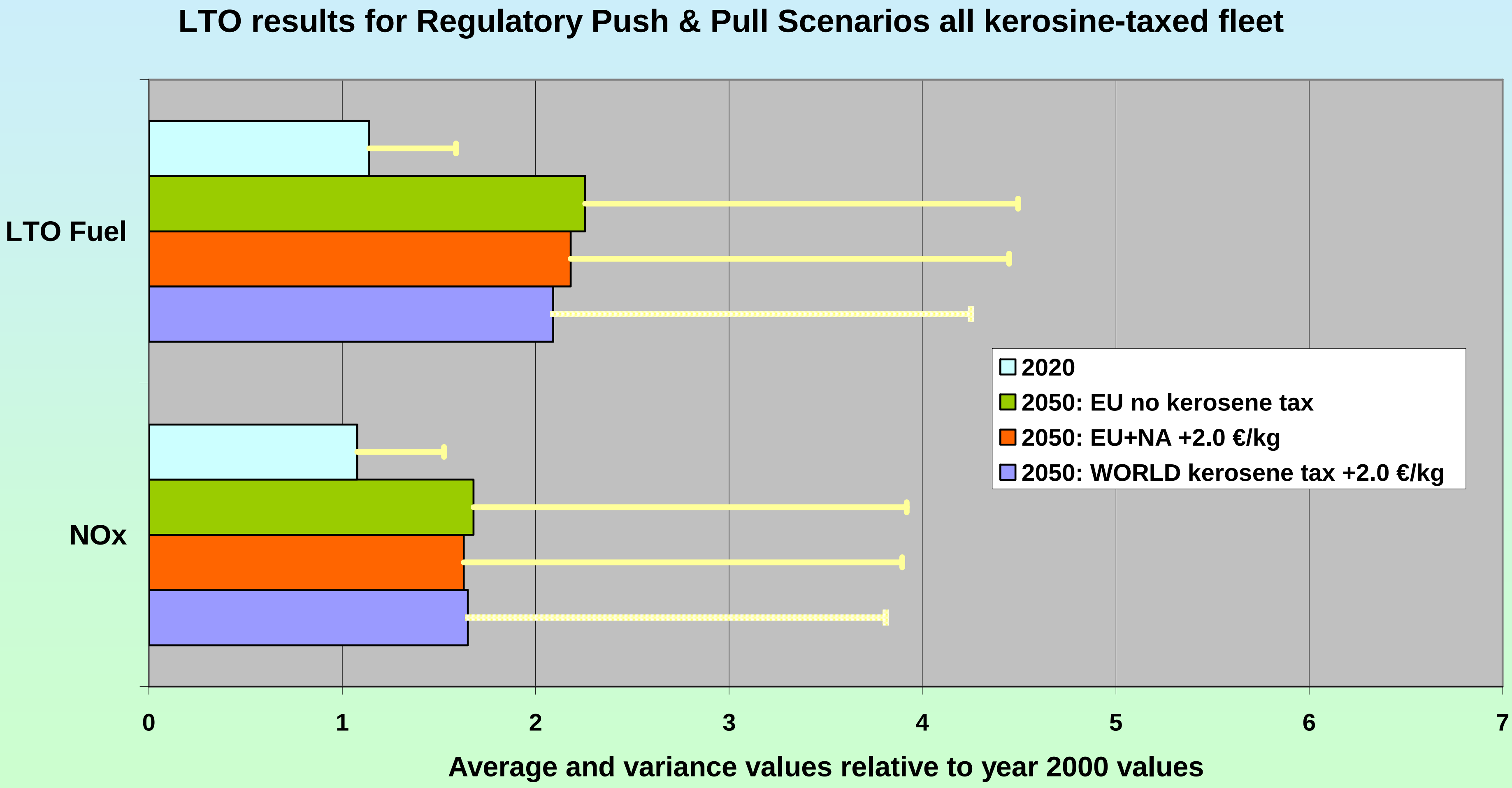
- In Regulatory Push & Pull with the all kerosene powered fleet scenario, local air quality obviously worsens, but at a lower pace than the Unlimited Skies. Also obvious, application of a kerosene tax (of the order of 10 % of the kerosene price) has only a small effect: Airlines and demand responses 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 if faced with heavy losses, even if they have sought the best possible position in fare levels.

Local air quality – LTO results for Unlimited Skies

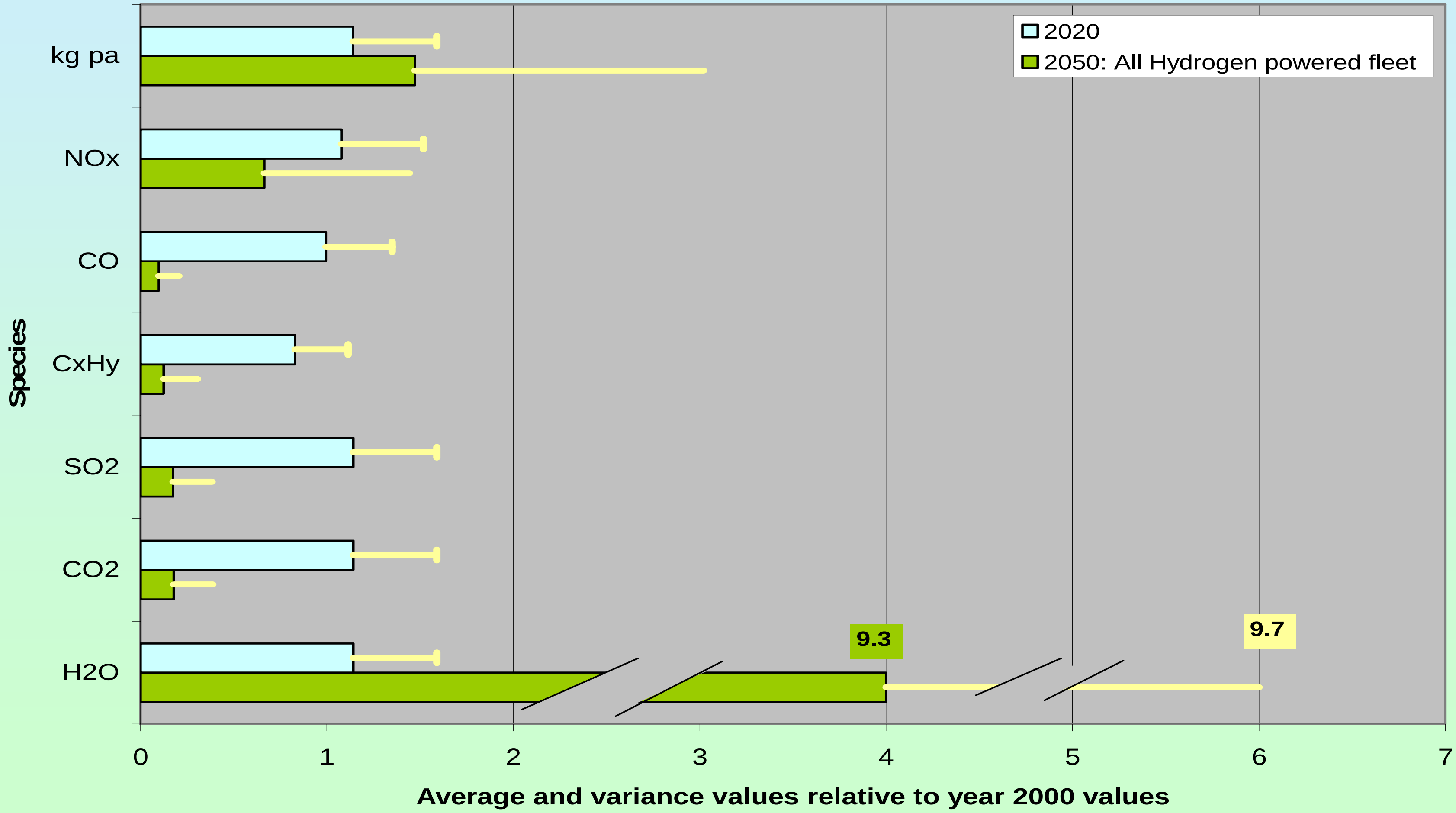


Local air quality – LTO results for Regulatory Push & Pull /Kerosene

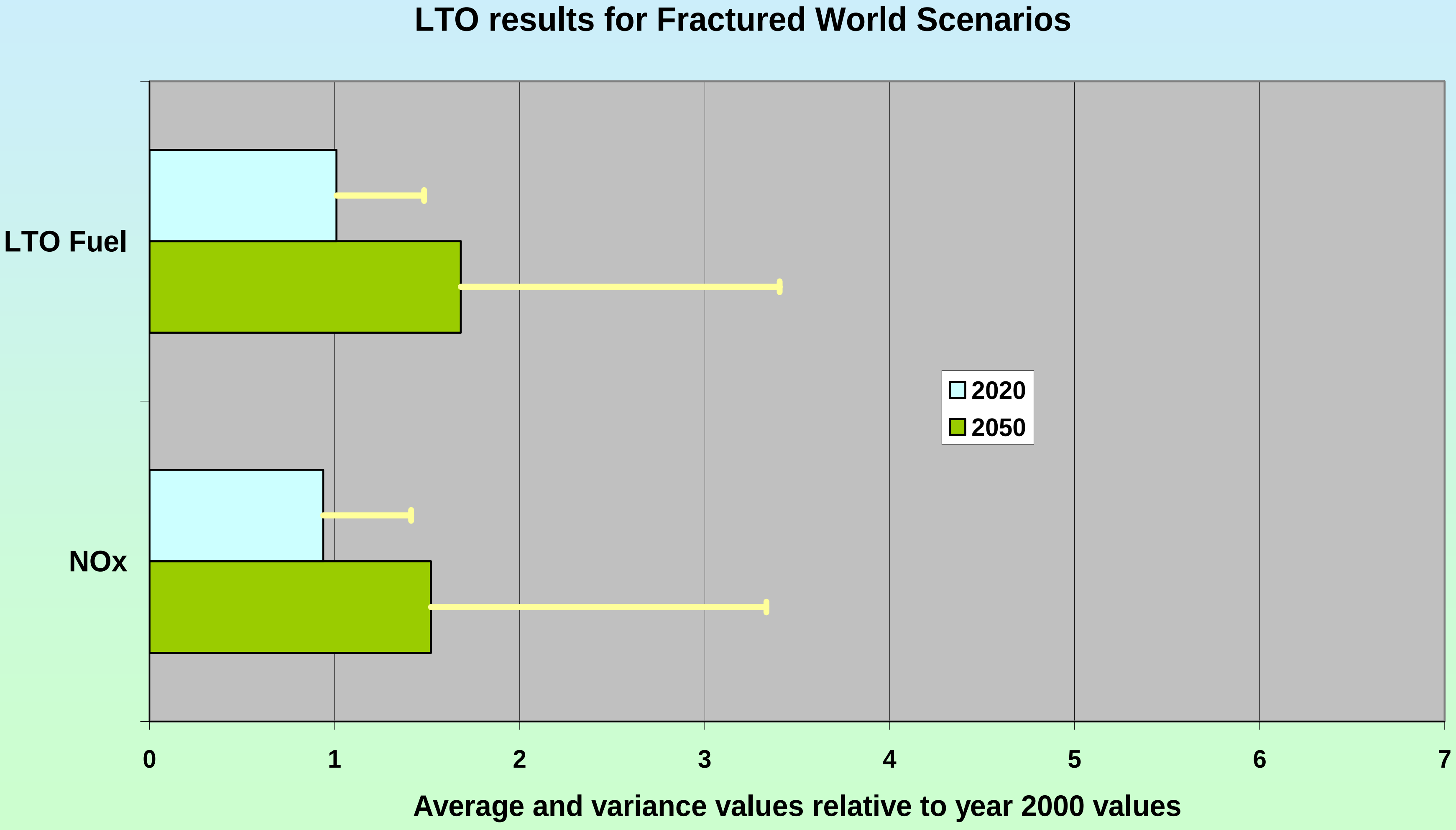


Local air quality – LTO results for Regulatory Push & Pull /Hydrogen

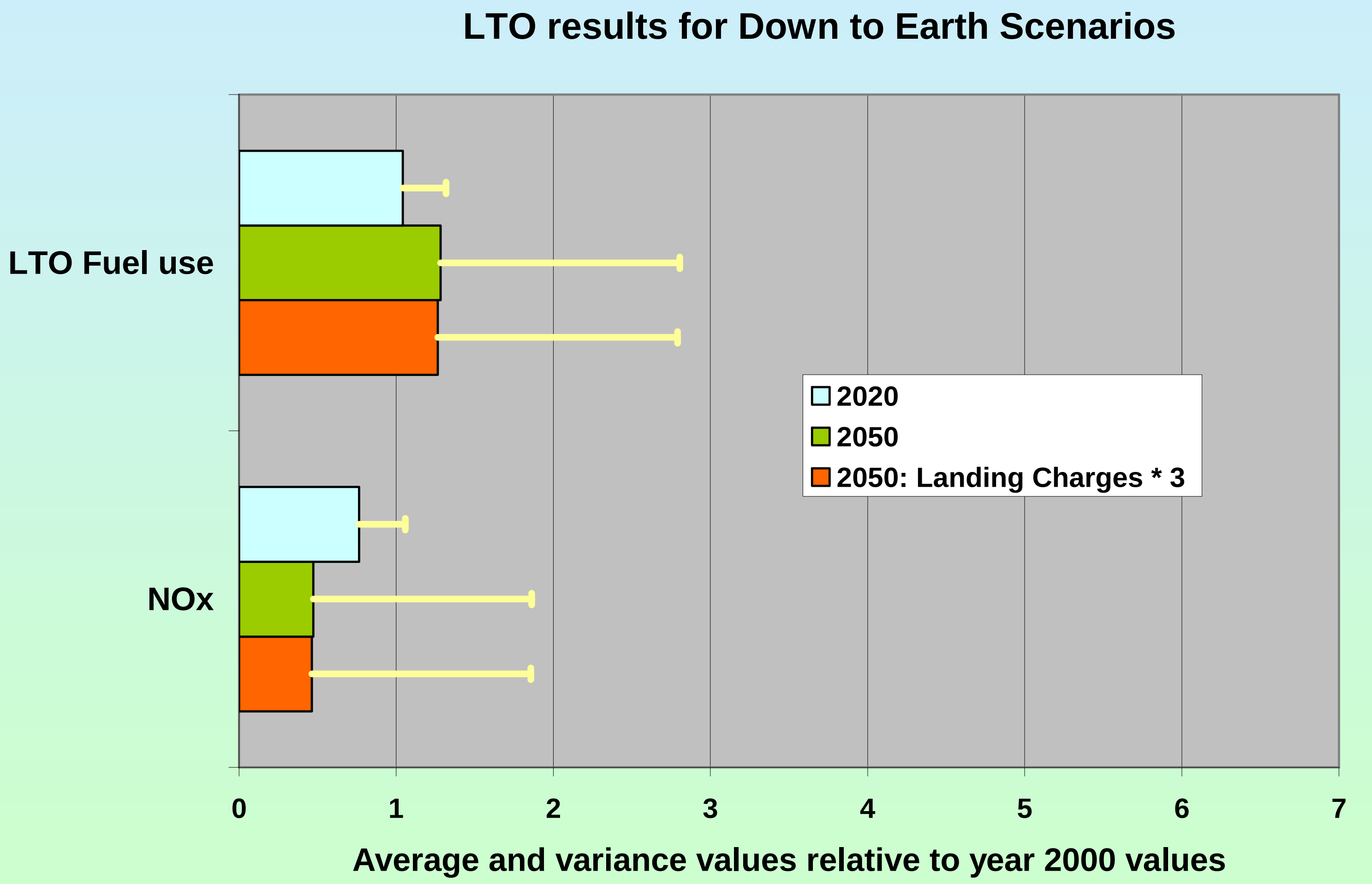
LTO results for Regulatory Push & Pull Scenario with transition to Hydrogen



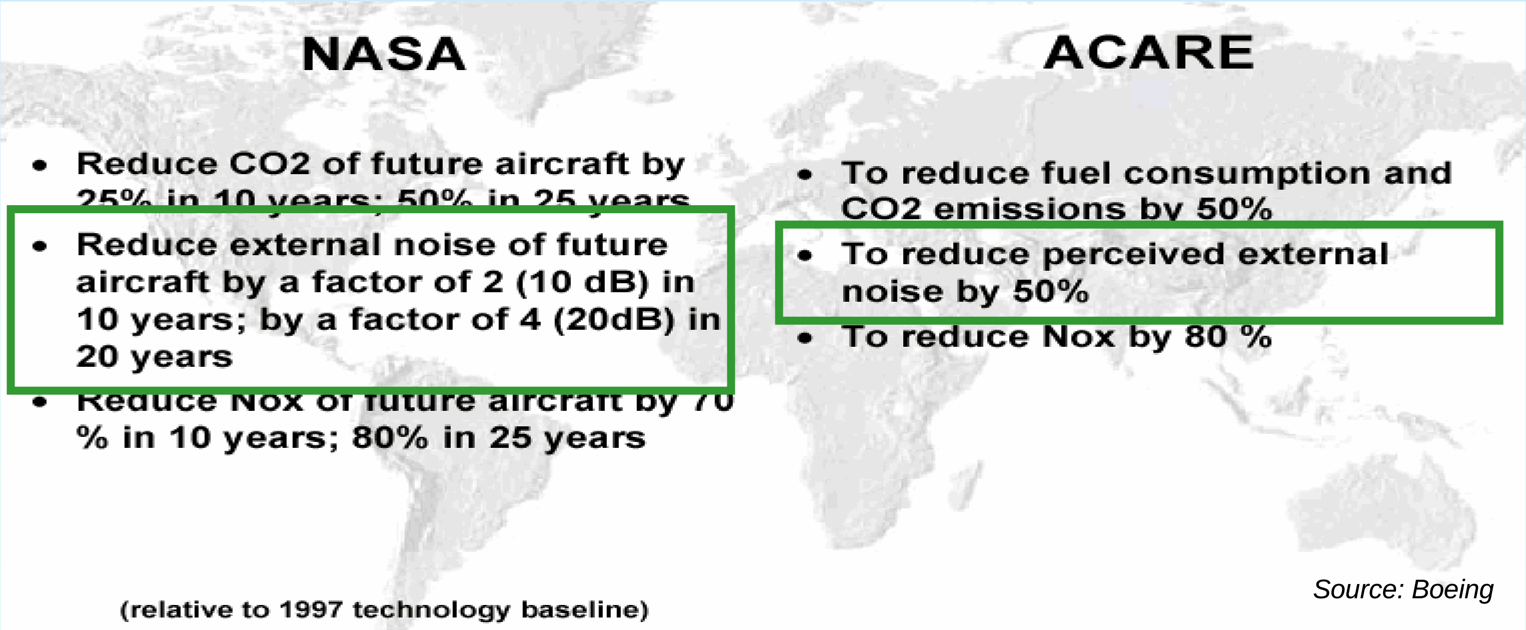
Local air quality – LTO results for Fractured World



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



Noise reduction in 2050



NASA

- Reduce CO2 of future aircraft by 25% in 10 years; 50% in 25 years
- Reduce external noise of future aircraft by a factor of 2 (10 dB) in 10 years; by a factor of 4 (20dB) in 20 years
- Reduce Nox of future aircraft by 70 % in 10 years; 80% in 25 years

(relative to 1997 technology baseline)

ACARE

- To reduce fuel consumption and CO2 emissions by 50%
- To reduce perceived external noise by 50%
- To reduce Nox by 80 %

Source: Boeing

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 Efficency				Profitability in	
	Demand	**Aircraft**	**Movements**	**NOx**	**2020**	**2050**
ULS (charge factor 1.1)					8.14%	6.88%
ULS (charge factor 10)	2.1%	4.7%	22.5%	1.3%		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:

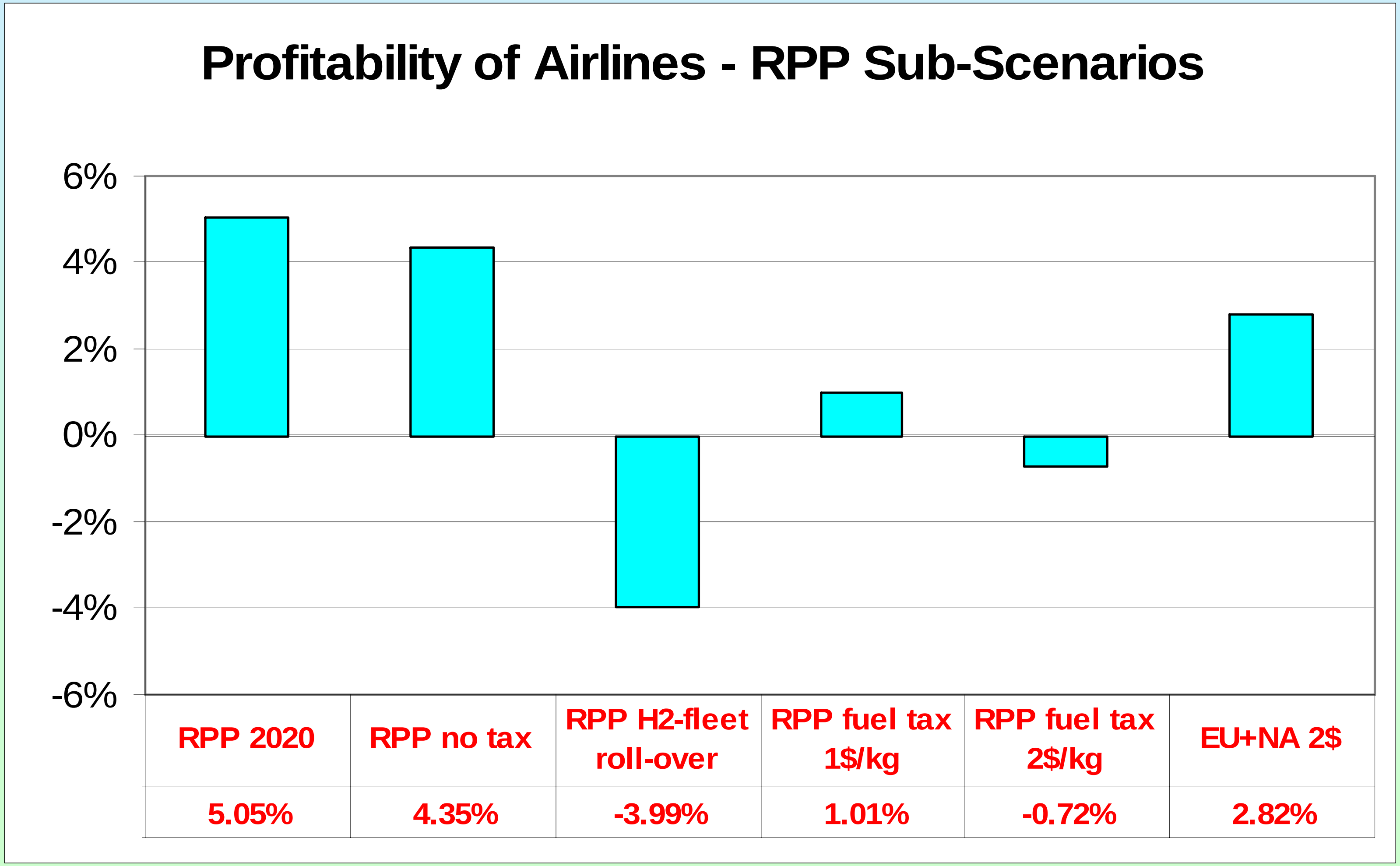
RPP Fuel Tax	Reduction compared to "no measure"			
	Demand	**Aircraft**	**CO2**	**NOx**
RPP (1$/kg)	2.6%	8.4%	5.5%	5.4%
RPP (2$/kg)	5.1%	14.5%	10.2%	10.1%
RPP Hydrogen	5.1%	8.6%	95.4%	71.9%

Assessment for Regulators:

RPP Fuel Tax	Measure Efficency				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)



RPP 2020	RPP no tax	RPP H2-fleet roll-over	RPP fuel tax 1$/kg	RPP fuel tax 2$/kg	EU+NA 2$
5.05%	4.35%	-3.99%	1.01%	-0.72%	2.82%

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