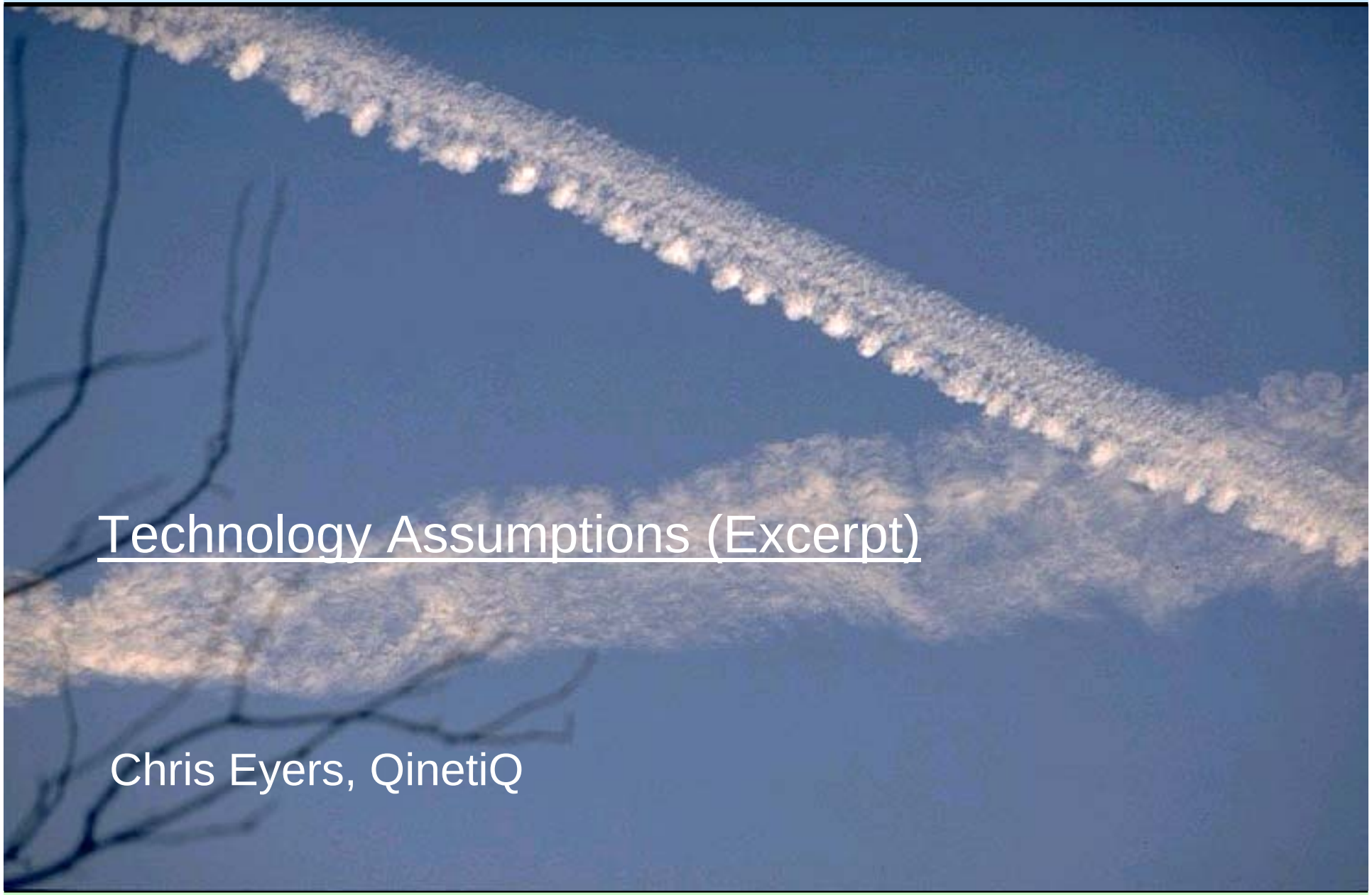


Technology Assumptions (Excerpt)

Chris Eyers, QinetiQ

Objective for the “Technical Assumptions”

- To provide aircraft and engine related technology assumptions for input to the AERO model

Key Assumptions

- Technology changes for conventional kerosene-fuelled aircraft from now to 2050 (2100)
  - fuel efficiency and emissions - CO_2, NOx and noise
  - fleet rollover, aircraft size, load factor, utilisation
- Emerging technologies - now to 2050 (2100)
  - hydrogen
  - others

Conventionally fuelled aircraft

- Technology assumptions were taken from a range of sources including:
  - 1999 IPCC report
  - CAEP
  - CRYOPLANE (EC FP5 project)
  - QinetiQ technology review
- Assumptions were adjusted to match scenarios (ie they are not simply the standard research goals)
- Assumptions are “best available” technology

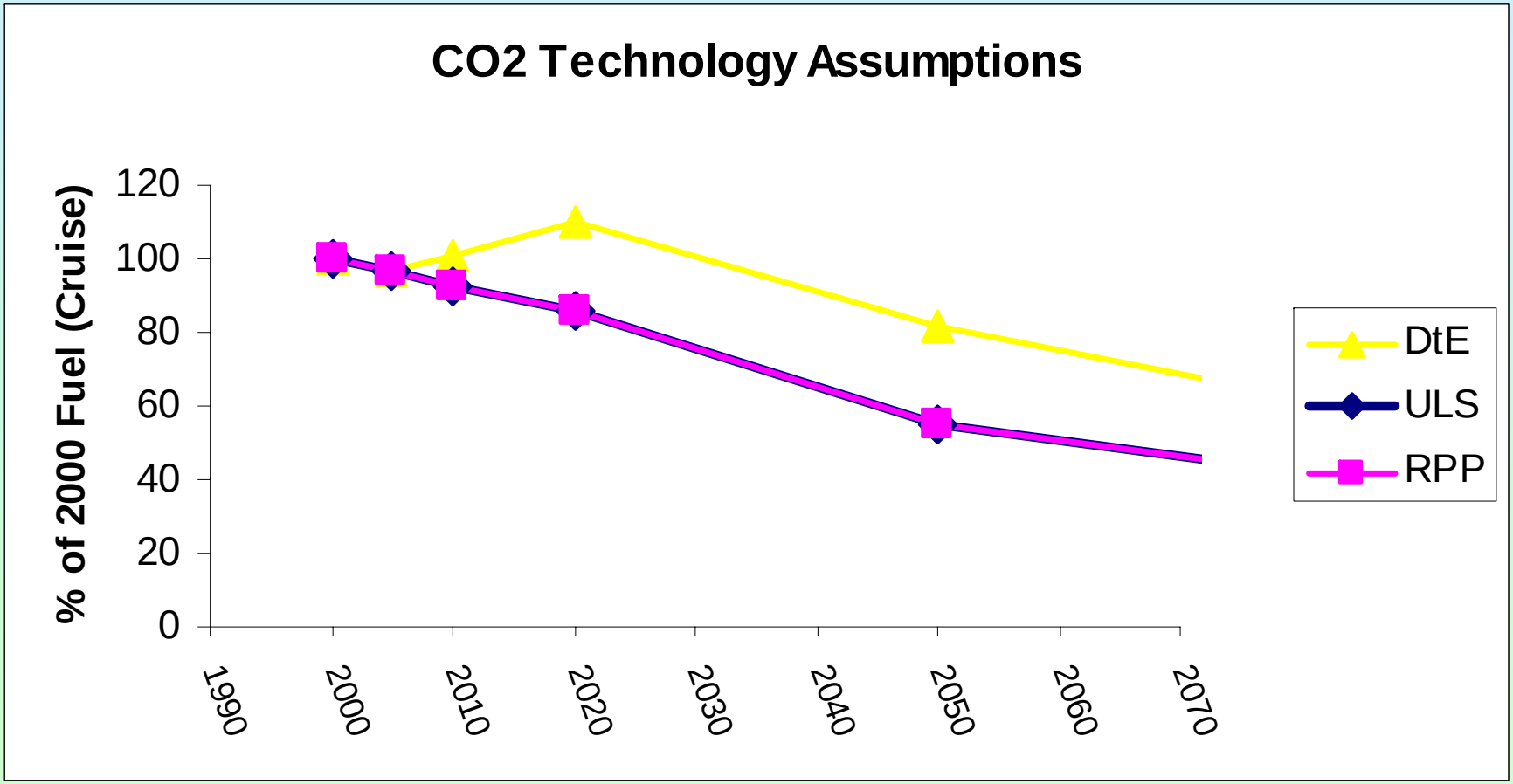
Conventionally fuelled aircraft – Emissions Assumptions

- CO_2 – a combination of aircraft and propulsion system improvements for cruise
- NOx – expressed as D_p/F_{oo} improvements (LTO)
- Scenarios dictate the CO_2/NOx trade-off:

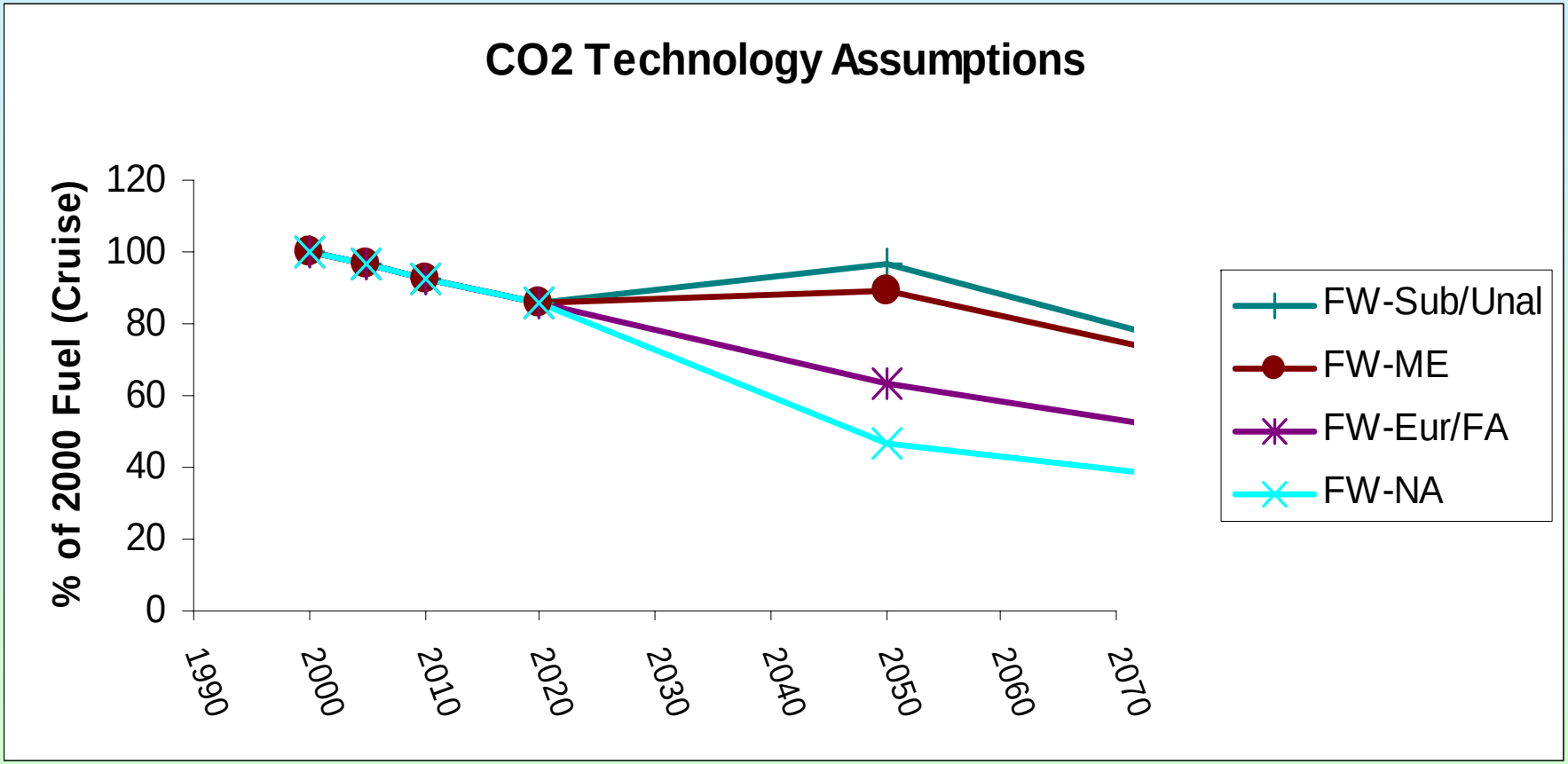
Conventionally fuelled aircraft - CO2

- Assumptions guided by current research goals to 2020
- Then progressive introduction on new technologies such as BWB, geared fans
- By 2050, these assumptions lead to CO2 efficiency improvements between 4% and 46%

Conventionally fuelled aircraft



Conventionally fuelled aircraft - CO2



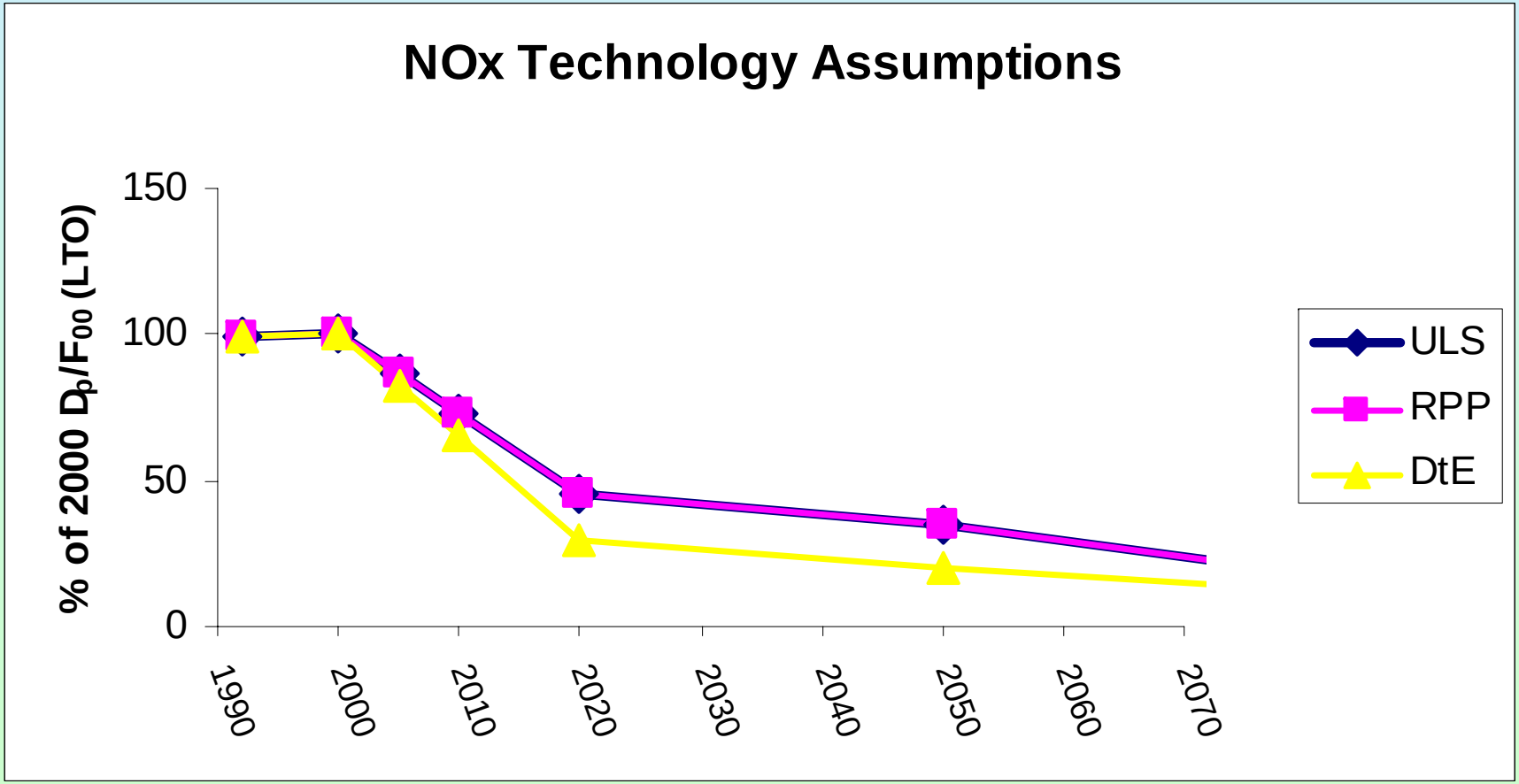
Conventionally fuelled aircraft - CO2

Variables and AERO Parameters	Estimations from QinetiQ			
	Unlimited Skies	Regulat. Push & Pull	Fractured World	Down to Earth
Technology assumption used	balanced NOx and CO2 reductions	balanced NOx and CO2 reductions	aggressive CO2 reduction (regional)	aggressive NOx reduction
Fuel efficiency change for kerosene fuelled aircraft over time (new technology)	2020: -10 to -20% below 2000 level (0.75% reduction p.a.)	<---- ditto 2020	<---- ditto 2020	2020: +10% c.f. 2000 levels (+0.5% increase p.a.)
1992: tsfc at SLS TO = 0.34 kg/hr/kg	2050: 1.5% reduction p.a. after 2020	<---- ditto 2050	2050: regional	2050: 1% reduction p.a. after 2020
2000: 0% change p.a.			N.America - 2% reduction p.a. after 2020; Eurasia, Far East - 1% reduction p.a.; Other regions, use same assumptions as described above for NOx	
	2100: Continue 1% p.a. reductions	2100: Continue 1% p.a. reductions	2100: Continue 1% p.a. reductions	2100: Continue 1% p.a. reductions

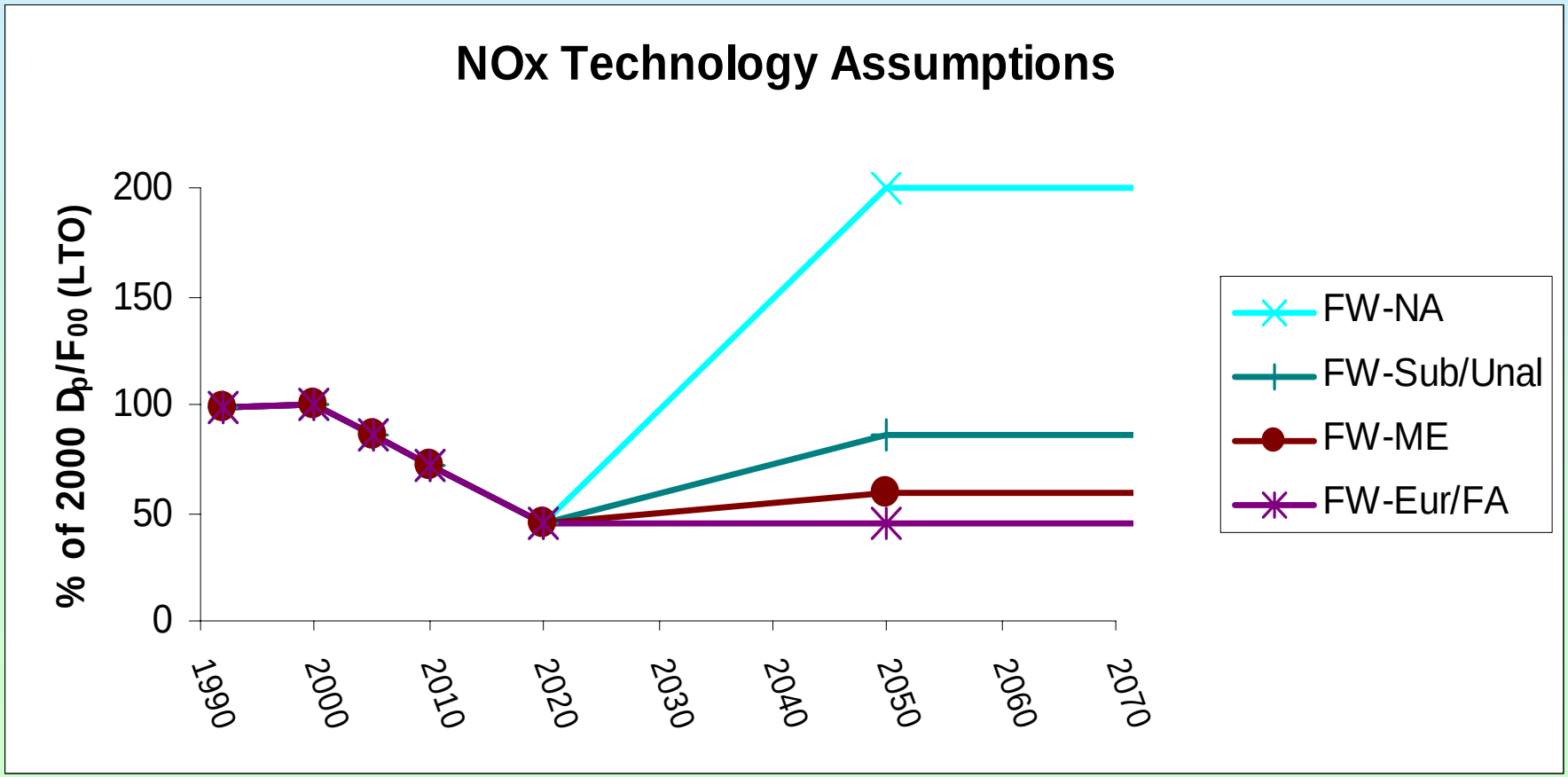
Conventionally fuelled aircraft - NOx

- Assumptions guided by current research goals to 2020
- Then further improvements become progressively more difficult, perhaps achieving levels similar to industrial GTs by 2100
- By 2050, these assumptions lead to NOx reductions between 65% and 80% for the 3 global scenarios

Conventionally fuelled aircraft - NOx



Conventionally fuelled aircraft - NOx



Conventionally fuelled aircraft - NOx

Variables and AERO Parameters	Estimations from QinetiQ			
	Unlimited Skies	Regulat. Push & Pull	Fractured World	Down to Earth
Emission change (NOx) for kerosene fuelled aircraft over time (new technology)	2020: -50 to -60% below 2000 level (2.25% reduction p.a.) **= 45% of 2000**	<---- ditto 2020	<---- ditto 2020	2020: CAEP/2 -75% (3.4% reduction p.a.) **= 30% of 2000**
1992: LTO Dp/Foo = 62 2000: +0.12% increase p.a	2050: -60 to -70% below 2000 level (0.33% reduction p.a.) **= 35% of 2000**	<---- ditto 2050	2050: regional	2050: CAEP/2 -80% (no further change)
			N.America - gradual increase to 2x 2000 levels (+15% increase p.a. average); Eurasia, Far East - maintain 2020 tech levels; Middle East - 2010 to 2020 aircraft mean levels; Subcontinent, Unaligned	
.	2100: CAEP/2 -95% (approx 0.6% p.a.) **= 7% of 2000**	<---- ditto 2100	2100: no further change	2100: CAEP/2 -95% (approx 0.5% p.a.) **= 7% of 2000**

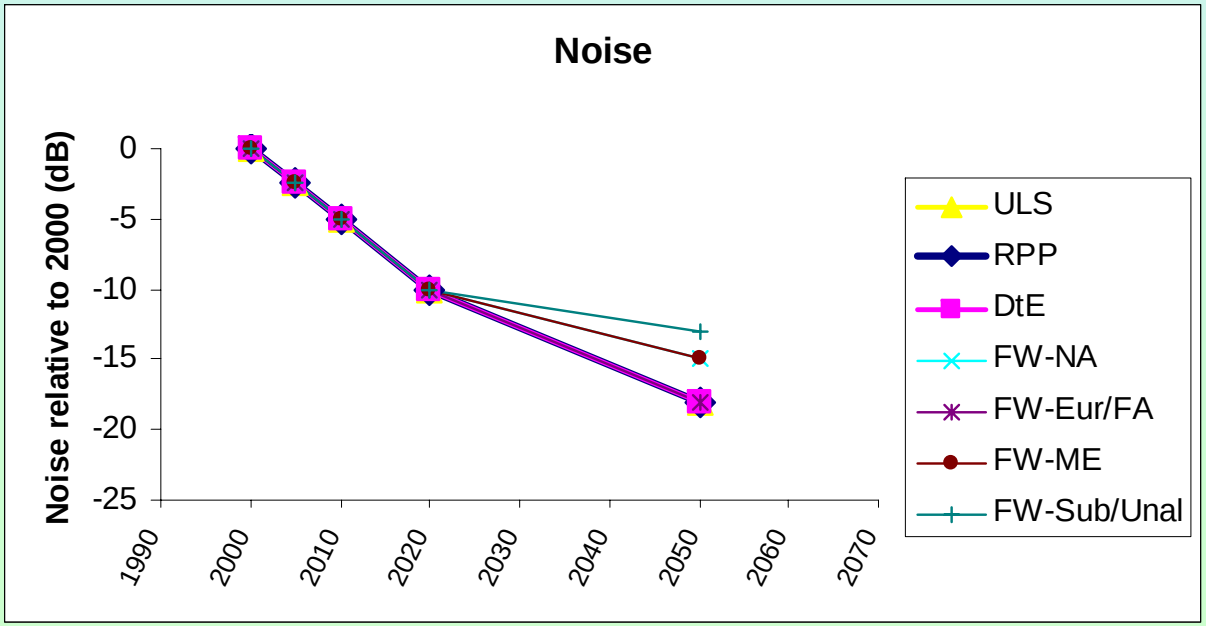
Fleet Assumptions

- Fleet Lifespan (except during LH2 changeover)

- Aircraft size growth – v large aircraft developed for global scenarios (Fleet average 220 ⮝ 287 seats)
- Load factor 71% ⮝ 77% ⮝ 80% (85% for FW)

Noise

- Assumed achievement of ACARE SRA targets to 2020
- Thereafter BWB, engines above wing, trailing edge nozzle and other detail measures give a further 8 dB by 2050, except in FW regions



Beyond Kerosene?

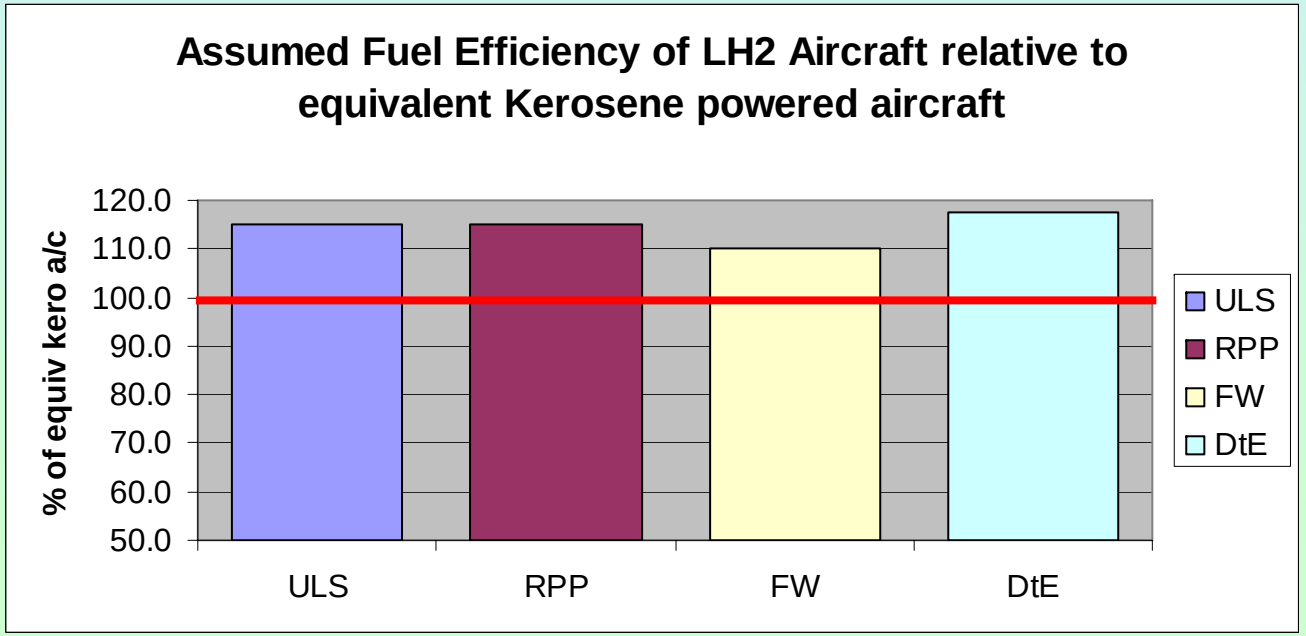
- 1999 IPCC Report: "Given the current state of technology there are simply no other energy conversion systems identified to date that can offer competitive levels of thermal efficiency and power-to-weight ratio for aircraft propulsion"
- Examined available data on fuels including EC CRYOPLANE plus a range of other data.
- Considered no fuel change, biofuels, zero-emissions air vehicles
- Best available assumption to provide useful scenarios:
  - Hydrogen-fuelled gas turbine power (based on CRYOPLANE) with fleet introduction varied by scenario

Beyond Kerosene? – LH2

- Fleet Introduction
  - Hydrogen–fuelled aircraft – possible by 2015
  - Airbus perspective
    - No manufacturer can produce 2 different technologies
    - Similarly the aviation industry cannot support 2 infrastructures
    - Therefore quick fleet rollover
  - CONSAVE Assumptions
    - Unlimited Skies – LH2 insignificant before 2050
    - Reg Push and Pull – short rollover 2040-2050
    - Fractured World – LH2 insignificant before 2050
    - Down to Earth – longer rollover 2040 to 2060
- Emissions?

Beyond Kerosene? - LH2 Emissions

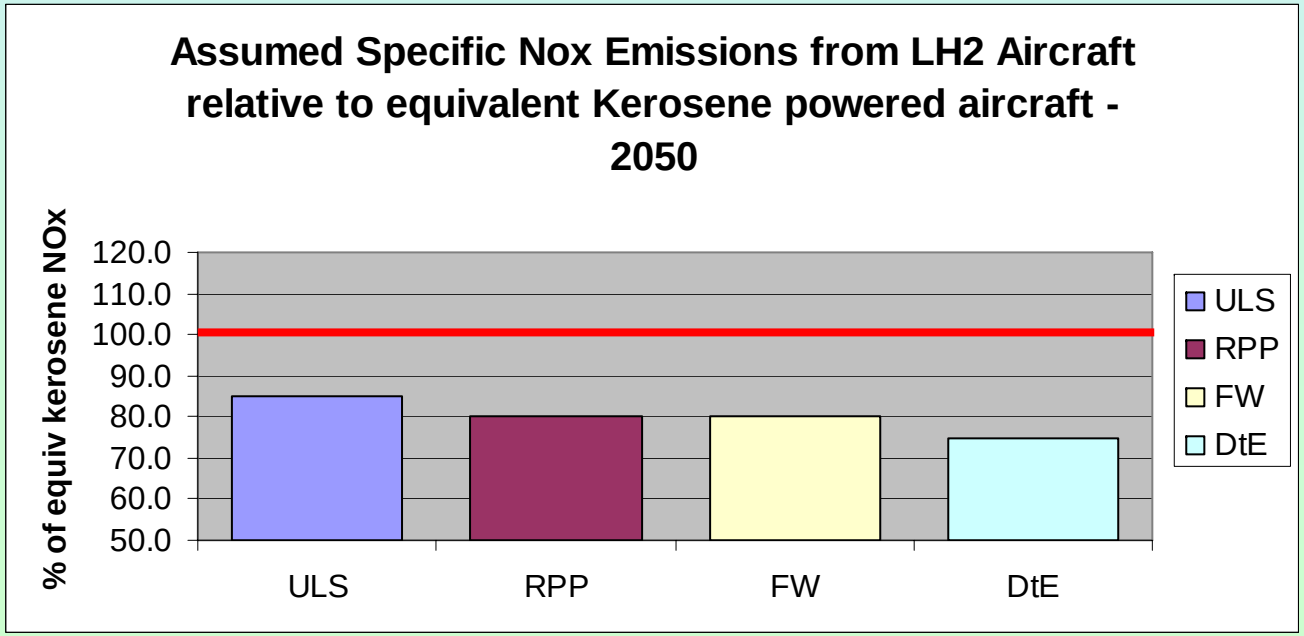
- **Emissions – CO2**
  - No CO2, but fuel consumption higher relative to equivalent technology kerosene-fuelled aircraft ⮙ water/particulates



Source: QinetiQ review based on CRYOPLANE/NASA Studies

Beyond Kerosene? – LH2 Emissions

- **Emissions – NOx**
  - Potentially very low but we have assumed that technology will not deliver this potential in full



Source: QinetiQ review based on CRYOPLANE/NASA Studies

Beyond Kerosene?

Variables and AERO Parameters	Estimations from QinetiQ			
	Unlimited Skies	Regulat. Push & Pull	Fractured World	Down to Earth
Proportion of fleet kerosene fuelled	100% in 2020	<---- ditto 2020	<---- ditto 2020	100% in 2020
	75% in 2050	50% in 2050	90% in 2050	40% in 2050
	0% in 2100	0% in 2100	75% in 2100	0% in 2100

- No CO2 from aircraft, but worse fuel efficiency

Hydrogen fueled vehicles - Fuel efficiency change over time	+15% compared to equivalent technology kero aircraft	+15% compared to equivalent technology kero aircraft	+10% compared to equivalent technology kero aircraft	+17.5% compared to equivalent technology kero aircraft

- NOx

Hydrogen fueled vehicles - Emission change (NOx) over time	Introduction:15% less NOx than equivalent technology kero aircraft	<---- ditto Introduction	<---- ditto Introduction (Eurasia only)	<---- ditto Introduction
	2050: 20% less NOx than equivalent technology kero aircraft	<---- ditto 2050	<---- ditto 2050 (Eurasia only)	30% less NOx than equivalent technology kero aircraft
.	2100: 25% less NOx than equivalent technology kero aircraft	<---- ditto 2100	<---- ditto 2100 (Eurasia only)	50% less NOx than equivalent technology kero aircraft

Summary

- CONSAVE Technical Assumptions have been generated as required by AERO model
- Some are clear, some subjective, some highly scenario dependent.
- Assumptions are made for 2020 and 2050, but beyond this speculation, even generalised, appears to have little value

Issues

- Introduction of “kerosene” replacement is both technically and economically uncertain and highly sensitive to other scenario assumptions
- Beyond 2050, aviation propulsion technology is highly uncertain i.e. not yet invented?
- Noise - difficult to express as a “technical assumption”
- Cirrus