Long Term Technology Goals for CAEP/7

WG3 and IE Chair

Introduction

Presented to the Seventh Meeting of CAEP

Peter Newton
LTTG Leader, WG3
February, 2007

Overview Schedule

- Introductions – Peter Newton
  - Technology Goals, Definitions,Review Process, Independent Experts
- Technology Readiness Levels (TRLs) and Technology Goals – Curtis Holsclaw
- Science Review – Malcolm Ko
- Technology Presentations – Will Dodds
- Review and Goal Setting – Malcolm Ralph
- Questions/comments
- Summary and Recommendations – Dave Lister

NOx Technology Goals

- Assessments of industry capability to reduce emissions
- Result from independent assessment
- Defined in certification parameters
- Both long and medium term …..
- …..10 and 20 years
- First goal setting review of this kind for whole aviation industry

Genesis

- Proposal that CAEP to be informed on possible future emissions reduction trends
- Policymaking needs long term view
- To be able to consider future possibilities for emissions improvements/standards
- Other views exist…..but CAEP needs its own…

Goal-Setting Process

- CAEP remit
  - WG3 emissions task
- Goal definition agreed
  - Linked to TRL levels
- Technology review process
- Science Input
- Independent Experts (IEs) and Review Panel
- Review schedule defined

CAEP Remit - 1

From CAEP/6, recorded in the Appendix A to the CAEP/6 report on Agenda Item 4, reference paragraph E.4.2, as follows:

"….for the purposes of establishing long term technology goals for aircraft emissions reductions:

a) implement a CAEP-approved process to **set, periodically review and update technology goals** and identify environmental benefits, taking into account progress in ongoing **R&D efforts** towards reducing aircraft emissions, environmental interdependencies and **trade-offs**, and **scientific understanding** of the effects of aircraft engine emissions;

b) support and monitor development of methods for understanding the interrelationship of technology goals targeting individual emissions performance improvements: and

c) develop the inputs appropriate for use of air quality and climate impact models to be used by CAEP to quantify the value of emissions reduction and to estimate the benefit from long term goals."

CAEP Remit - 2

- “Focus on NOx….and it would be envisaged to take into account any impact on other areas such as noise, CO2 etc. as second step, once CAEP has gained confidence in the process.”

- “Agreed the use of an impartial body of experts to contribute to a technology review that provides an independent assessment of future technology goals.”

Goal Definition*

- “**Medium term goal** - a declaration of the level of emissions performance from a specific engine thrust category that ……can be offered from an engine for aircraft service in ten years’ time. Such goals could potentially be framed with reference to the level of emissions performance demonstrated, for example, at Technology Readiness Level (TRL) 6. Experience to date suggests that demonstration at such levels may potentially be brought forward to TRL 8 over approximately ten years, assuming appropriate funding and support.”

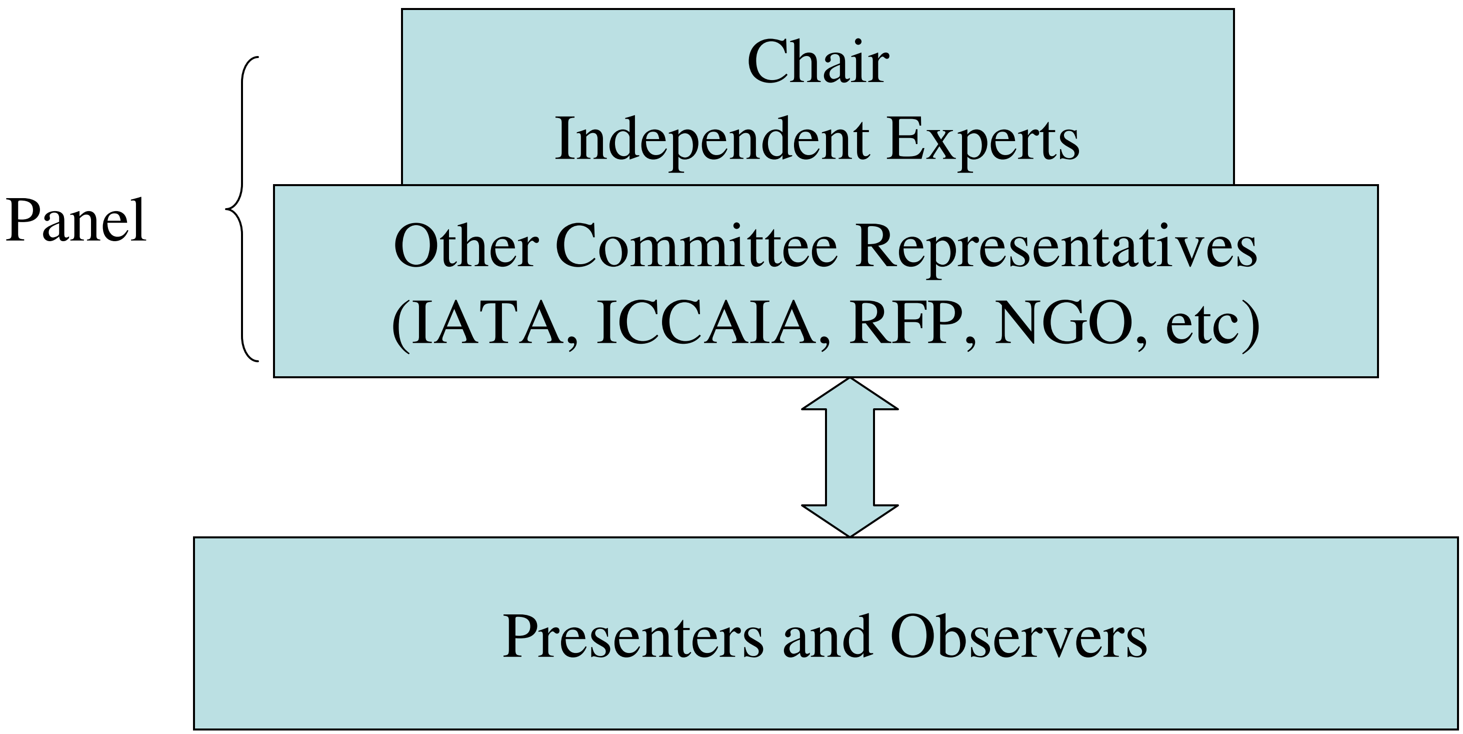
- “**Long term goal** – an aspirational declaration of ….. improved engine emissions performance in about twenty years. These goals could potentially be framed with reference to the level of emissions performance established for an engine/thrust category in research that is classified at, for example, TRL 2. Experience suggests that research at such levels could potentially take approximately twenty or more years to develop to TRL 8, assuming appropriate funding and support. Long term goals may be advanced to Mid Term Goals as research progresses through higher TRLs.”

* **Evolved during the IE review**

Technology Review Process

- Held in open forum
  - Data presented showed individual strategies (RR, P&W, GE and Snecma)
- Scene-setting overview
  - Policy, NGO, Science, Research Activities (NASA and Europe)
- Airline industry perspective
- Industry and Research Presentations:
  - Combustion technology “facts of life”
  - Recent certifications
  - Mid-term results (evolution)
  - Long-term prospects (revolutionary)
  - Technology Transition and Trade-Offs
- Goals needed to be quantified:
  - Parameter agreed as Dp/Foo for mid term goal prior to review
  - Parameter for long term not agreed and was to be determined at the review

LTTG Review Committee



Independent Experts and Review Panel

- Requested from interested states ……
  - Lourdes Maurice, Ben Zinn, Dan Webb – US
  - Malcolm Ralph, John Tilston - UK
  - Paul Kuentzmann – France
- Chair elected by IEs
- Panel members included industry
  - IATA and ICCAIA
- Facilitation from UK and US
- Review hosted by UK

Relationship Between the CAEP Goal-Setting and Standard-Setting Processes

Presented to the Seventh Meeting of CAEP

Curtis Holsclaw
Deputy Rapporteur, WG3
February, 2007

Background

- Underlying ICAO CAEP principles for standard-setting
  – Technological feasibility
  – Economic reasonableness
  – Environmental benefits
  – Environmental interrelationships and tradeoffs
- Recognized that relationship between goals and standard-setting processes needed to be understood

NOx Emissions Stringency Assessment at CAEP/6

- Working assumption agreed
  - “In the context of technology for improved emissions performance to be used as part of the basis for ICAO standard setting, technological feasibility refers to any technology demonstrated to be safe and airworthy, and available for application over a sufficient range of newly certificated aircraft.”

Technology Readiness

- Use of the Technology Readiness Level (TRL) scale
- Transition from long term to mid term goals, to consideration of certification standards
- Agreement on transition points
- Recognized that goal-setting will involve some degree of judgment on the performance outcome that is likely through the development process dependent upon TRL demonstration

Technology Readiness Scale

(Excerpted from CAEP/6-IP/4, Appendix A)

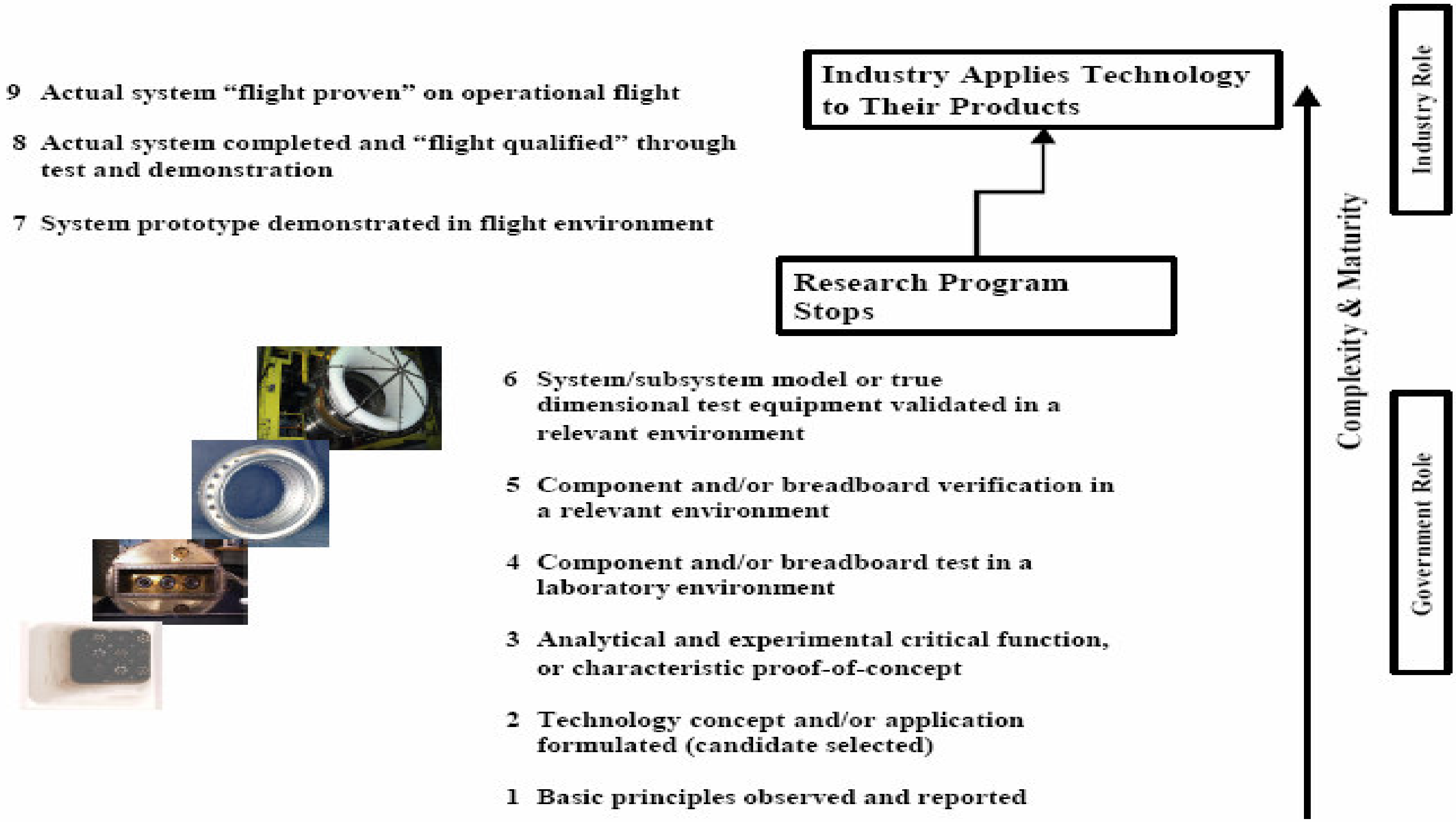


Figure 1. Technology readiness levels

Transition Points

- TRL8 is the point at which technologies are deemed to be technological feasible in the context of ICAO standard-setting
- Technologies demonstrated up to and including TRL7 are appropriate for consideration in goal-setting processes
  – Long term goals; TRL2-5
  – Mid term goals; TRL6-7

Technological Feasibility

- "In the context of technology for improved emissions environmental performance to be used as part of the basis for ICAO certification standard setting, technological feasibility refers to any technology demonstrated to be safe and airworthy proven to TRL8, and available for application in the short term over a sufficient range of newly certificated aircraft. Technologies demonstrated up to and including TRL7 are appropriate for consideration in medium and long-term goal-setting and review process."

Conclusions

- The TRL scale will be used as the primary mechanism for judging the state of development of technologies that are considered under both the goal and standard setting processes
- The transition from mid term technology goals to considerations for further standard setting, based in-part upon the technologies shown to have achieved such goals, is defined by technologies that have matured to the point that TRL8 status has been demonstrated
- The establishment of long term goals involves more uncertainty with regards to potential performance outcome and is farther removed from the standard-setting process

Science Review

Presented to the Seventh Meeting of CAEP

Malcolm Ko
RFP, WG3
February, 2007

Science Overview

Contributors

- –Claus Brüning (European Commission, Research, DG)
- –Malcolm Ko (NASA Langley Research Center, USA)
- –David Lee (Manchester Metropolitan University, UK)
- –Richard Miake-Lye (Aerodyne Research Inc., USA)

Scope

- "Provide an overview of the latest scientific consensus understanding of the effect of aviation emissions on the atmosphere for both local air quality and climate change in order to provide a contextual framework for raising future questions to help assess the environmental benefits of technology improvements in trade-off studies."
  - Trade-offs among aviation emissions and their environmental effects are only beginning to be studied in detail by the science community
  - Review is limited to environmental effects from emissions. Noise is not discussed, even though it could be part of the trade space.
  - "Science" refers to atmospheric science in studying global climate (GC) and local air quality (LAQ)

The Framework for Trade-off Studies

- Emissions
  - CO_2, H_2O, NOx, CO, UHC, HAP, SO_2, soot, PM
- The trade-off question
  - If technology improvements result in decrease in one emission at the expense of others, how does one determine whether those trades are beneficial?
- Steps

Emission	Concentrations	Impact	Common metric
CO_2	CO_2	global climate	GWP-weighted emissions?
H_2O, PM, SO_2, soot	contrail, cirrus	global climate	?
NOx	ozone	global climate, LAQ	?
NOx, UHC	NO_2	LAQ, health	?
PM, SO_2, soot, HAP	PM, HAP	health	?

- Associated uncertainties
  - Emission: depends on the airplanes and how they are operated
  - Concentrations: as predicted by models with uncertainties
  - Impact: global climate, LAQ: as predicted by models with uncertainties

Science and Policy in Trade-off Studies

- Science predicts **change in concentrations** and **impacts** from **emissions**
- Definition of a **common metric** across different impacts is a science/policy issue
- Ideal interactions between Science and Policy
  - Policy decisions are based on valid Science taking into account the associated uncertainties
  - Policy helps focus the scientific community on policy relevant topics
- Effective roles for the science community
  - Continue to look for answers in remaining scientific questions
  - Follow established process to produce a consensus view on policy relevant information from scientific findings
  - Use policy focus to bring different scientific communities together to begin work on trade-off issues

Current Status

- Decoupling of LTO and non-LTO emissions
  - LTO emissions dominate impacts on local Air Quality (LAQ)
  - Non-LTO emissions dominate impacts on global climate (GC)
- Absence of dialogue between GC and LAQ
  - The communities dealing with the two issues are quite distinct
- Because of different levels of understanding and current abilities to predict the environmental impacts, different approaches are being used to quantify the different environmental impacts of aviation emissions
  - Global climate, more emphasis on quantifying the actual impact
  - LAQ, more emphasis on using emission inventories to compare with other non-aviation emission sources

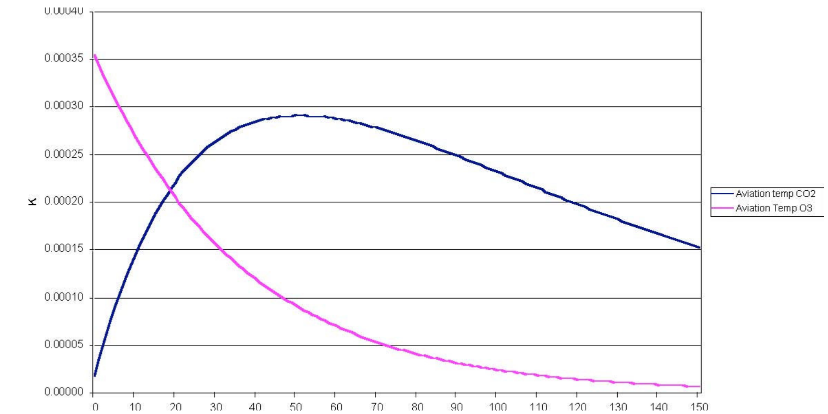
Global Climate

- **Environmental impact**/**Metric**
  - Global warming as a proxy for impacts such as sea-level rise, etc.
  - Radiative forcing is the proxy for warming effects of long-lived GHGs
  - GWP weighted CO_2 equivalent is the emission metric for long-lived GHGs
-

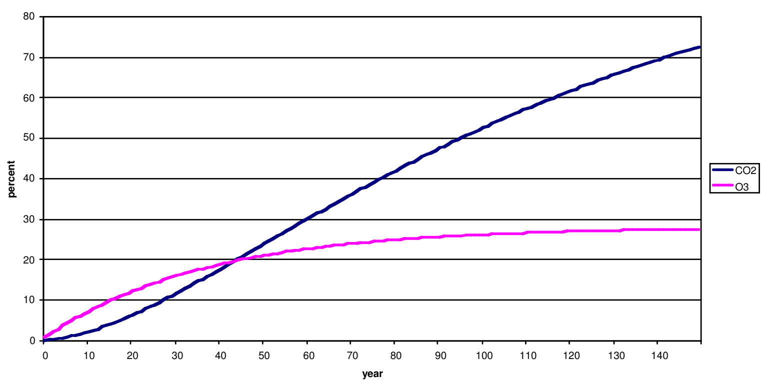
Key uncertainties	**CO_2/CO_2**	**NOx/O_3**	**NOx/CH_4**	**H_2O, PM/ contrail, cirrus**
Uncertainties in predicting changes in concentrations		X	X	X
Uncertainties in predicting forcing		X[1]		X[1,2]

[1] Forcing associated with short-lived GHGs. Does the same globally averaged radiative forcing for Short-lived GHG gives the same climate response as that from a long-lived GHGs?
[2] Optical properties of cloud and contrails.

Metric and Trade-off



Cumulative percentage contribution from aviation CO_2 and O_3 from NO_x to total global mean surface temperature response with a fleet 'pulse' of 100 Tg C/yr with an $EINO_x$ of 12 (O_3 efficacy of 1 assumed)



Trade-off Question: If a new design/operation leads to a reduction in NO_x emission, but an increase in CO_2, one needs to know what % reduction in CO_2 has the same effect as 1% reduction in NO_x. The answer depends very much on what metric one chooses.

Metric adopted	% reduction in CO_2 that will have the same effect as 1% reduction in NO_x	
	O_3 only	O_3 and CH_4
Instantaneous RF	18%	
Integrated pulse RF, 100 yrs	.01%	0.004%
Integrated pulse T, 50 yrs	1%	
Integrated pulse T, 100 yrs	0.5%	

Values are notional for illustration only, do not use for policy decision

Local Air Quality

- Engine emissions
  - **NOx, UHC** / **ozone, PM, NO_2**
  - **SO_2, PM, HAP** / **PM, HAP**
- Environmental impact
  - Health effects from exposure to ozone, NO_2,PM, HAP
  - Visibility impairment from NOx and PM

Local Air Quality

- Requirements are driven by local regulations
- Local response is site specific
  - Ozone response depend on background emissions at specific sites
  - Health impact depends on population exposure
  - This makes it extra difficult to define a common metric
- Inventory approach
  - Aviation at airport is one of many sources
  - Relative source strength provides a measure of the concentration response

Input needed from the science community

- Within global climate
  - Reduce uncertainties on impacts from contrails and cirrus
  - Need proxy for short-lived GHGs
  - Need "equality" metric for long-lived and short-lived GHGs
  - Need to reduce uncertainties
- Within LAQ
  - Site specific, how to define metric to cover range of conditions
- Trade-off
  - Agreement on how to compare different impacts, e.g. LAQ and climate change. Monetization is one possible approach
  - The scientific community must quantify uncertainties of actual environmental impacts to inform the decision making process.

ICCAIA Technology Presentation

…..to be added

Report of the Independent Experts on the 2006 Review of NOx Technologies and the setting of Medium and Long Term Goals

Presented to the seventh meeting of CAEP

Malcolm Ralph – IE Chairman, WG3

Montreal

February 2007

Report of the Independent Experts (IEs)

- Independent view
- Evidence based
- Honest endeavour within Terms of Reference
- 1st Review of its kind - learning by doing

Acknowledgements & Thanks:

Fellow IEs, Industry Committee members - Moderators - Manufacturer and Airline representatives – Science RFPs – Review participants

IE Panel Terms of Reference

IE Panel to Review and Report:

- Latest scientific understanding of aircraft emissions effects on Local and Regional Air Quality, and Climate Change
- Environmental need related to aircraft NOx emissions
- Environmental tradeoffs
- NOx reduction technology status
- NOx reduction technologies research outlook
- Review likely application of technologies in MT (10 year)
- Review more revolutionary technologies in LT (20 year)
- To set consensus Medium Term (MT) 10yr & Long Term (LT) 20 yr Goals for NOx reduction

The IE Report of the Review and Goals

- Comprehensive – we believe balanced
- Main Report is 60 pages – 116 pages including Executive Summary and Appendices
- The Report includes:
  - Lists of participants & presentations
  - Agreed summaries of Review presentations
- IE Reporting strategy:-
  - 1st Review therefore full Report
  - Subsequent Reviews recommend shorter updates

Process

- Panel of IEs + Industry members worked well
- Very good participation / commitment from all
- Follow-up Question & Answer sessions were very useful - some issues about ground rules
- Broad costs were considered but no Cost-benefit analysis (CBA) of the Goals was undertaken - insufficient time and lack of agreed models/scenarios
- Learning by doing

  Proposals for improving future Reviews
- Regional representation – room for improvement

Messages taken from Background Overviews

- Goals differ from Standards Stringency - fundamental differences
- Though Goals & Stringency are linked through TRLs
- Aviation is 2% of anthropogenic CO_2, 3.5%RF (but 1999 IPCC and 1992 data)
- But growing - UNFCCC key category - 15% of transport – IPCC estimate 5% of all combustion sources by 2050
- Some Climate impacts are very long term (example CO_2 100+ yrs) but assessments on such timescales are difficult
- Confirmed consideration of NOx is important, but need to consider other pollutants as well and noise

Long term trends

- No aviation trend information offered to Review
- IEs used 1999 IPCC (note 1992 base year)
- 1999 IPCC (CAEP FESG) 50 years:

  mid case: fuel x 2.5 to 2015, x 4 to 2050

  NOx x 2.7 to 2015, x 4.9 to 2050
- Rate of Stringency impact – only new certificated types - slow progressive introduction of new types & slow fleet rollover
- IEs view: scenarios at least 20-30yrs to 50yrs
- IEs informed of new trend analysis but this was not included as still ongoing and requiring agreement on methodologies and external review

Messages taken from Science / Need – Local Air Quality (LAQ)

- Limited consensus scientific information is available, however RFPs provided a balanced assessment and noted the uncertainties (LAQ & Global Climate change)
- Significant LAQ pressure exists already - noted 2010 NO_2 EU directive exceeded today at several EU airports – noted 80% of US top 50 airports in Ozone non attainment areas
- NOx is most significant LAQ pollutant today, but PM & UHC need to be studied in the future
- Source attribution near airports is a key issue.
- Aircraft contribution significant to 1km, relatively small 2-3 km away
- Note: no quantification was given of NOx reductions needed for LAQ (or Climate Change) targets

Science / Need
LAQ continued

- Pressure for further aircraft NOx reductions will continue at least in the 10 year MT
- More analysis is needed for 20 year LT including Cost Benefit Analysis if other sources reduce to provide headroom
- But continued growth in air transport likely to maintain the pressure on aircraft

Messages taken from Science / Need - Global Climate Change (GCC)

- Continuing uncertainties examples cirrus (0-Very Large impact) and PM
- NOx ranked highly, probably 2^{nd} only to CO2
- Climate response integration time is a key factor

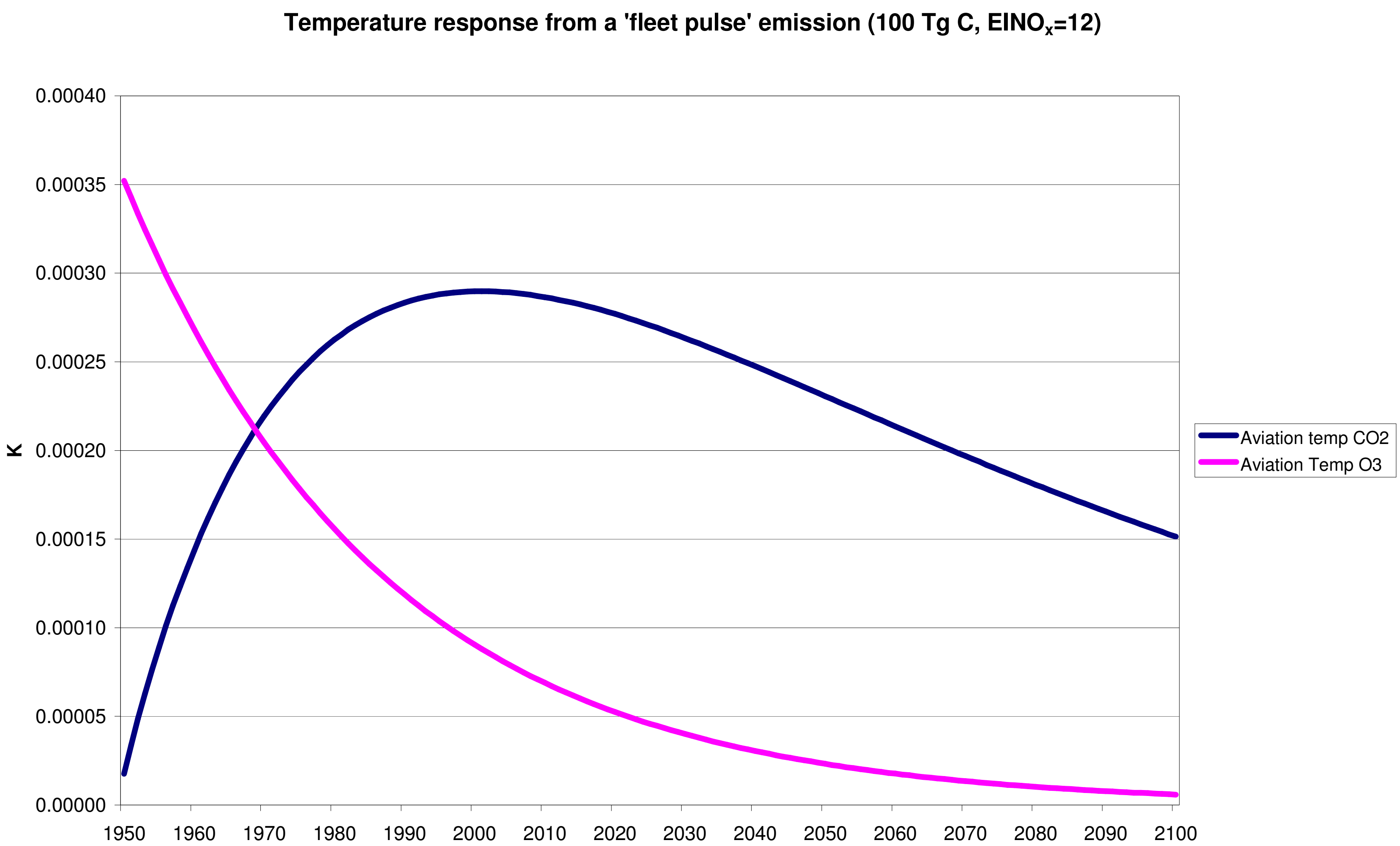
  Illustration of relative impacts:

  -instantaneous forcing CO2<<NOx

  -about 50yr temp. integrated response CO2 = NOx

  -and 100+yr temp. integrated response CO2 > NOx
- IE’s Concluded GCC pressure on aircraft NOx will continue at least in MT

Significance of Integration Time – Nox & CO_2



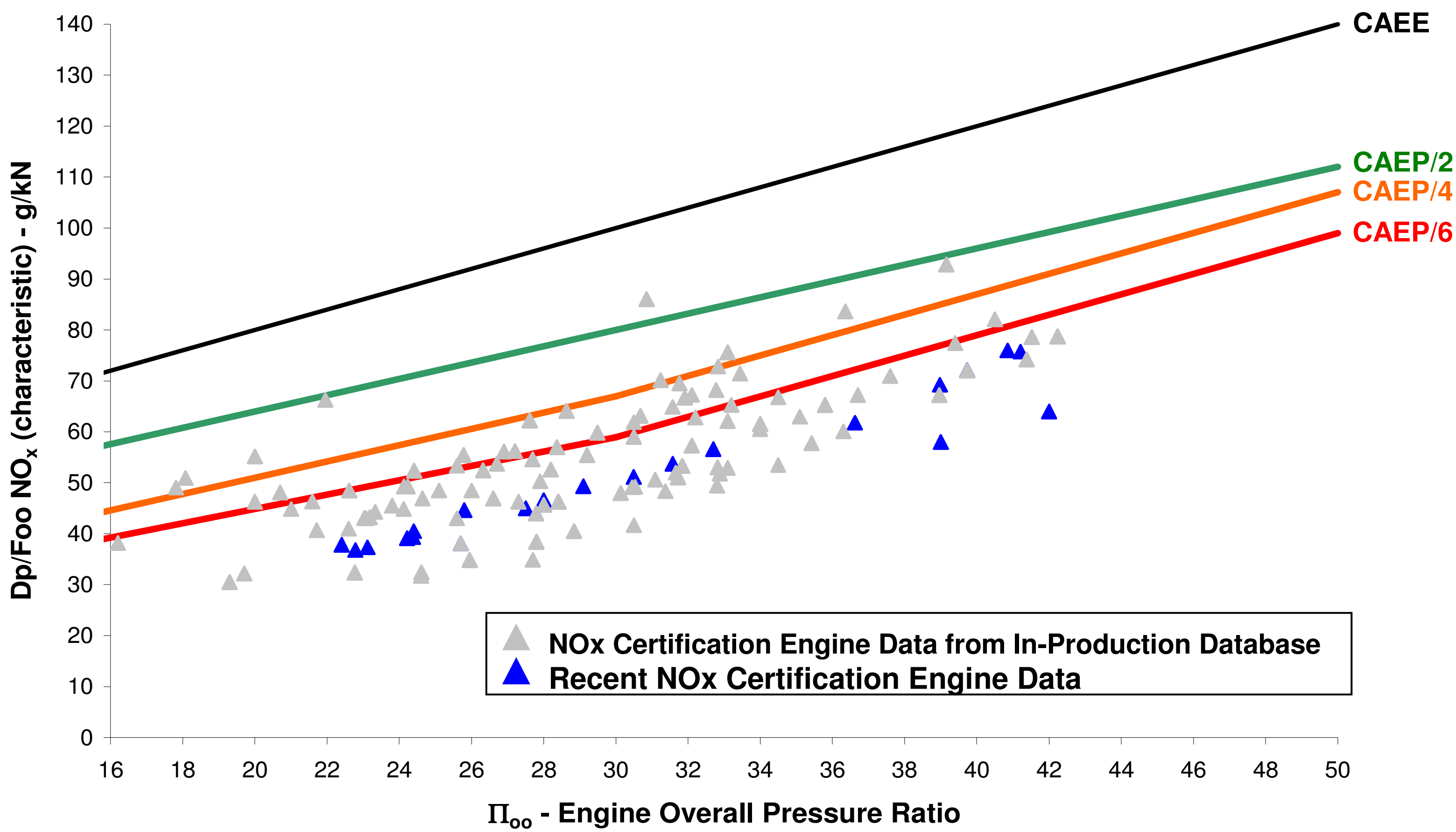
Trade-off Messages

- Potential trade: +(CO & HC) for -NOx but +CO_2
- One example: -11% NOx = +1% CO_2
  - but new technologies?
- One example: Min Noise = +1.5% NOx penalty
  - but new technologies?
- 30k ft. relight capability could challenge lean burn concepts
  - IEs recommended acceptability of 25k ft. be considered ?
- For Local Air Quality the conclusion was that today there is insufficient cost and benefit information to guide robust conclusions
- IEs concluded that from a climate perspective it would not be advisable to trade NOx and CO2 as reductions in both are important
- There is a need for more quantification to guide consideration at future Reviews
- NOx vs. Noise - not raised as a big issue at the Review
  - IEs believe this needs addressing in the future

Messages from Technology Review

- Successive increases in standards stringency
- Improvement rate: evolutionary TRL5/6-8 5-10yrs,
  revolutionary TRL2-8 20yrs
- Steeper family (throttle push) NOx slopes
- Recent engine certifications are below CAEP6 @ 5-20%
- Engines under development (eg B787) for mid 2008 are at TRL7 today & predicted @ CAEP6 -40%
- Past funding has provided today's technology pipeline
- MT costs were assumed affordable as substantially included in planned development programmes
- Concerns expressed by some over LT research funding
- Alternative fuels not expected to impact MT, and possibly LT also. Limited NOx reduction potential.

Engine certifications relative to CAEP stringency



Messages from Technology Review -links to Goals

MT: - Upcoming aircraft programmes (eg B787 yr 2008) considered likely to be within about 10%CAEP6 of MT Goal

- And A350 (yr 2013) and anticipated new narrow bodied aircraft will provide further focus for MT technologies

- Examples GE (TAPS 2), PW (Talon X Annular), (RR T1000), Snecma SaM146

- Different approaches (Lean & Rich burn) – give confidence

LT: - Examples GE/CFM (Taps 3), PW (Talon X Sector Rig), RR (Lean Burn)

- Fall within or close to LT Goal band

- Again different technical approaches increase confidence

- But currently pre TRL 3 - uncertainty

- Some Company targets and external Research targets noted, but these did not dictate the Goals

Goals philosophy – evolved during Review

- Environmental NOx pressure accepted - no direct link to quantified environmental need – Goals set more by predicted technology capability
- Compliance: leading edge of NOx technology - ‘best’ with reference to CAEP/6
- Goals fundamentally different from stringency
- A Goal has to be more aggressive than best available technology
- Goal met when one (or more) manufacturer reaches goal with a new product
- Accept this ‘simple’ approach raises issues:

  eg steeper family NOx slopes, competition, possible small engine issues, thrust alleviation, and note no CAEP6-style OPR 30 “kink” in Goal bands

  – all considered by IEs to be stringency issues
- Metric: Current LTO-based metric (for MT) said to provide reasonable cruise NOx estimation, but estimation accuracy not certain for new technologies
  - Note %CAEP/6 has been used for long term goal as well

Goals uncertainty

- Achievement is not guaranteed
- Goal bands used rather than single line
- Band width greater LT than MT, reflects greater uncertainty
- Uncertainty – both level & achievement date - note sub-scale technologies are at varying TRLs
- IEs consider there to be a 50% probability of achievement at mid band position
- Small engines relief - believe MT Goal achievable, may not be true LT

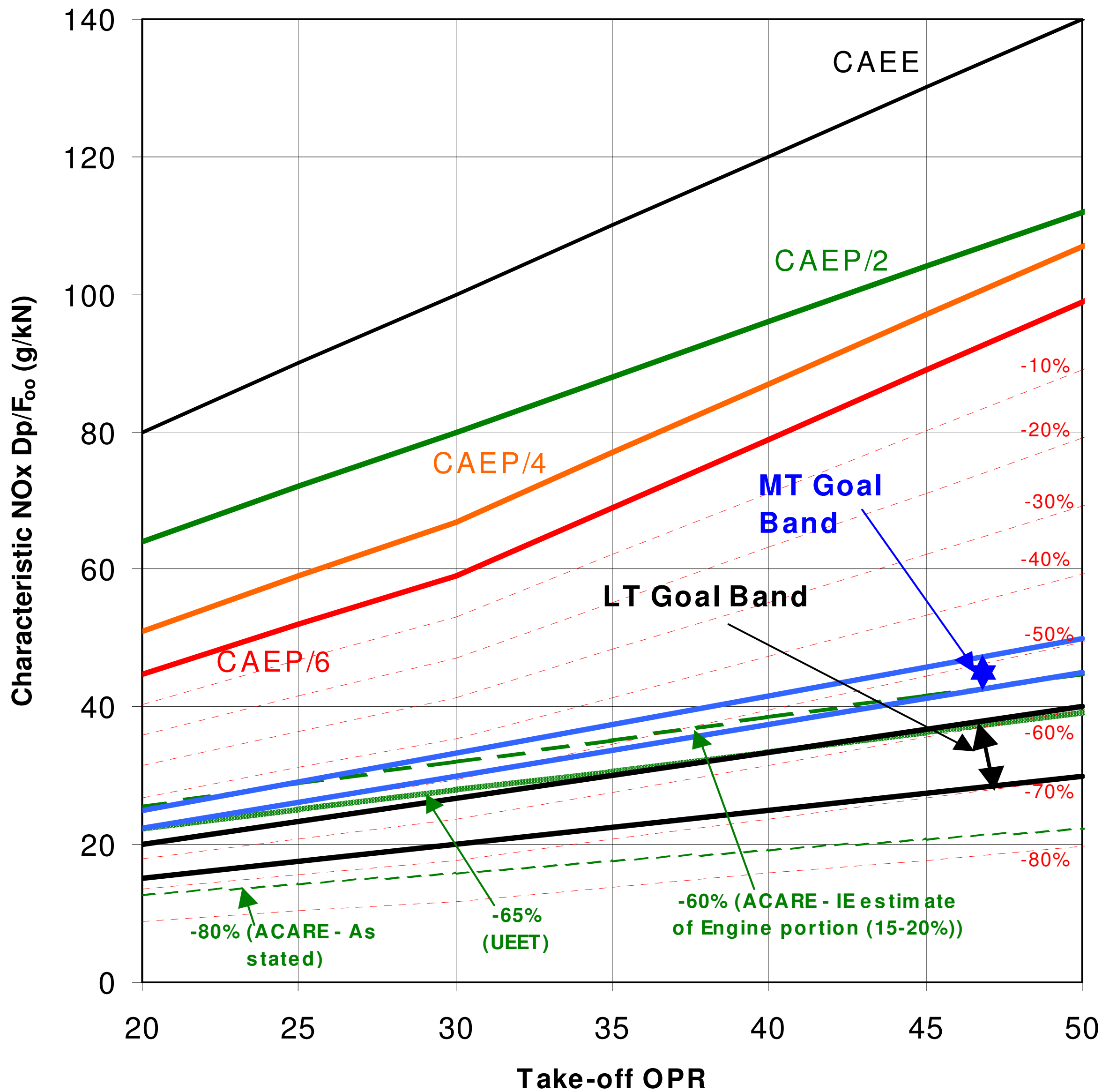
Recommended goals

- 2016 Medium Term Goal:

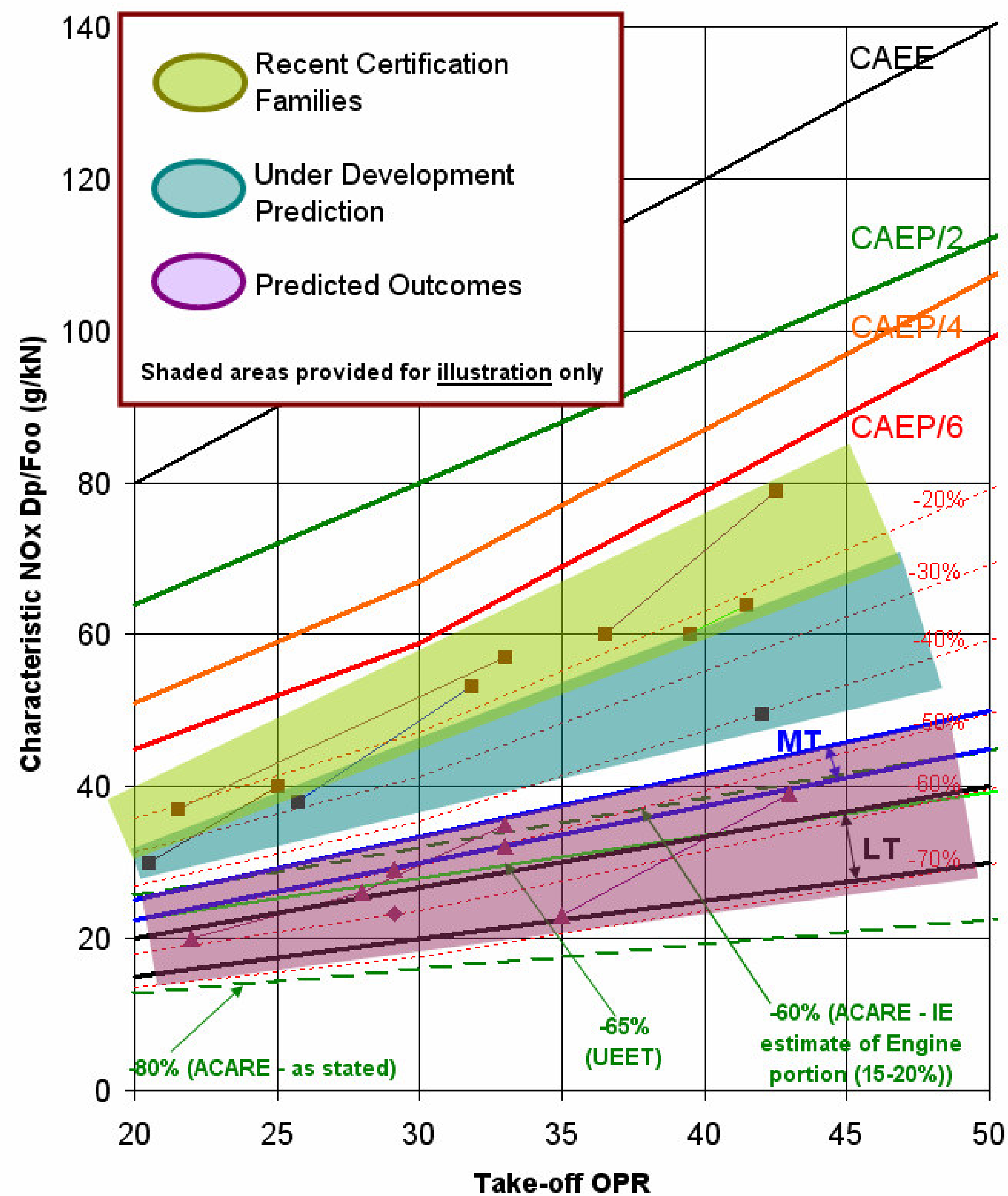
  CAEP6 -45% +/- 2.5% (of CAEP 6) @ OPR30
- 2026 Long Term Goal:

  CAEP6 -60% +/- 5%   (of CAEP6) @ OPR30
- Note large difference between CAEP6 and MT Goal, but smaller gap between MT and LT bands
  - this emphasises the differences between stringency and goals
- LT goals and beyond may offer diminishing returns
  - need for additional scientific advice and CBA

MT and LT goal bands



LTTG Technology Goals: Mid- and Long-Term



Consensus

- IE consensus on Goals and all major findings was readily achieved
- Active participation/engagement
- Participant access to drafts
- No remaining significant disagreements with participants

IE’s Shortlist of High Level Conclusions

1. Despite continuing scientific uncertainty, it was clear that both NOx and CO_2 must be addressed in future systems although the balance is tipped towards CO_2 having the greater long term impact

2. Due to significant investment in R&D during the 1990s and beyond there is sufficient technology in the pipeline to support a MT NOx Goal substantially below CAEP/6 with a relatively narrow band of uncertainty

3. Challenging LT Goals will require technology breakthrough and uncertainty is significantly greater nonetheless multiple research predictions support the chosen Goal

4. These Goals were based on technology capability driven by qualitative environmental need: future Reviews need to move towards quantifying need and assessing what technology can contribute

5. Given present knowledge no significant opportunities were found to trade one emission against another: it was considered inadvisable to trade lower NOx against increased CO_2: for consideration of other potential trades a better quantifying process and tools are required