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Advanced Manufacturing Research Centre

BOEING

Life Cycle Analysis of Advanced Manufacturing Methods and Transport in the Aviation Industry

Professor Alma Hodzic, AMRC Research Director

The University of Sheffield, UK

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Industry and Academia Working Together

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CATAPULT High Value Manufacturing

EUROPEAN UNION Investing in Your Future European Regional Development Fund 2007-13

Industry & Academia Working Together

Regional Impact of AMRC Composite Centre:

180 jobs created
83 Knowledge Collaborations
£3.5M Private investment
15 Instances of company’s leveraging R&D finance through collaboration

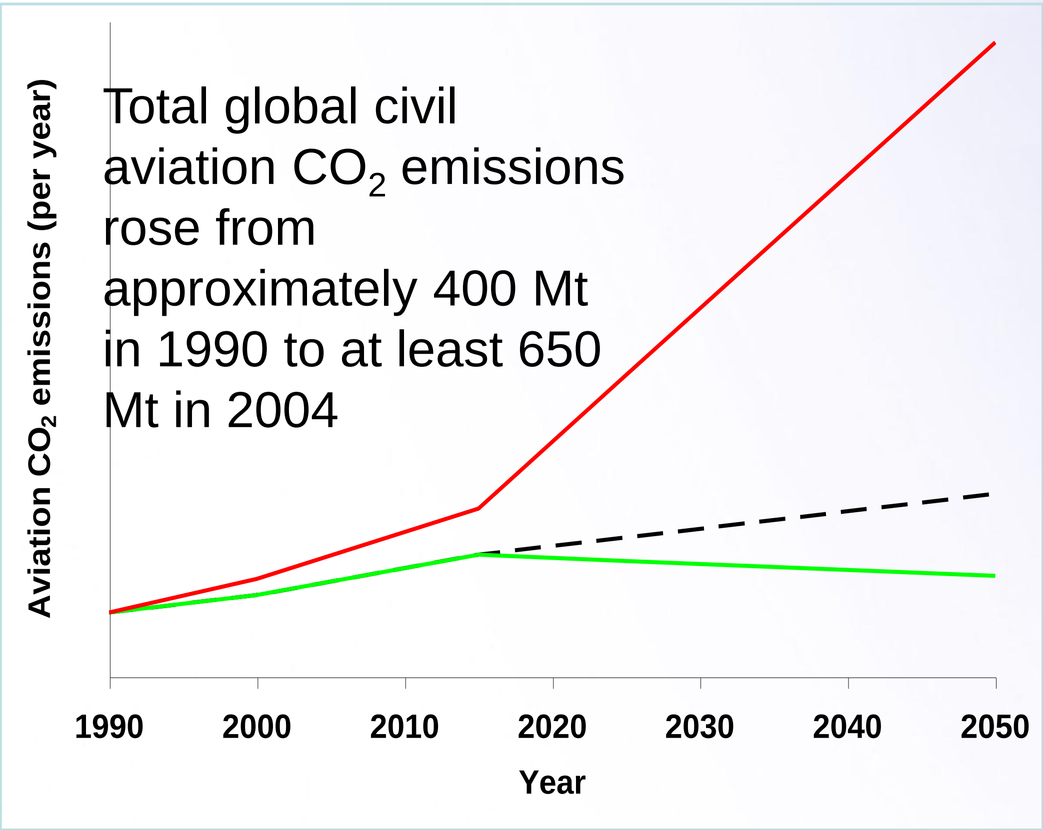
CSI Centre:

13 Core and 15 Affiliated Academics
40 Active Researchers
£4M live research income
…and growing.

Main processes causing atmospheric changes resulting from aircraft emissions

1. Direct emission of radiatively active substances (e.g. CO_2 or water vapor)
2. Emission of chemical species that produce or destroy radiatively active substances (e.g. NO_x, which modifies ozone concentration)
3. Emission of substances that trigger the generation of aerosol particles or lead to changes in natural clouds (e.g. contrails)

Predicted emissions level in the aviation

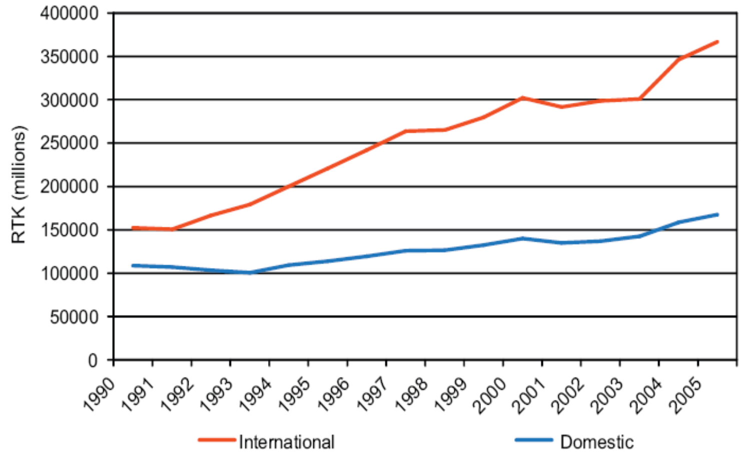


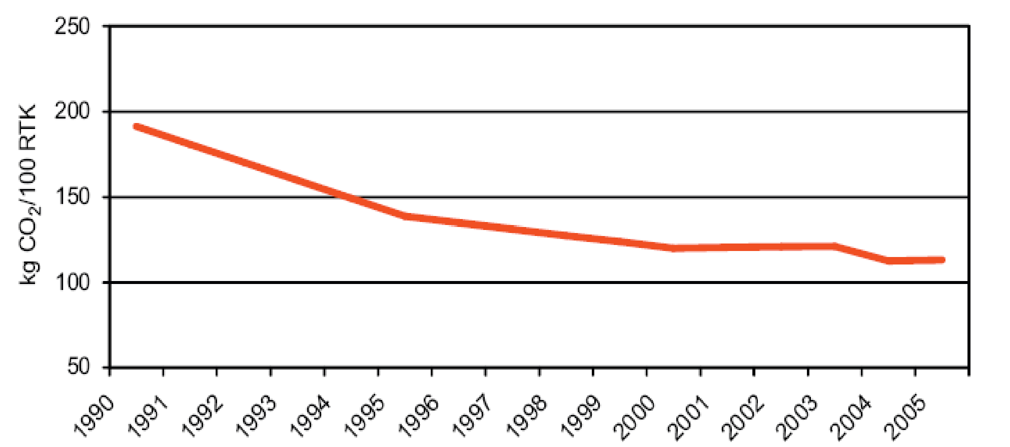
After J Penner et al, "Aviation and the Global Atmosphere"
http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/aviation/064.htm

Current technology: (e.g. kerosene) combined with increased aviation.

New developments and improved technology:
e.g. reduced weight,
Hydrogen-based fuel,
Engine design etc

Can we stabilise emissions without cutting demand?

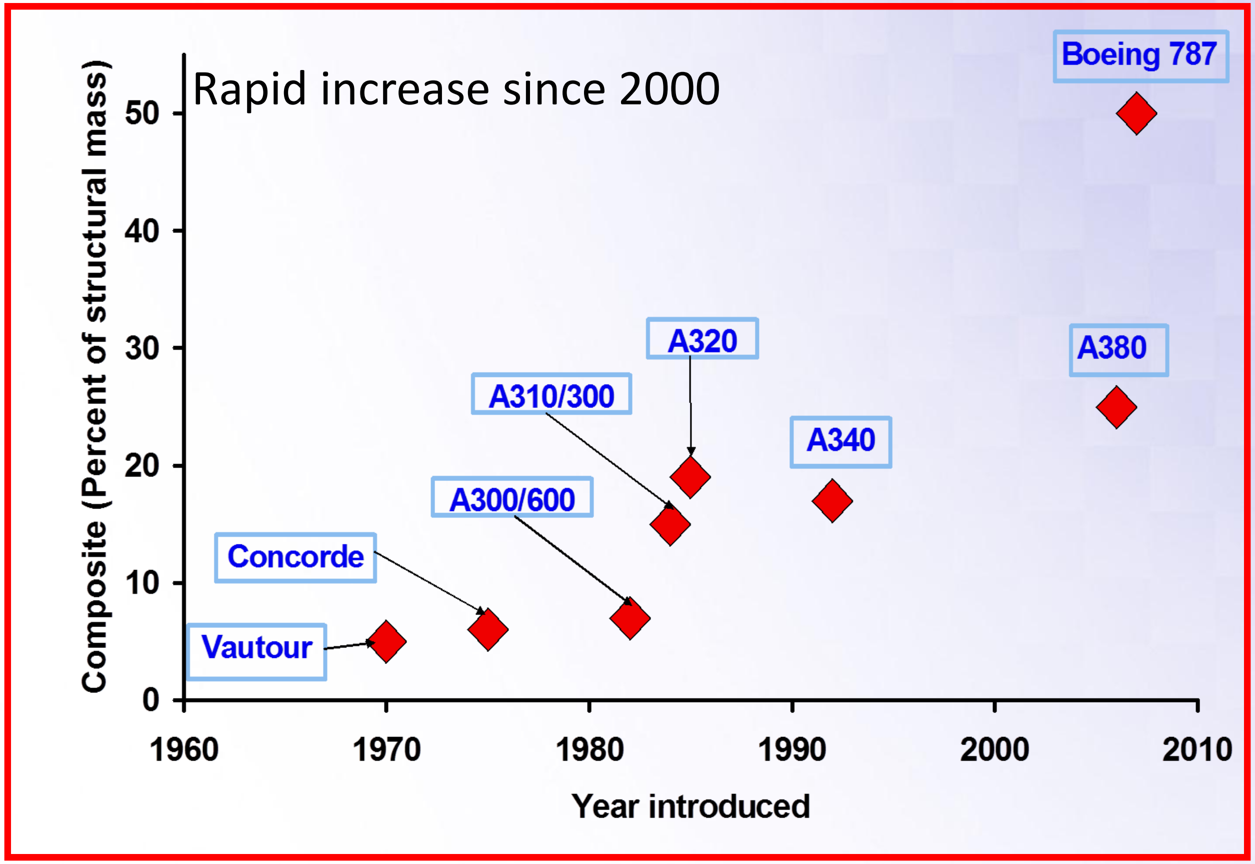




Source: A. Macintosh, L. Wallace, Energy Policy 37 (2009) 264–273

	Emission intensity in 2005 (kg CO_2/ 100 RTK)	Emission intensity 2025 (kg CO_2/ 100 RTK)	Average annual improvement (%)	Total improvement 2005–2025 (%)
S1	113	94	1.0	18
S2	113	81	1.7	29
S3	113	77	1.9	32
S4	113	39	5.2	65

Increased use of composites in aircraft since 1970

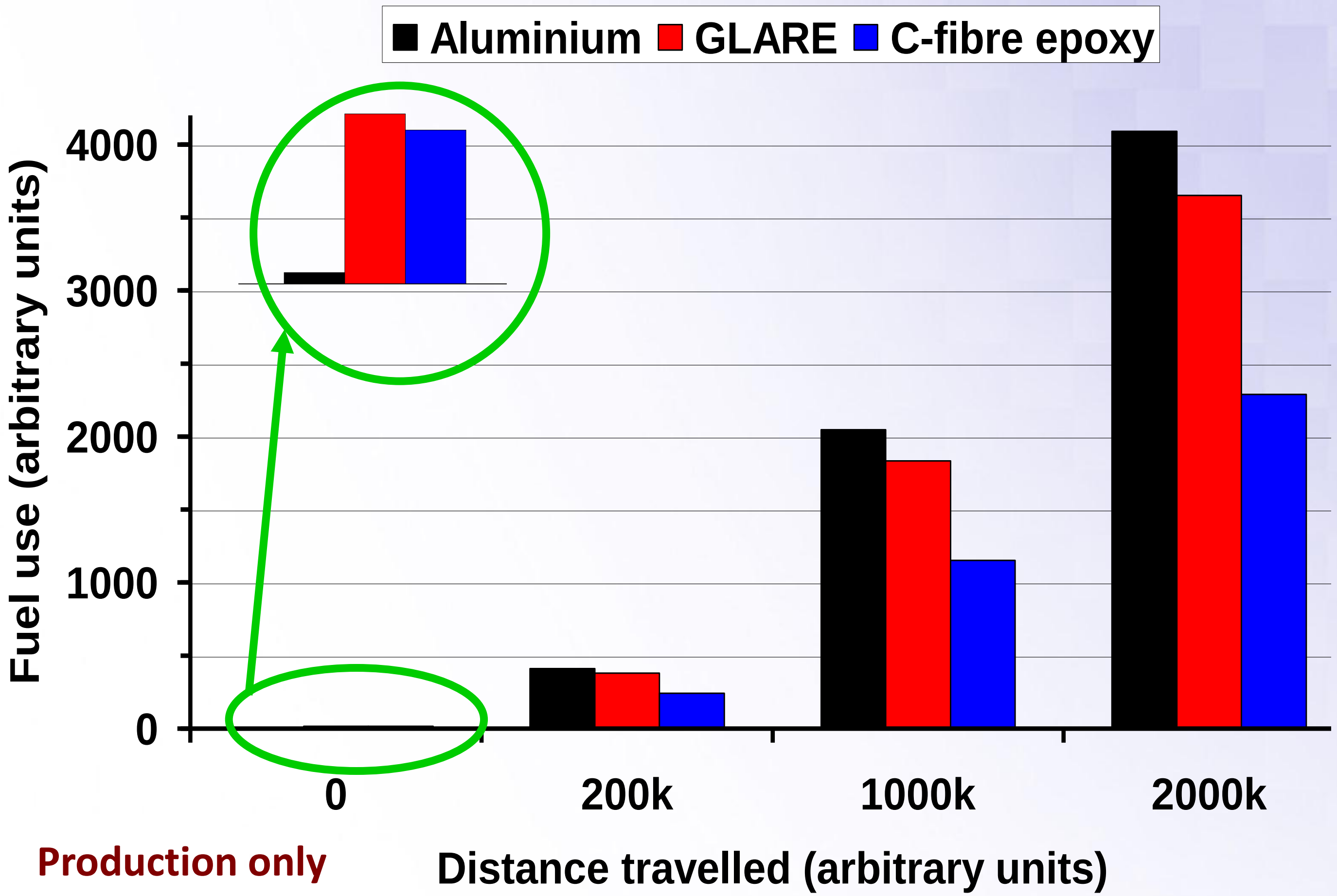


[1]Adapted from D Gay & SV Hoa, "Composite Materials, design and applications" 2nd edition, CRC press 2007

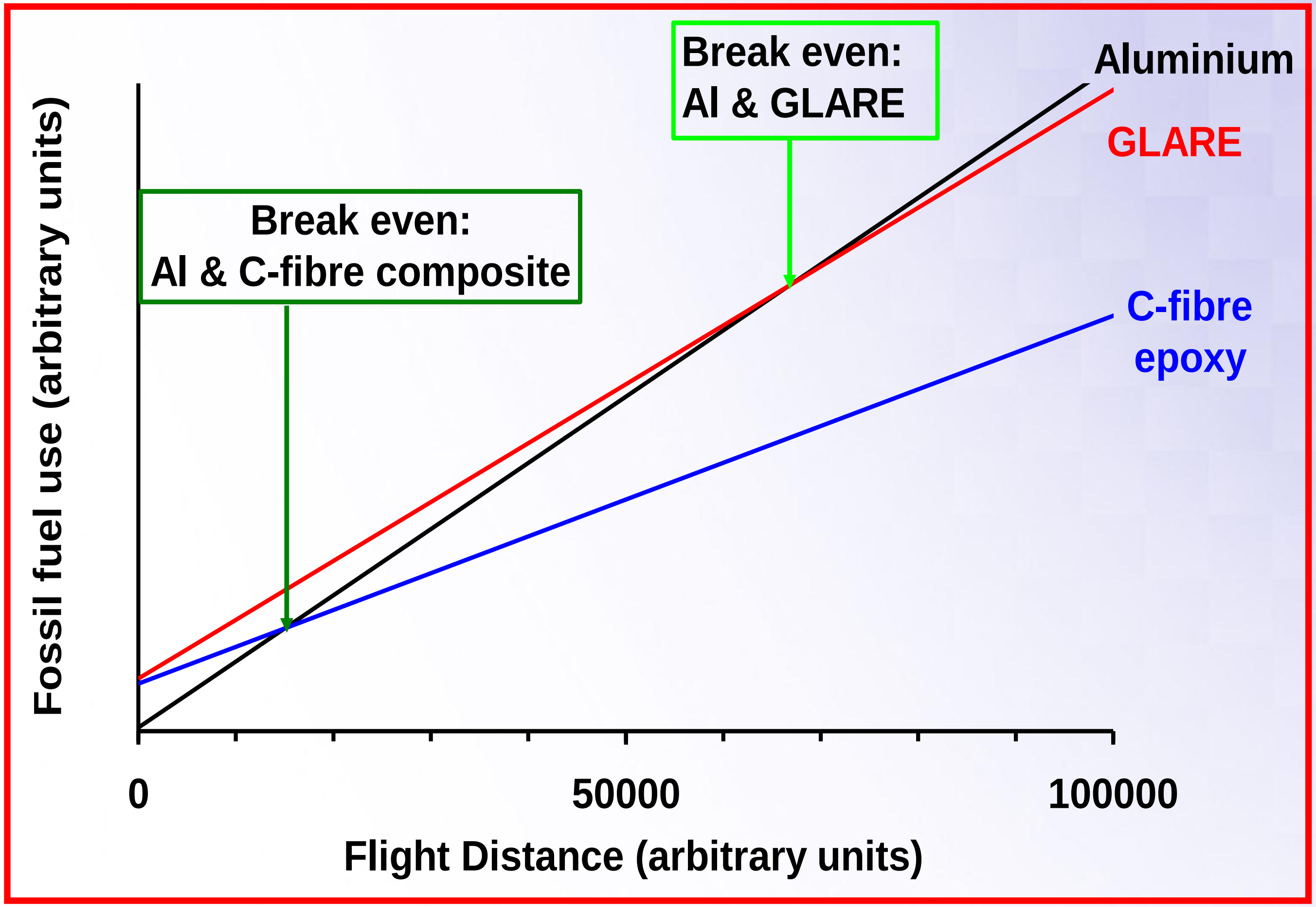
Substance	Unit	Aluminium	Carbon fibre epoxy resin composite	GLARE
Ammonia	g	0.01	12.61	0.04
Carbon monoxide	g	-16.85	15.89	45.55
Cyanide	g	0.00	26.70	0.00
Hydrocarbons, unspecified	g	0.86	10.32	3.72
Hydrogen chloride	g	0.36	0.11	1.42
Methane	g	-1.11	3.61	25.25
Nitrogen dioxide	g	0.64	1.04	0.54
Nitrogen oxides	g	0.93	19.94	44.58
Particulates, > 10 um	g	8.94	0.01	11.71
Particulates, SPM	g	0.32	3.31	0.59
Sulfur dioxide	g	68.08	0.94	82.47
Sulfur oxides	g	-56.72	12.10	1.27
VOC, volatile organic compounds	g	0.50	x	3.65
water	g	x	25.20	0.00
Carbon dioxide	kg	1.13	4.69	12.79

Comparison of selected airborne emissions for aluminium, glare and carbon fibre epoxy resin composite panels. The production and disposal stages are included.

Emissions levels in use



Break-even scenario



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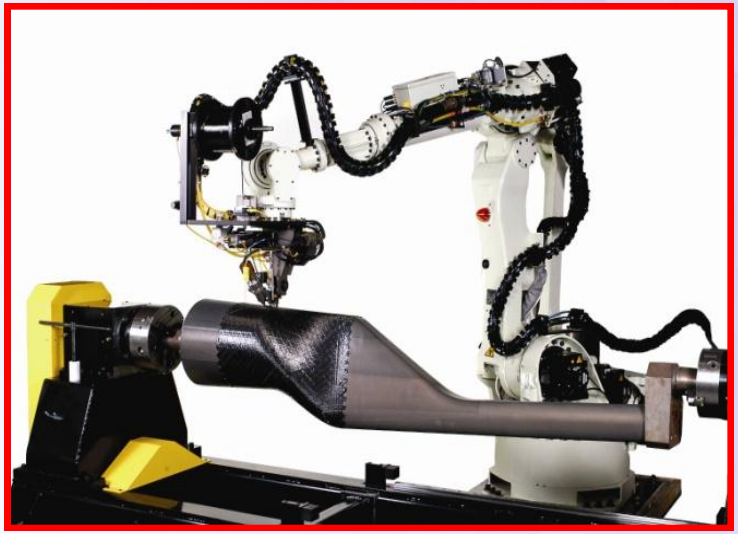
SAMPE, SEICO 10, PARIS, APRIL 2010
ADVANCED COMPOSITE MANUFACTURING METHODS AND LIFE CYCLE ANALYSIS OF EMISSIONS SAVINGS

L. Scelsi, M. Bonner, A. Hodzic, C. Soutis, C. Wilson, R. Scaife, K. Ridgway, **POTENTIAL EMISSIONS SAVINGS OF LIGHTWEIGHT COMPOSITE AIRCRAFT COMPONENTS EVALUATED THROUGH LIFE CYCLE ASSESSMENT,** eXPRESS Polymer Letters Vol.5, No.3 (2011) 209–217

STEEL TUBE REPLACED WITH CFRP IN TRANSPORT

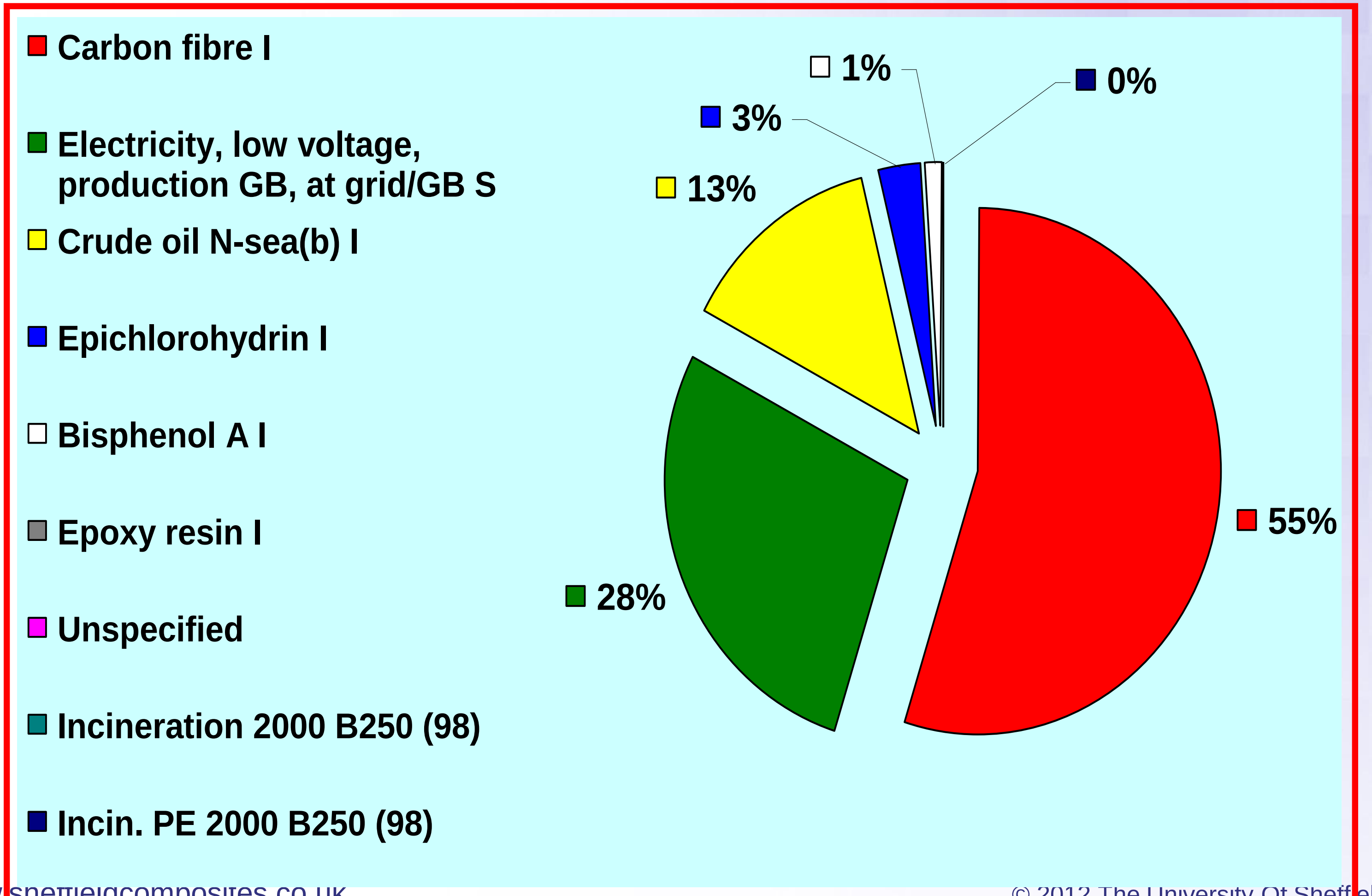
Manufacturing method

The tubular composite component:
- length of 660 mm
- inner diameter 670 mm
-wall thickness of 10 mm
- 75% hoop fibre with epoxy MTM49-3 with the density of 1.78 g/cc
-Standard Robot Arm power required to manufacture the component using Automatic Fibre Placement (AFP) was 25kW over 230 minutes
- Autoclave manufacturing method used for curing of the component required 20 kW over 240 minutes.

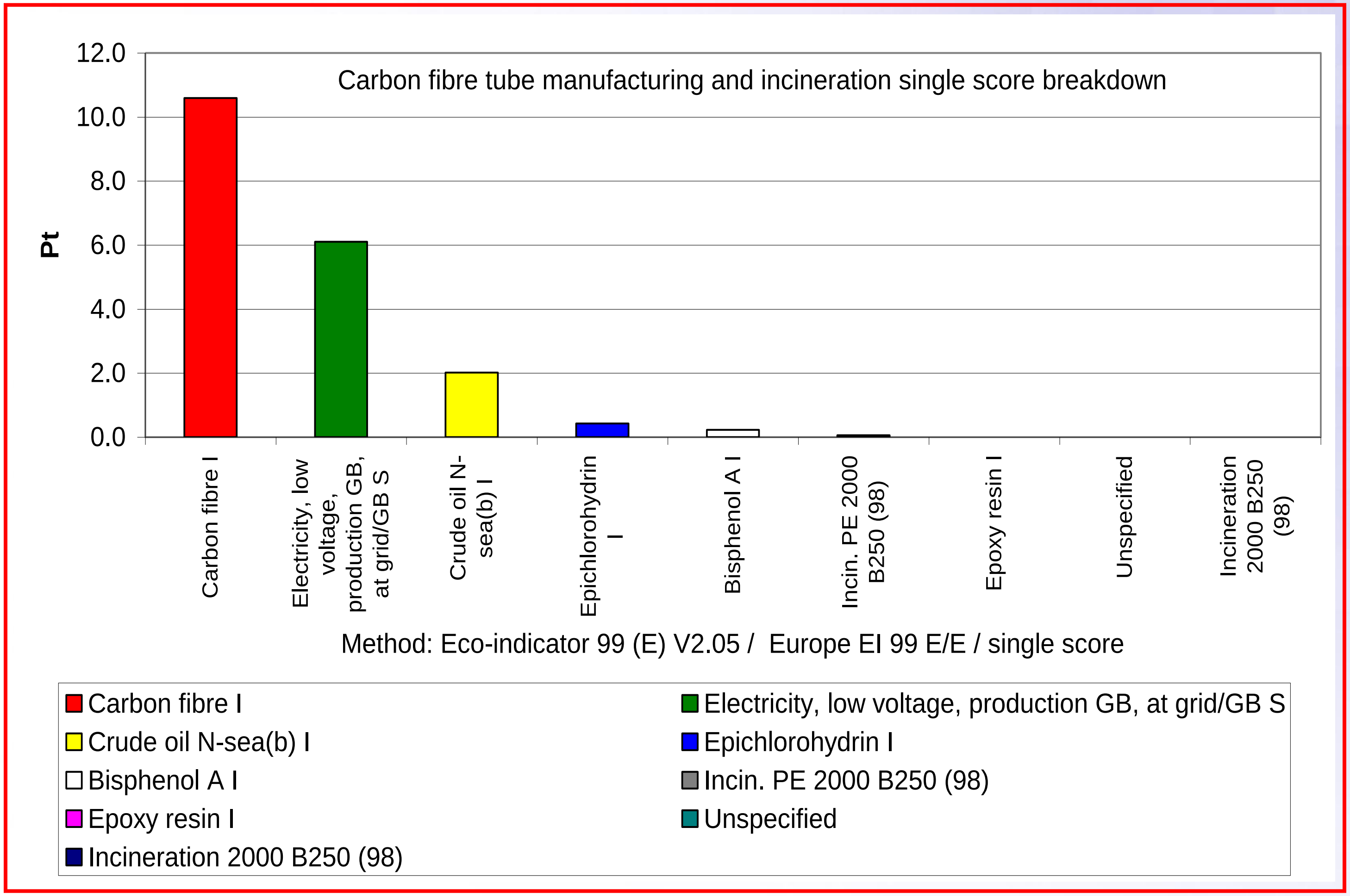


The equivalent steel tube used in LCA model:
- same dimensions, wall thickness of 5 mm.
- steel density was 7.85 g/cc.
- steel tube was manufactured as seam welded rolled steel sheet.

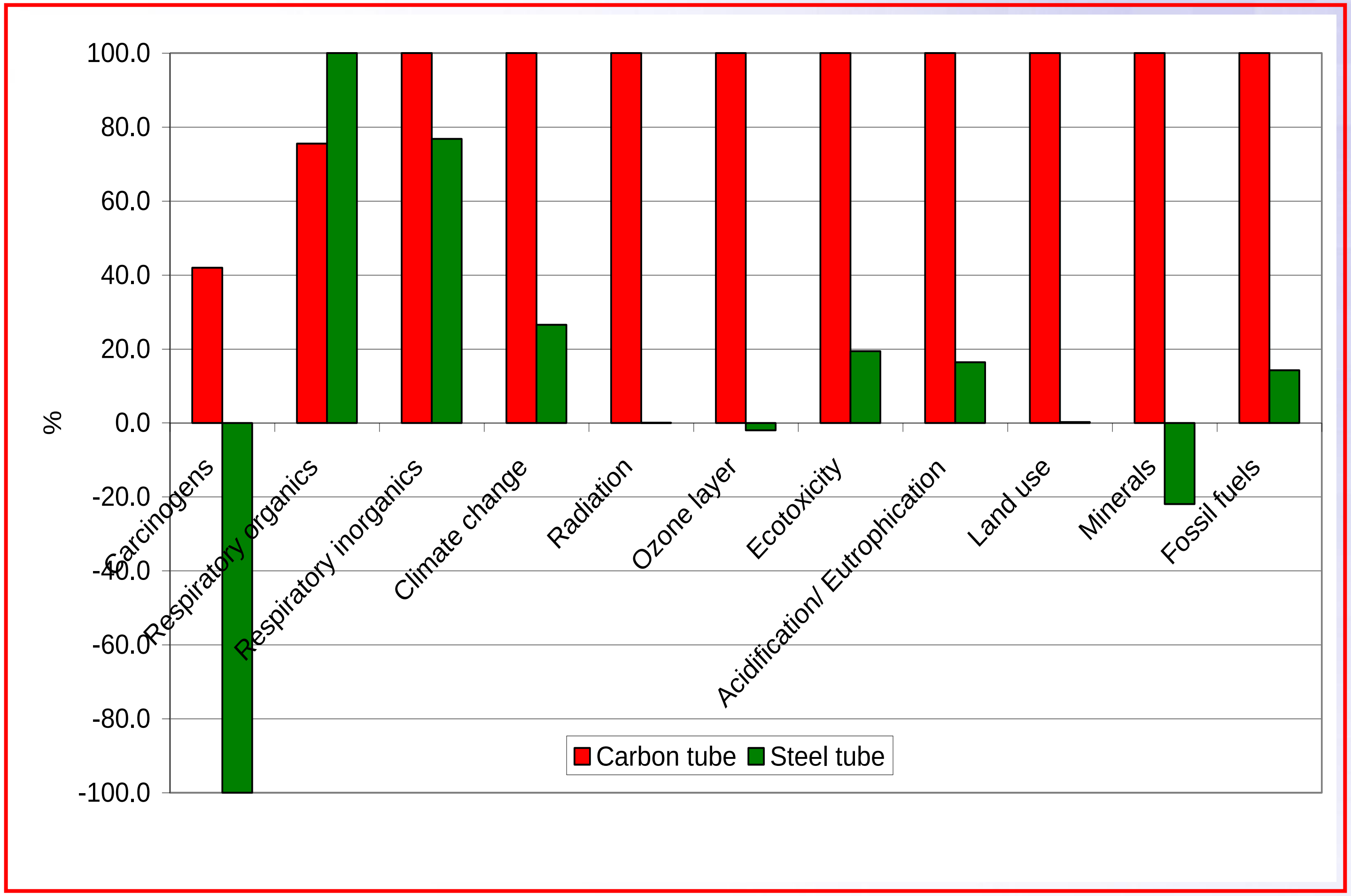
Manufacturing and disposal emissions



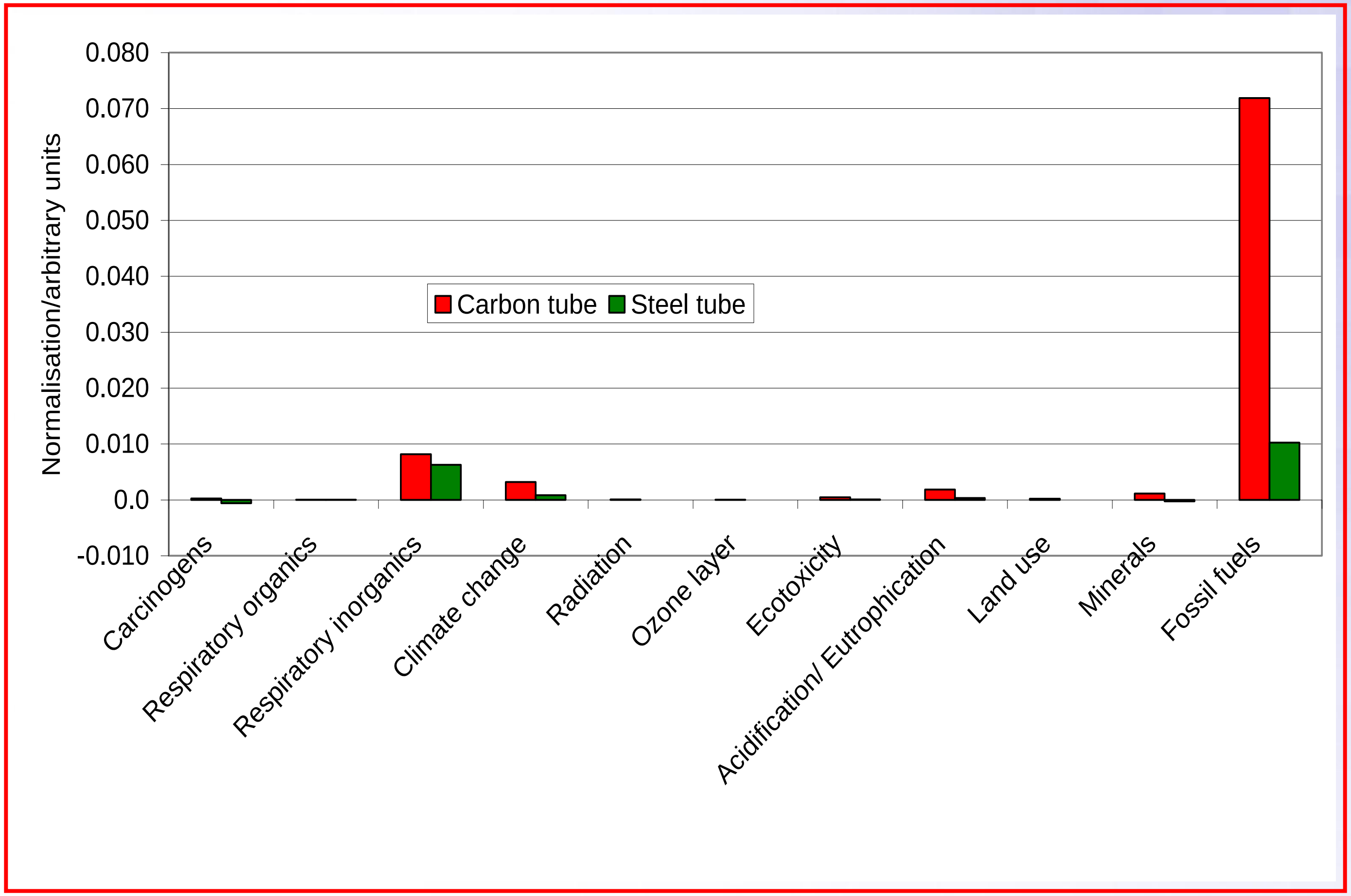
Steel tube replaced with CFRP tube



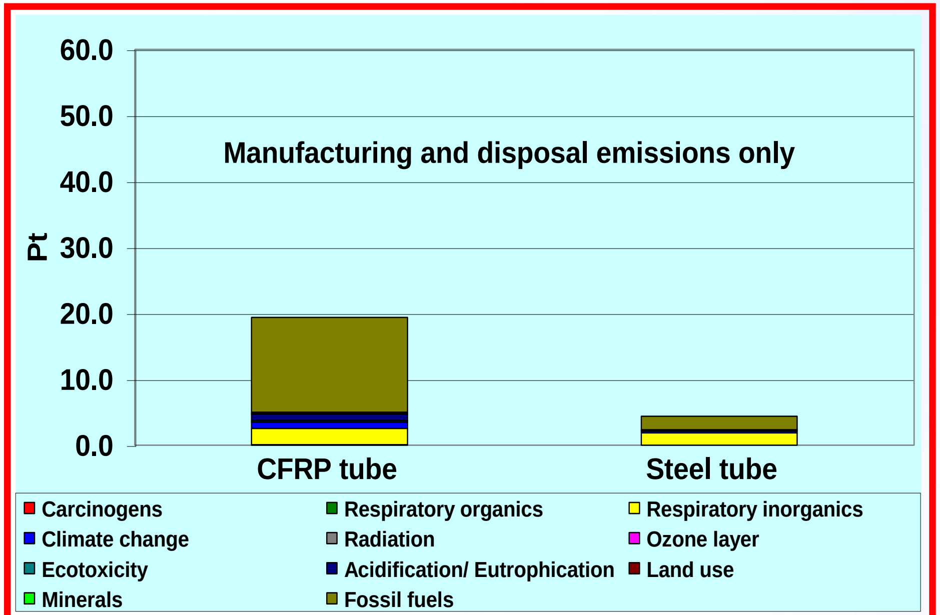
Weighting impact analysis



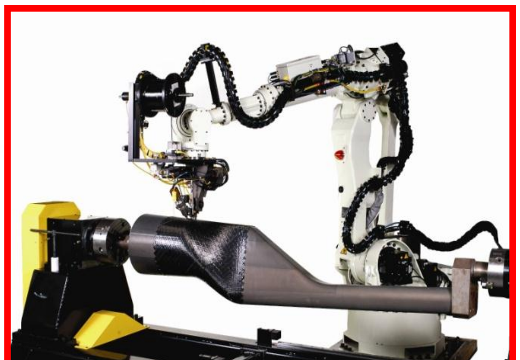
Normalisation Impact Analysis



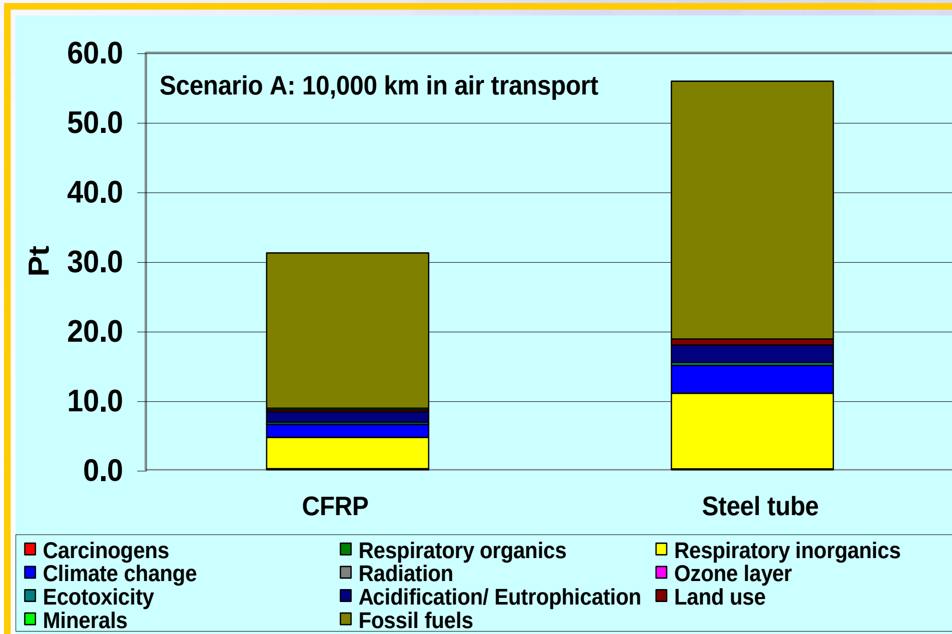
Aviation transport scenario



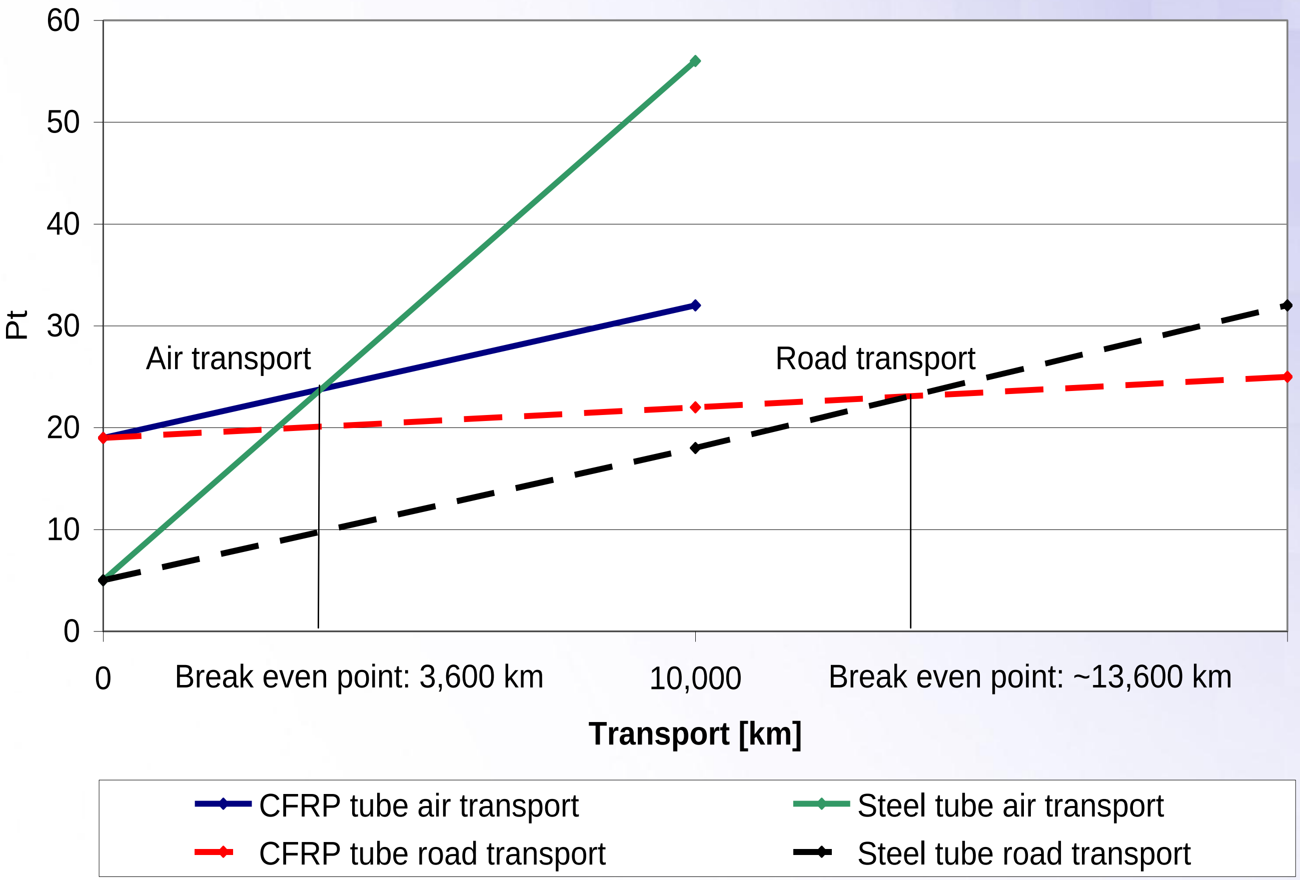
Production + Disposal



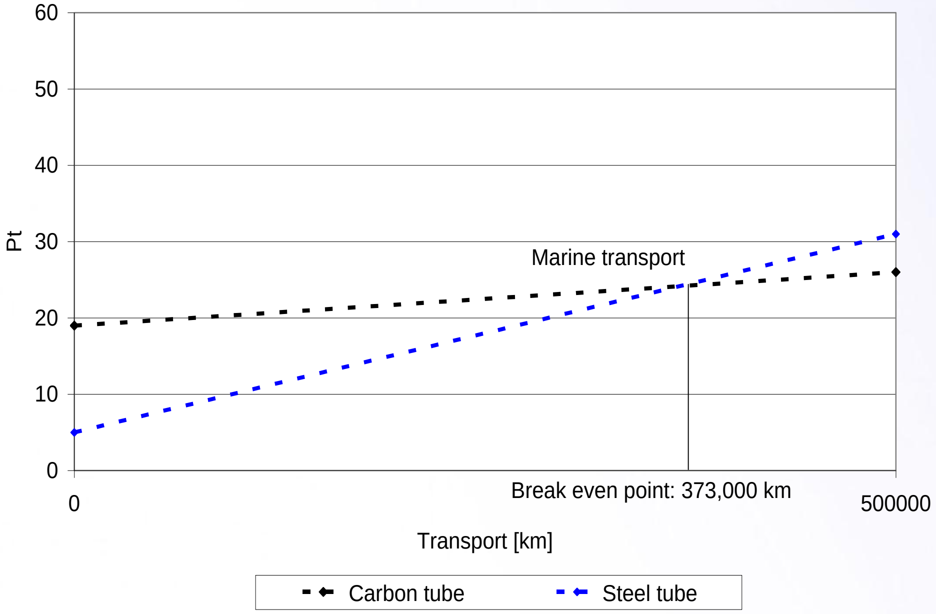
Production + Disposal
+ 10,000 km in air



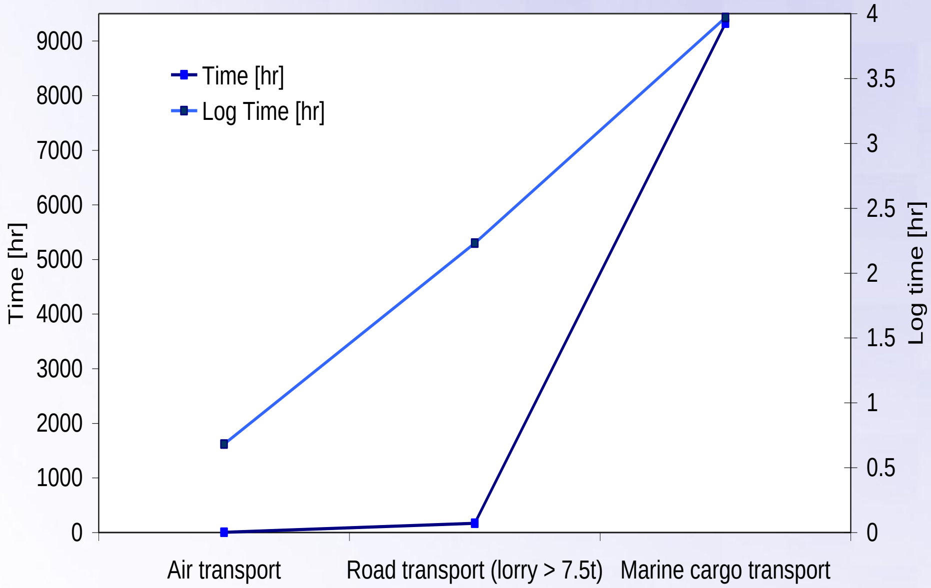
Air transport vs. Road transport



Marine Transport



Transport emissions translated into time



Conclusions

- Manufacturing and disposal emissions are significantly higher for CFRP compared to metallic structures due to the absence of recycling option for CFRP structures after use
- Compared to CFRP in use, to reach the same level of emissions savings, road transport required 35 and marine transport 1942 times more hours in operation, respectively.
- Implementation of lightweight materials is hence most beneficial in the air transport where the emissions are the highest
- Utilisation of composite materials in the aviation industry will lead to highest emissions savings compared to other environmentally beneficial technologies

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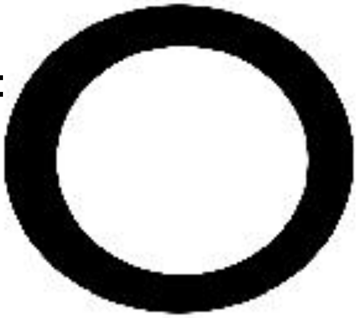
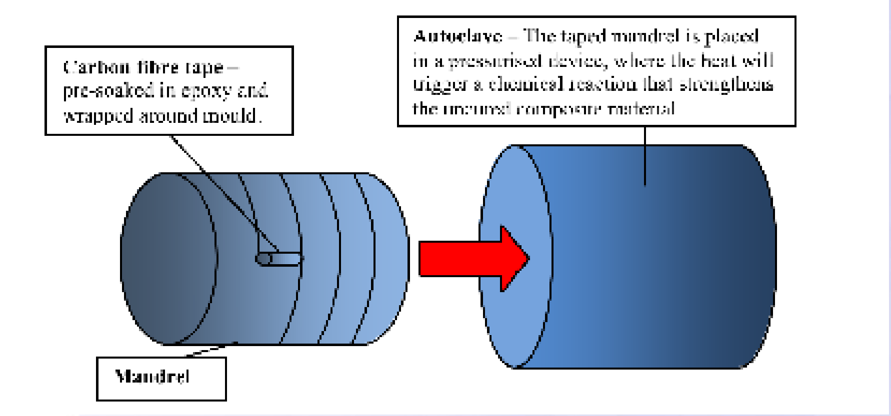
*AMRC with Boeing, The University of Sheffield

LCA OF BOEING 787 FUSELAGE SECTION 46

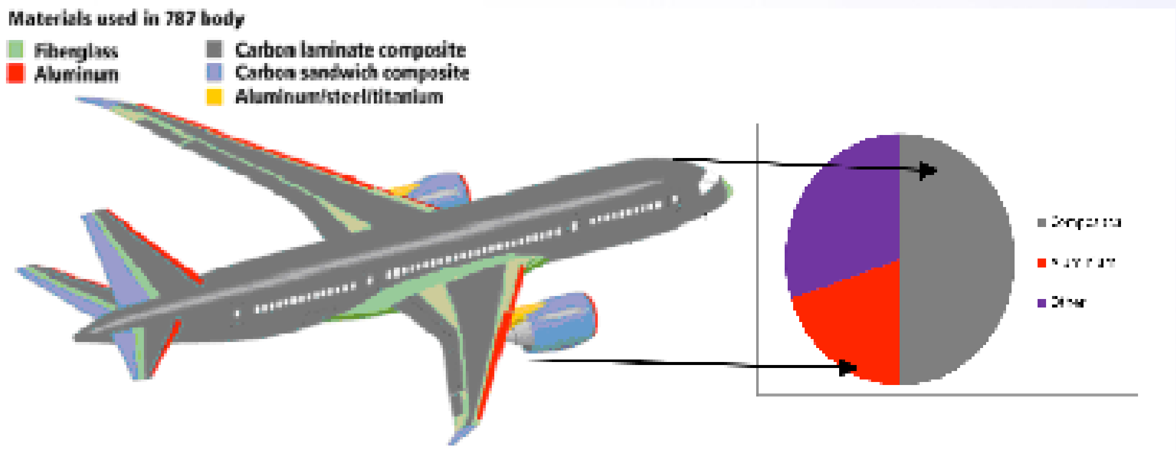
Boeing 787 Fuselage Section 46

=

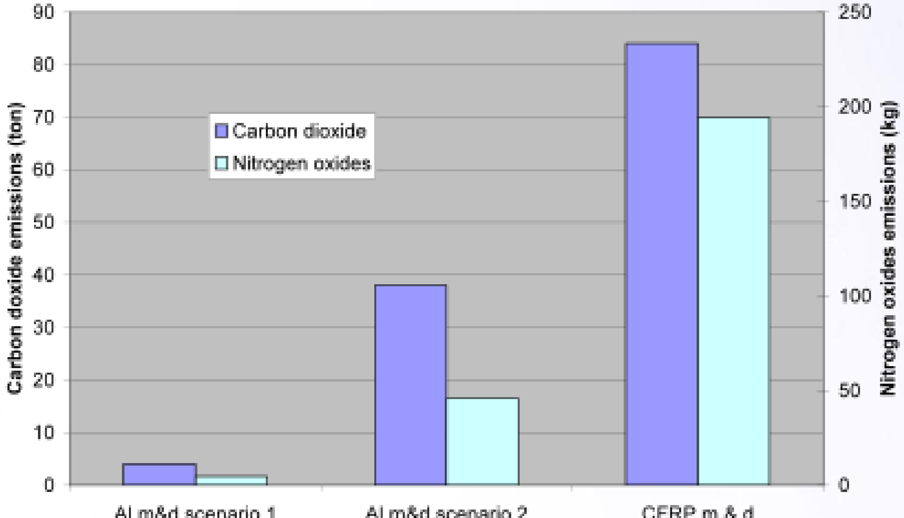




The length of section 46 is 33ft (396 in), the diameter is 19ft (228 in) and a typical density of CFRP is assumed to be 0.0556 lb/in^3. Using the relationship of mass (4,000lb) is equal to density (0.0556lb/in^3) multiplied by volume; the effective thickness for the fuselage is found to be 0.51 in or 12.95 mm.



Manufacturing & Disposal vs. Full Life Cycle

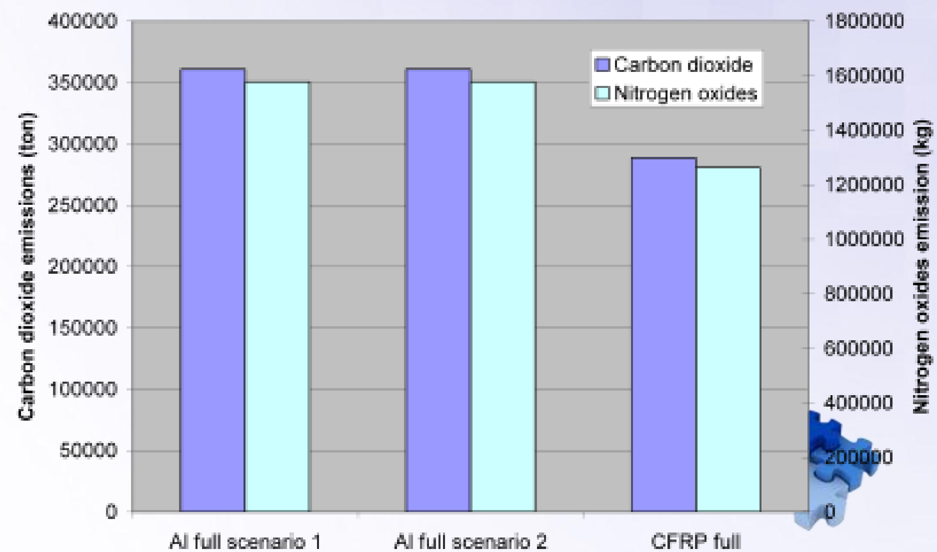


	CFRP vs. Aluminium scenario 1		CFRP vs. Aluminium scenario 2	
	Distance (km)	Time (h)	Distance (km)	Time (h)
Carbon dioxide	170,000	188	95,000	105
Nitrogen oxides	90,000	99	70,000	77
Crude Oil	55,000	61	55,000	61

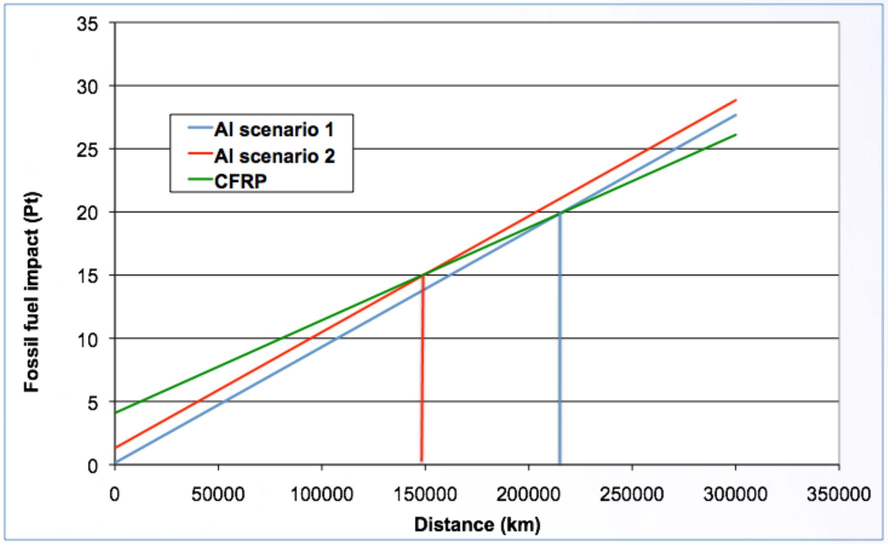
	0 km	50,000 km	100,000km	300,000km	153,300,000km
Carbon dioxide (ton)	-79.97	-56.40	-32.83	61.43	72187.11
Nitrogen oxides (kg)	-189.68	-86.62	-9144.77	428.70	315804
Crude oil (ton)	-8.55	-1.34	5.87	34.71	22104.27

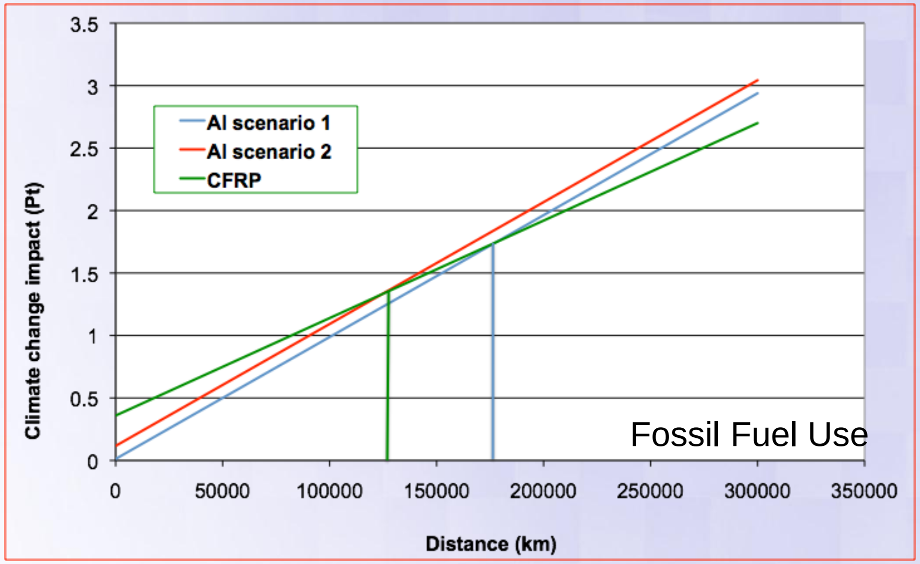
Al Scenario 1: Buy to Fly ratio 1:1
Al Scenario 2: Buy to Fly ratio 8:1 (standard)

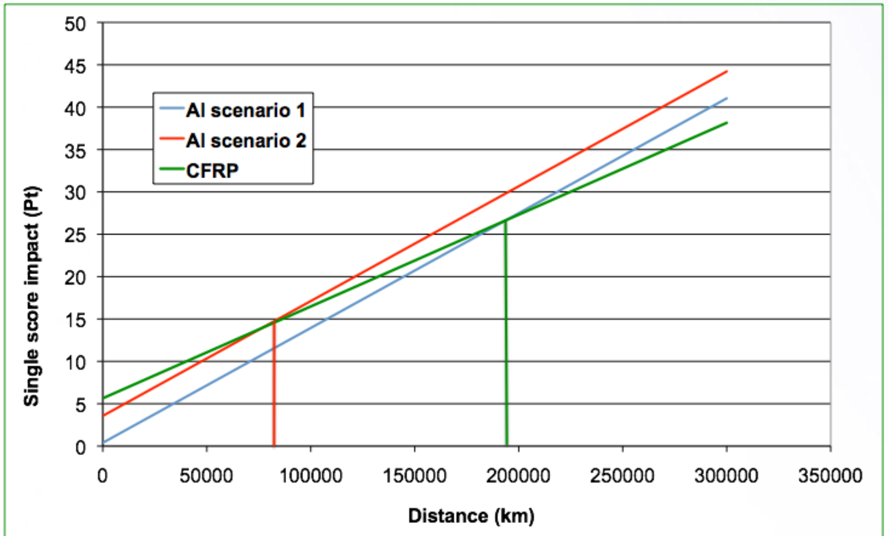
For the Boeing 787 it is reported that a one-piece fuselage section eliminates 1,500 aluminium sheets, 40,000 to 50,000 fasteners, and requires fewer than 10,000 holes to be drilled compared to the million required for Boeing 747.



Break-even points

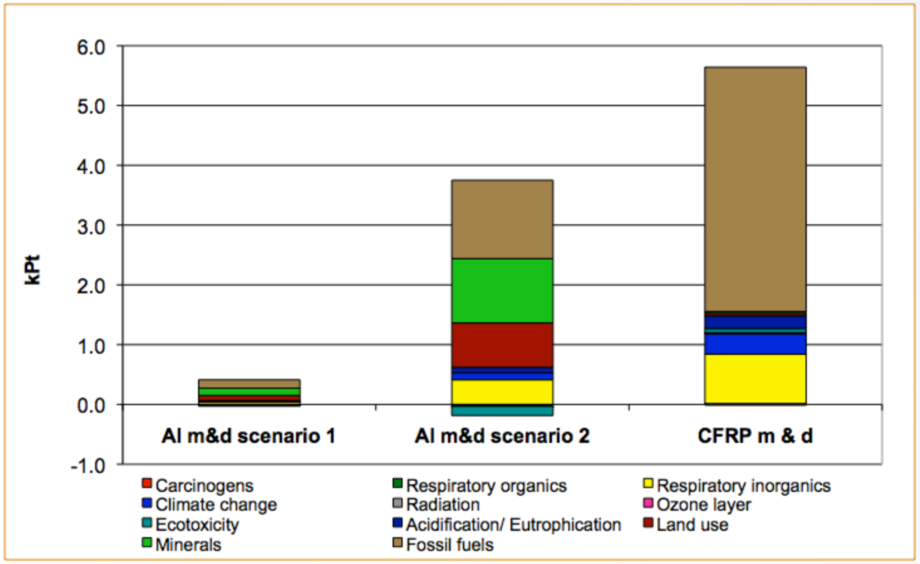




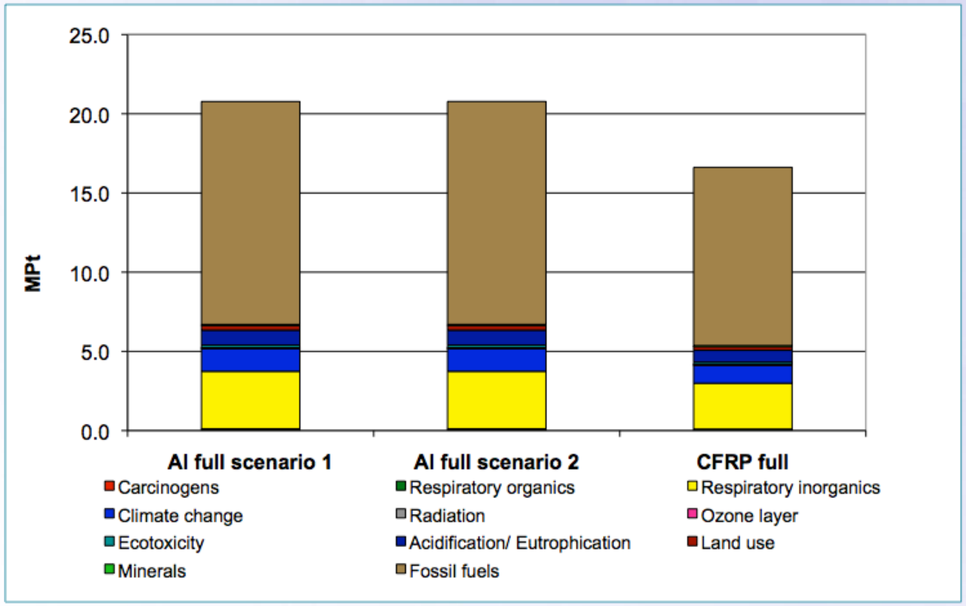


- The Boeing 787 has a range of 14,000km and a commercial aircraft typically has a 30-year life span.
- It is assumed that the aircraft will fly everyday, which results in a distance of 153,300,000km being travelled by a Boeing 787 in its lifetime.
- The distance travelled by a fleet of Boeing 787's can be estimated to be 2.684 x 10^{11} km based on Boeing's sales prediction of 1750 units.

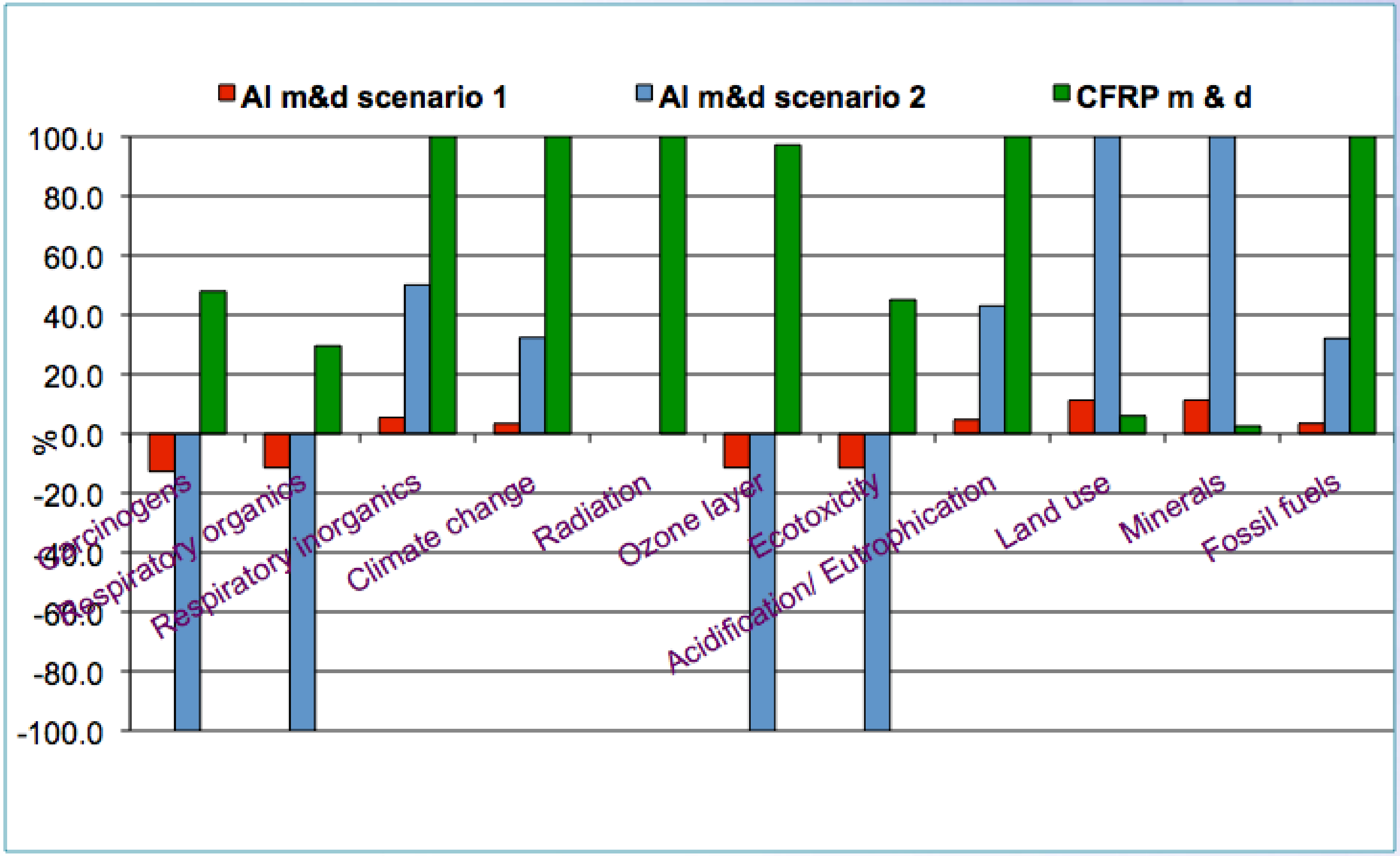
Single score life cycle



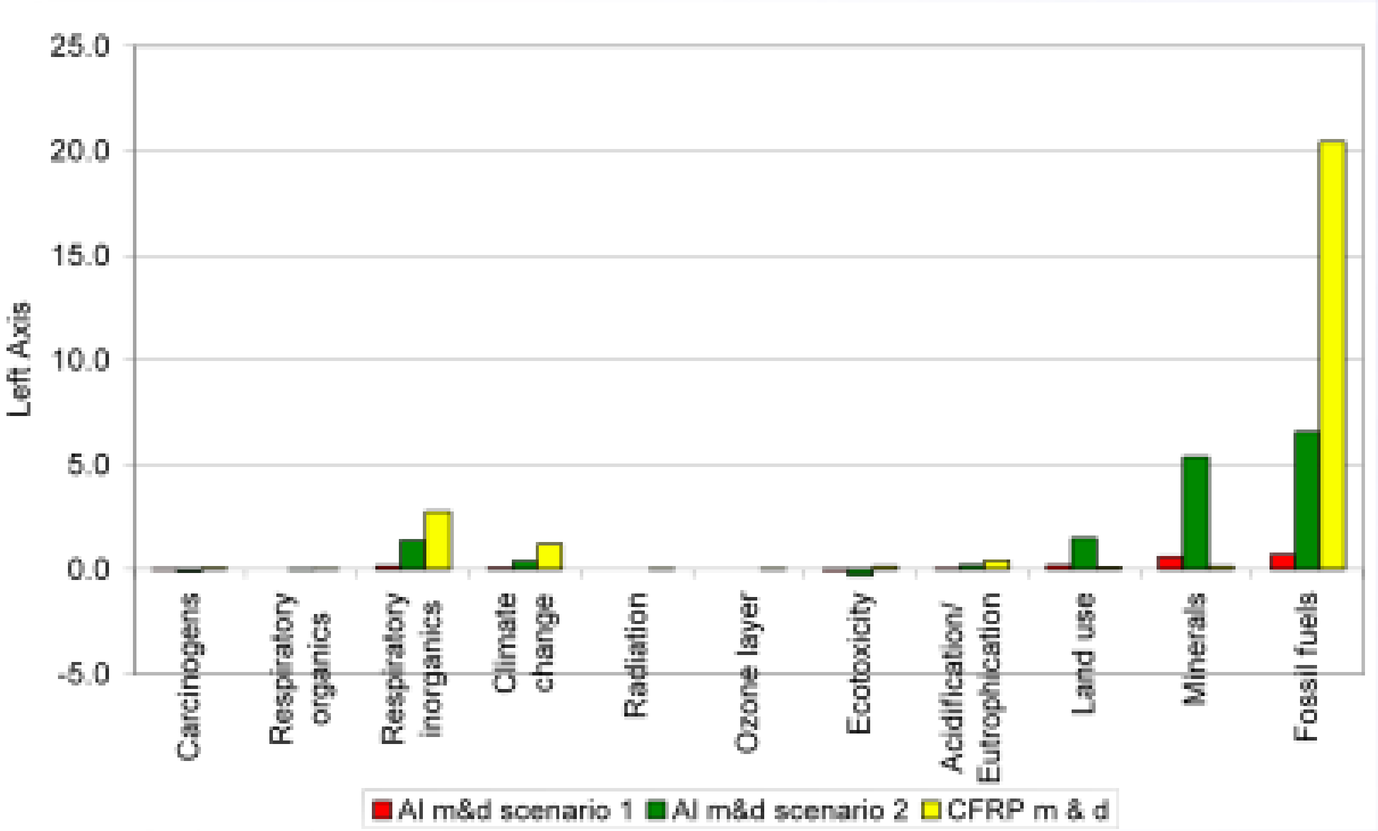
- CFRP section 46 is significantly less harmful for the environment after a certain time of use in aircraft operation
- The difference in emissions for the two manufacturing scenarios for the aluminium is negligible after a full life cycle



- The emissions produced due to fuel consumption significantly outweigh the emissions produced during manufacture and disposal
- The fossil fuel use dominates the impact of the three fuselage sections as a result of the jet fuel that has been consumed


Al m&d scenario 1
Al m&d scenario 2
CFRP m & d
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
%
Carcinogens
Respiratory organics
Respiratory inorganics
Climate change
Radiation
Ozone layer
Ecotoxicity
Acidification/ Eutrophication
Land use
Minerals
Fossil fuels

Normalisation



Design closed loop

Total takeoff weight: $W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$

C

Empty weight fraction for jet transport: $W_e/W_0 = AW_0^C = 0.97W_0^{-0.06}$

$W_0 = C + W_f + W_e/W_0 \times W_0$

$W_0 = C + W_f + 0.97W_0^{0.94}$

With 50% composites (10% W_e saving): $W_0 = C + W_{fr} + 0.873W_0^{0.94}$

Fuel weight reduction: $W_f - W_{fr} = 0.097W_0^{0.94}$

Comparative data: Dreamliner W_0 = 165t $W_f - W_{fr} \sim 12t$

Further iteration: 12t/165t ~ 5%

Total round emissions savings from 10% reduction in W_e: 15%

Conclusions

- A total of 72.2 kt of CO_2 emissions, 315.8t of NO_x emissions and 22.1 kt of crude oil were saved after the full LCA for the Dreamliner's fuselage section 46 only
- For the current fleet of Boeing 787's these savings will be multiplied by 1750, from one fuselage section only
- CFRP section 46 produces 20% fewer emissions and consumes 20% less crude oil than an aluminium section 46 regardless of the manufacturing and disposal scenario
- The raw materials used and emissions produced during manufacturing and disposal of the fuselage section are insignificant compared to the enormous amount of emissions that are produced during operation of the aircraft over 30 years
- The improvement in efficiency and reduction in emissions is proportional to the reduction in part weight.

Future Considerations

- Including the cost ration between the initial cost and the maintenance cost for technical improvements to materials selection and aircraft design
- Scheduling in maintenance cost and emissions
- Expanding LCA on biofuels, greener design, energy harvesting and self-amelioration concepts
- Building an algorithm for materials selection and manufacturing process optimisation in aircraft design
- Inclusion of durability parameters
- LCA design safety factor to include blast & impact resistance

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APPLICATION OF AFP TO STRUCTURAL AEROSPACE COMPONENTS UTILISING OUT OF AUTOCLAVE MATERIALS

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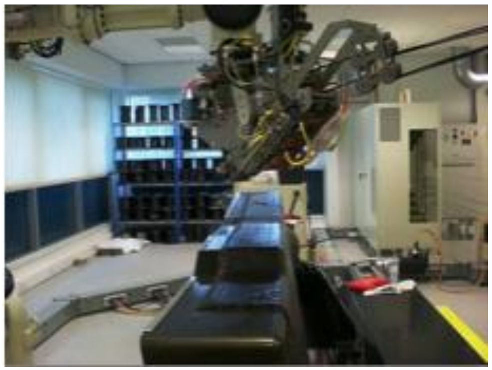
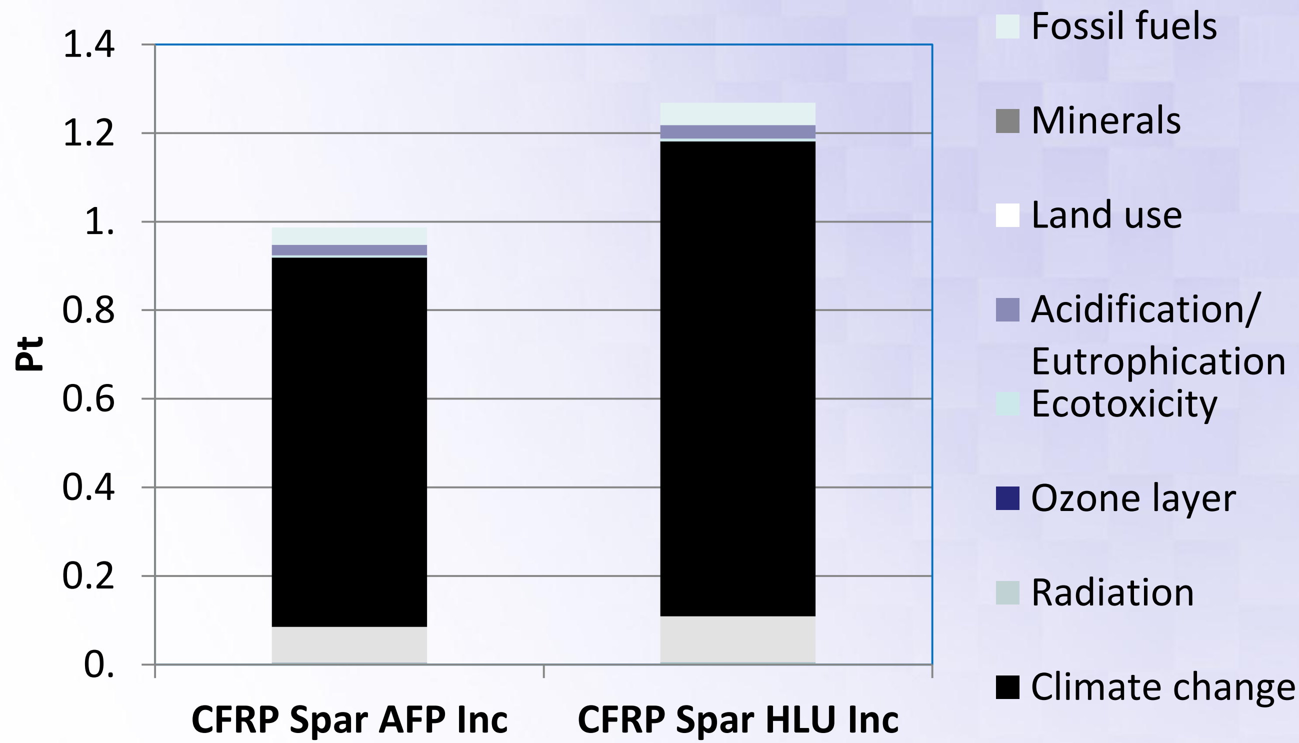
APPLICATION OF AFP ON A WING SPAR PROTOTYPE AT AMRC WITH BOEING

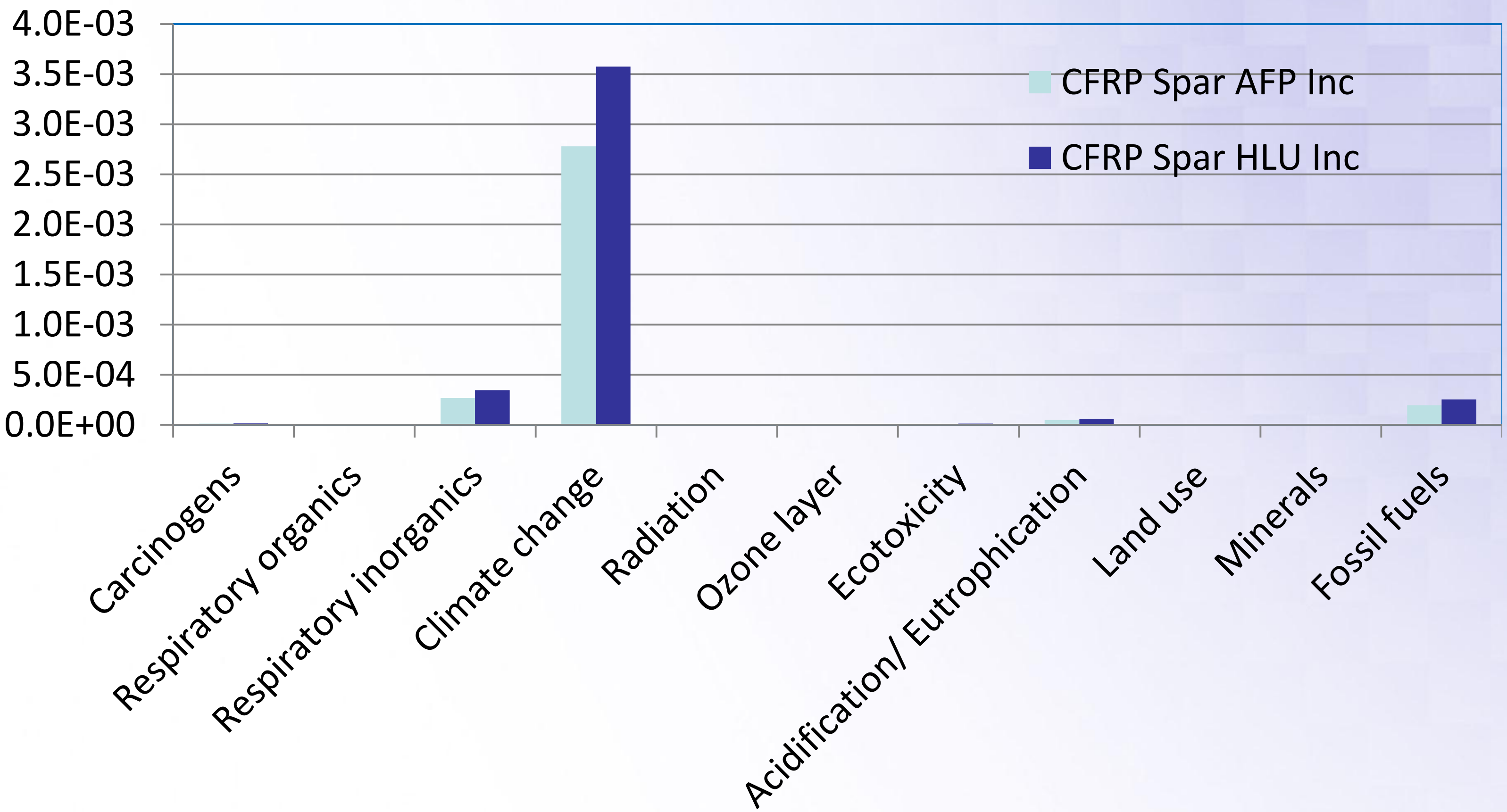
AFP vs. Hand lay-up of wing spar





Both manufacturing methods show very similar results; although the hand lay-up (HLU) should in theory produce lower emissions due to utilising less power in its processing stages, the higher scrap (35%) and longer autoclave processing times contribute to high emissions.

Normalisation



Acknowledgements

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Dr. Barton Moenster

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Aviation in a sustainable world

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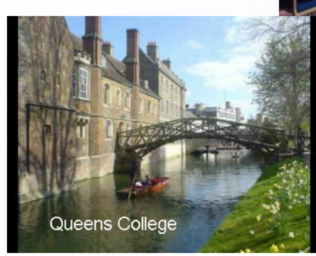

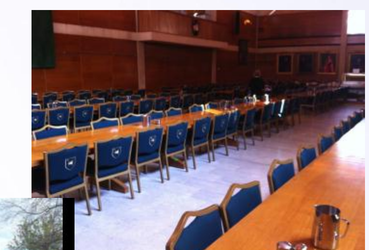

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in Cambridge (Queens')
8-11 April 2013
Celebrating 85 years of
Anthony Kelly

http://www.sheffield.ac.uk/compositesconference