GreenLet RESEARCH

Gaseous and Non-Volatile Particulate Emissions from a Private Jet

Using Conventional Jet A-1 and a 30% HEFA-SPK Blend

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Cessna Citation 560XL | **30% SAF Blend** | **Emission Analysis**

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Business Jets: Small but Significant Impact?

Growing Footprint

~2% of aviation CO_2

High demand and disproportionate pollutant impact

Small Engine Challenges

Short combustors with high surface-to-volume ratios

Lower combustion efficiency

Regulatory Gap

Small engines **<26.7 kN** exempt from ICAO regulations except for visible smoke

?

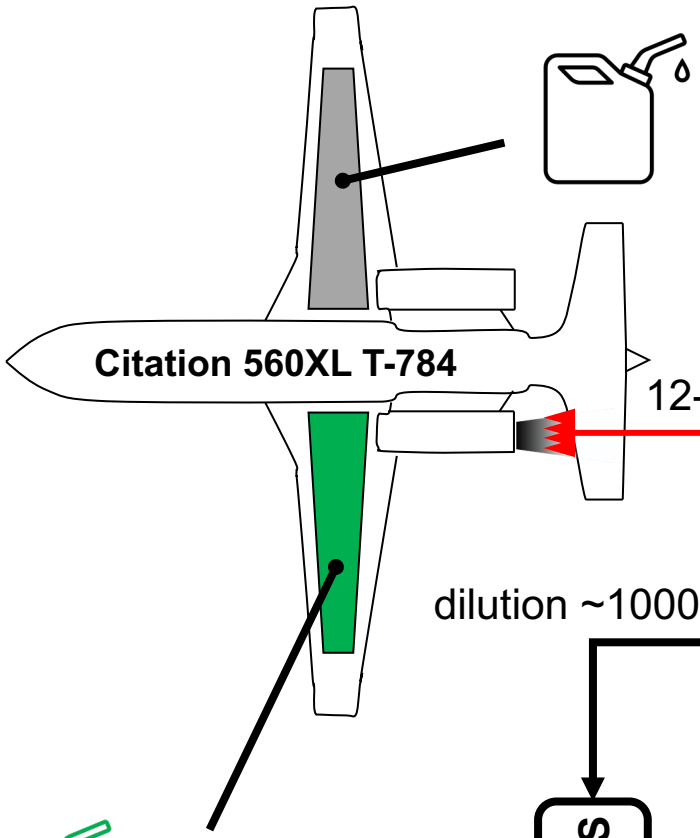
Can a small jet emit more particles at an airport than a jumbo jet?

?

Does sustainable aviation fuel (SAF) improve its pollutant emissions?

Photo Credit: Ryan Patterson

Emission measurements with SMARTEMIS & Vocus



Conventional Jet A-1 (2 batches)

Jet A-1 with 30% HEFA-SPK

12-point sampling probe & heated line

dilution ~1000:1

Engine Pratt & Whitney PW545A

- **Thrust 16.92 kN**
- **Pressure ratio 15:1**
- **Bypass ratio 4:1**

Swiss Mobile Aircraft Emissions Measurement System (SMARTEMIS)

diluter box

dilution ~8:1

60°C

nvPM system
nvPM number (AVL APC)
nvPM mass (AVL MSS)
diluted CO_2
particle size distribution (TSI SMPS)

undiluted

160°C

raw gas system
CO_2, CO, HC, NO_x, SO_2

Vocus PTR-TOF-MS

SMARTEMIS racks

Exhaust probe

Diluter box

Vocus PTR-TOF-MS

Heated sample lines
to SMARTEMIS racks

Fuel Composition: The Key Differences

Conventional Jet A-1 #1 , #2		
Sulfur (ppmm):	680	1080
Aromatics (%v):	16.4	17.7
Naphthalenes (%v):	1.14	1.17
Hydrogen (%m):	13.97	14.00

30% HEFA-SPK blend	
Sulfur (ppmm):	230
Aromatics (%v):	12.7
Naphthalenes (%v):	0.67
Hydrogen (%m):	14.31

Key Changes

- -79% Sulfur
- -28% Aromatics
- -43% Naphthalenes
- ΔH = 0.33%

Sulfur → SO_2 & vPM

Direct: Fuel S → SO_2 emissions

Secondary: SO_3 → H_2SO_4 → volatile PM nucleation

Aromatics → VOCs

Composition: Reduced complex hydrocarbons

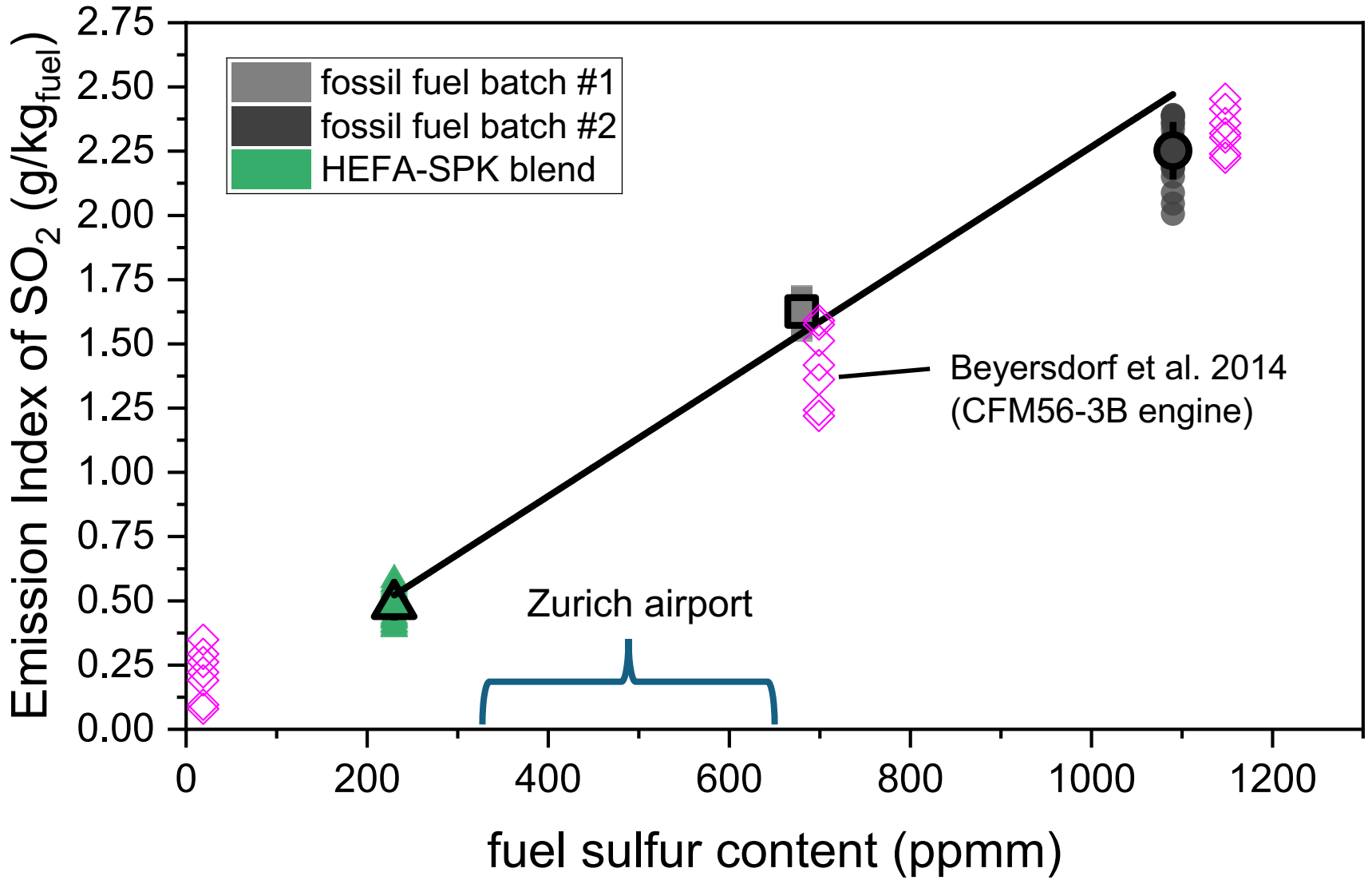
Reactivity: Lower degree of unsaturation

Hydrogen → nvPM

Predictor: Higher H content → cleaner burn

Mechanism: More H, fewer double & triple bonds

Result #1: Fuel Sulfur Effects on SO_2 Emissions



SO_2 emissions directly proportional to FSC

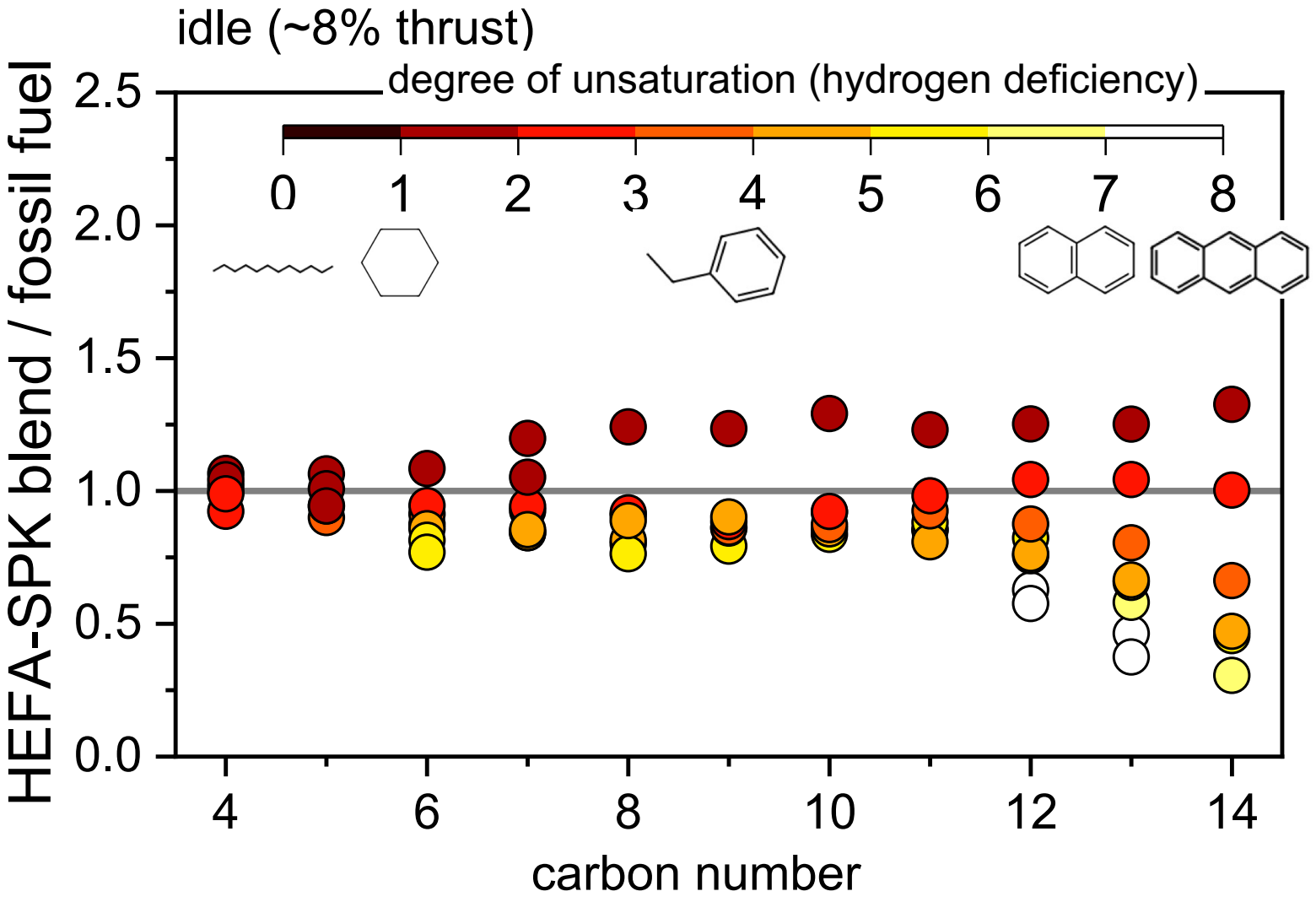
Airport Air Quality & Climate Impact

Direct SO_2: Respiratory irritant

Volatile PM: Ultrafine particles, deep lung penetration

Secondary effects: Coating of soot -> ice nucleation ability

Result #2: VOC Composition Changes



Reduction of complex VOCs with high hydrogen deficiency, proportional to lower naphthalenes & total aromatics in the SAF blend

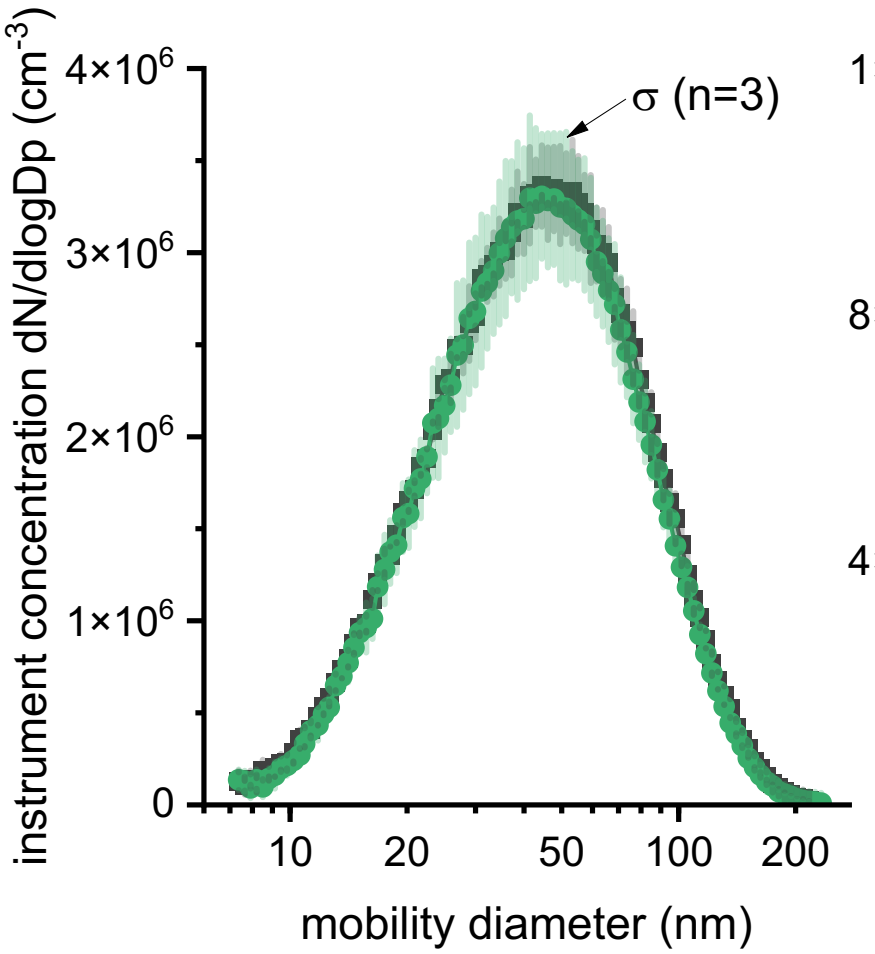
Airport Air Quality & Climate Impact

Health: potential toxicity reduction

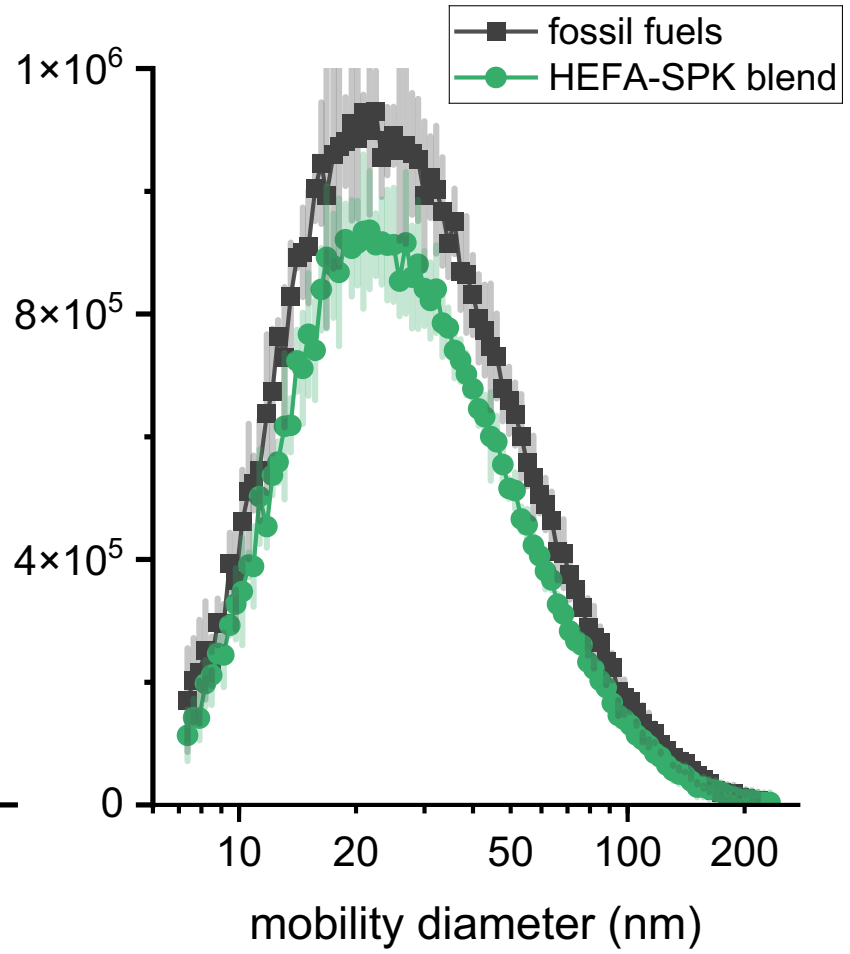
Volatile PM: Decreased secondary organic aerosol potential

Result #3: nvPM – Size Distributions & Fuel Effects

Take-off (100%)



Idle (8%)



Minor reduction in geometric mean diameters and standard deviations with the SAF blend

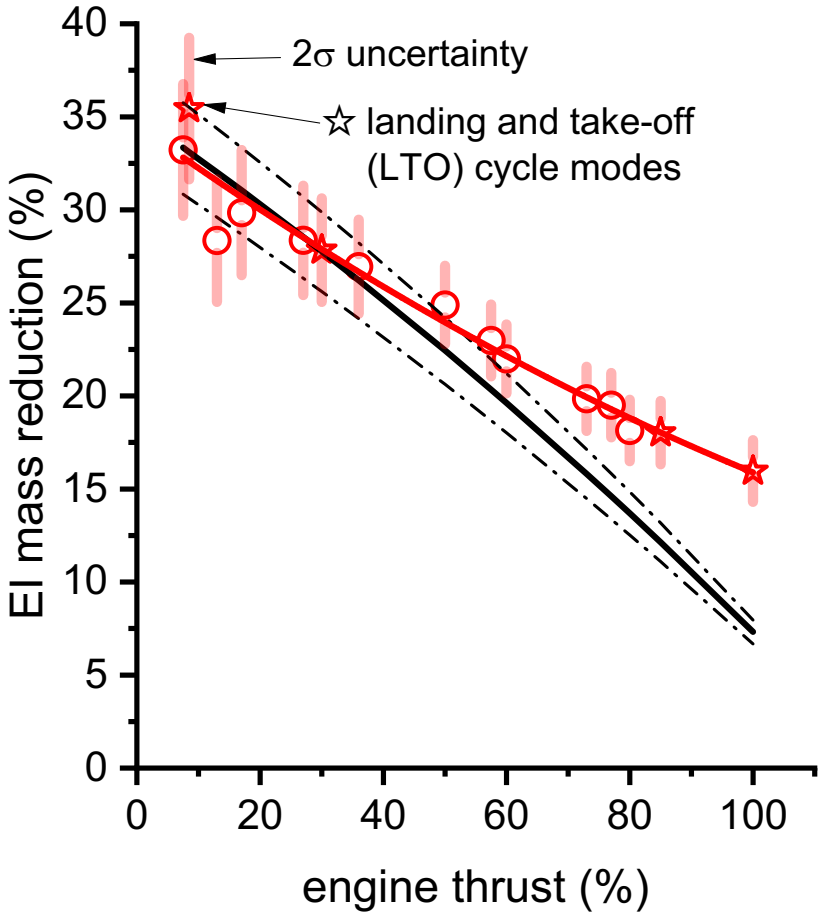
Increasing SAF effect on concentration with decreasing thrust

Airport Air Quality & Climate Impact

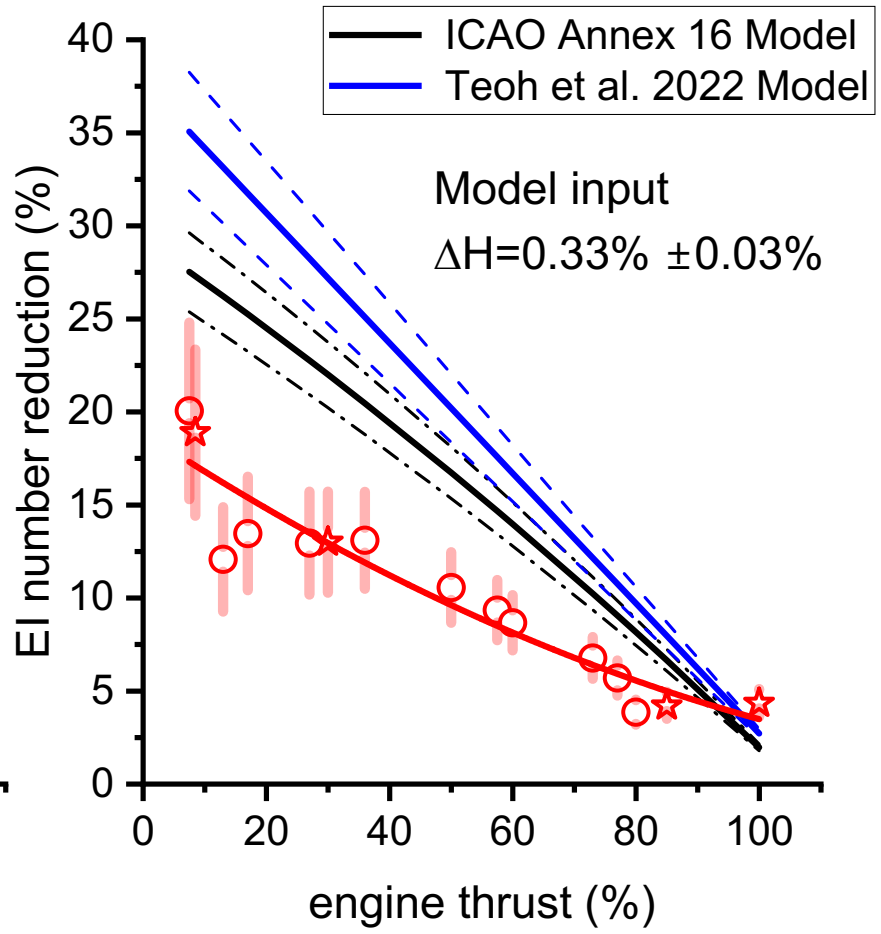
Smaller size: potential effect on lung deposition, unlikely impact on contrail formation

Result #3: Thrust-dependent nvPM mass & number reductions

Mass



Number



At idle

35% Mass Reduction

20% Number Reduction

Models overpredicted nvPM number reductions

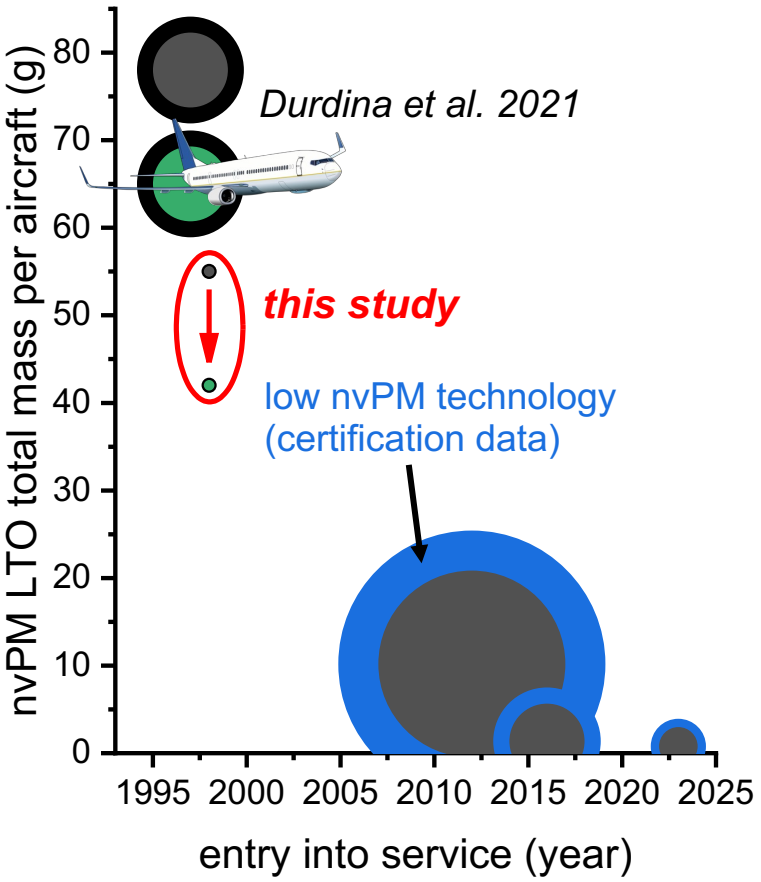
Airport Air Quality & Climate Impact

Lower UFPs: Improved air quality

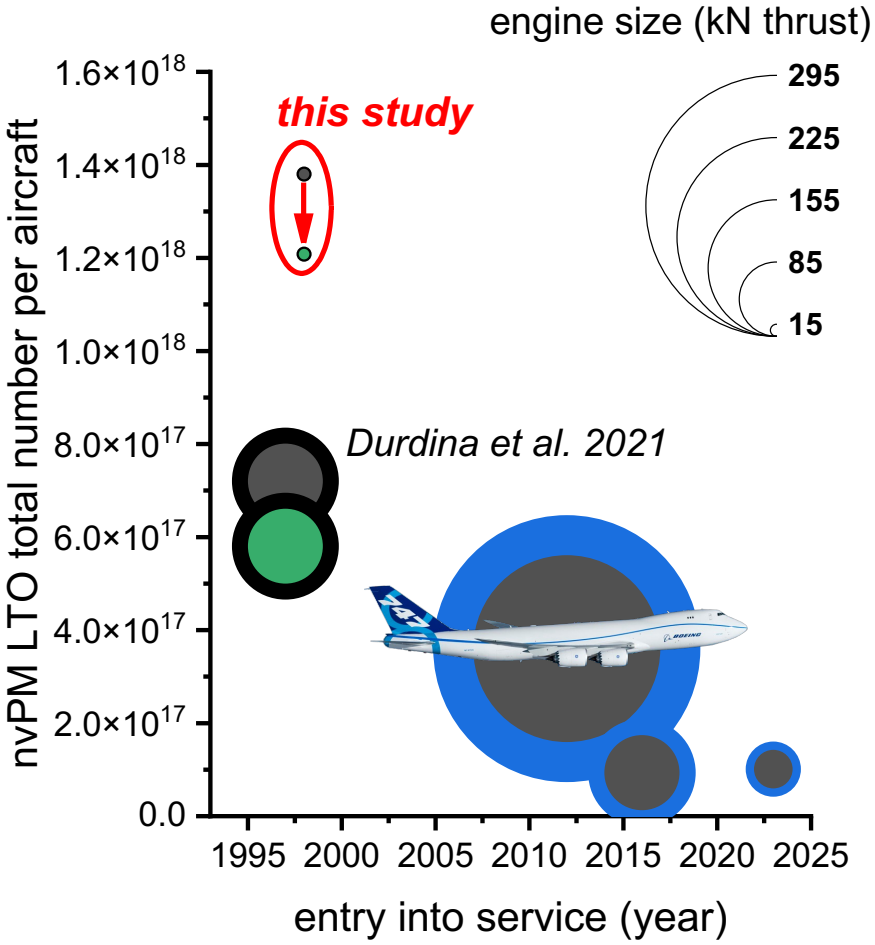
Cruise emissions: predicted ~10% lower nvPM number (proportional to ice crystal concentration in the "soot-rich" regime)

Result #3: Landing & Take-off (LTO) nvPM emissions

Mass



Number



LTO cycle emissions

20% reduction

Clean technology outperforms clean fuel

LTO cycle

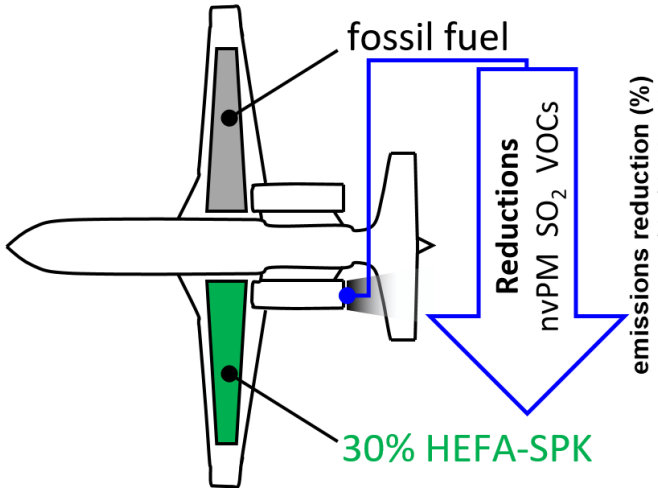
Mode	Thrust	Time
Take-off	100%	0.7 min
Climb	85%	2.2 min
Approach	30%	4.0 min
Taxi	7%	26 min

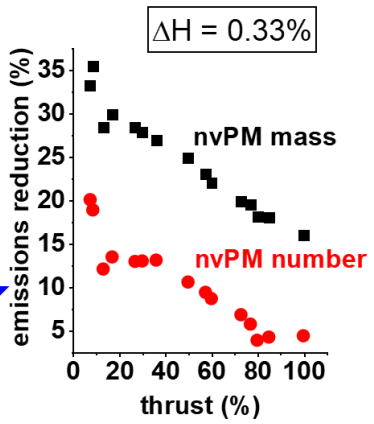
Summary & Implications

? Can a small jet emit more particles at an airport than a jumbo jet?

YES. In the same test cycle, small jets may emit more nvPM than modern large airliners.

? Does sustainable aviation fuel (SAF) improve its pollutant emissions?





Policy Implications

Regulatory gap: First ICAO-compliant small jet EIs reported with a SAF blend.

Fuel composition - nvPM: New data for future model development.

Future Directions

Fleet studies: Tests on new, representative small jets on the ground and at cruise.

Assessment & certification: Smoke number standard replacement for engines <26.7 kN.

Acknowledgements

ONERA

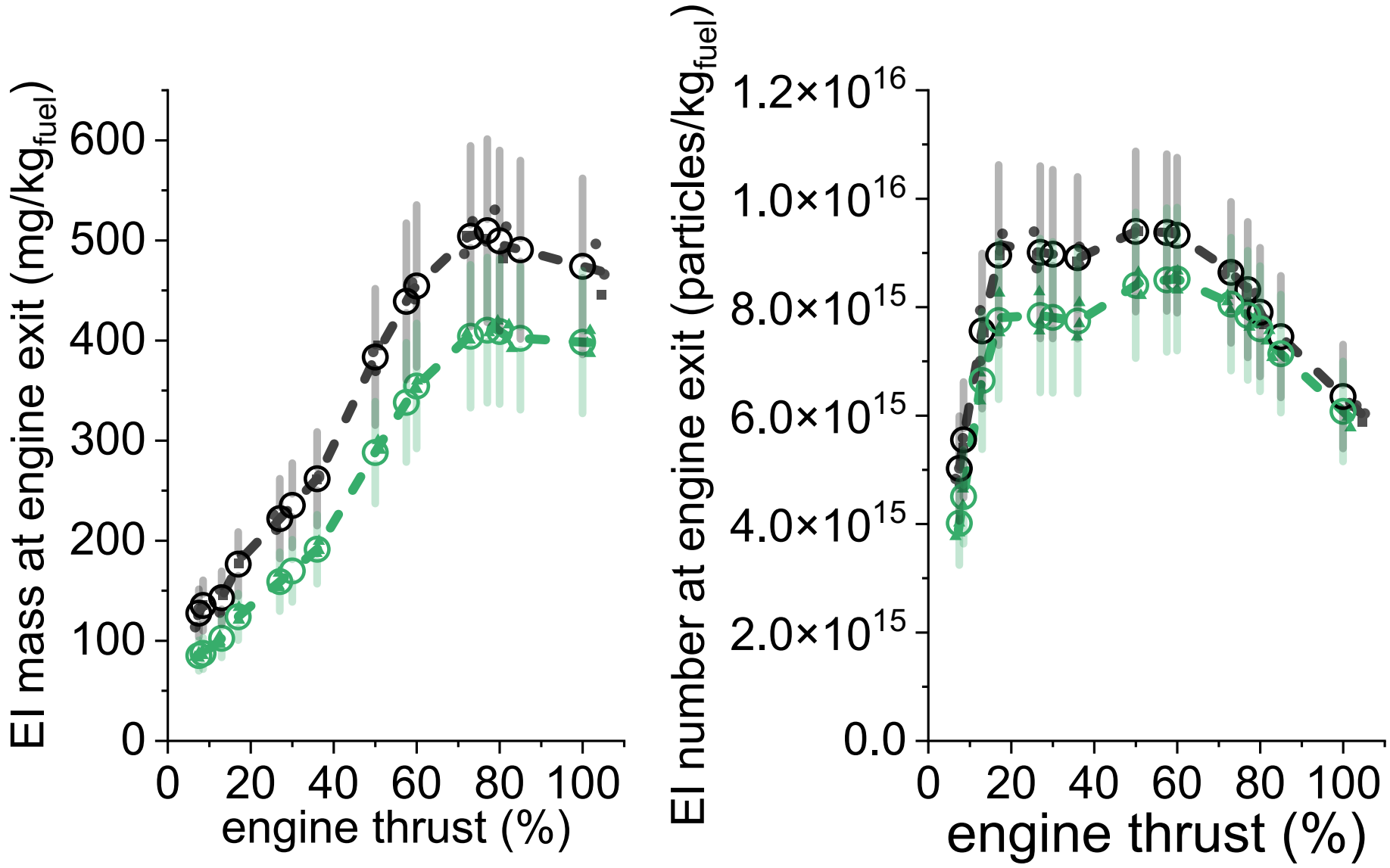
Published article

ACS ES&T Air

Supporting graphics

- nvPM EIs (loss-corrected)
- Gaseous EIs and combustion efficiency

nvPM mass and number EIs (loss-corrected)



Gaseous EIs (ICAO Annex 16 corrected)