

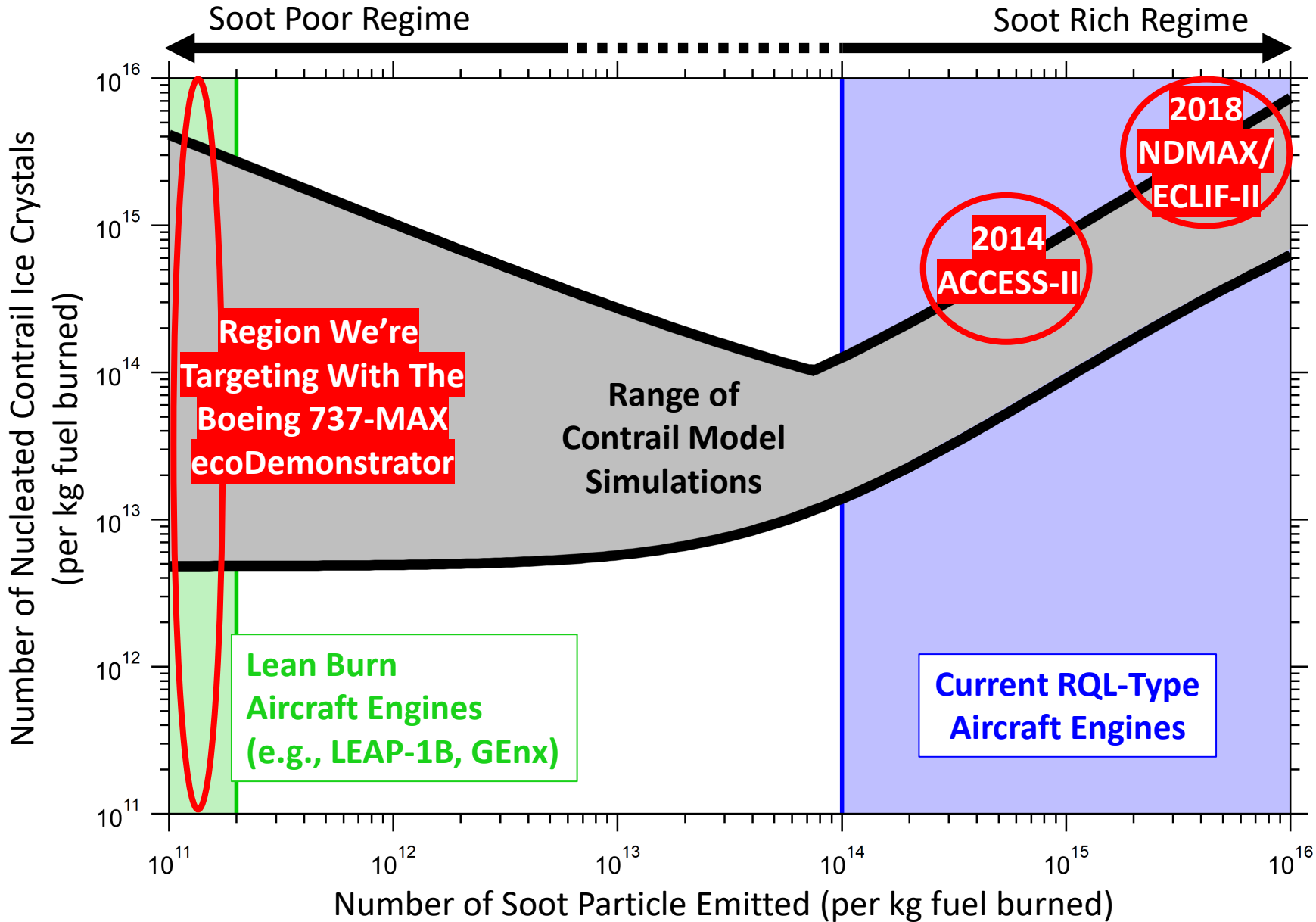
Particle and Trace Gas Emissions Indices Measured During the 2021 Boeing ecoDemonstrator Emissions Ground Test



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Great Potential of SAF and Advanced Combustor Technology



Need to understand engine particle emissions in the “soot-poor” regime in order to connect to contrail formation and climate impacts

Emissions reductions also beneficial for air quality

Figure adapted from Kärcher, *Nature Communications*, 2018.

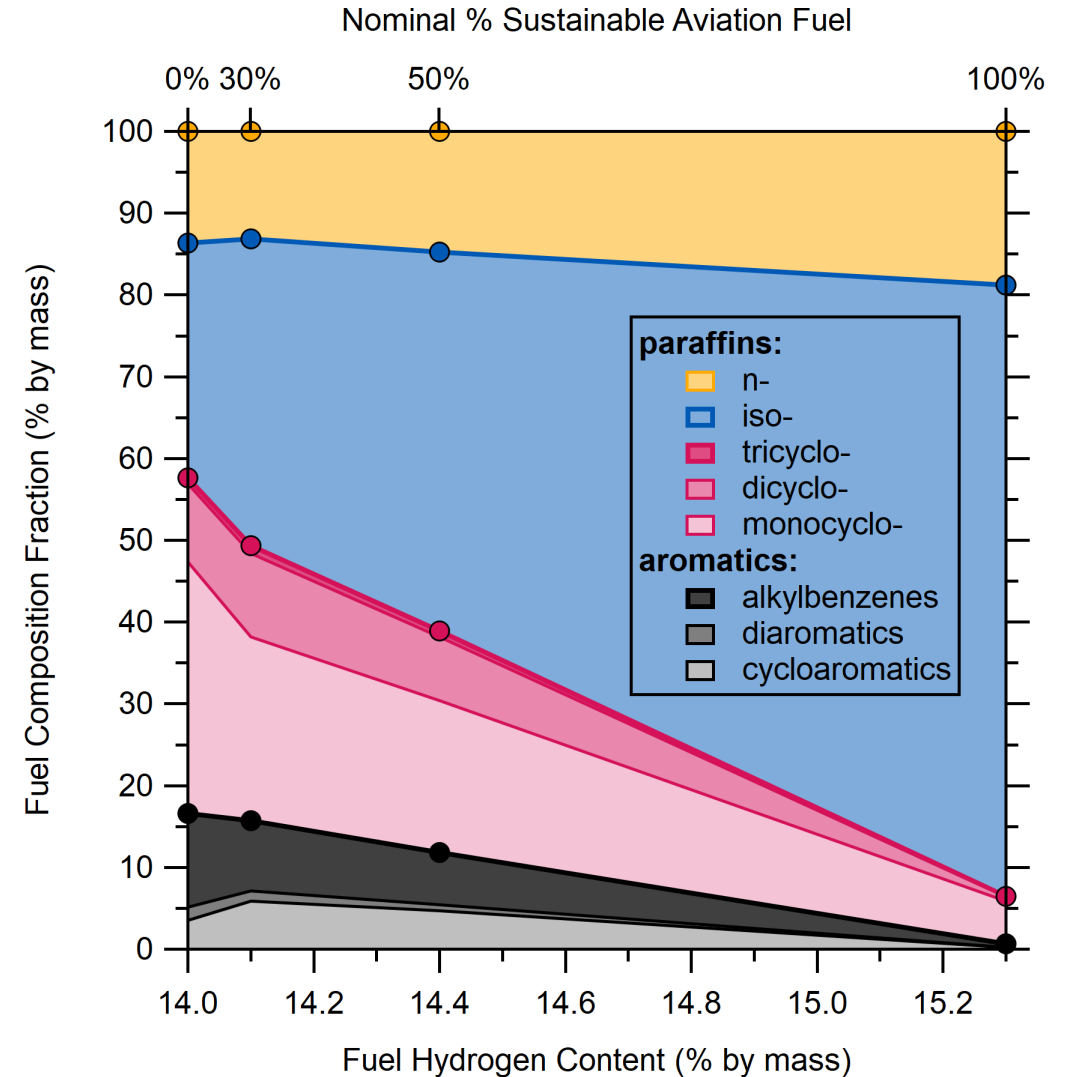
Red circles show the approximate Number EIs observed during the 2014 ACCESS-II and 2018 ND-MAX/ECLIF-II flight test series.

Moore et al., *Nature*, 2017; Voigt et al., *Nature Comms. Earth & Environ.*, 2021

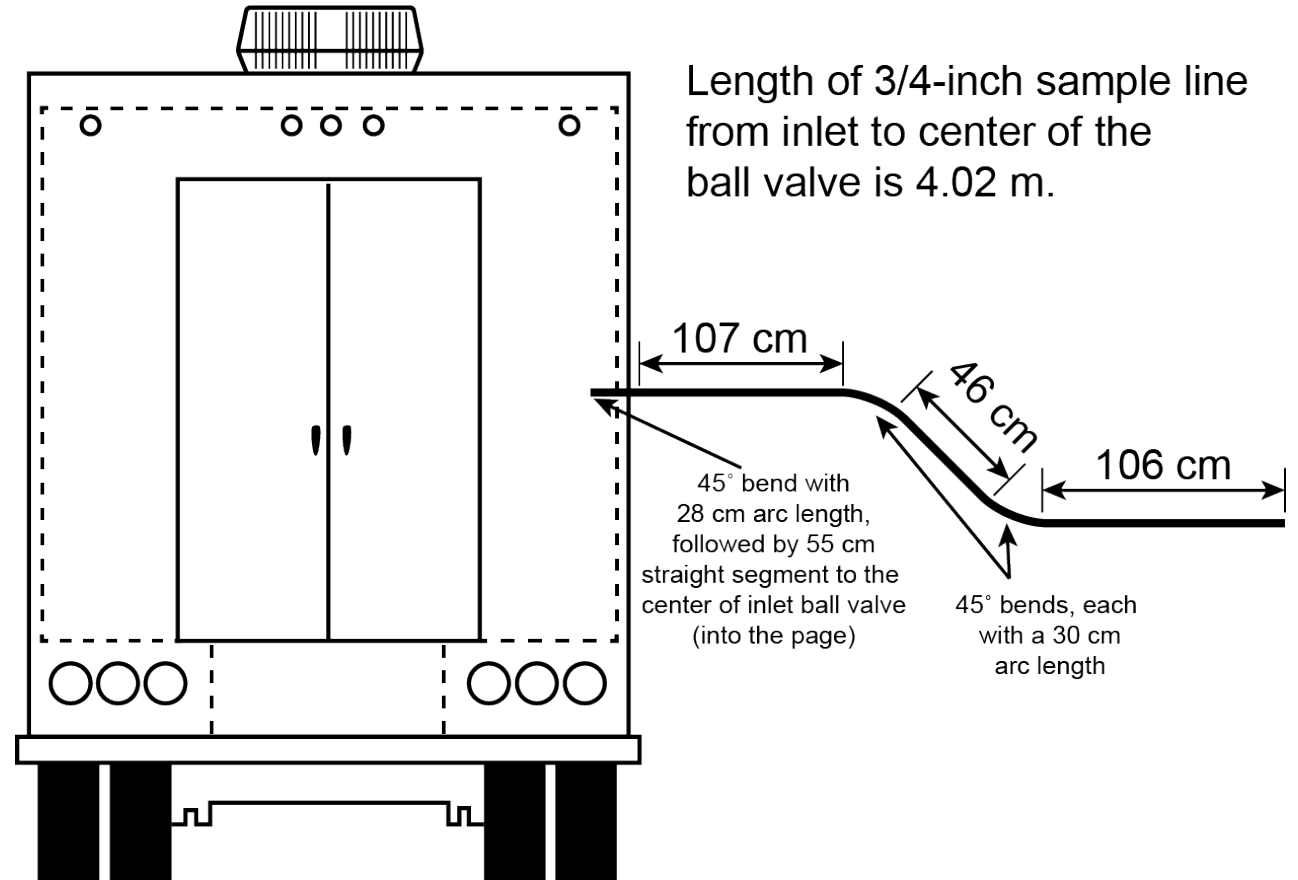
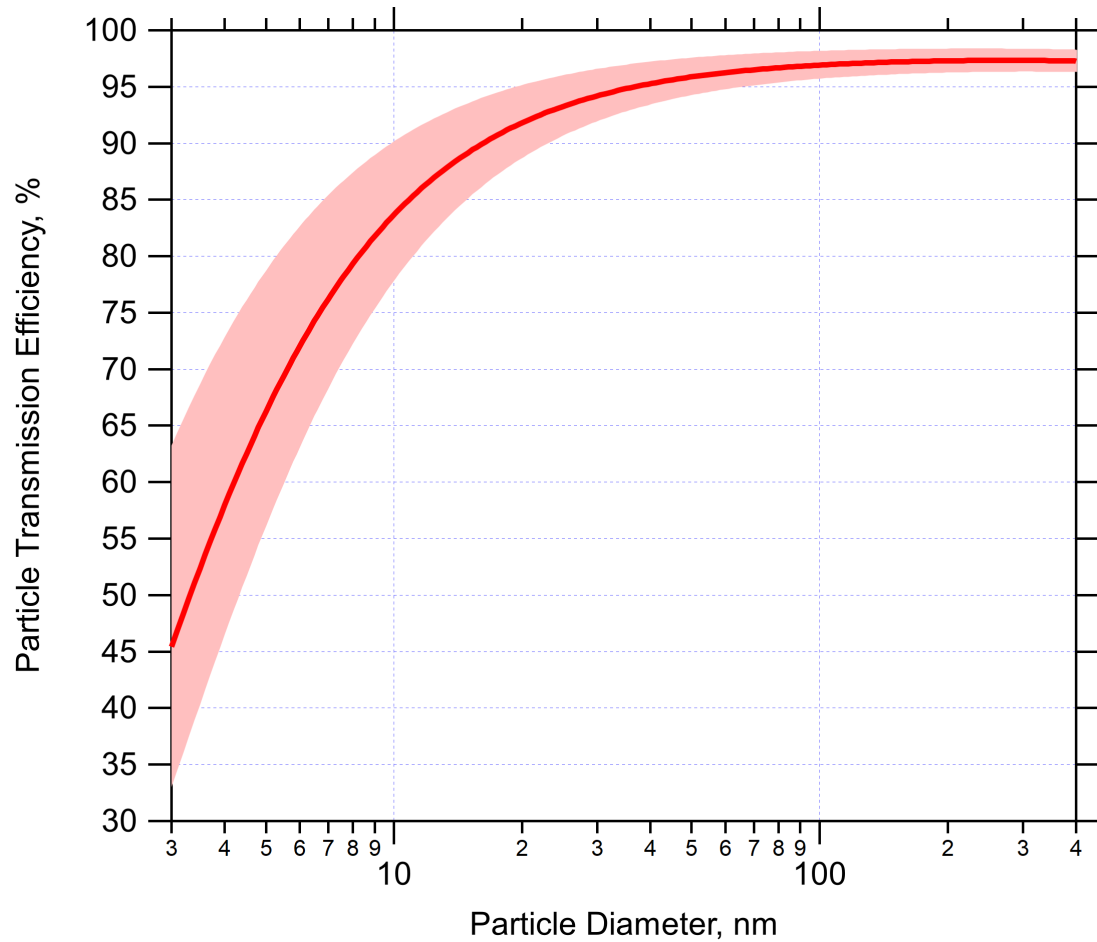
Fuel Composition Does Not Necessarily Scale Linearly With %SAF



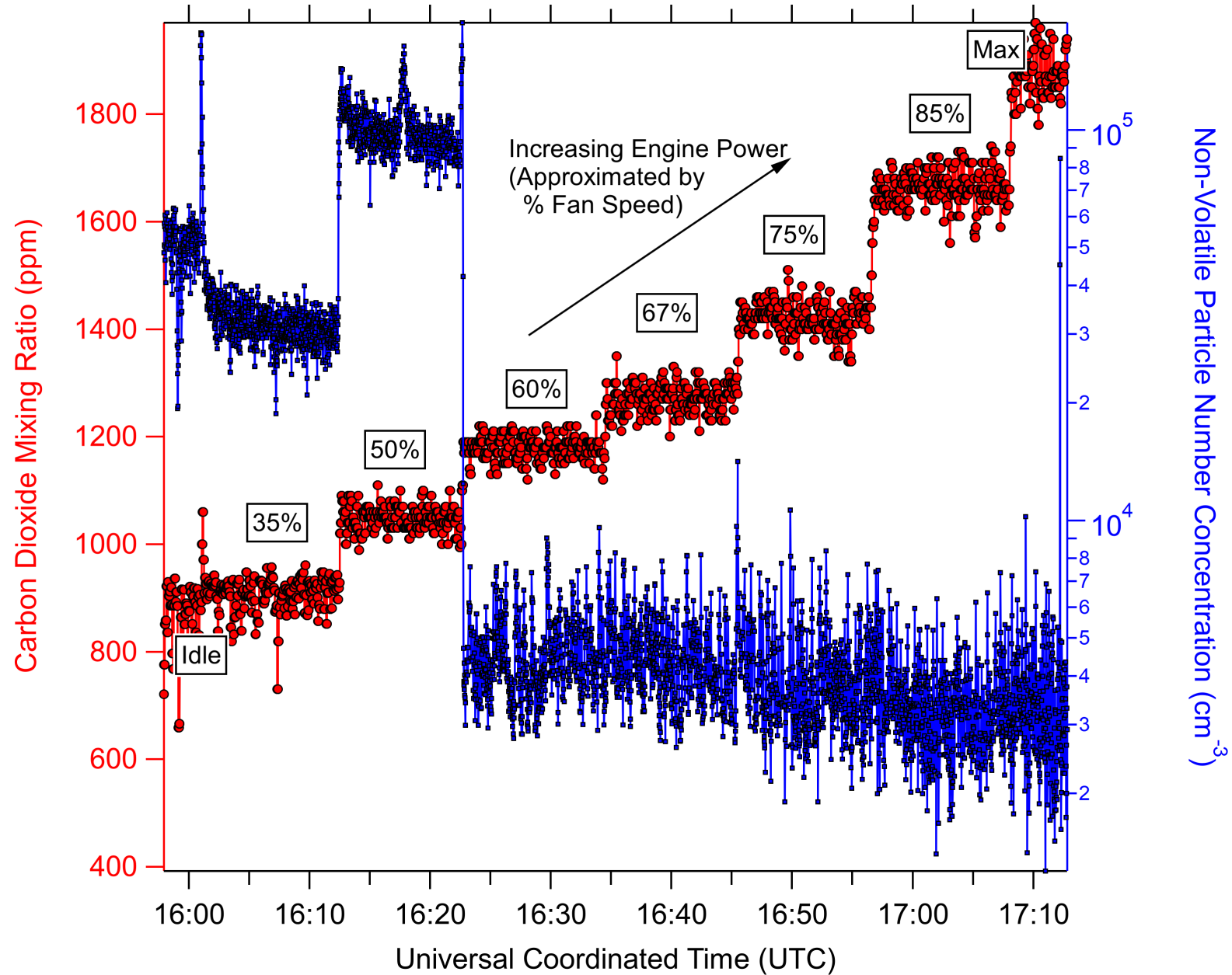
- Investigated four fuels:
 - 100% SAF
 - 50% SAF with Jet A¹
 - 30% SAF with Jet A²
 - 100% Jet A³
- Good linearity between aromatics and %hydrogen
- 50% SAF tested is NOT halfway between 0% and 100% in terms of aromatics or %hydrogen



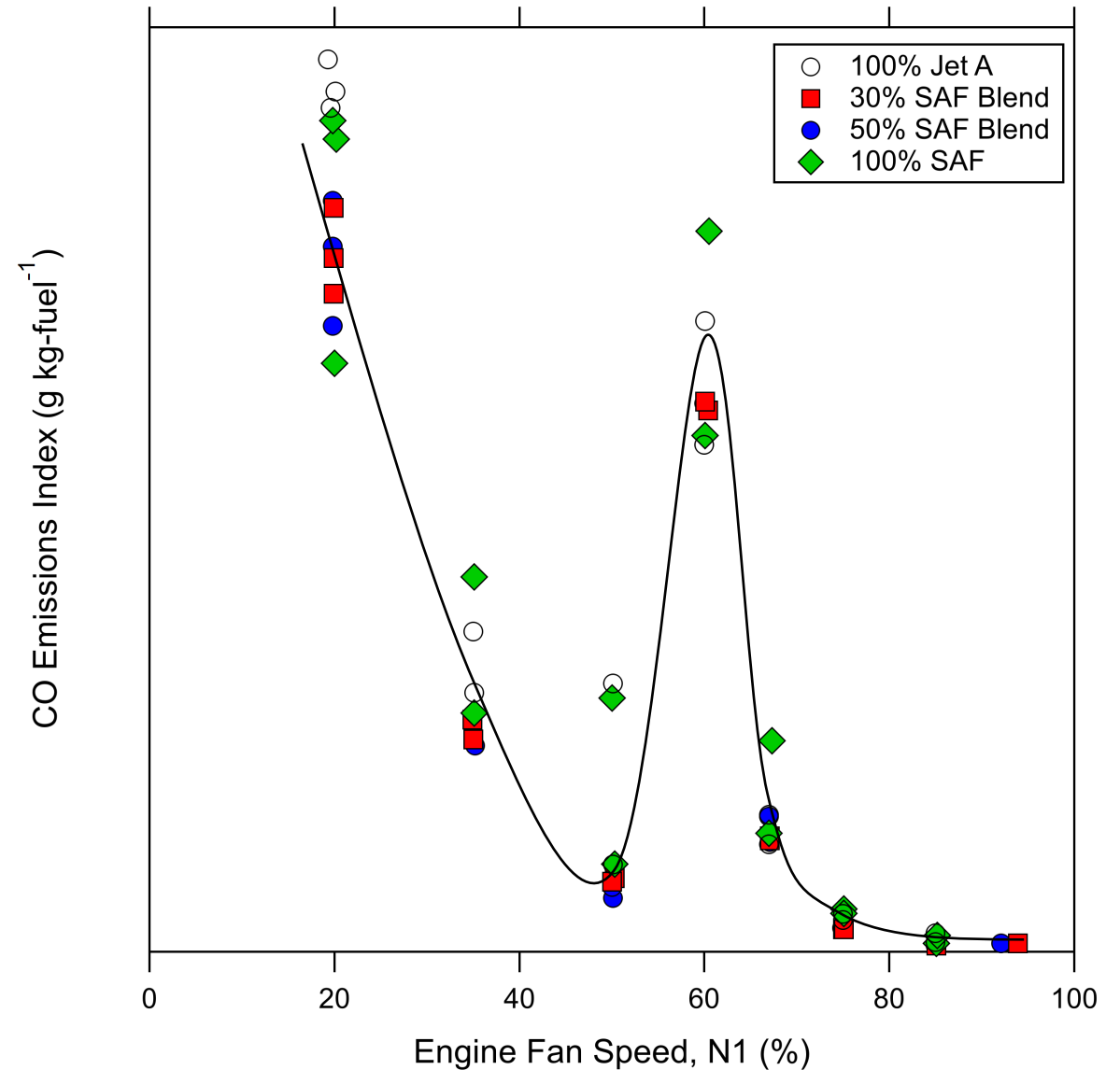
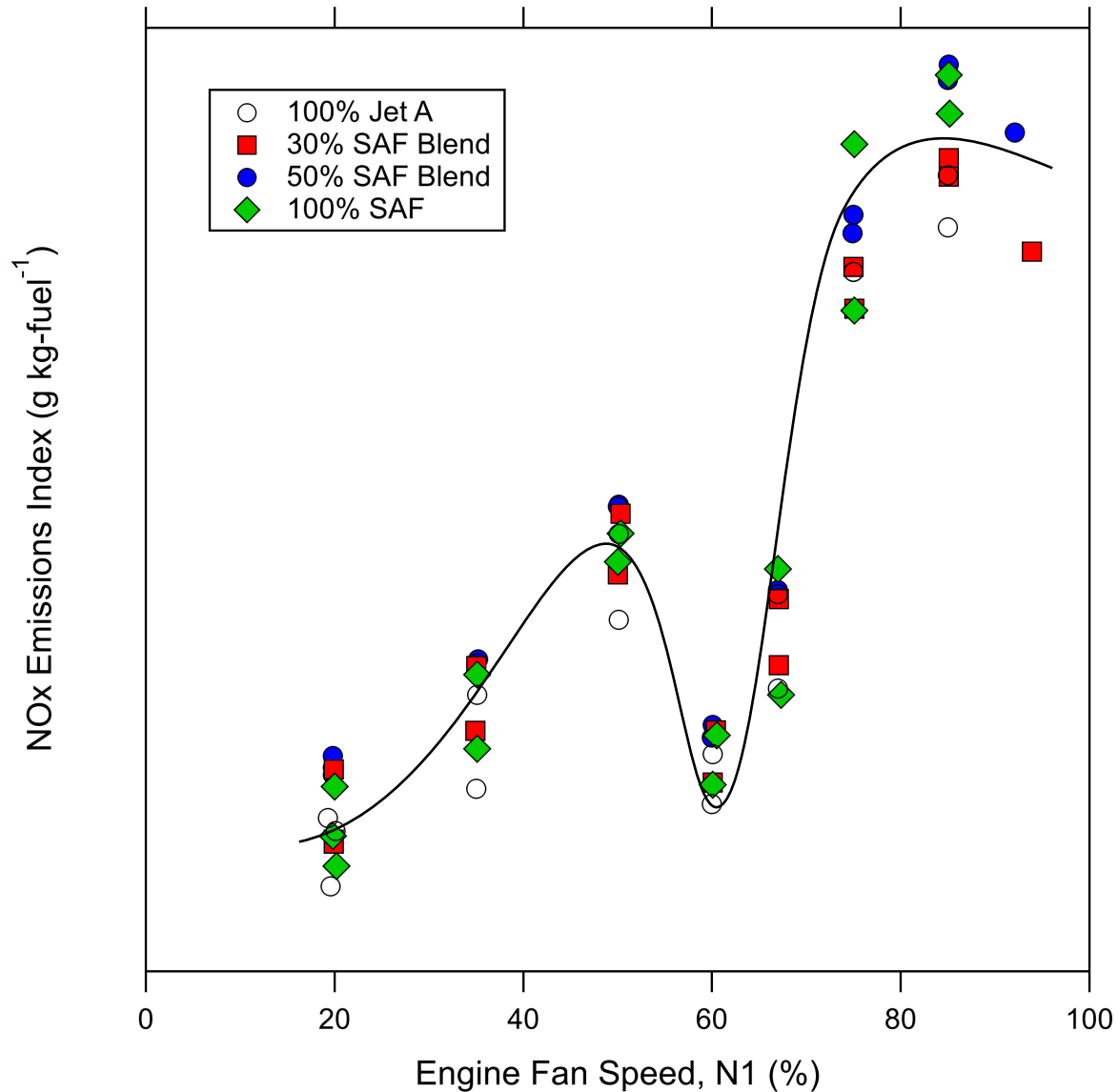
Theoretical line losses are very low, owing to short transmission line



Test Matrix Sampled 8 Thrust Conditions Both in Ascending, Descending

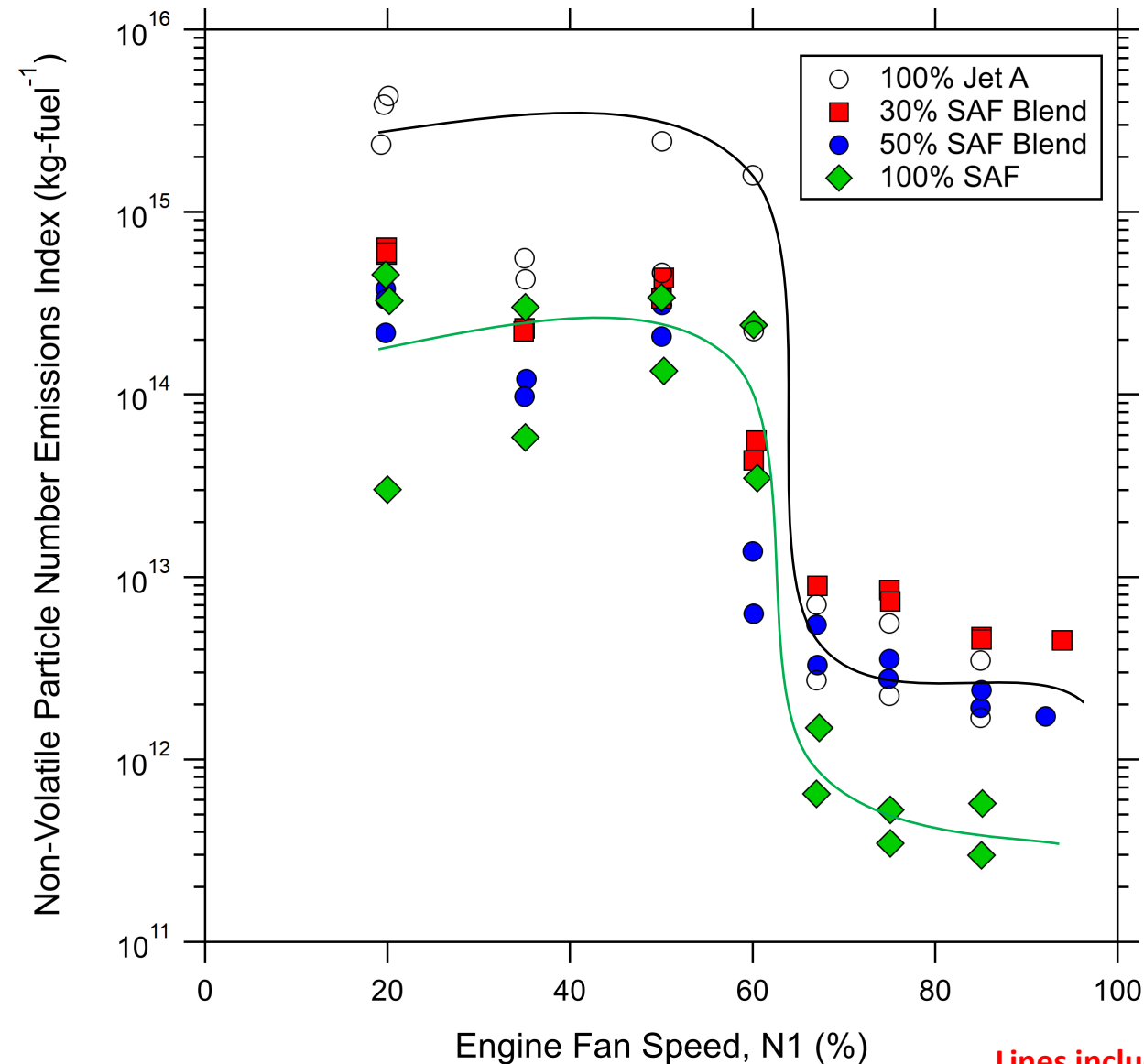
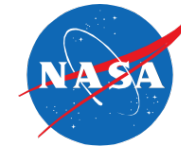


Trace Gas Emissions Indices Invariant With Fuel (as expected)

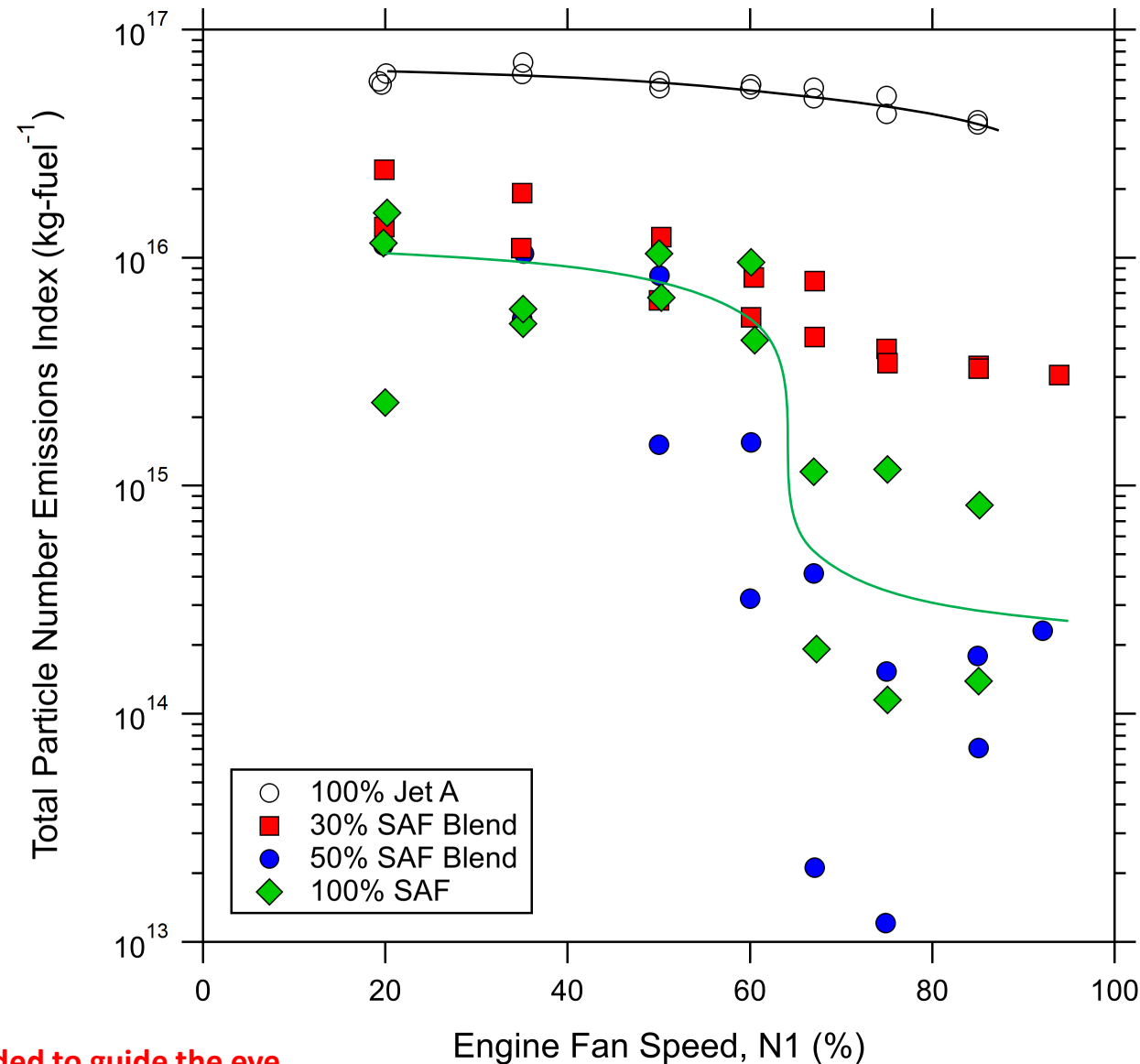


Lines included to guide the eye

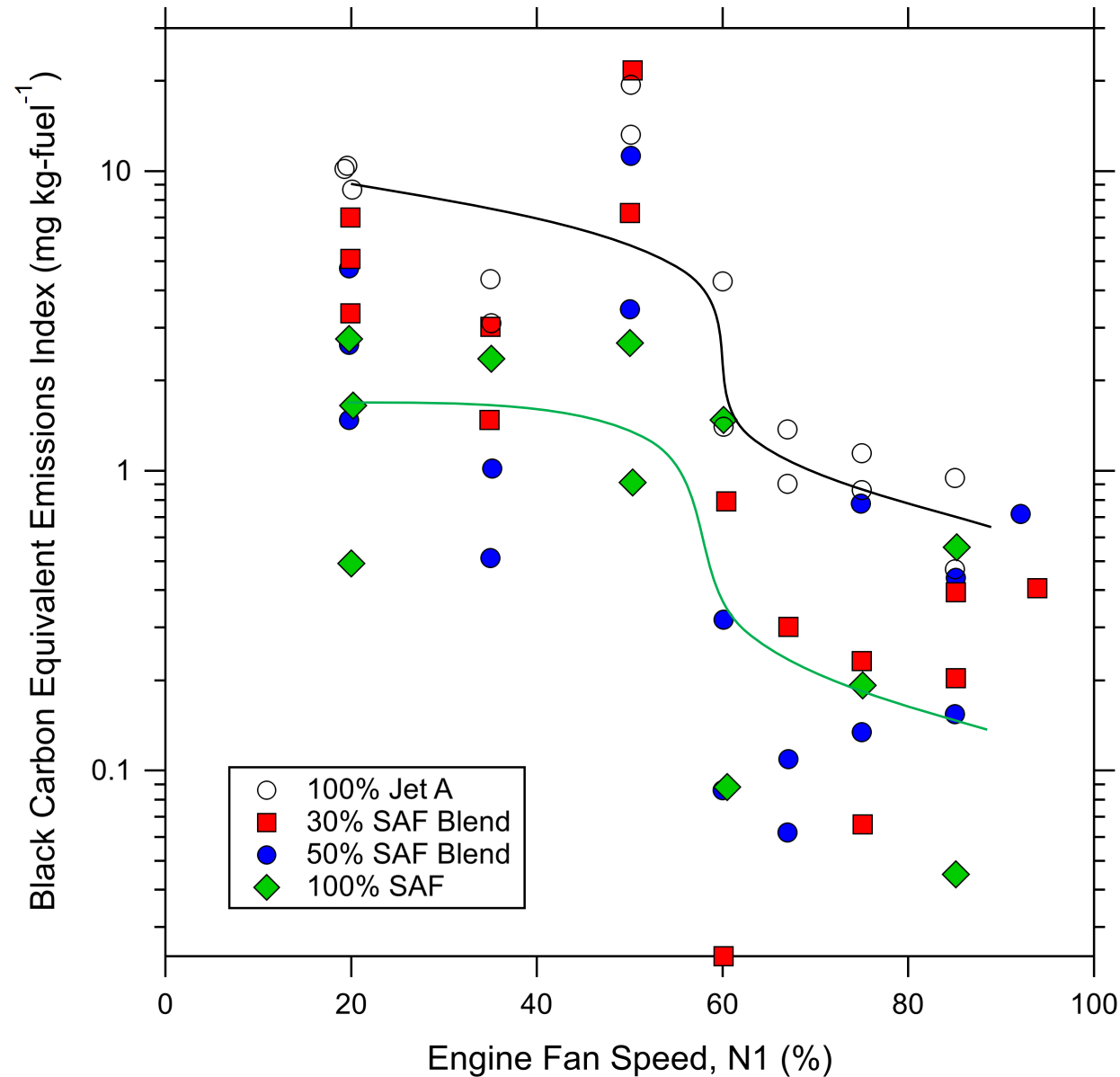
Significant Fuel Impacts on Non-Volatile and Total Particle Number



Lines included to guide the eye

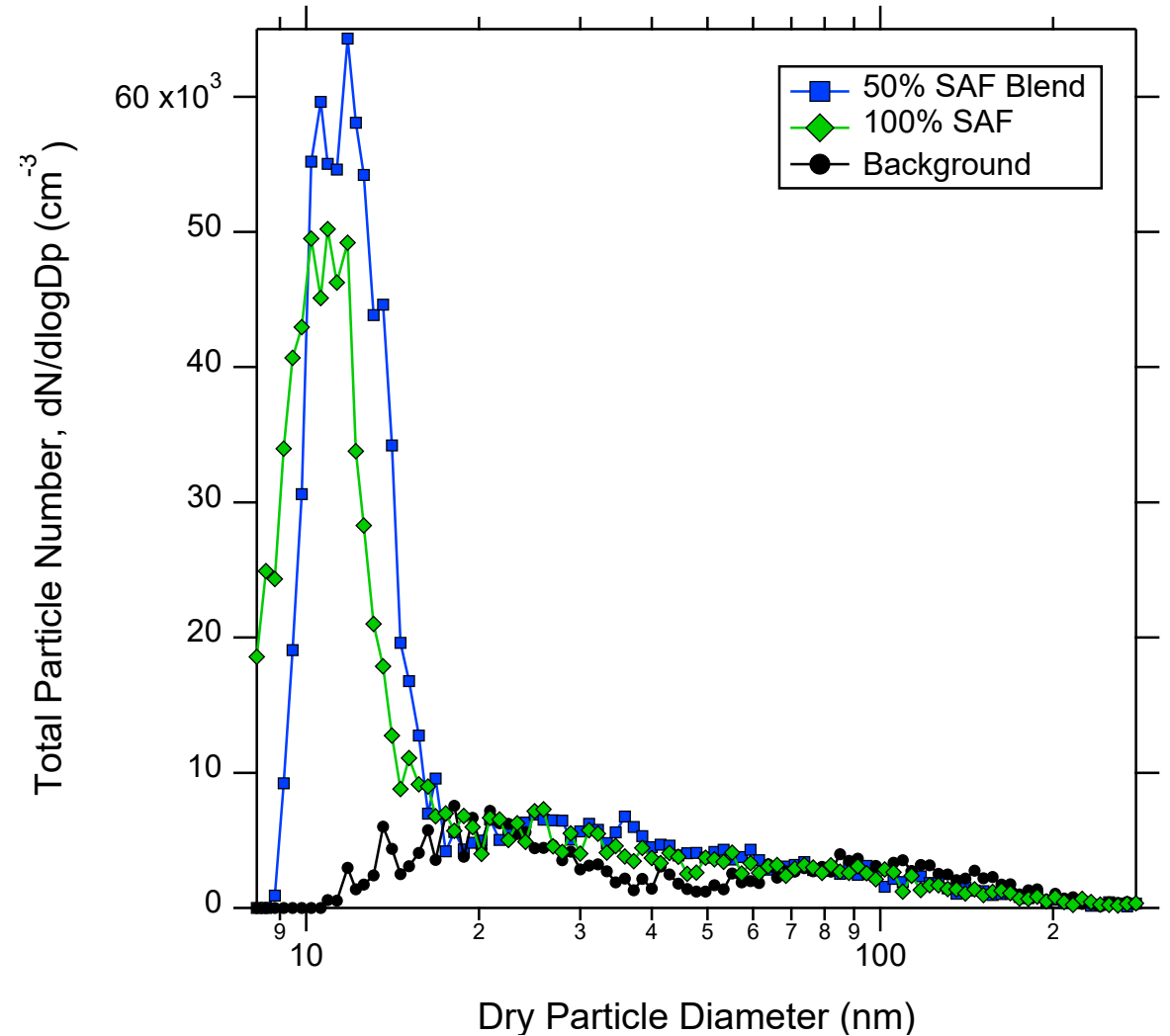
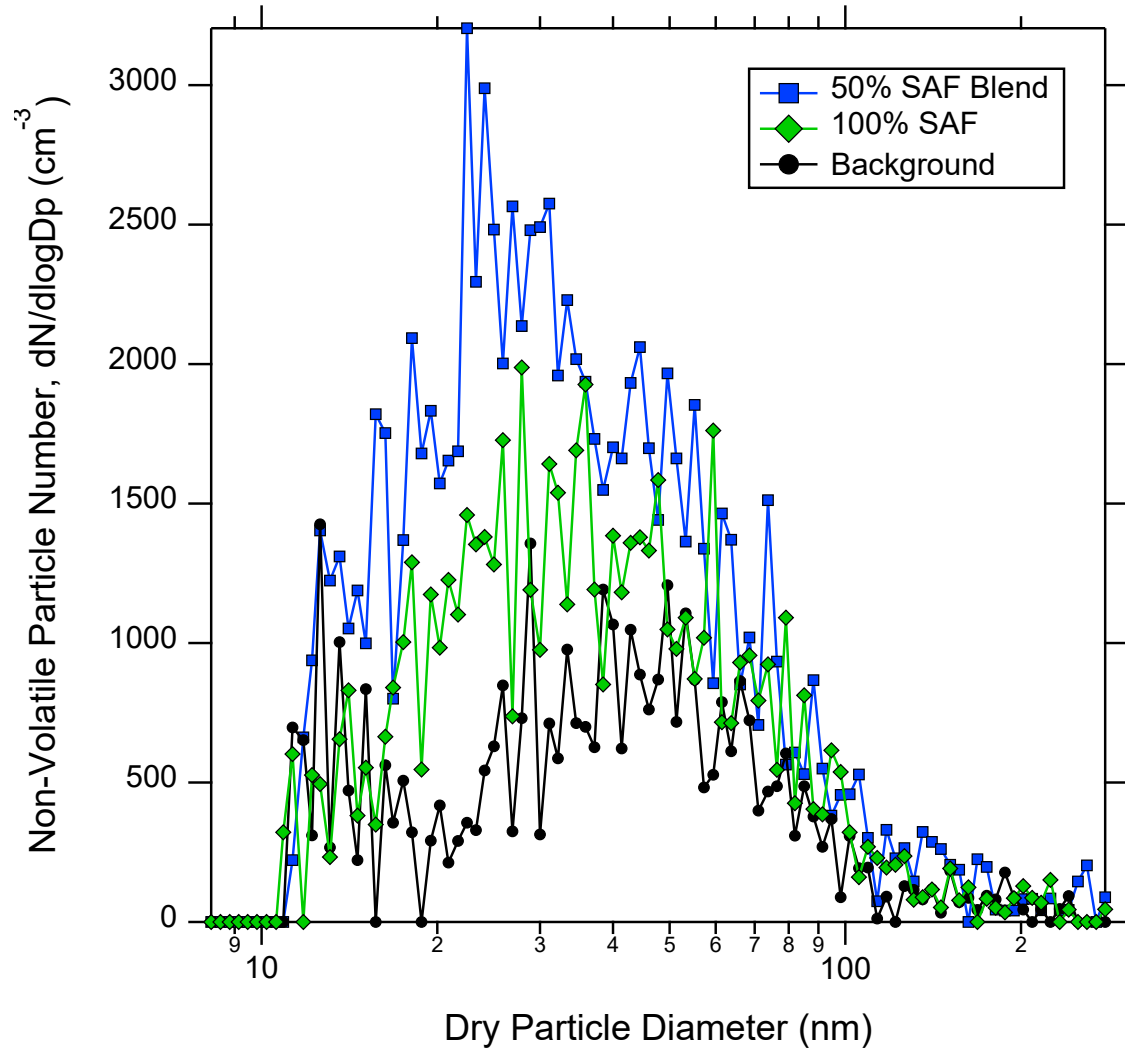


Fuels Also Impact Black Carbon Mass; Although, Noisy Because Absorption-Based Mass Measurements Are Near Background Values



Lines included to guide the eye

Example Size Distributions at 85% Thrust Demonstrate The Challenge With Integrated Mass (Volume) Measurements Versus Number





Take Home Points

- Staged lean burn engines + 100% SAF yield dramatic particle emissions reductions
 - $\sim 10^{14}$ to $\sim 10^{11}$ per kg-fuel for non-volatile particle number
 - $\sim 10^{16}$ to $\sim 10^{14}$ per kg-fuel total particle number
 - ~ 10 - 100 to <1 mg per kg-fuel for particle mass
- 100% SAF also lowers particle emissions even at low power conditions (relevant for air quality)
- High fuel sulfur content yield large numbers of volatile particles even at high thrust
- Low-emitting engines emphasize the need for on-wing measurements
 - Ground measurements with short sampling lines minimize losses and improve signal-to-noise
 - Ground measurements can cover many power settings and allow for more detailed information (e.g., size distributions)
 - Cruise measurements connect the detailed measurements on the ground to real-world, contrail-forming conditions

