VERIFIED CARBON STANDARD
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Approved VCS Methodology
VM0013

Version 1.0
Sectoral Scope 3

Calculating Emission Reductions from Jet Engine Washing

Scope

This methodology provides a procedure to determine the net CO_2 emissions reductions associated with the on-wing washing of jet turbine engine washing.

Methodology Developer

The methodology was developed by Pratt & Whitney, in collaboration with United Technologies Corporation and Det Norske Veritas Certification, Ltd.

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1 SUMMARY

This methodology was developed to calculate the emission reductions generated by washing jet engines. All engines become contaminated through normal operation leading to restricted airflow, higher exhaust gas temperature, and increased fuel consumption. By eliminating engine contamination, engine washings improve propulsive efficiency measured as a decrease in thrust specific fuel consumption or TSFC, resulting in decreased emissions of carbon dioxide (CO_2).

It is anticipated that the methodology will be used by airline owners of jet engines who wish to utilize on-wing jet engine washing as a means of increasing engine thrust efficiency and reducing CO_2 emissions. Jet engine washing technology service providers might also use the methodology to assist airline customers in overall engine emissions reduction measurement.

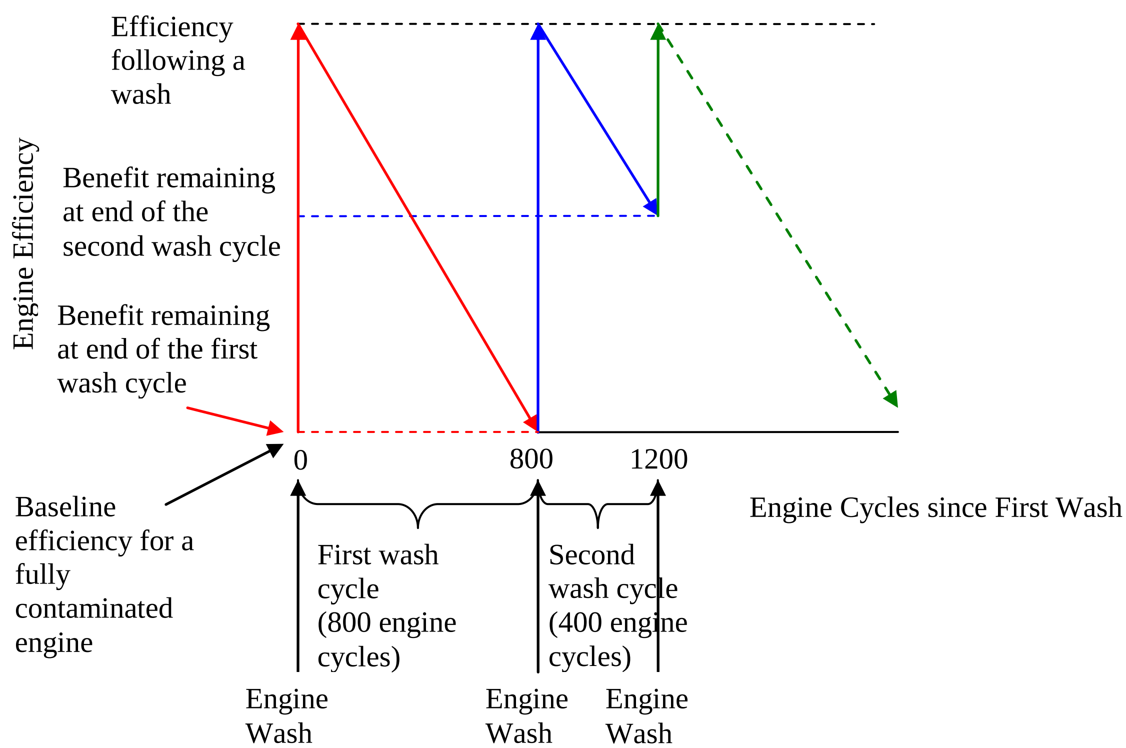
Figure 1 illustrates the general process of washing a jet engine. Once an engine is washed, it starts a wash cycle defined as the interval between two consecutive washes. As a result of the washing, engines will experience improved propulsive efficiency while in operation; the operation of an engine between one takeoff and one subsequent landing is called an engine cycle. As the number of engine cycles increase, the engine will become re-contaminated and the efficiency improvement realized by the washing will decline until the engine is washed again. The change in the efficiency improvement during the first washing cycle is tracked in red in Figure 1. This second washing terminates the first cycle and begins the subsequent cycle. The change in efficiency during the second wash cycle is tracked in blue in Figure 1. As demonstrated in Figure 1, washing cycles may not contain the same number of engine cycles for a variety of reasons, including:

Safety procedures – Some maintenance procedures prevent all engines on an aircraft from being washed at the same time. This reduces the risk that the same mistake made on one engine will be repeated on all engines of an aircraft, thus reducing the chance that all engines will fail at the same time.

Scheduling – Due to time constraints, it may not be feasible to wash all engines on an aircraft at once. Also, as engines are routinely switched between airplanes, the optimal wash interval for one engine may be different from that of the other engine on the same plane.

Since the number of engine cycles is directly correlated to the change in efficiency following a washing, the average efficiency improvement realized during the washing cycle will differ. Taking into account the average efficiency benefit realized during the wash cycle and the amount of fuel consumed by each engine cycle in a wash cycle, the fuel savings can be calculated and converted to emission reductions. As an additional environmental benefit, the methodology uses a closed-loop system for the collection, filtration and reuse of water used to wash the engine. This both saves water (of particular importance in water constrained areas of the world where engines may be washed) and eliminates the potential contamination of soil and groundwater associated with non closed-loop engine washing.

Figure 1 – Illustration of Engine Washing Process



2 SOURCE, DEFINITIONS AND APPLICABILITY

2.1 Source

- The approach for this baseline and monitoring methodology is based on elements from AMS II.J., the approved CDM (Clean Development Mechanism) small-scale baseline and monitoring methodology for demand-side activities for efficient lighting technologies. Jet engine washing technology is similar to lighting technology under AMS II.J. since both technologies provide benefits that may increase their market penetration in the baseline scenario. However, the market penetration of both technologies will increase far more rapidly under the project case. In the two methodologies, it is the additional market penetration growth achieved due to the project activities that are counted as emission reductions.

For more information regarding the methodology, please refer to http://cdm.unfccc.int/goto/MPappmeth.

2.2 Defintions

For the purpose of this methodology, the following definitions apply:

- **Engine cycle** The operation of an engine between one takeoff and one subsequent landing
- **Fleet** refers to a group of identical engines that use the same type of jet fuel and are attached to the same type of aircraft frame
- **Cruise EGT** refers to exhaust gas temperature (degrees Celsius) recorded during flight
- **Cruise Fuel Flow** refers to the rate (kg per hour or m^3 per hour) at which fuel is consumed by the engines during flight
- **Exhaust Gas Temp (EGT)** refers to temperature of the engine exhaust gases resulting from combustion of the fuel mixture, expressed in degree Celsius
- **Participant** refers to an individual airline that has agreed to wash all or a part of their fleet
- **Project Proponent** refers to the entity that is organizing airlines to wash all or part of their fleet
- **Project's engine washing technology** refers to any engine washing technology that decreases TSFC through the removal of engine contamination
- **Take off EGT** refers to engine exhaust gas temperature (degrees Celsius) recorded during takeoff
- **Thrust Specific Fuel Consumption (TSFC)** is an engineering term referring to fuel efficiency of an engine. TSFC represents the amount of fuel an engine burns to produce thrust, as measured in (Kg/hr)/Newton of thrust.
- **Wash** refers to the cleaning of an individual jet engine
- **Washing cycle** refers to the interval between consecutive washes for a particular engine

2.3 Applicability Conditions

The methodology is applicable to engine washing technology that meets the following conditions:

- The engine washing technology cleans any or all three of the compressive components of an engine: fan, low pressure compressor, and high pressure compressor.

- The engine washing was performed and completed in compliance with the wash requirements as provided in the engine's maintenance manual, or an alternative specification document as approved by a governing aviation regulatory body, such as the United States Federal Aviation Administration. Compliance with this condition will be indicated by the completion and maintenance supervisor signature on a 'released to service' form. Released to service forms are globally required for all aircraft undergoing any maintenance prior to their being put back into service.

- The only emission reductions claimed under this methodology are those related to increased propulsive efficiency due to engine washing. The project will not claim any emissions reductions as a result of other measures that result in changes in fuel consumption, e.g., changes in routes, operators' behaviour, etc, or fuel chemical property changes which increase fuel combustion efficiency.

- The engine is left on-wing during the washing and the engine washing technology is transported to the engine as opposed to removing the engine from the wing and transporting it to another location for the engine wash.

- The engine washing project will include a minimum of 100 engine washes per fleet to assure the methodology adequately compensates for single-engine model data variability.

- Applicable engines will be only those which during the period for which engine washing benefit is measured have not undergone an on-wing modification that could improve efficiency as measured by TSFC.

3 BASELINE METHODOLOGY PROCEDURE

3.1 Project Boundary

The project boundary is the physical, geographical location of each engine washed by the project technology, and the flight routes on which the emissions reductions occur. The project boundary includes emissions from generators and equipment used to transport engine wash equipment to the wash location.

The greenhouse gases included in or excluded from the project boundary are shown in Table 1.

Table 1: Emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification / Explanation
Baseline	Jet engines that are washed in the project case	CO_2	Yes	Emissions from fuel combustion represent the major emission source in the baseline
		CH_4	No	Negligible
		N_2O	No	Negligible
Project activity	Jet engines that are washed by the project technology	CO_2	Yes	Emissions from fuel combustion represent the major emission source in the project case
		CH_4	No	Negligible
		N_2O	No	Negligible
	Energy use during engine wash	CO_2	Yes	Maybe an important emission source
		CH_4	No	Negligible
		N_2O	No	Negligible
	Vehicles that transport engine wash equipment	CO_2	Yes	Maybe an important emission source
		CH_4	No	Negligible
		N_2O	No	Negligible

3.2 Identification of the baseline scenario

The project baseline activity will be demonstrated using the latest version of the *"Combined tool to identify the baseline scenario and demonstrate additionality"* that is available on the UNFCCC website.

3.3 Procedure for demonstrating additionality

Additionality shall be demonstrated using the latest version of the *"Combined tool to identify the baseline scenario and demonstrate additionality"* that is available on the UNFCCC website.

3.4 Baseline emissions

The following equations are used to estimate the baseline emissions for jet engines:

$$BE_y = \sum_{m}^{z} \left(BFC_y * EF_{CO2,ACFuel,y} \right) \quad (1)$$

Where:

BE_y	=	Baseline emissions in year *y* (t CO_2/yr)
M	=	An individual fleet
Z	=	Total number of fleets
BFC_y	=	Baseline fuel consumption by all engines in fleet m in year y (mass or volume unit)
$EF_{CO2,ACFuel,y}$	=	CO_2 emission factor for fuel used in fleet *m* engines (ton CO_2/mass or volume unit)

Procedure for estimating the CO_2 emission factor for fuel used in jet engines, $EF_{CO2,ACFuel,y}$

$$EF_{CO2,ACFuel,y} = EF_{C,ACFuel,y} * 44/12 * OXID_{ACFuel} * NCV_{ACFuel} \quad (1.1)$$

Where:

$EF_{CO2,ACFuel,y}$	=	CO_2 emission factor for fuel used in aircraft engines in fleet *m* (tonne of CO_2/mass or volume unit)
$EF_{C,ACFuel,y}$	=	Carbon content of fuel used in aircraft engines in fleet *m* (tonne/Tera Joule)
$OXID_{ACFuel}$	=	Oxidation factor of fuel used in aircraft engines in fleet *m*
NCV_{ACFuel}	=	Net caloric value of fuel used in aircraft engines in fleet *m* (Tera Joule/mass or volume units)

Procedure for estimating the baseline fuel consumption, BFC_y

$$BFC_y = \sum_{j=1}^{n} \left[\sum_{wc=1}^{x} \left[\sum_{ec=1}^{NECj,wc} MFC_r \right] \right] \quad (1.2)$$

Where:

BFC_y	=	Baseline fuel consumption by all engines in fleet *m* in year *y* (mass or volume units)
J	=	An individual engine in fleet *m*
N	=	Total number of engines in fleet *m* in year *y*
Wc	=	A wash cycle, or the interval between two consecutive washes
X	=	Total number of wash cycles for engine *j* in year *y*
$NEC_{j,wc}$	=	Number of engine cycles for engine *j* during wash cycle, *wc*, not to exceed $ACFC_m$

(number of cycles leading to full engine contamonation without a wash)
Ec = An engine cycle
MFC_r = Modelled fuel consumption in the baseline case, based on engine utilization (*r*) during the engine cycle (mass or volume units)

- Note: If the fuel used in an engine is changed during the project crediting period, the engine will be assigned to a different fleet corresponding to the appropriate combination of aircraft frame, engine type and fuel type for the wash cycle when the fuel switch occurs and all subsequent wash cycles where the new fuel is used.

- The methodology uses a Business Penetration (BP) factor, by which emissions reductions compared to baseline are reduced to reflect the current market penetration of jet engine washing technology. The BP factor is applied to the total modelled fuel consumption units to develop MFC_r as used above.

3.5 Project emissions

The following equation estimates the project emissions:

$$PE_y = \sum_{m}^{z} \left(PE_{EA,y} + PE_{WE,y} \right) \quad \textbf{(2)}$$

Where:
PE_y = Project emissions in year *y* (t CO_2)
m = An individual fleet
Z = Total number of fleets
$PE_{EA,y}$ = Emissions from fuel combustion by fleet *m* in year y (t CO_2)
$PE_{WE,y}$ = Emissions generated in the process of washing fleet *m* engines in year y (t CO_2)

Procedure for estimating the project emissions associated with fuel combustion by fleet *m* engines in year *y*, $PE_{EA,y}$

$$PE_{EA,y} = FC_{.y} * EF_{CO2,ACFuel,y} \quad \textbf{(2.1)}$$

Where:
$PE_{EA,y}$ = Emissions from jet engine fuel combustion in year *y* (tonne of CO_2)
FC_y = Fuel consumption by fleet *m* in year *y* (mass or volume unit)
$EF_{CO2,ACFuel,m,y}$ = Carbon dioxide emission factor of fuel used in fleet *m* engines (tonne of CO_2/ mass or volume unit)

Procedure for estimating the CO_2 emission factor for the fuel used in engines in year *y*, $EF_{CO2,ACFuel,y}$

$$EF_{CO2,ACFuel,y} = EF_{C,ACFuel,y} * 44/12 * OXID_{ACFuel} * NCV_{ACFuel} \tag{2.1.1}$$

Where:

$EF_{CO2,ACFuel,y}$	=	Carbon dioxide emission factor of fuel used in fleet *m* engines (tonne of CO_2/ mass or volume unit)
$EF_{C,ACFuel,y}$	=	Carbon content of fuel used in aircraft engines (tonne/Tera Joule)
$OXID_{ACFuel}$	=	Oxidation factor of fuel used in aircraft engines
NCV_{ACFuel}	=	Net caloric value of fuel used in aircraft engines (Tera Joule/mass or volume units)

Procedure for estimating the fuel consumption by fleet *m* in year *y*, $FC_{m,y}$

$$FC_y = \sum_{j=1}^{n}\left[\sum_{wc=1}^{x}\left[\left(\sum_{ec=1}^{NECj,wc} MFC_r\right) * \left(1 - \overline{TSFC_{j,wc}}\right)\right]\right] \tag{2.1.2}$$

Where:

FC_y	=	Fuel consumption by all engines in fleet *m* in year *y* (mass or volume units)
J	=	An individual engine in fleet *m*
N	=	Total number of engines in fleet *m* in year *y*
Wc	=	A wash cycle, or the interval between two consecutive washes
X	=	Total number of wash cycles for engine *j* in year *y*
$NEC_{j,wc}$	=	Number of engine cycles for engine *j* during wash cycle, *wc*, not to exceed $ACFC_m$
Ec	=	An engine cycle
MFC_r	=	Modelled fuel consumption in the baseline case, based on engine utilization (*r*) during the engine cycle (mass or volume units)
$\overline{TSFC_{j,wc}}$	=	Average TSFC improvement for engine *j* throughout the wash cycle, *wc*, due to wash *w* (%)

- As described above, the benefit of a wash will vary for each washing cycle depending on the number of engine cycles. However, airlines do not track fuel consumption at the level of detail that would be required to determine fuel consumption per wash cycle (fuel consumption is tracked at the fleet level, not by aircraft, engine or cycle). Since data limitations prevent accurate reporting of fuel consumption by wash cycle in the project case, the baseline fuel consumption for each engine cycle is determined using industry standard models (as described in section 4) and aggregated for each washing cycle. Wash cycle fuel consumption is then adjusted based on the average TSFC benefit realized during the wash cycle, to determine the wash cycle fuel consumption in the project case. This is aggregated across all wash cycles to determine annual fuel consumption for an engine, and then engine fuel consumption is aggregated across the fleet.

- Note 1: If the fuel used in an engine is changed during the project crediting period, the engine will be assigned to a different fleet (corresponding to the appropriate combination of aircraft frame, engine type and fuel type) for the wash cycle when the fuel switch occurs and all subsequent wash cycles where the new fuel is used.

- Note 2: Fuel consumption associated with engine cycles that are in excess of $ACFC_m$ during a particular wash cycle will not be included in this calculation. This is described further under equation 2.1.2.1.2

Procedure for estimating the average TSFC improvement per wash cycle, $\overline{TSFC_{j,wc}}$

$$\overline{TSFC_{j,wc}} = \left(\frac{\Delta TSFC_{j,w} + \Delta TSFC_{j,NECj,wc}}{2} \right) \tag{2.1.2.1}$$

Where:

$\overline{TSFC_{j,wc}}$	=	Average TSFC improvement for engine *j* throughout the washing cycle, *wc*, due to wash *w* (%)
$\Delta TSFC_{j,w}$	=	TSFC improvement for engine *j* following wash *w* (%)
$\Delta TSFC_{j,NECj,wc}$	=	TSFC improvement remaining for engine *j* after $NEC_{j,wc}$ cycles following a wash
W	=	An individual engine washing

Immediately following a wash, aircraft engines will realize the greatest increase in TSFC (represented by $\Delta TSFC_{j,w}$) and this declines in a linear fashion as the engine becomes more contaminated with each engine cycle (as shown in Figure 1 above) until the end of the wash cycle (the TSFC improvement remaining at the end of the wash cycle is represented by $\Delta TSFC_{j,NECj,wc}$). Since this decline is linear, the net effect of the wash throughout the wash cycle can be expressed as the average TSFC benefit.

Procedure for estimating the TSFC improvement for engine *j* following wash *w*, $\Delta TSFC_{j,w}$

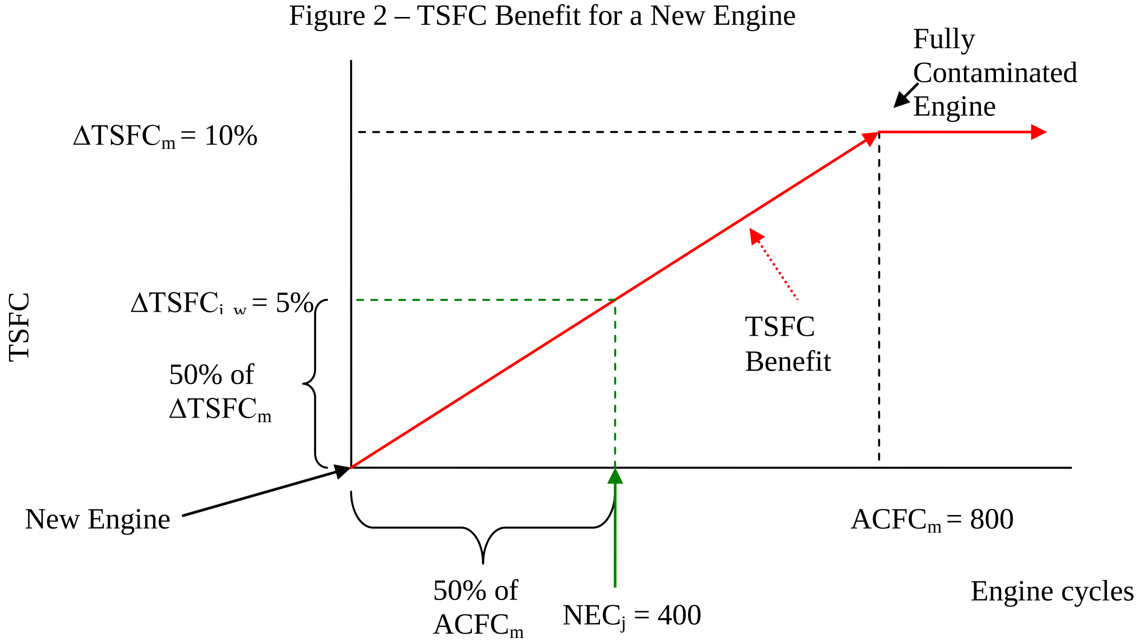
$$\Delta TSFC_{j,w} = \Delta TSFC_m * \left(\frac{NEC_j}{ACFC_m} \right) \tag{2.1.2.1.1}$$

Where:

$\Delta TSFC_{j,w}$	=	TSFC improvement for engine *j* following wash *w* (%)
$\Delta TSFC_m$	=	TSFC improvement for an engine in fleet *m* following a wash (%)
NEC_j	=	Number of engine cycles for engine j since it was put into service, not to exceed $ACFC_m$
$ACFC_m$	=	Number of engine cycles that, in the absence of any engine washings, will lead a clean engine in fleet *m* to become fully contaminated.

The TSFC improvement following washing in the project case ($\Delta TSFC_{j,w}$) can, in most cases, be compared to a fully contaminated engine, as defined by $\Delta TSFC_m$. The exception is an engine that has not yet travelled the number of cycles that causes full contamination as defined by $ACFC_m$, such as a new engine that has just been put into service. If an engine is washed before it reaches $ACFC_m$ cycles, it would be inappropriate to compare the wash benefit to the fully contaminated case. As engine contamination increases in a linear fashion relative to engine cycles until $ACFC_m$ is reached, and because engine contamination and TSFC benefit are directly correlated, the TSFC benefit for a wash that occurs before $ACFC_m$ cycles can be found by discounting the maximum TSFC benefit by the proportion of $ACFC_m$ cycles that has been reached before the wash takes place (see Figure 2).

Figure 2 – TSFC Benefit for a New Engine



Procedure for estimating the TSFC improvement remaining at the end of the wash cycle, $\boldsymbol{\Delta TSFC_{j,NECj,wc}}$

$$\Delta TSFC_{j,NECj,wc} = \left(\Delta TSFC_m * \left(1 - \frac{NEC_{j,wc}}{ACFC_m} \right) \right) \qquad \textbf{(2.1.2.1.2)}$$

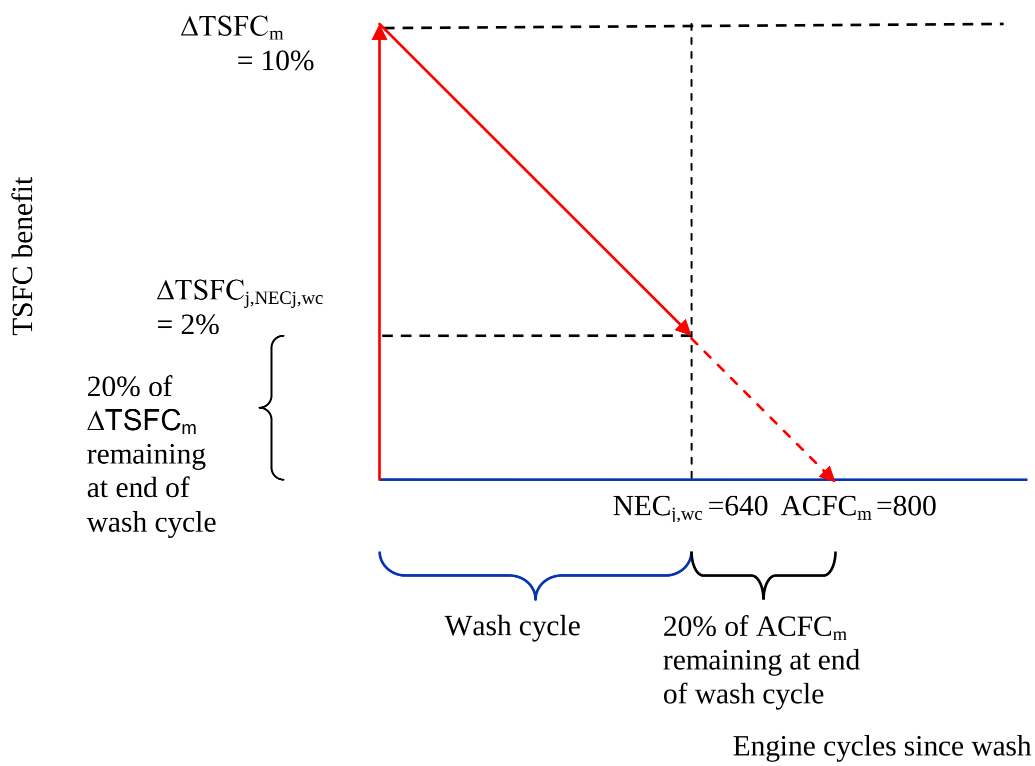
Where:

$\Delta TSFC_{j,NECj,wc}$	=	TSFC improvement for engine *j* after $NEC_{j,wc}$ cycles following a wash
$\Delta TSFC_m$	=	TSFC improvement for engine *j* following a wash (%)
$NEC_{j,wc}$	=	Number of engine cycles for engine ***j*** during wash cycle, *wc*, not to exceed $ACFC_m$
$ACFC_m$	=	Number of engine cycles that, in the absence of any engine washings, will lead a clean engine in fleet *m* to become fully contaminated.
W	=	An individual wash

If it were certain that the wash cycle would contain $ACFC_m$ engine cycles, equation 2.1.2.1 would simply take the average between $\Delta TSFC_{j,w}$ (the benefit immediately following wash *w*) and 0 (since $ACFC_m$ represents the point where the TSFC benefit is entirely lost). However, project participants may elect to shorten the wash cycle (note that cycles in excess of $ACFC_m$ are eliminated from consideration – see below), as demonstrated in figure 3. As a result, the TSFC benefit remaining at the end of this shortened wash cycle, $\Delta TSFC_{j,NECj,wc}$, is calculated in equation 2.1.2.1.2 Since the decline in TSFC is linear as the number of engine cycles increases, this equation calculates $\Delta TSFC_{j,NECj,wc}$ by multiplying the initial TSFC benefit by one minus the proportion of the maximum engine cycles realized during the wash cycle. For instance, if $ACFC_m$ is 800 and $NEC_{j,wc}$ is 640, then 1-(640/800) = 0.2. If the $\Delta TSFC_m$ is 10%, then the remaining TSFC benefit is 10% * 0.2 =2%.

As mentioned above, cycles in excess of $ACFC_m$ following a wash are eliminated from consideration. Once an engine reaches $ACFC_m$ cycles following a wash, it is by definition fully contaminated. The fuel efficiency is therefore no better than it would have been in the baseline and so the project does not provide any additional benefit.

Figure 3 – TSFC Benefit Remaining at End of Wash Cycle



Procedure for estimating the emissions generated during the engine washing process per year, *$PE_{WE,y}$*

$$PE_{WE,m,y} = GE_{m,y} + TE_{m,y} \qquad \textbf{(2.2)}$$

Where:

$PE_{WE,y}$	=	Emissions generated during the washing process in year *y* (t CO_2)
$GE_{m,,y}$	=	Emissions from energy usage to run generators during the washing of engines in fleet *m* in year *y* (t CO_2)
$TE_{m,y}$	=	Emissions from the transport of washing technology to the wash engines in fleet *m* in year *y* (t CO_2)

Procedure for estimating the emissions from energy usage to run the generator during the washing of engines in fleet *m*, $GE_{m,y}$

$$GE_{m,y} = \sum_{g}^{q} \left(FC_{gen,y} * EF_{CO2,GenFuel,y} \right) \quad \textbf{(2.2.1)}$$

Where:

$GE_{m,y}$	=	Emissions from energy usage to run generators during the washing of engines in fleet *m* in year *y* (t CO_2)
G	=	A particular fuel used by generators during the washing of fleet *m* engines
Q	=	Total number of different fuels used by all generators to wash engines in year *y*
$FC_{gen,y}$	=	Fuel consumption by generators used to wash the engines of fleet m in year *y* (mass or volume of fuel)
$EF_{CO2,GenFuel,y}$	=	CO_2 emission factor for the fuel consumed by generator *g* in year *y* (t CO_2/ mass or volume unit)

Procedure for estimating the fuel consumption by generators used to wash the engines of fleet *m* in year *y*, $FC_{gen,y}$

$$FC_{gen,y} = \sum_{j}^{n} \left[\sum_{w}^{x} \left(CR_{fuel} * D_{w} \right) \right] \quad \textbf{(2.2.1.1)}$$

Where:

$FC_{gen,y}$	=	Fuel consumption by generators used to wash the engines of fleet *m* in year *y* (mass or volume of fuel)
J	=	An individual engine in fleet *m*
N	=	Total number of engines in fleet *m* in year *y*
W	=	An engine wash
X	=	Total number of engine washes for engine *j* in year *y* (note that the number of wash cycles is equal to the number of washes, and so the same variable *x* is used)
CR_{fuel}	=	Fuel consumption rate of the generator in year *y* (mass or volume of fuel per hour)
D_w	=	Length of time that the generator is in use during a wash (hours)

Procedure for estimating the CO_2 emission factor for the fuel consumed by the generator in year *y*, $EF_{CO2,GenFuel,y}$

$$EF_{CO2,GenFuel,y} = EF_{C,GenFuel,y} * 44/12 * OXID_{GenFuel} * NCV_{GenFuel} \quad \textbf{(2.2.1.2)}$$

Where:

$EF_{CO2,GenFuel,y}$ = CO_2 emission factor for the fuel consumed by the generator in year *y* (tonne of CO_2/ mass or volume unit)
$EF_{C,GenFuel,y}$ = Carbon content of the fuel consumed by the generator (ton/Tera Joule)
$OXID_{GenFuel}$ = Oxidation factor of the fuel consumed by the generator (%)
$NCV_{GenFuel}$ = Net caloric value of the fuel consumed by the generator (Tera Joule/mass or volume units)

Procedure for estimating the emissions from the transport of washing technology to the wash location in year *y*, *TE_y*

$$TE_{m,y} = \sum_{f=1}^{l} \left(FC_{TV,fuel} * EF_{CO2,TVFuel,y} \right) \quad \textbf{(2.2.2)}$$

Where:

$TE_{m,y}$ = Emissions from the combustion of fuel in vehicles used to transport washing equipment to the wash location in year *y* (mass or volume unit)
F = A particular fuel used by vehicles to transport wash equipment to wash engines in fleet *m*
L = Total number of different fuels that are used by vehicles to transport wash equipment (i.e., propane and electricity)
FC_{TVF} = Fuel consumption by vehicles during the transport of washing equipment in year *y* (volume units)
$EF_{CO2,TVFuel,y}$ = CO2 emission factor for a fuel consumed by transport vehicles in year *y* (tonnetonneof CO_2/mass or volume unit)

Procedure for estimating the quantity of a particular fuel consumed in the transport of washing equipment, FC_{ETF}

$$FC_{TV,fuel} = \sum_{j=1}^{n}\left[\sum_{w=1}^{x}\left[\sum_{v=1}^{p}\left(TD/FE\right)\right]\right] \quad \textbf{(2.2.2.1)}$$

Where:

$FC_{TV,fuel}$	=	Fuel consumption by vehicles during the transport of engine washing equipment in year *y* (volume units)
J	=	An individual engine in fleet m
N	=	Total number of engines in fleet m in year y
W	=	A wash
X	=	Total number of washings for engine *j*
V	=	A vehicle used to transport engine washing equipment for a wash
P	=	Total number of vehicles used to transport engine washing equipment for a wash
TD	=	Total distance travelled by a vehicle to transport washing equipment for a wash (distance units)
FE	=	Fuel efficiency of a vehicle used to transport washing equipment (volume units per distance units)

Procedure for estimating the CO_2 emission factor for fuel consumed by transport vehicles in year *y*, $EF_{CO2,TVF,y}$

$$EF_{CO2,TVFuel,y} = EF_{C,TVFuel,y} * 44/12 * OXID_{TVFuel} * NCV_{TVFuel} \quad \textbf{(2.2.2.2)}$$

Where:

$EF_{CO2,TVFuel,y}$	=	CO_2 emission factor for fuel consumed by transport vehicles in year *y* (tonne of CO_2/mass or volume unit)
$EF_{C,TVFuel,y}$	=	Carbon content of the fuel consumed by transport vehicles (tonne/Tera Joule)
$OXID_{TVFuel}$	=	Oxidation factor of the fuel consumed by transport vehicles (%)
NCV_{TVFuel}	=	Net caloric value of the fuel consumed by transport vehicles (Tera Joule/mass or volume units)

3.6 Leakage

There are no identified sources of leakage for this project activity

3.7 Emission reductions

Since the impact of an engine wash will vary by fleet, the calculation of emission reductions is done for each fleet and then aggregated across all fleets. Emission reductions are calculated as follows:

$$ER_y = (BE_y - PE_y) \quad \textbf{(3)}$$

Where:

ER_y	=	Emission reductions in year *y* (tonne of CO_2e/yr)
BE_y	=	Baseline emissions in year *y* (tonne of CO_2e/yr)
PE_y	=	Project emissions in year *y* (tonne of CO_2/yr)

4 MONITORING METHODOLOGY

All data collected as part of monitoring will be archived electronically and will be kept at least for 2 years after the end of the last crediting period. The data to be monitored is listed in the tables below. All measurements will be conducted with calibrated measurement equipment according to relevant industry standards.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

4.1 Data and parameters not monitored

In addition to the parameters listed in the tables below, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

Data / parameter:	BP
Data unit:	%
Description:	Business penetration factor
Source of data:	Fleet-specific wash penetration data.
Measurement procedures (if any):	Option 1: Project proponents must use fleet-specific wash penetration data to establish this parameter. The parameter is expressed as the percentage of engines washed in a given fleet (i.e., Number of engine washes / total potential engine washes). Option 2: Where fleet-specific data is not available, a default BP factor of 5% shall be used. The default BP factor was developed to discount total project emissions reductions by an amount comparable to the small market adoption of the project technology by potential project participants prior to commencement of the project. The factor was developed using aviation industry estimates indicating that in 2009 approximately 3,000 engines were washed on wing. The commercial aviation market eligible for the project has 40,000 jet engines and to improve performance and reduce emissions, each of these engines should be washed approximately twice per year, for a total of 80,000 potential washes. Using these figures, the project technology market penetration in 2009 was estimated at 3.75%. To provide a more conservative analysis of the market penetration data, the 3.75% has been rounded up to 5%.
Any comment:	The BP factor shall be determined at validation and at the renewal of each crediting period.

Data / parameter:	$ACFC_m$
Data unit:	Cycles
Description:	Number of engine cycles that, in the absence of any engine washings will lead a clean engine in fleet *m* to be fully contaminated.
Source of data:	Previous data analysis indicates that aircraft engines become fully contaminated between 800-1200 engine cycles, depending on the fleet and route. To assure the conservativeness of the emission reduction calculations, the default value has been set at 800 cycles. As an option, projects may use a fleet-specific $ACFC_m$ calculated as follows. The optional $ACFC_m$ value will apply for the complete duration of the crediting period and will reflect the composition of the fleet included in the project.
Measurement procedures (if any):	To calculate $\Delta TSFC_m$, data must be collected for a period of time before and after the wash such that accurate levels can be obtained for each period of time. This data is then analyzed to determine the TSFC benefit of each wash. The TSFC benefit corresponding to the wash cycle length (which corresponds to the number of engine cycles in the wash cycle or the number of cycles required for the engine to become fully contaminated) can then be determined through interpretation of the individual wash TSFC benefits plotted vs. NEC on a scatter plot. The point at which the TSFC benefit plateaus is the benefit that can be expected by a wash of a fully contaminated engine, or $\Delta TSFC_m$. The number of engine cycles that corresponds to $\Delta TSFC_m$ is $ACFC_m$.
Any comment:	Default value = 800

4.2 Data and parameters monitored

Data / parameter:	R
Data unit:	Hours
Description:	Engine utilization for each cycle or hours of operation
Source of data:	Engine operator records
Measurement procedures (if any):	Record hours per cycle, as well as date and time of cycle and the engine serial number, so that utilization can be allocated to a particular engine and wash cycle
Monitoring frequency:	Continuously
QA/QC procedures:	
Any comment:	

Data / parameter:	w
Data unit:	Wash
Description:	A wash for engine j
Source of data:	Engine operator records
Measurement procedures (if any):	Record date and time of the aircraft engine wash as well as the engine serial number, so that fuel consumption can be assigned to a particular engine and wash cycle.
Monitoring frequency:	Continuously
QA/QC procedures:	A signed 'Release to Service' form following completion of engine washing
Any comment:	

Data / parameter:	Ec / NECj,wc
Data unit:	Engine Cycle
Description:	Engine cycle for engine *j*, where an engine cycle includes one takeoff and one landing.
Source of data:	Aircraft engine operator records
Measurement procedures (if any):	Record data and time of cycle, as well as engine serial number so that engine cycle can be assigned to a wash cycle
Monitoring frequency:	Continuously, aggregated per wash cycle to determine $NEC_{j,wc}$. Cycles in excess of $ACFC_m$ during a wash cycle are eliminated from consideration, as described in equation 2.1.2.1.2
QA/QC procedures:	
Any comment:	

Data / parameter:	g
Data unit:	Fuel type
Description:	Fuel type consumed by each generator that is used to wash engines in year *y*
Source of data:	Operator records
Measurement procedures (if any):	
Monitoring frequency:	Recorded one time per year
QA/QC procedures:	
Any comment:	

Data / parameter:	CR_{fuel}
Data unit:	Mass or volume of fuel per hour
Description:	Fuel consumption rate for each generator used to wash engines in year *y*
Source of data:	Vehicle manufacturers specification sheet
Measurement procedures (if any):	
Monitoring frequency:	Recorded one time per year
QA/QC procedures:	
Any comment:	

Data / parameter:	D_w
Data unit:	Hours
Description:	Length of time that a generator is in use during a wash
Source of data:	Measurements by project proponent
Measurement procedures (if any):	In addition to duration of generator use, record date and time of wash, as well as engine serial number(s). In lieu of continuously recording wash duration, average duration of 15 washes for engines with at least $ACFC_m$ cycles may be used as default value for all washes in the fleet. Fully contaminated engines can take longer to clean, resulting in a more conservative estimation of project emissions.
Monitoring frequency:	Continuously If default value is used, record during first engine wash.
QA/QC procedures:	Data taken from written wash log data sheets
Any comment:	The use of default values is acceptable because the emissions associated with energy use during the washing process are likely to be de-minimus.

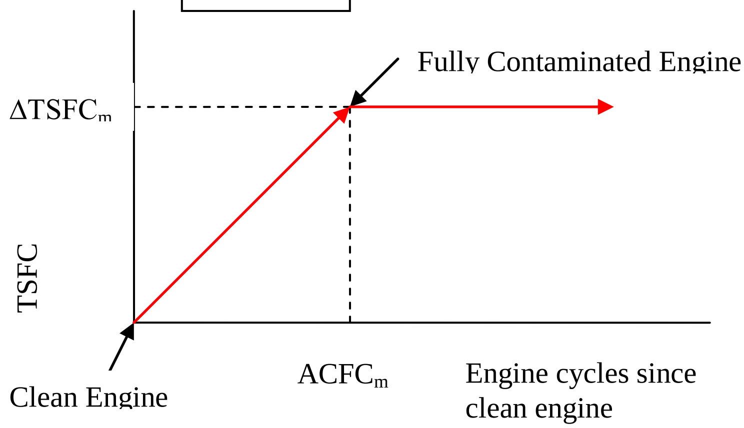
Data / parameter:	f
Data unit:	Fuel type
Description:	Fuel type consumed by a transport vehicle to transport wash equipment in year *y*
Source of data:	Vehicle operator records
Measurement procedures (if any):	
Monitoring frequency:	Continuously
QA/QC procedures:	
Any comment:	

Data / parameter:	TD_{TV}
Data unit:	Distance units
Description:	Total distance travelled by vehicles transporting engine washing equipment per engine wash
Source of data:	Vehicle odometer
Measurement procedures (if any):	Vehicle operator must record the roundtrip distance travelled for each engine wash, as well as the engine serial number that was washed and the time and date that the wash occurs. Alternatively, the vehicle operator can record the greatest roundtrip distance travelled to perform an engine wash for each location (i.e., airport), and this distance can be used as a default value for all other washings.
Monitoring frequency:	Roundtrip distance recorded for every washing. Alternatively, the distance is recorded once based on the greatest possible distance.
QA/QC procedures:	
Any comment:	

Data / parameter:	FE_{TV}
Data unit:	Mass or volume units per distance units
Description:	Fuel efficiency of a vehicle used to transport engine washing equipment to the wash location
Source of data:	Vehicle manufacturers specification sheet
Measurement procedures (if any):	
Monitoring frequency:	Recorded one time per year
QA/QC procedures:	
Any comment:	

Data / parameter:	$\Delta TSFC_m$
Data unit:	%
Description:	TSFC improvement for an engine in fleet *m* following a wash (%)
Source of data:	Engine trend data obtained from aircraft operator, including Takeoff EG Margin, Cruise EGT and Cruise Fuel Flow

Measurement procedures (if any):	To calculate $\Delta TSFC_m$, data must be collected for a period of time before and after the wash such that accurate levels can be obtained for each period of time. This data is then analyzed to determine the TSFC benefit of each wash. The TSFC benefit corresponding to the wash cycle length (which corresponds to the number of engine cycles in the wash cycle or the number of cycles required for the engine to become fully contaminated) can then be determined through interpretation of the individual wash TSFC benefits plotted vs. NEC on a scatter plot. The point at which the TSFC benefit plateaus is the benefit that can be expected by a wash of a fully contaminated engine, or $\Delta TSFC_m$. The number of engine cycles that corresponds to $\Delta TSFC_m$ is $ACFC_m$. This is shown in Figure 1. Step 1 - To calculate the TSFC improvement for varying wash cycle lengths, the following procedure is used: For each of the following variables - Takeoff EGT Margin, Cruise EGT and Cruise Fuel Flow data – obtain 20 data points before the wash and 20 data points after the wash from engine trend data. These data should be available from the aircraft on board flight performance tracking system, and should be collected immediately preceding and immediately following the wash for washed engines of the fleet in question. Make sure that all data acquired is normalized to account for differences in ambient conditions and power setting. Most industry-standard engine monitoring software programs provide fully normalized data that can be evaluated directly. If this is not available, raw data can be acquired and normalized manually. Detect and correct any biases that may be present in the data. Identify any trends in the data or performance shifts occurring before or after the wash that are not related to the wash. Omit data before the wash or after the wash that show the trend or performance shift. Omit outlier data that is greater than the appropriate variation threshold (typically 2 standard deviations) from the data population average. A minimum of 10 data points before the wash and 10 data points following the wash must remain following step 2 for accurate analysis. If fewer than 10 data points are available, a new dataset must be collected. For each variable, calculate the difference between the average of the remaining points following the wash and the remaining points prior to the wash. This difference will be defined as the "delta_delta". Input the measured "delta_delta" parameters into a thermodynamic engine model or use an applicable correlation coefficient to calculate the TSFC improvement for that wash. If correlations are used, compare the TSFC calculated based on WF and EGT to ensure accurate results. If the TSFC benefits calculated based on various parameters agree within an acceptable threshold, the data are considered valid and the wash benefit for that wash ($\Delta TSFC$)

	Step 2 – Once sufficient data points have been collected under Step 1 for the fleet (approximately 30), they are analyzed to determine $\Delta TSFC_{m.}$ This is accomplished through a linear regression of wash TSFC benefits vs. engine contamination cycles, where the regression is forced through the origin. For the purposes of this regression, all washes taking place after more than $ACFC_m$ cycles will be re-defined as taking place at $ACFC_m$ cycles. The $\Delta TSFC_m$ benefit for each fleet will then be equivalent to the $ACFC_m$ contamination cycle intercept of the TSFC benefit regression line. Figure 1 
Monitoring frequency:	Analysis is conducted when data from a minimum of 100 engine washes has been collected from each fleet. Analysis is performed once and the resulting $\Delta TSFC_m$ value is applicable for the entire crediting period.
QA/QC procedures:	
Any comment:	- Project proponents must demonstrate to the VCS project validator applicability of the models used in Steps 1 and 2. - No performance shifting activities (i.e., as instrumentation changes, software upgrades, engine maintenance or upgrades) should be conducted between the measurement of pre and post-wash data.

Data / parameter:	MFC_r
Data unit:	Mass or volume units
Description:	Modelled fuel consumption in the baseline case, based on engine utilization (*r*) during the engine cycle
Source of data:	Data is modelled based on: utilization rates (average cycles per year and hours/cycle) as reported from aircraft operators, and fleet performance specifications obtained from airplane performance documents.
Measurement procedures (if any):	Aircraft operators report total engine cycles and total hours per year for the fleet. The average cycles per year and average hours per cycle for the fleet are calculated and these averages are used as inputs to the model.
Monitoring frequency:	Annual ex-post analysis
QA/QC procedures:	
Any comment:	At validation, project proponents must demonstrate the applicability of the model used to estimate fuel consumption. Acceptable models must have been approved by an aircraft engine manufacturer, and include those used in the certification of aircraft engine performance standards. Calculation of MFC_r must include application of the Business Penetration factor to eliminate potential non-additional emissions reductions associated with engines washed prior to methodology approval. When applied in calculation of project modelled fuel consumption, MFCr, the Business Penetration factor is expressed as 1 – BP.

Data / parameter:	NCV_{ACFuel}
Data unit:	Mega Joule / mass or volume units
Description:	Net caloric value of fuel used in aircraft engines
Source of data:	Actual measured or local data are to be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$EF_{C,ACFuel,y}$
Data unit:	tonnes of carbon / mass or volume units
Description:	Carbon content of the fuel combusted in aircraft engines
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$OXID_{ACFuel}$
Data unit:	Fraction
Description:	Oxidation factor for the fuel used in aircraft engines
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data is local or regional

Data / parameter:	$OXID_{GenFuel}$
Data unit:	Fraction
Description:	Oxidation factor for the fuel consumed by the generator
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$NCV_{GenFuel}$
Data unit:	Mega Joule / mass or volume units
Description:	Net caloric value of the fuel consumed by the generator
Source of data:	Actual measured or local data are to be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$EF_{C,GenFuel, y}$
Data unit:	tonnes of carbon / mass or volume units
Description:	Carbon content of the fuel consumed by the generator
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$OXID_{TVFuel}$
Data unit:	Fraction
Description:	Oxidation factor for the fuel consumed by transport vehicles
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	NCV_{TVFuel}
Data unit:	Mega Joule / mass or volume units
Description:	Net caloric value of the fuel consumed by transport vehicles
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$EF_{C,TVFuel, y}$
Data unit:	tonne of carbon / mass or volume units
Description:	Carbon content of the fuel consumed by transport vehicles
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	Δ Takeoff EGT Margin
Data unit:	°C
Description:	Change in Takeoff Exhaust Gas Temperature Margin resulting from the engine wash
Source of data:	Aircraft on-board flight performance tracking system
Measurement procedures (if any):	
Any comment:	Comparison to other measured parameters should be made to ensure validity. Values are to be used in conjunction with engineering judgment by a professional with experience in engine performance analysis.

Data / parameter:	Δ Cruise EGT
Data unit:	°C
Description:	Change in Cruise Exhaust Gas Temperature resulting from the engine wash
Source of data:	Aircraft on-board flight performance tracking system
Measurement procedures (if any):	
Any comment:	Comparison to other measured parameters should be made to ensure validity. Values are to be used in conjunction with engineering judgment by a professional with experience in engine performance analysis.

Data / parameter:	Δ Cruise fuel flow
Data unit:	%
Description:	Change in Cruise fuel flow resulting from the engine wash
Source of data:	Aircraft on-board flight performance tracking system
Measurement procedures (if any):	
Any comment:	Comparison to other measured parameters should be made to ensure validity. Values are to be used in conjunction with engineering judgment by a professional with experience in engine performance analysis.