Submission by E Haig
Comparison of Glen Sannox' Emissions on LNG Dual-Fuel with MGO alone.

1. CalMac's Calculations are Bogus and Grossly Underestimate Emissions, ***Again***

1.1 The writer understands that the NZET Committee is focused on current issues. However no estimate of emissions has been accurate enough to resolve if LNG fuel actually reduces emissions compared with MGO alone, leaving that an unresolved current issue. Hitherto CMAL has answered questions on 801/2's emissions and has invariably provided inaccurate or misleading statements. Glen Sannox has now moved from the procurement stage into operation, and it falls to CalMac to provide estimates of emissions.

1.2 CalMac's response to a recent FOI question about emissions is attached to this submission as Annex A. It is once again wildly inaccurate. The writer used CalMac's own data for consumption of MGO and LNG to calculate Glen Sannox' emissions more accurately;-
(a) using MGO only, and
(b) using LNG/MGO dual fuel.
The writer used an accurate method of calculation instead of the approximations used by CalMac's contractor. A different picture emerges when methane slip and its exponential decay are calculated correctly, also persistence of emissions over multiple years and other aspects omitted by CalMac.

Table 1 - Global Warming Potential in CO_2 -Equivalent GWP-years (GWP/CH_4 =120 GWP/CO_2)

	Fuel and Resulting Emissions over 30-year Life	
	MGO Only	LNG/MGO Dual Fuel
Glen Sannox - GWP/years at CO_2 levels from Main Engines	3,601,604	2,402,400
Glen Sannox on MGO - GWP/years at CO_2 levels from Generators	512,014	382,882
Glen Sannox on Dual Fuel - GWP/years of CO_2 from LNG burnt as fuel	NA	2,785,282
Glen Sannox on Dual Fuel - GWP/years of CO_2 from 'Other' MGO burnt as fuel	1,053,786	1,053,786
Glen Sannox on Dual Fuel - GWP/years of methane slip	NA	2,113,315
Glen Sannox on Dual Fuel - GWP/years from CO_2 from MGO burnt in Main Engines and Generators as fuel	NA	Omitted by CalMac
Glen Sannox on Dual Fuel - CO_2 from fuel from road tankers	Under-estimated by CalMac	Under-estimated by CalMac
GWP/years from un-decayed CH_4 after end of Glen Sannox' service	NA	1,911,748
Total (GWP/years at CO_2 level)	**5,167,403**	**7,864,131**

Glen Sannox would cause less global warming if fuelled by MGO alone rather than LNG/MGO Dual Fuel.

1.3 The major shortcomings in CalMac's contractor's method for estimating emissions are:-

- GWP for gases that decay require either analysis by mathematical methods or by a more complex arithmetic method than for gases that do not decay.
- CalMac's consultant (whoever it is) mis-used a simplification of CH_4 's decay and forced it to fit the different circumstances of successive quanta of CH_4. The fit is very poor.
- it neglects the year-by year accumulation of CO_2 when running on MGO alone,
- CH_4 's rate of decay does not keep up with methane slip. 897.39 tonnes of un-decayed CH_4 accumulates across a ship life of 30 years,
- CalMac's consultant omitted the MGO used by Main Engines and Generators when running mostly on LNG..
- CalMac's consultant calculated methane slip's GWP by an inaccurate method and ignored the 30-year lifetime accumulation.

1.4 The writer views the work to produce this submission as well within what could normally be expected of a diligent, experienced and properly-educated Engineer of any specialisation but no such work has been ever presented by Wärtsilä, CMAL, or CalMac. Inadequate and misleading disclosures have been offered instead. Wärtsilä must have Engineers capable of this work; CMAL does not: CalMac is a vessel operator and has no need to employ Engineers trained in design or its management.

1.5 Beginning on 8 August 2012 CMAL justified the inclusion of Wärtsilä's propulsion machinery because it would reduce emissions and GWP, but it does not. CMAL abrogated its rôle in managing the ship design to Wärtsila, whose engagement of Houlder failed to remedy the shortcomings in the ship design and machinery package proposed by Wärtsilä. FMEL was contracted by CMAL to build a ship to a design that had not been validated. The ship design was mistaken, the machinery package added to its deficiencies, and the procurement process as invented by CMAL left Wärtsilä free of redress because CMAL took responsibility for the Wärtsilä's design.

2. Errors in Calculation

2.1 Some of the CH_4 Glen Sannox releases in every year of operation does not decay but accumulates and applies GWP at 120 x the GWP of CO_2 every year for the remainder of vessel life. The quantum added in year 1 applies its GWP every year for the next 30 years until vessel disposal and after. The quantum added in year 2 has its GWP every year for the next 29 years until disposal, and after, decaying as the years pass. And so on for year 3 and every subsequent year. This adds to 465 years in a ship life of 30 years, with 'year 0' counting as a year of methane slip and decay. The amount of CH_4 for each year and the effect on GWP of molecular decay must be calculated, and that total added to to the decaying GWP of every year. CalMac's contractor's method omitted all of that.

2.2 The 100-year approximation produced in Kyoto in 1997 has no application to continuous emission and continuous decay such as methane slip. Somewhat ironically that approximation is relevant only to the methane left in the atmosphere **after** Glen Sannox ceases service, because it can be handled as a quantum. The simplified arithmetic is weight of methane x average GWP/year at CO_2 levels x 100years, or:-

897 tonnes x 28 average GWP for 100 years x 100 years = 2,511,600 GWP years

rather than the 1,911,748 GWP years in Table 1, but it includes the GWP from CO_2 evolved from decay of methane.

2.2 When fuelled by MGO only, the addition of the same quantum of CO_2 every year for a ship life of 30 years must be similarly added. This adds to a surprising 455 years of the same GWP effect in one year because the CO_2 from previous years does not go away but remains to repeat its effect. This is easy to calculate when fuelled by CO_2 only, because CO_2 's GWP in the absence of decay is constant and easily represented arithmetically. CalMac's contractor's analysis does none of these things.

2.3 This repeated application is even more important when fuelled by LNG because methane's GWP is x120x that of CO_2 and is only partly offset by decay. CalMac's Annex A makes use of a linear simplification of the exponential decay of CH_4 such as '20 year' and '100 year' factors, and '100yr methane slip' - a term invented by or for CalMac but CalMac does not disclose its provenance, of which there is none. That simplification was formed at Kyoto in 1997 to convey the profile of exponential decay, and was not intended to be part of any engineering design method.

2.4 The annual average of 86 for the GWP of methane is an approximation to the GWP of a single quantum of CH_4's decay over the first 20 years of its decay over 100 years. It does not remotely describe the amount of CH_4 persisting in the atmosphere from regular releases of CH_4 over a ship life of 30 years. CalMac does not describe the mathematic or arithmetic process that the un-named consultant used in creating Annex A, nor does Annex A describe or quantify the long-term accumulation of either CH_4 or CO_2. That denies anyone the ability to question or validate CalMac's assertions, which is the reason the writer devised his own method, using CalMac's data for fuel consumption and emissions to show their falsity.

2.5 CalMac's contractor has released mathematical gibberish. The writer can find nothing in technical literature that suggests or attempts to use these simplifications for estimates of emissions. The writer challenges CalMac to give a description of the arithmetical method and to name the contractor. The writer defies anyone to say they understand Annex A or the method of calculation behind it.

3. Physics of Global Warming

3.1 The physics of Global Warming by 'greenhouse gases' are easily described. 'Greenhouse Gases' have the effect of a two-way mirror. Solar Radiation penetrates the atmosphere, is partly reflected by the Earth's surface, and some of the reflections are reflected by the gases. This is termed 'Radiative Forcing'. CH_4 's Radiative Forcing is 120 times that of CO_2 [Ref1] and its half-life as most recently assessed is about 12 years. [2].

3.2 Radiative Forcing is a molecular property which does not and cannot decay - Global Warming Potential decays only because CH_4 molecules decay to CO_2. The Global Warming Potential of CH_4 molecules remains at 120 x that of CO_2 [Ref 1]; the reduction in the Radiative Forcing/GWP of a quantum of CH_4 comes about because CH_4 decays into a different molecule (CO_2). Rate of decay is exponential; it cannot in nature follow any other form, and it is certainly not linear. The mathematics of exponential decay are well-known.

3.3 The unit of Radiative Forcing is the Watt per m^2 per part per billion, billion being molecules. CO_2's Radiative Forcing is taken as unity and is the datum for comparison with the GWP of other gases: this facilitates calculation of the CO_2 -equivalent Radiative Forcing or the GWP-year/tonne of CO_2 and CH_4.

3.4 Nature has no use for methane. To the writer's knowledge methane plays no part in growing any organism or vegetable. Methane is removed from the atmosphere by burning or by decay, with CO_2 being the dominant product. CO_2 does not decay but is removed from the atmosphere mostly by photo-synthesis into vegetable growth. The average life of a CO_2 molecule in the atmosphere is estimated to be ~100 years.

4. MV Glen Sannox - If fuelled by MGO Alone - CO_2 Emissions in a Life of 30 Years

4.1 CalMac's Annex A states MV Glen Sannox uses 70.848 tonnes/week of MGO excluding fuel for delivery tankers. The Annex gives fuel for delivery by road tanker as 2.3 kg/week or 2.58 l/week which would take a road tanker about 4.6 miles. This looks erroneous. Ignoring this low figure for deliveries, 70.848 tonnes/week of MGO produces 227.139 tonnes of CO_2 per week, 11,356.93 tonnes in an operating year of 50 weeks, or 340,707.9 tonnes in a 30-year life.

4.2 Once emitted, each year's quantum of CO_2 does not go away but hangs in the atmosphere with its GWP being increased by quanta in other years for the operating life of the vessel, ie 30+29+28+27+26….. +3+2+1 years. This rolling total is 455 years in a 30-year operating life.

In a 30-year life MV Glen Sannox will emit
5,167,403.2 GWP-years of CO_2 if fuelled by MGO alone

5 MV Glen Sannox - If fuelled by MGO/LNG Dual Fuel - CO_2 Equivalent of Emissions

5.1 If fuelled by MGO/LNG dual-fuel then Glen Sannox will generate CO_2 from:-

- burning LNG,
- burning MGO,
- the decay of methane slip.

The three need to be calculated separately because methane slip decays exponentially whilst CO_2 does not. The rate of decay does not keep up with the rate of increase. The amount of each can be calculated across the assumed 30-year life then added to give the total across life.

5.2 CalMac's Annex A ignores Boil-Off Gas, the MGO burnt in Main Engines along with LNG, and under-estimates fuel for road transport of fuel. The writer will let CalMac's errors and omissions stand so that the only inaccuracies will be CalMac's. The writer's calculations are based on the normal definition that 1.0 tonne of CO_2 in the atmosphere for 1.0 years equals1.0 GWP-years. The accepted definition of the GWP of a tonne of CH_4 in the atmosphere is x 120 that of CO_2. This enables the GWP of CO_2 and methane to be presented as CO_2 GWP-years, and facilitates comparison.

5.3 Beginning with LNG burnt as fuel, CalMac's Annex A states that the 38.4 tonnes of LNG burnt by Glen Sannox in Main Engines and 6.12 tonnes in Generators per week will burn to 122.43 tonnes of CO_2 in a week. This CO_2 does not disperse or decay any more than does any other CO_2 but accumulates every year and adds its GWP to that of previous years as in Section 2, for a total of 455 yearly periods in which GWP is applied.

In a 30-year life Glen Sannox will evolve 2,785,282.5 GWP-years of CO_2 from LNG burnt in Main Engines and generators.

5.4 CalMac's Annex A discloses burning 14,448 tonnes of MGO per week for 'other' ship use but omits the MGO burnt in Main Engines when fuelled mostly by LNG. Annex A gives the *weekly* weight of CO_2 evolved but does not present the annual weight of CO_2 evolved. This 'Other' MGO converts and multiplies to 23,160 tonnes of CO_2 per 50-week operating year, or, as presented in Section 4.2 for a 30-year life:-

In a 30-year life Glen Sannox will evolve 1,053,786 GWP-years of CO_2 from MGO in addition to CO_2 from burning LNG and methane slip.

6 CalMac's Disclosure of Glen Sannox' Emissions is Optimistic Once Again

6.1 Methane slip occurs year after year and requires to be calculated by a method that deals with exponential decay. The 100-year linear approximation proposed at the Kyoto Conference in 1997 applied to a single quantum, not to successive quanta. The operating life of Glen Sannox is not a close fit to the 100-year period of the approximation, nor is it a close fit to the first 20-years of that approximation whose GWP allegedly has an average GWP of 86 x that of CO_2. Te approximation did not set out to deal with successive quanta and is not capable of doing so.

6.2 The science of Global Warming and methane decay has improved greatly since 1997. The half-life of methane decay is now estimated to be 10 to 12.5 years. CalMac's contractor attempted to fit Glen Sannox' emissions to the 1997 figures for the linear simplification of a single quantum in which half-life was estimated at 6 year., so CalMac's current simplification of exponential decay of successive quanta with half-life of 12 years is even less accurate or representative now than it would have been in 1997. In the writer's view attempting to fit Glen Sannox' profile of emissions to any linearisation is misleading and professionally dishonest.

6.3 CalMac's Annex A give methane slip as 1.296 tonnes/week decaying into CO_2 with a GWP equivalent to 36.28 tonnes of CO_2 per year. If the reader cannot follow that, neither can the writer because it is nonsense. It does not remotely model continuous release of CH_4 or its exponential decay. The writer considers it unprofessional practice to peddle such a bogus mathematical process as relevant.

6.4 The physics and mathematics are that in one week only 0.00622 tonnes out of 1.292 tonnes of methane slip will decay into CO_2, or taking a whole year of methane slip as a single quantum of 64.8 tonnes, only 3.2 tonnes will decay. Decay of 3.2 tonnes CH_4 in a year evolves ~10.00 tonnes of CO_2 because of the change in atomic weight as carbon exchanges its hydrogen atoms for oxygen, leaving 61.6 tonnes of CH_4 . The remaining CH_4 has GWP x 120 that of CO_2 ;the CO_2 has GWP = 1.0, neither of which is not remotely similar to the 36.28 tonnes alleged in para 6.3. Someone is misleading CalMac into presenting absurd arithmetic, and CalMac is allowing itself to be misled.

In a 30-year life Glen Sannox' methane slip will create

2,113,315 GWP-years at CO_2 levels in addition to GWP at CO_2 levels from burning LNG and MGO.

6.5 The writer used an ordinary spreadsheet to calculate the decay of continuously-emitted methane slip as quanta of 64.8 tonnes of CH_4 every year for 30 years. The spreadsheet takes account of exponential decay from CH_4 to CO_2, the change in atomic weight, it uses correct values of GWP for each of CH_4 and CO_2, and it calculates the GWP-tonnes of CH_4 and CO_2 evolved each year. It is much more accurate than the crude approximation invented by someone for CalMac, and the calculation can be followed and examined for correctness. CalMac's method concealed that Glen Sannox' dual-fuel machinery 'slips' so much CH_4 each year that 897.39 tonnes accumulates in 30 years of operation.

LNG/MGO will Leave a Legacy of un-decayed Methane Slip

7.1 LNG or methane slip in the atmosphere dominates CO_2 because its GWP is 120 x that of CO_2. The rate of adding methane by methane slip exceeds its rate of decay into CO_2. At the end of the 30-year operating life assumed by the writer, 897.39 tonnes of CH_4 will have accumulated in the atmosphere. It will take eight half-lives after or 96 years to decay to 3.5 tonnes, in which period un-decayed methane slip in the atmosphere will add another 1,911,748 GWP-years at CO_2 levels. The CO_2 into which this legacy methane slip decays will add a small number of GWP-years at CO_2 levels. It has not been calculated due to its paucity compared with other emissions.

References

1. Boston Consulting Group
www.bcg.com/publications/2023/methane-global-warming-potential

2. SeaLevel.info
www.sealevel.info/methane.html

Calmac FOI 4025 - Data Tables

FOI 4025 Annex A
LNG Carbon Emissions Report
Appendix 1
Simplified Fuel Figures

MGO	Weekly fuel (kg) (60 hours per week)	CO2 weekly (tonnes)	CO2 annually (50 weeks/year)
Main Engine 70% MCR	49380	158.31228	
Generator	7020	22.50612	
Other MGO	14448	46.320288	
Methane slip	0	0	
Total Ship		227.138688	11356.9344
Deliveries LNG	0	0	
Deliveries MGO	2.3	0.3749	18.745
Total		227.513588	11375.6794

LNG	Weekly fuel (kg) (60 hours per week)	CO2 weekly (tonnes)	CO2 annually (50 weeks/year)
Main Engine 70% MCR	38400	105.6	
Genrator	6120	16.83	
Other MGO	14448	46.320288	
Methane slip	1296	36.28	CO2 Equivalent
Total ship		205.030288	10251.5144
Deliveries LNG	2	2.716	
Deliveries MGO	0.5	0.0815	
Total deliveries		2.7975	139.875
Total		207.827788	10391.3894

Assumptions	
Proposed new ships timetable used to align these figures with current cost estimates	
60 hrs per week akin to proposed new timetable allows for daily variances	
Worst case Methane slip figs 5.5g.kWh	
Standard ISO LNG figs used 431.9kg/m3 LHV 49470kJ/kg	
LHV MGO 43000kJ/kg	
Density of MGO 0.86	
2400 lts MGO per day covers harbour generator, pilot fuel and boiler - allows for no shore power overnight - does not allow for seasonal variances - in reality expect this to be higher due to menoeuvering on MGO and variances in hotel load through the day as well as seasonal	
600kW load on generator does not allow for use of shaft alternator which is anticipated to save fuel - offset by the need to use generators in port at all times due to non provision of shore power	
Fuel consumption of road tractor unit running on diesel (Average) 10mpg (28.248l/100km)	
Conversion factor tractor unit kg Diesel fuel - KG CO2 = 2.6	
Conversion factor KG CO2 per mile unladen 0.99454	
Conversion factor KG CO2 per mile laden 1.65757	
Mileage Grangemouth - Ardrossan 62 miles (99.78km)	
Mileage Isle of Grain to Ardrossan 512 miles (824km) - varies per route plan	
Conversion factor tonnes CO2 per tonne LNG (IMO) 2.75	
Conversion factor tonnes CO2 per tonne MGO (IMO) 3.206	
CO2 equivalent methane = Methane x 86	

Methane Slip	Tonnes CO2 annual	
Factor	20 year	100 year
2.8g/kWh (Source Engine OEM website)	3467t	1128t
4.5g/kWh (Source Engine OEM direct - based on DF34)	5572t	1814t
5.5g/kWh (Source ICCT/IMO)	6811t	2217t
109m3 annual (Source Naviniblu)	4406t	1844t

CO2 emissions including delivery (No Methane Slip)	Tonnes CO2 annual
MGO only	11375
Duel Fuel	8577
CO2 emissions including delivery (Including 100yr Methane Slip @4.5g/kWh)	Tonnes CO2 annual + equiv CO2
MGO only	11375
Duel Fuel	10391