September 24, 2021

Chair Liane Randolph and Honorable Board Members
California Air Resources Board
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Re: Woodward, Inc.'s Comments on Proposed Clean Miles Standard Regulation

Woodward, Inc. (WWD) appreciates the California Air Resources boards' ('CARB') provides the opportunity to comment on the proposed regulation order for the California Clean Miles Standard.

WWD has significant content of systems level and components level products and services for heavy-duty natural gas engines OMEs around the world. There are also significant opportunities for WWD in the future electrification of heavy-duty transportation sectors.

Natural gas vs. other hydrocarbon fuels

Natural gas is an alternative and natural form of energy, which can be used to replace traditional fossil fuel. Natural gas can come from landfill gas and water/sewage treatment, coal-derived, or gas that's trapped in sub-surface porous rock reservoirs. Natural gas can be used for power generation and transportation. Among natural gas, there are conventional natural gas and renewable natural gas (RNG). When methane is produced from non-fossil sources. It can literally take carbon out of the air. RNG is essentially purified biogas that is a pipeline-quality gas that is fully interchangeable with conventional natural gas and thus can be used in natural gas vehicles. When RNG is used it does not leave carbon footprint. Argonne National Laboratory (ANL) Renewable Natural Gas Database provides a comprehensive list of biogas projects that are upgrading gas for pipeline injection or use as vehicle fuel.

Also, the amount of CO_2 produced when a fuel is combusted is a function of the carbon content of the fuel. The amount of energy is released through combustion is determined by the carbon and hydrogen content of the fuel. Natural gas is primarily methane, which has a higher energy content relative to other fuels. Hence, it has a relatively low CO_2-to-energy content. The table below shows how much CO_2 is emitted from the production of 1,000,000 BTUs of energy from various hydrocarbon fuels. Also, it has highest hydro carbon ratio (HCR) to further reduce its CO_2 footprint.

Table 1 Pounds of CO_2 emitted per million British thermal units (Btu) of energy for various fuels

Coal (anthracite)	228.6
Coal (bituminous)	205.7
Coal (lignite)	215.4
Coal (subbituminous)	214.3
Diesel fuel and heating oil	161.3
Gasoline (without ethanol)	157.2
Propane	139.0
Natural gas	117.0

Hence, Equation 1 proposed in the regulation should reflect the benefits of natural gas as an alternative fuel, especially when RNG was used.

$$\frac{CO_2}{PMT} = \frac{\sum(VMT_{P1,P2,P3} \times CO_2\ factor\ \times NG\ factor)_{trip}}{\sum(VMT_{P3} \times occupancy)_{trip}}$$

Where "*NG factor*"*<1* and it is a function of combining the natural gas and RNG were used by the transportation network company (TNC). When only conventional natural gas was used, NG factor is 0.735 and it is calculated from the ratio of the amount of CO_2 emitted from natural gas compare to diesel and gasoline when the same amount of energy was produced. When RNG is used, NG factor should be further reduced as RNG does not add GHG footprint, the proposed number is 0.2. If mixed of conventional natural gas and RNG were used, the NG factor is between 0.2 and 0.735 based on the ratio of conventional natural gas and RNG were used.

California energy profile analysis

Energy source concerns

California's renewable portfolio standard (RPS) was enacted in 2002 and was revised several times till now. It requires that 33% of electricity retail sales in California come from eligible renewable resources by 2020, 60% by 2030 and 100% by 2045. This shows that there is still 40% electricity is generated from non-renewable energy source when the proposed regulation is enforced.

Efficiency concerns

Considering efficiency of energy generation, transmission, electronics and electrical motor efficiencies as well as battery storage losses. The overall energy efficiency is not as high as one would think. The efficiency of a large electrical generator is typically 99%. The U.S. Energy Information Administration (EIA) estimates that electricity transmission and distribution (T&D) losses equaled about 5% of the electricity transmitted and distributed in the United States in 2015 and 2019. By considering the efficiency of inverter, battery and motor efficiency as listed below, the overall system efficiency can be found numerically as follow. During charging process, the overall efficiency is about 87.6%.

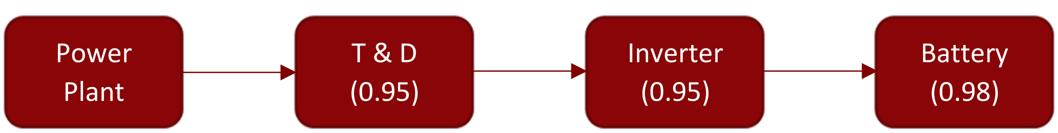

Figure 1 Power plant to battery efficiency

And during discharging process, the overall efficiency is about 83.8%.

Figure 2 Battery to motor efficiency

The overall system efficiency is then dropping to around 74.1%.

Now let us consider the overall system efficiency numerically, assuming the break thermal efficiency (BTE) of a natural gas engine is at 42%, by considering 99% of electrical generator efficiency, 95% of transmission and distribution efficiency and 95% of inverter efficiency and 90% electrical motor efficiency and 98% of battery efficiency. The overall efficiency drops to below 31%. That is without considering when the electrical motor is operated at low torque region where its efficiency is even lower. Considering 31% overall efficiency of the system, it is lower than a modern natural gas engine running a world harmonic transient cycle (WHTC) efficiency that is around 33%. Here WHTC shown below covers typical driving conditions in the EU, USA, Japan and Australia. It has been adopted by the Euro VI emission regulation for heavy-duty engines. One can see the cycle demonstrates many hard speed and torque transients.

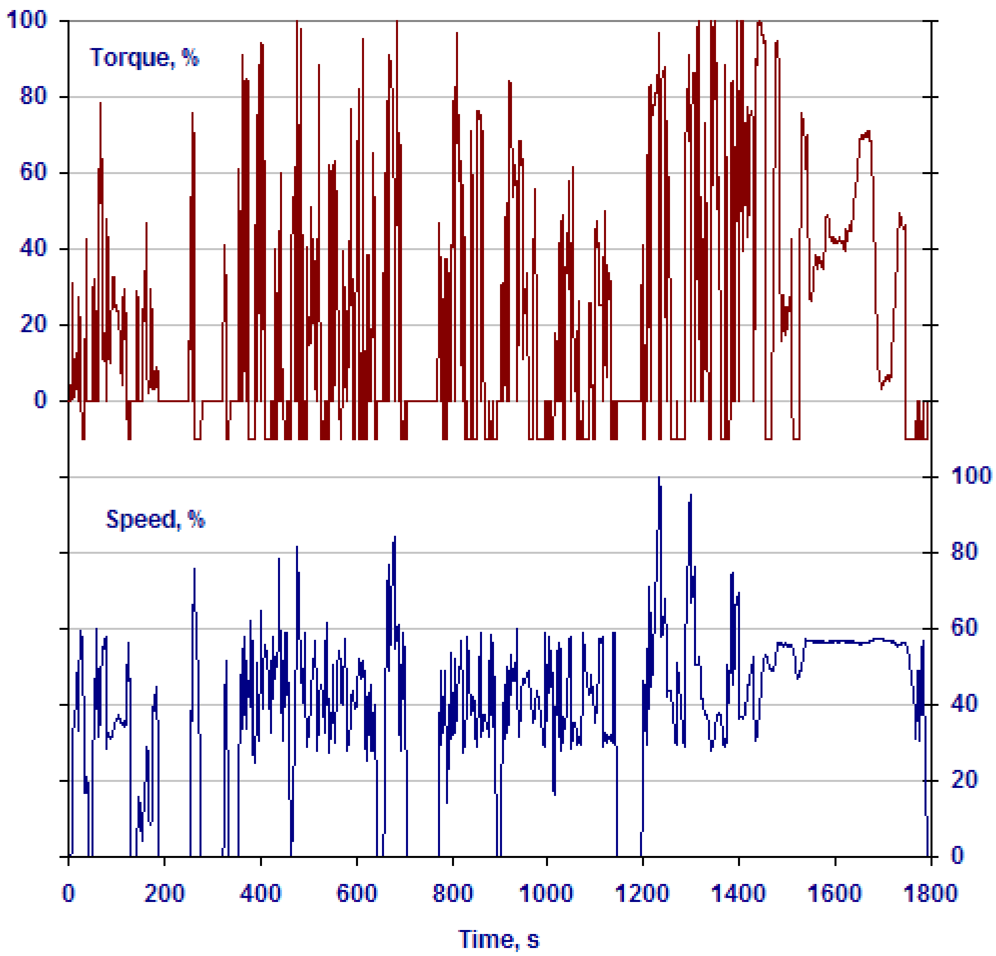

Figure 3 WHTC cycle

Hence, before California energy source is fully shifted to renewable energy in 2045, TNC should still be allowed to operate alternative fuel vehicles.

Heavy duty vs. light duty

In the proposed regulation, annual GHG targets for a TNC passenger service fleet is defined in CO_2 /PMT. A CO_2 factor for passenger car (PC) vehicle was defined in g CO_2 /mile. And it further stated that 'All TNC vehicles that do not fall into light truck vehicle category shall use the passenger car category'. However, heavy-duty engine and light duty engine including passenger cars operate on the speed and torque curve differently in terms of both time and location. This operational difference leads to fuel consumption rate difference and leads to CO_2 and emission differences. A typical cruise point for a heavy-duty engine is 1600rpm, 13 bar BMEP and a typical cruise point for a light duty vehicle is 2000rpm, 2 bar BMEP. This differences lead to that heavy-duty trucks have high overall efficiency compare to light duty vehicle and passenger cars, hence it produces less CO_2 when the same amount energy was produced.

Propose road map

Proposed CO_2 factor for natural gas vehicle is shown below in Table 2. Compare to the original CO_2 factor table, the proposed column (the 6th column) shows that after 2021 the CO2 factor is reduced based on the CO_2 reduction of diesel till 2045. The proposed table allows two improvements: 1) Enables continuous CO_2 reduction till California has 100% renewable energy source. 2) Allows natural gas vehicle to be operated along with a hybrid system for extended period.

The hybrid can be combination of ICE with battery and motor or it can be ICE with fuel cells or other form of prime movers.

Table 2 Proposed CO_2 factor for natural gas

Model Year	Diesel LT	Gasoline LT	HEV/PHEV LT	CNG	Proposed NG
2008	634	505	468	251	251
2009	593	477	442	251	251
2010	589	469	435	251	251
2011	574	458	424	251	251
2012	556	442	410	227	227
2013	534	427	396	218	218
2014	529	425	394	218	218
2015	518	414	384	218	218
2016	497	398	369	218	218
2017	477	383	355	218	218
2018	454	367	340	218	218
2019	434	351	325	218	218
2020	413	335	310	218	218
2021	392	319	296	218	218
2022	377	307	285	218	207
2023	362	295	273	218	198
2024	346	282	262	218	189
2025	330	270	251	218	179

2026	330	270	251	218	172
2027	331	271	251	218	165
2028	331	270	251	218	158
2029	327	271	251	218	151
2030	322	271	251	218	151
2031	304	271	251	218	151
2032					151
2033					149
2034					147
2035					139
2036					139
2037					139
2038					139
2039					139
2040					139
2041					139
2042					139
2043					139
2044					139
2045					139

Conclusion

To summary our comments, there are three items:

1) Introduce a natural gas factor to equation 1.
2) Extend the usage of natural gas to align with California energy policy
3) Considering the differences between heavy and light duty trucks
4) Proposed CO_2 factor for natural gas and its hybrid system

Reference:

1) https://www.americangeosciences.org/critical-issues/faq/how-much-carbon-dioxide-produced-when-different-fuels-are-burned
2) https://www.socalgas.com/stay-safe/methane-emissions/methane-and-the-environment
3) https://www.latimes.com/environment/newsletter/2021-02-11/california-pledge-clean-energy-boiling-point
4) https://focus.senate.ca.gov/sb100/faqs
5) https://www.eia.gov/tools/faqs/faq.php?id=73&t=11
6) https://www.eia.gov/tools/faqs/faq.php?id=105&t=3#:~:text=The%20U.S.%20Energy%20Information%20Administration,States%20in%202015%20through%202019.
7) https://afdc.energy.gov/fuels/natural_gas_renewable.html
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9) https://wecanfigurethisout.org/ENERGY/Web_notes/Bigger_Picture/Where_do_we_go_Supporting_Files/Efficiency%20in%20Electricity%20Generation%20-%20EURELECTRIC.pdf
10) https://dieselnet.com/standards/cycles/whtc.php