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Power Generation: The Emissions Shifting Problem

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Executive Summary

- There is a tremendous reliance on diesel generators for residential, commercial and microgrid applications. **Sales of diesel generators have significantly increased due to electric grid disturbances caused by severe weather events, exacerbating local air quality concerns.**
- **Propane can displace diesel generators in these markets and significantly improve local air quality,** particularly by mitigating nitrogen oxides and particulate matter.
- **Dedicated propane engines and/or renewable propane can facilitate decarbonization.** Renewable propane is functionally and structurally identical to conventional propane.
- **Combined heat and power solutions offer both power and heat (and/or cooling), while providing significant reductions** in nitrogen oxides, particulate matter, and carbon dioxide emissions.

Introduction

Decarbonization across all energy-consuming sectors - transportation, electricity generation, residential, commercial, industrial, and agricultural - has seen unprecedented momentum since the beginning of the COVID-19 crisis. Popular opinion has been that electrification of everything is the only solution for the climate crisis, with some reliance on biofuels for the hard-to-electrify sectors such as industrial, marine and aviation. Unfortunately, this is a very simplistic one-dimensional proposal for an extremely complex multi-dimensional energy and climate problem. The focus of this article is to look at recent trends in power generation and highlight the benefits of propane (or Liquefied petroleum gas - LPG) power generation solutions that can work as standalone systems or in tandem with renewables, providing a low emissions and resilient alternative solution.

The Problem

We can all agree that climate change is no longer a problem of the future, but of the present, as experienced by frequent extreme

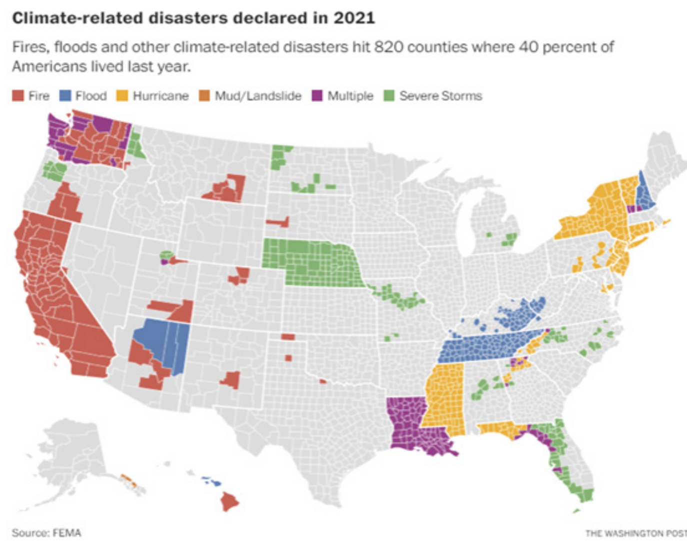

***Figure 1**: Climate related disasters declared in 2021 (Source: The Washington Post).*

weather events. A recent article in the Washington Post[1] shows that more than 40% of the US population reside in counties that experienced extreme weather events in 2021. Figure 1, also taken from The Washington Post, shows the grim image of extreme weather events in 2021 including forest fires, floods, hurricanes, landslides, and severe storms. There were more than 650 casualties in 2021 alone, with a projected loss of over $104 billion (not counting for the disasters in December 2021). More than 13% of the population was affected by fire-declared disasters in 2020 and more than 15% was affected in 2021. According to recent data from NASA and NOAA[2], the earth was about 1.1°C warmer in 2021 than the late 19th century average.

In addition to the environmental and economic impact, these events strain the electric grid infrastructure and result in several power outages. For example, Hurricane Ida caused at least 1.2 million electricity customers to lose power in 2021[3] and more than 4 million Texans lost power due to Winter Storm Uri[4].

1. https://www.washingtonpost.com/climate-environment/2022/01/05/climate-disasters-2021-fires/
2. https://www.nasa.gov/press-release/2021-tied-for-6th-warmest-year-in-continued-trend-nasa-analysis-shows
3. https://www.eia.gov/todayinenergy/detail.php?id=49556#:~:text=Hurricane%20Ida%20caused%20at%20least%201.2%20million%20electricity%20customers%20to%20lose%20power,-Source%3A%20Graph%20by&text=Hurricane%20Ida%20made%20landfall%20on,Louisiana%2C%20Mississippi%2C%20and%20Alabama.
4. https://tcaptx.com/industry-news/blog-new-ercot-data-details-reasons-behind-winter-storm-uri-electricity-outages

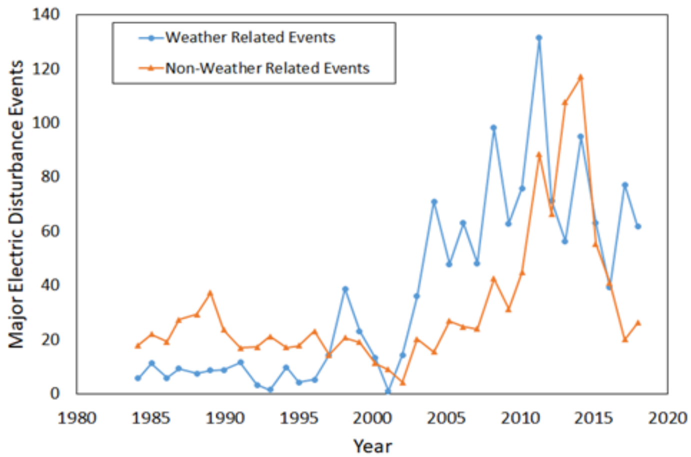

***Figure 2**: Major electric disturbance events between 1984 and 2018 (Recreated from Ericson and Olis[5]).*

Figure 2, recreated from Ericson and Olis[5], shows the alarming uptick in both weather and non-weather events responsible for major electrical grid disturbances.

The Knee-Jerk Response

Three major trends that I note here because of extreme weather events and energy market dynamics are in:

1. Prime Power Generation: The US economy slowly rebounded in 2021 and energy prices including gasoline, natural gas and propane fluctuated significantly. Particularly, US-produced natural gas and propane were catering extensively to export demand. This led to coal being a cheaper asset than natural gas for prime power generation. US coal usage had plummeted in 2019 and 2020, but saw an increase of 9%, globally, in 2021 relative to 2020[6]. In the US alone, coal-fired power generation increased by 17% according to preliminary US greenhouse gas (GHG) estimates by the Rhodium Group[7]. This marks the first annual increase in coal-fired generation since 2014. The uptick in coal-fired generation, along with rapid rebound in freight transportation, increased US GHG emissions by 6.2% in 2021 relative to 2020 but was still 5% below 2019 levels. Note, the increase in GHG emissions grew faster than the year-on-year gross domestic product growth of 5.7%. US GHG emissions trend reversed in 2021 moving from 22.2% below 2005 levels in 2020 to 17.4% below 2005 levels in 2021.

This trend is considered by many to be an aberration and it is expected that coal generation will fall in 2022 and beyond[8]. But this blip also exposes a complex energy dynamic -- without stable natural gas prices, we are left with more polluting options for prime power generation. This complexity arises as current nuclear powerplants (fission) are good at providing baseload, but not for load following operation. Renewables are intermittent and cannot always follow load unless there are massive grid scale

↑17%
2021 US coal fired generation compared to 2020

↑6.2%
2021 US GHG emissions compared to 2020

batteries, the economics for which favor 4-6 hours of storage capacity. In other words, without the availability of long duration energy storage, natural gas offers the cheapest and cleanest load following power generation option.

2. Backup Power Generation: The article, "Thrum and haze of diesel generators spread across America" in the Financial Times[9] clearly articulates how residential customers are responding to power outages by purchasing more diesel generators. The article goes on to say that Americans will spend $15,000-$20,000 to buy a home back-up diesel system or even spend $75,000 for a new gasoline-powered Ford F-150 pickup truck, which has a 7.5 kW built-in generator (Note, some homeowners used this option during winter storm Uri in Texas[10]). The increasing sales of the generators are seen in storm-wrecked coastal areas, inland tornado alleys and particularly, in California and Texas.

A report published by M.Cubed[11], an economic and public policy consulting group, shows that back-up generators have increased by 34% in the Bay Area Quality Management District (BAAQMD) relative to 2018 and by 22% in the South Coast Air Quality Management District (SCAQMD) relative to 2020. 90% of the backup generators in both the districts are powered by diesel. These collectively produce annual emissions of 86,899 Metric tons (MT) of carbon dioxide (CO_2), 20 MT of fine particulate matter (PM), 62 MT of volatile organic compounds (VOCs) and 1,000 MT of nitrogen oxides (NO_x). The controversial public safety power shutoffs (PSPS), implemented for mitigating wildfires in California, are responsible for the increase in sales of diesel backup generators. Backup generators in these two districts alone can result in 15% of generation of the entire California grid.

↑34%
BAAQMD backup generators compared to 2018

↑22%
SCAQMD backup generators compared to 2020

~90%
backup generators are diesel powered

Up to 15%
of generation in CA is attributed to backup gensets

5. Ericson, S. J., & Olis, D. R. (2019). A comparison of fuel choice for backup generators (No. NREL/TP-6A50-72509). National Renewable Energy Lab.(NREL), Golden, CO (United States).
6. https://www.iea.org/news/coal-power-s-sharp-rebound-is-taking-it-to-a-new-record-in-2021-threatening-net-zero-goals
7. https://rhg.com/research/preliminary-us-emissions-2021/
8. https://www.eia.gov/outlooks/steo/report/coal.php#:~:text=Coal%20consumption.,by%202%20MMst%20in%202023.
9. https://www.ft.com/content/c376b2fa-1af5-4920-88cf-27ac297ed8f2
10. https://www.cnbc.com/2021/02/18/some-texans-use-2021-ford-f-150-hybrids-to-power-homes-amid-winter-storm.html
11. https://www.bloomenergy.com/wp-content/uploads/diesel-back-up-generator-population-grows-rapidly.pdf

3. Microgrids: Microgrids provide a great decentralized and distributed energy resource for facilities while enabling partial or total grid independence. Several microgrids use solar-photovoltaic (PV) along with energy storage (primarily batteries) with backup power generation either directly providing power to the facility or for charging the batteries, or both.

As per data from the US Department of Energy[12], there are about 461 microgrid installations in the US of which 164 are in the state of Texas followed by 61 in California. In terms of fuel-fired generation capacity in the US, natural gas leads with 721 MW and diesel, the second most, with 371 MW while biofuel capacity contribution is only 148.5 MW. Texas has over 217 MW of the natural gas capacity (~30% of US) and 59 MW of diesel capacity (~16% of US), while California has only 27 MW of natural gas capacity (~3.7% of US) and nearly 48 MW of diesel capacity (~13% of US). Most of these microgrid systems are grid connected and are not remote/isolated. California has installed more than 10 MW diesel capacity post 2015 while Texas has installed only 0.5 MW diesel capacity in that same time. Of note, California installed only 3 MW of natural gas capacity after 2015 while Texas installed more than 200 MW of natural gas capacity around the same time. The newer microgrid systems in California are still reliant on diesel, but not in Texas. In other words, there is tremendous amount of dependence on diesel in microgrids, particularly in a climate champion state like California.

~371 MW
diesel capacity in US microgrids

~59 MW
diesel capacity in TX microgrids

~48 MW
diesel capacity in CA microgrids

These trends bring attention to the title of this article - are we just shifting emissions due to factors such as market dynamics and extreme weather events, one being controlled purely by economics and other by consumer preference. The carbon intensity of electricity, at least in the near term, will fluctuate with fragile market dynamics and thus it is imperative to have low carbon economic and flexible assets in the power portfolio. Consumer preference is largely skewed toward diesel as it is a "known" fuel. This is where the propane industry can contribute significantly by replacing diesel assets, contributing toward significant air quality improvement and decarbonization. Thus, it is markedly important to just not focus on electrification of all sectors but on a diversified portfolio that accounts for both market dynamics and consumer preferences. While at macro level, renewables play a major role in cleaning up the electric grid but diesel still dominates at a micro level (i.e., as a distributed energy resource and resiliency), which begs the question - are we just shifting emissions and degrading local air quality?

Propane as a Replacement for Diesel

Solutions that can assist in reversing the second and third trends (given above) are discussed below. Note, propane prime power generation is limited due to extensive use of natural gas in this sector.

- **Analysis of M-cubed report:** A quick analysis of the report published by M.Cubed shows the benefits of using propane as an option for backup generation. Figure 3(a-d) shows the data for tailpipe CO2, PM, VOC, and NOx emissions from these generators for SCAQMD, all normalized with respect to their generation in kWh i.e., the data represent the total emissions per total power delivered for the specific fuel generator fleet. We believe the PM emissions for gasoline and methanol (Figure 3b) as recorded as zero as the generators were run sparingly evidenced by their significantly lower generation in MWh as compared to the other fuels from the report. Specifically, with respect to LPG, the CO2 emissions are 9.2% higher than diesel, while PM and NOx emissions are one order of magnitude lower than diesel. VOC emissions are found to be comparable with respect to diesel.

One of the chief reasons CO2 emissions are higher for propane is that all propane backup generators are spark ignited and are not dedicated propane engines. In other words, existing natural gas or gasoline engines are converted for propane operation. If a natural gas engine is operated with propane, the engine must be derated to account for the lower octane rating of propane relative to natural gas. If a gasoline engine is converted to propane, the hardware is too conservative for propane operation due to the lower octane rating of gasoline (for example, one can extract more efficiency while using propane with an increased compression ratio). In either case, the engine is not optimized for propane operation thus resulting in unoptimized performance in terms of fuel efficiency and conversely, CO2 emissions. However, even an unoptimized propane engine leads to significant PM and NOx emissions reductions relative to diesel thus improving air quality.

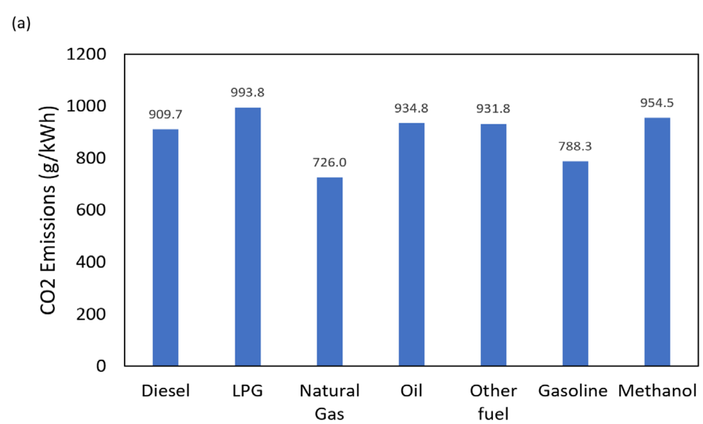

Figure 3: *Cumulative fleet backup generator emissions comparisons of (a) CO2 for different fuels.*

12. https://doe.icfwebservices.com/microgrid

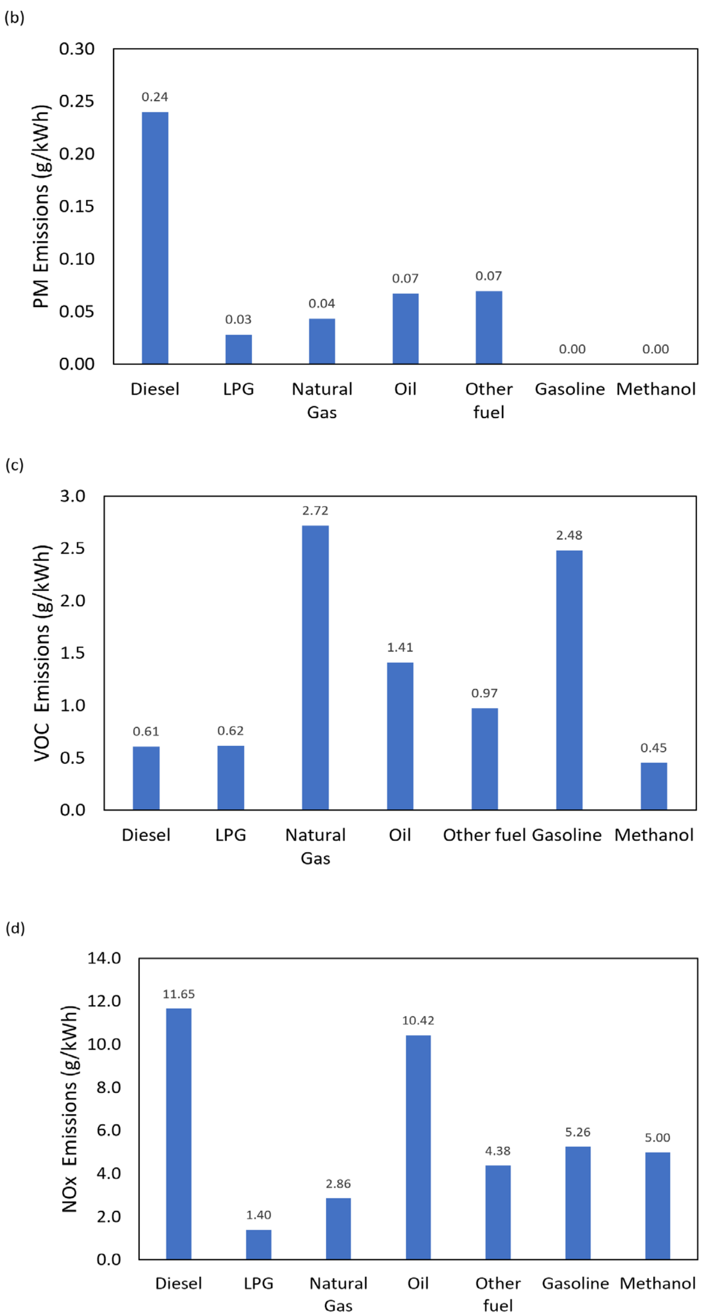

Figure 3: *Cumulative fleet backup generator emissions comparisons of (b) PM, (c) VOC and (d) NOx for different fuels.*

• **Propane Combined Heat and Power (CHP) and Distributed Energy Solutions:** Propane is being used for several combined heat and power solutions in the 1 kW - 1 MW range (residential, commercial, and industrial). Typically, the engines employed for CHP have higher thermal efficiency (>30% fuel to electrical conversion efficiency), higher durability (40,000-60,000 hours) and low emissions. A list of some commercial CHP and distributed generation products are shown in Table 1, which could also be used in backup generators (Note, this is not an exhaustive list). The biggest challenge in using these solutions in the backup generator market is their high capital cost since the attributes and expectations of the CHP products are different from the low cost and low durability backup generator products. However, if there is a significant increase in backup generator demand, the higher capital cost can be amortized over the increased sales volume.

Company	Product Name	Technology	Electrical Output (kWe)	Electrical Efficiency (%)[13]	Tailpipe CO2 (g/kWh)
Yanmar[14]	CP 10	Internal Combustion Engine (ICE)	10	30	774.2
Gridiron Energy[15]	H24	ICE	20-24	30	774.2
TEDOM[16]	Micro 35	ICE	35	31.5	737.3
TEDOM[16]	Micro 55	ICE	52	30.9	751.6
2G Energy[17]	avus	ICE	300 - 1,555	37.5 - 41	566.5 - 619.4
Siemens[18]	SGE-SM	ICE	303-873	36.3	639.8
Capstone[19]	C65	Microturbine	65	28	829.5
FlexEnergy[20]	GT333S	Microturbine	333	33	703.8
Upstart[21]	Upgen NXG	Fuel cell	1.25	33	701

Table 1: *Attributes of commercial propane CHP products currently available in the market.*

As can be seen from the above table, depending on the size of the unit, a 16%-43% reduction in CO2 emissions can be realized using these solutions in the backup generator market relative to the data shown for LPG in Figure 3(a). Propane also opens the door for fuel cells, a high efficiency and low emissions technology that is seldom used with diesel. In terms of exhaust emissions, PERC is working with at least two manufacturers to achieve the CARB distributed generation certification standards of NOx (0.03 g/kWh), CO (0.045 g/kWh) and VOCs (0.01 g/kWh), which practically makes them near-zero emission solutions. In addition, fuel cells such as the Upgen NXG produce very low NOx (0.03 g/kWh) and CO (0.045 g/kWh) emissions[21]. For added resiliency, CHP solutions are a perfect fit for residential, commercial, and industrial applications providing not only much needed electricity but also heat and/or hot water (and/or cooling) during power outage situations. When used in CHP mode, these solutions can have more than 80% fuel conversion efficiency to electricity and useful heat.

13. Lower heating value based efficiency
14. https://www.yanmarenergysystems.com/webres/File/CP10WN-Spec-Sheet.pdf
15. https://microgridstorage.com/Home/Specifications
16. https://www.tedom.com/en/chp-units/lpg/
17. https://www.2g-energy.com/products/propane
18. https://assets.new.siemens.com/siemens/assets/api/uuid:9bc49909-dd4d-4381-8b58-6a0736407342/version:1599737241/gasengines-overview.pdf
19. https://www.capstonegreenenergy.com/products/energy-generation-technologies/capstone-microturbines/c65
20. https://www.flexenergy.com/wp-content/uploads/2020/03/FLX-SPEC-GT333S-71000067-Rev-H-1.pdf
21. https://www.upstartpower.com/products/

• **Microgrids**

There are several microgrids, particularly remote ones, that are being supported by propane today[22]. BoxPower and Generac are providing Solar-PV with battery backup and propane generator solutions for remote wildfire-prone locations in California. Instead of ruggedizing the transmission and distribution (T&D) lines, which could cost more than a million dollars per mile in remote locations, electric utilities are deenergizing the T&D lines and installing microgrid solutions to avert forest fires. Pacific Gas & Electric (PG&E) identify in their 2021 wildfire mitigation plan report[23] that a technology combination of Solar PV and battery energy storage with supplemental propane gensets is not only the most cost effective and reliable, but also the cleanest solution for initial remote grid sites. In most locations, the supplemental propane generators are used to charge the batteries when the batteries reach a lower state of the charge. In other instances, the propane generator is also used for providing supplemental electricity due to higher electricity demand prices charged by the electric utility. I have previously covered propane microgrids and its benefits from an emissions and economics perspective relative to diesel in a separate whitepaper that has been published in Microgrid Knowledge[24]. Remote microgrids often depend on diesel for fuel supply but, more recently, propane is receiving significant traction due to its ability to reduce emissions and improve local air quality.

What the Future Holds for Propane

• Typical propane engines provide an excellent option in improving the local air quality relative to diesel particularly by reducing NOx and PM emissions. CO2 emissions reduction can be significantly enabled using optimized propane engines. One example is the Siemens SG series lean burn engine that operates with a Miller cycle (i.e., variable compression ratio)[25]. Such technologies are optimized for propane operation and the switch from natural gas to propane is seamless without leading to a significant derate of the engine. Dedicated propane engines provide a fantastic reduction in CO2 emissions relative to diesel (11-13%). One example is the engine being developed by Cummins for on-road propane applications[26]. Propane engines developed for CHP applications are a great fit for not only reducing criteria pollutants, but also CO2 emissions.

• An alternate option is to employ a propane CHP solution with black-start capability that not only provides power but also heat (and/or cooling) even when the grid is down. CHP solutions are capital intensive due to lower sales volumes and specific product attributes (e.g., use of a water-cooled engine, superior engine durability, heat capture system integration, complex controls, installation complexity and cost etc.). For enabling CHP solutions, propane retailers could take a page from the solar-PV industry and other behind-the-meter solutions to provide energy-as-a-service (EaaS) with potential collaboration with the equipment manufacturer or system integrator. Propane retailers are not new to the XaaS business models as propane tanks and propane autogas filling stations are routinely leased or provided as a service to the end customer and fleets, respectively.

• Renewable propane is structurally and functionally identical to conventional propane and is produced from renewable feedstocks (e.g., used cooking oil, animal tallow etc.) using hydrotreated vegetable oil process. Typical renewable diesel and sustainable aviation fuel biorefineries that depend on soybean oil as feedstock will also produce renewable propane as a byproduct. Currently, the incentives for renewable propane are structured in such a way that it is viable for on-road transportation applications. This is where policymakers could make an impact by subsidizing the use of renewable propane for power generation applications. The market pull enabled by the incentive structure will spur additional production of renewable propane. Renewable propane can lead to a 50%-70% reduction in lifecycle CO2 emissions compared to conventional diesel and can accelerate deep decarbonization[27]. Blends of conventional and renewable propane are also practical solutions for accelerating decarbonization.

In summary, propane powered solutions offer a complementary pathway for improving local air quality and decarbonization specifically by replacing diesel powered solutions.

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22. https://www.generac.com/Industrial/professional-resources/information-resources/case-studies
23. https://www.pge.com/pge_global/common/pdfs/safety/emergency-preparedness/natural-disaster/wildfires/wildfire-mitigation-plan/2021-Wildfire-Safety-Plan.pdf
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26. Rengarajan, S., Liu, Z., Lerin, C., Stetter, J., Narang, V., & Lana, C. (2020). LPG direct injection engine for medium duty trucks (No. 2020-01-5008). SAE Technical Paper.
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