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Dual Fuel-Engine Interactions: A Review of the Impact of Fuels on Internal Combustion Engine Emissions and Performance

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Petroleum-based fuels are finite, and the urgent need for alternative, non-petroleum fuels for internal combustion engines (ICEs) has become increasingly evident. In recent years, the automotive industry has faced increasing pressure to reduce the harmful emissions produced by direct-injection diesel engines. To address this challenge, various strategies have been explored, among which the 'dual-fuel concept' has emerged as a promising approach for controlling both nitrogen oxides (NO_x) and soot emissions, even in existing diesel engines. One such strategy involves the incorporation of gaseous fuels with conventional diesel. These gaseous fuels, which typically possess high octane numbers and exhibit gasoline-like characteristics, are more resistant to auto-ignition. The primary goal of dual-fuel operations with diesel and gaseous fuels is to reduce emissions of particulate matter (PM) and NO_x. The main objective of this study is to provide a comprehensive review on the effects of gaseous fuels, such as hydrogen gas, natural gas (NG), biogas, liquefied petroleum gas (LPG) and syngas in dual-fuel operation with diesel. The review focuses on comparing these effects to those of conventional diesel combustion in terms of engine emissions and performance. Understanding the synergy of the dual-fuel concept helps to revolutionize ICE technology, highlighting its potential economic benefits and contributions toward more sustainable and environmentally friendly transportation solutions.

1. Introduction

The growing global demand for energy and the environmental consequences of fossil fuel consumption have brought renewed focus to the limitations of petroleum-based fuels. These resources are finite, and their continued use contributes significantly to greenhouse gas (GHG) emissions, particularly in the transportation sector. Diesel engines, widely used for their high thermal efficiency and durability, are major contributors to air pollution due to their emission of NO_x and PM. As climate concerns and regulatory pressures intensify, the search for sustainable alternatives to conventional diesel combustion has become a critical area of research in engine and fuel technology.

One promising pathway to mitigate diesel engine emissions without completely overhauling existing infrastructure is the dual-fuel combustion strategy. In this approach, a high-cetane fuel such as diesel is used for pilot ignition, while a secondary, typically gaseous, fuel is introduced into the intake air stream. These gaseous fuels such as hydrogen, NG, biogas, LPG and syngas, generally have high octane numbers and resist auto-ignition, enabling cleaner, more controlled combustion (Wan et al., 2013). Dual-fuel operation aims to retain the power and efficiency of diesel while reducing harmful emissions through partial substitution with low-carbon

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or carbon-free gaseous fuels.Despite numerous studies demonstrating the emission-reduction benefits of dual-fuel combustion, there remains a lack of systematic comparison across different gaseous fuels regarding their impacts on engine performance and emissions. Existing research tends to focus on individual fuels or specific operating conditions, making it difficult to draw general conclusions or provide guidance for practical implementation. Moreover, variations in fuel properties, substitution ratios, combustion stability, and engine load behavior make direct comparisons complex. This fragmented understanding limits the broader adoption of dual-fuel systems, especially in commercial and heavy-duty applications where operational flexibility and emissions compliance are critical.

Therefore, this study aims to provide a comprehensive and comparative review of the effects of selected gaseous fuels such as hydrogen, NG, biogas, LPG and syngas, when used in dual-fuel operation with diesel. This review consolidates findings from the literature to evaluate how these fuels influence combustion characteristics, thermal efficiency, and pollutant emissions compared to conventional diesel combustion. By addressing the current knowledge gap, the study aims to offer valuable insights into the relative advantages and challenges of each fuel, ultimately contributing to the advancement of cleaner and more sustainable ICE technologies.

2. Combustion mechanism in dual fuel diesel engine

Dual-fuel ICEs represent a significant advancement in the transportation sector, addressing the growing concerns over carbon emissions and stringent environmental regulations (Gopinathan and Ibrahim, 2025). These engines are designed to operate on two different types of fuels simultaneously or alternately, typically combining a primary low-reactivity gaseous fuel, such as hydrogen, NG, biogas, LPG or syngas with a secondary high-reactivity liquid fuel like diesel. Most of the energy released during combustion comes from the gaseous fuel, while the liquid fuel mainly serves to initiate ignition and supplies a smaller portion of the total energy during the process (Karim, 2015). Among these gases, NG appears to be the most common gaseous fuel used in dual fuel diesel engine. Alternative green fuels such as ammonia and methanol are gaining growing interest in recent dual-fuel marine engine research. However, their technical readiness still needs further development before they can be widely commercialized (Wang et al., 2022).

This dual fuel concept offers significant advantages, including the potential to reduce fuel consumption and lower pollutant emissions like CO_2, NO_x, and PM, thereby enhancing engine efficiency compared to conventional diesel engines (Stettler et al., 2016). Dual-fuel engines are considered a crucial step in the “Energy Transition" and a viable pathway for decarbonizing transport, enabling the efficient and clean combustion of sustainable and carbon-free alternative fuels, while also providing fuel flexibility and operational safety by maintaining liquid fuel redundancy for emergencies (Tang et al., 2025).

Dual-fuel engines can operate in various modes, such as the gas-diesel mode and micro-pilot mode. The gas-diesel mode, often referred to as the “Diesel Substitution” mode, is capable of operating with varying ratios of gas and diesel fuel mixtures. It is the mode where gas content can reach up to 85 % with diesel fuel still providing a substantial amount of energy (Korakianitis et al., 2011). The gas-diesel mode requires significantly fewer hardware modifications compared to the micro-pilot mode because it relies on conventional diesel injection systems with minimal changes. The gas-diesel mode is especially popular in land-based applications such as locomotives, oil and gas divisions. In terms of micro-pilot mode, it utilized less than 5 % pilot fuel for ignition, favored for marine applications including offshore vessels, tug boats and ferries (Tang et al., 2025).

The combustion process in dual-fuel engines is notably complex, particularly in micro-pilot ignited systems. It typically begins with the gaseous fuel forming a premixed charge with air, followed by the injection of a small quantity of high-reactivity liquid pilot fuel towards the end of the compression stroke to initiate ignition (Gopinathan and Ibrahim, 2025).This pilot ignition is crucial as it controls the subsequent combustion and acting as flame kernels that rapidly spread and propagate through the air-gas mixture (Azimov et al., 2013). The ignition process itself can be a three-stage volumetric process: (i) early heat release from low-temperature chemistry, (ii) ignition at the pilot spray tip activated by high-temperature reactivity, and (iii) subsequent initiation of a premixed flame throughout the gaseous fuel (Tang et al., 2025). Figure 1 illustrates that the combustion process in a dual-fuel engine typically progresses through three distinct stages: low-temperature heat release (LTHR) initiated by pilot diesel injection, high-temperature ignition at the diesel spray tip forming flame kernels, and propagation of the premixed flame in the gaseous-air mixture. Engine efficiency and emissions are influenced by factors like the global air-fuel ratio, temperature, pressure, and turbulence within the combustion chamber, which affect flame speed (Tang et al., 2025). While some dual-fuel engines are Otto cycle-based (premixed combustion with low-pressure gas injection), advanced systems like Dual-Fuel Direct Injection (DFDI) involve two independent direct injection systems for precise control over fuel reactivity and distribution within the cylinder, addressing the limitations of traditional methods such as poor stability and low fuel substitution rates (Li et al., 2025). Strategies such as split injection of the pilot fuel can further optimize performance by influencing

in-cylinder pressure and heat release rate, and are crucial for improving combustion stability and extending the operating range (Niki et al., 2019).

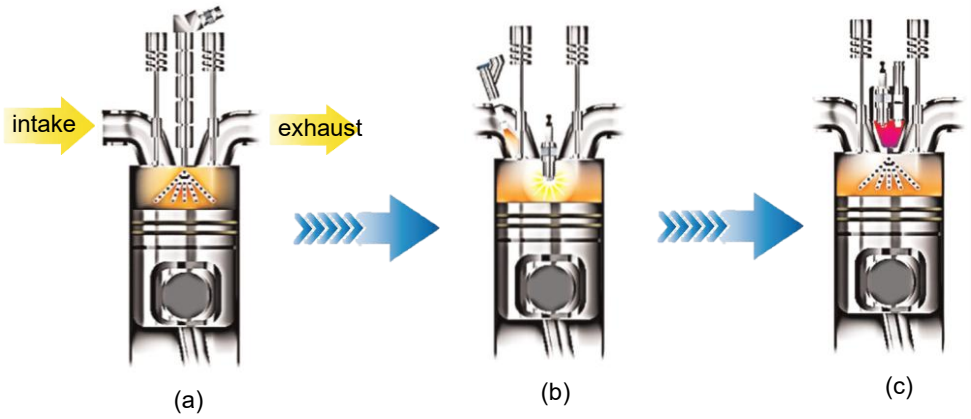

Figure 1: Combustion mechanism in a dual-fuel engine: (a) LTHR initiated by pilot diesel injection, (b) high-temperature ignition at the diesel spray tip forming flame kernels, and (c) propagation of the premixed flame in the gaseous-air mixture. (Adapted from (Curran et al., 2024))

3. Type and physicochemical properties of different gaseous fuels

Hydrogen is a clean, carbon-free fuel known for its high calorific value, fast flame speed, and wide flammability range. It can be sustainably produced through processes such as water electrolysis or biomass conversion. NG, primarily composed of methane (CH_4), is a low-carbon fossil fuel commonly extracted from NG fields and petroleum reservoirs. Biogas, a renewable alternative, is produced via the anaerobic digestion of organic biomass and typically contains a mixture of CH_4 and carbon dioxide (CO_2). LPG, mainly consisting of propane and butane, is derived as a byproduct of NG processing and crude oil refining. Syngas, or synthesis gas, is a blend of hydrogen, carbon monoxide (CO), CO_2, and traces of CH_4, generated through the gasification of coal, biomass, or waste materials. Each of these gaseous fuels varies in origin, composition, and combustion behavior, making them promising candidates for dual-fuel engine applications aimed at lowering emissions and enhancing sustainability. The comparative analysis of these gaseous fuels relative to conventional diesel, as presented in Table 1, evaluates their performance and environmental impacts in dual-fuel engine applications. This assessment is based on key thermochemical and combustion parameters, including energy content, density, relative efficiency, combustion effects, and emission characteristics, highlighting significant distinctions that influence the feasibility, sustainability, and performance of each fuel type in ICEs.

Based on Table 1, diesel, as the baseline fuel, possesses a high lower energy content (~45.5 MJ/kg) and liquid density (~0.82–0.86 kg/L), facilitating compact energy storage and sustained power delivery in compression ignition (CI) engines. Among the gaseous fuels, hydrogen stands out for its high energy content (~120 MJ/kg), yet its extremely low density of ~0.0899 kg/m³ at normal temperature and pressure limits its volumetric energy storage, demanding high-pressure or cryogenic solutions.

NG, which is primarily made up of CH_4, offers moderate energy content of ~50 MJ/kg but also has similarly low volumetric density (~0.72 kg/m³), which constrains energy availability per cylinder cycle. Biogas, a CH_4-CO_2 mixture, has significantly reduced energy content (~20–25 MJ/kg) due to CO_2 dilution and a higher density (~1.15 kg/m³), contributing to lower flame temperatures and thermal output. Syngas, with an even broader and lower energy range (~10–20 MJ/kg), poses challenges in achieving consistent combustion without auxiliary fuels or enhancements. These disparities in energy content necessitate careful consideration of pilot injection strategy, gaseous substitution rates, and in-cylinder thermodynamic management in dual-fuel operation.

In dual-fuel engines, diesel acts as the pilot fuel to initiate ignition, while gaseous fuels are pre-mixed with intake air. The combustion behavior is strongly influenced by the properties of the gaseous fuel. Hydrogen, with its ultra-fast flame speed and wide flammability limits, enables rapid combustion and lean operation, improving thermal efficiency under certain regimes. However, hydrogen also poses knock risks and pre-ignition tendencies due to its low ignition energy, requiring advanced control of pilot timing and charge temperature (Yip et al., 2024).

Table 1: Comparative characteristics of diesel and various gaseous fuels used in dual-fuel engines

Type of fuel	Energy content (MJ/kg)	Fuel density	Efficiency (vs Diesel)	Combustion effects	Emission effects	References
Diesel (base fuel)	~45.5 MJ/kg	~0.82–0.86 kg/L (liquid)	Baseline (High)	Auto-ignition via compression; high torque	-High NO_x, PM -Lower CO & HC due to full combustion	(National Research Council, 2011; Huth and Heilos, 2013)
Hydrogen	~120 MJ/kg	~0.0899 kg/m³ (gas)	Higher at lean burn	Very fast flame speed; risk of knock	-Zero CO_2, PM -High NO_x unless diluted or EGR used	Beccari et al. (2023)
NG	~50 MJ/kg (CH_4-rich)	~0.72 kg/m³ (gas)	Similar or slightly lower	Lean premixed; smoother but slower combustion	-Lower PM, CO_2 -Higher CH_4 (methane slip), possibly NO_x	Liang (2022)
Biogas	~20–25 MJ/kg (CH_4 + CO_2 mix)	~1.15 kg/m³	Lower	Incomplete combustion risk due to CO_2 content	-Low SO_x, PM -Higher CH_4 slip and CO	Kabeyi and Olanrewaju (2024)
LPG	~46 MJ/kg	~0.54 kg/L (liquid)	Slightly lower or similar	Clean burn; moderate ignition delay	-Lower PM, SO_x, CO_2 -Potential NO_x rise at high temps	Synák et al. (2019)
Syngas	~10–20 MJ/kg (varies)	Varies (low energy density)	Lower	Slower, inconsistent flame propagation	Higher CO, HC -Lower PM, NO_x varies with gas composition	Komarov et al. (2022)

NG promotes smooth combustion with lower cyclic variability but slower flame propagation compared to hydrogen, resulting in a longer combustion duration (Duan et al., 2020). Dual-fuel NG-diesel systems typically achieve reasonable efficiency under high loads but suffer at low loads due to poor mixture reactivity. Biogas, owing to its CO_2 fraction, further reduces reactivity and combustion stability, often leading to misfire, incomplete combustion, or increased reliance on pilot diesel to maintain ignition.

LPG, when used in dual-fuel systems, exhibits moderate flame speeds and improved combustion cleanliness, though with ignition delays under certain engine conditions. Syngas, with its low calorific value and variable composition, presents significant challenges in flame stability and propagation, often necessitating higher diesel pilot fractions to sustain combustion. These effects underline the importance of fuel reactivity matching and combustion phasing control for optimal dual-fuel operation.

The efficiency of dual-fuel ICE systems is influenced by load conditions, the substitution ratio and the fuel–air equivalence ratio (Mirmohammadsadeghi et al., 2019). Diesel-only operation maintains high indicated thermal efficiency, particularly under high-load conditions due to the inherently high cetane number and energy density (Yalong et al., 2023). In contrast, dual-fuel systems utilizing hydrogen can surpass diesel efficiency in lean-burn regimes by reducing throttling losses and enhancing charge cooling. However, efficiency may drop under part-load due to increased unburned fuel losses and combustion instability.

NG and LPG tend to yield comparable or slightly reduced efficiency relative to diesel, contingent on substitution ratio and combustion completeness (Karagöz et al., 2016). Biogas and syngas typically exhibit lower engine efficiency in dual-fuel mode, primarily due to low flame temperature, inert gas dilution, inconsistent combustion behavior and low energy density (de Carvalho et al., 2024), which necessitate higher diesel input to sustain performance. These trends underscore the importance of optimizing the diesel-gas substitution strategy to balance combustion stability and efficiency.

The shift to dual-fuel operation significantly alters engine-out emissions. Diesel combustion is associated with high NO_x and PM due to local high-temperature regions and diffusion flame mechanisms (Gowrishankar et al., 2024). Introduction of gaseous fuels generally reduces PM formation due to cleaner premixed combustion. Hydrogen contributes zero CO_2 and PM, offering a carbon-free pathway; however, it elevates NO_x due to high flame temperatures unless mitigated by dilution or exhaust gas recirculation (EGR) (Algayyim et al., 2024).
NG and LPG exhibit notable reductions in PM, sulfur monoxide (SO_x), and CO_2 emissions compared to diesel. However, they may cause CH_4 slip (especially NG and biogas), contributing to GHG emissions. Biogas increases CO and unburned hydrocarbon (HC) emissions due to its low reactivity and incomplete combustion at low loads (Kumar et al., 2020). Syngas similarly contributes to high CO and HC levels, depending on its H_2/CO ratio and the presence of inert gases.
Dual-fuel strategies incorporating gaseous fuels offer substantial benefits in terms of soot and CO_2 reduction but can introduce new challenges related to unburned fuel emissions, NO_x control, and combustion variability, particularly with low-quality gaseous fuels. In summary, hydrogen stands out for its zero-carbon emissions potential and high energy content, albeit with significant storage and combustion control challenges. NG and LPG present promising lower-emission alternatives with moderate infrastructure compatibility. Biogas and syngas, while renewable and locally producible, are limited by lower energy density and combustion consistency. Each alternative fuel exhibits specific advantages and trade-offs, indicating the optimal fuel choice must be aligned with application-specific priorities such as energy density, emissions targets, and engine compatibility.

4. Conclusion

The dual-fuel concept presents a viable strategy to reduce harmful emissions from ICEs while partially displacing diesel with cleaner gaseous fuels. This review has shown that incorporating gaseous fuels such as hydrogen, NG, biogas, LPG, and syngas into diesel combustion systems significantly influences engine performance, efficiency, and emission profiles. Hydrogen offers the greatest potential for decarbonization due to its high energy content and zero carbon emissions, but it demands advanced storage and combustion control technologies. NG and LPG provide a balance between emissions reduction and infrastructure compatibility, while biogas and syngas, although renewable and locally available, face performance limitations due to low energy density and combustion instability.
The findings underscore that no single gaseous fuel is universally optimal; instead, their effectiveness in dual-fuel applications depends on multiple factors, including engine load, substitution ratio, fuel composition, and desired emissions outcomes. Addressing the challenges associated with fuel reactivity, knock tendency, and emission control—particularly for low-reactivity or dilute fuels like biogas and syngas—is essential for successful integration. Future research should focus on real-time combustion optimization strategies, advanced control systems, and hybridized fuel delivery methods to fully exploit the environmental and economic benefits of dual-fuel systems across diverse engine platforms and duty cycles.

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References

Algayyim S. J. M., Saleh K., Wandel A. P., Fattah I. M. R., Yusaf T., Alrazen H. A., 2024, Influence of natural gas and hydrogen properties on internal combustion engine performance, combustion, and emissions: A review, Fuel, 362, 130844.
Azimov U., Tomita E., Kawahara N., 2013, Combustion and exhaust emission characteristics of diesel micro-pilot ignited dual-fuel engine, Diesel Engine-Combustion, Emissions and Condition Monitoring, IntechOpen, London, UK.
Beccari S., Pipitone E., Caltabellotta S., 2023, Analysis of the Combustion Process in a Hydrogen-Fueled CFR Engine, Energies, 16(5), 2351.
Curran S., Onorati A., Payri R., Agarwal A. K., Arcoumanis C., Bae C., Boulouchos K., Dal Forno Chuahy F., Gavaises M., Hampson G. J., 2024, The future of ship engines: Renewable fuels and enabling technologies for decarbonization, International Journal of Engine Research, 25(1), 85-110.
de Carvalho F. S., Rufino C. H., de Oliveira E. M., Mendoza A. P., dos Santos, L. R., Machin E. B., Pedroso D. T., Lacava P. T., 2024, Experimental investigation of hydrogen-producer gas mixtures in an optically accessible SI engine, International Journal of Hydrogen Energy, 58, 500-513.

Duan X., Deng B., Liu Y., Zou S., Liu J., Feng R., 2020, An experimental study the impact of the hydrogen enrichment on cycle-to-cycle variations of the large bore and lean burn natural gas spark-ignition engine, Fuel, 282, 118868.

Gopinathan R., Ibrahim M. M., 2025, Ammonia as a sustainable fuel for diesel engines: Exploring advanced combustion strategies for green transportation, Journal of the Energy Institute, 121, 102159.

Gowrishankar S., Rastogi P., Krishnasamy A., Basavaraj M. G., Kaisare N., Aidhen I. S., 2024, Synthesis and characterization of emulsion fuels–Implications to spray and engine studies, Progress in Energy and Combustion Science, 101, 101133.

Huth M., Heilos A., 2013, Fuel flexibility in gas turbine systems: Impact on burner design and performance, Modern Gas Turbine Systems, Woodhead Publishing, pp. 635-684.

Kabeyi M. J. B., Olanrewaju O. A., 2024, Biogas as a sustainable fuel and feedstock: Properties, purification, and applications, From Biomass to Biobased Products, IntechOpen, London, UK.

Karagöz Y., Sandalcı T., Koylu U. O., Dalkılıç A. S., Wongwises S., 2016, Effect of the use of natural gas–diesel fuel mixture on performance, emissions, and combustion characteristics of a compression ignition engine, Advances in Mechanical Engineering, 8(4), 1687814016643228.

Karim G. A., 2015, Dual-Fuel Diesel Engines, CRC press, Boca Raton, USA.

Komarov I., Rogalev N., Osipov S., Zlyvko O., Kharlamova D., 2022, Development of a mathematical model for solid fuel gasification and its sensitivity analysis, Inventions, 7(3), 65.

Korakianitis T., Namasivayam A., Crookes R. J., 2011, Natural-gas fueled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions, Progress in Energy and Combustion Science, 37(1), 89-112.

Kumar M., Xiong X., Wan Z., Sun Y., Tsang D. C., Gupta J., Gao B., Cao X., Tang J., Ok Y. S., 2020, Ball milling as a mechanochemical technology for fabrication of novel biochar nanomaterials, Bioresource Technology, 312, 123613.

Li T., Zhao P., He H., Wang C., Zhang H., Chen Z., Chen H., 2025, Dual-fuel dual-direct injection: An efficient and clean combustion technology for diesel engines, Journal of the Energy Institute, 119, 102006.

Liang Y., 2022, A review of the effect of compressed natural gas (CNG) on combustion and emission performance of internal combustion engines, Trends in Renewable Energy, 8(2), 119-129.

Mirmohammadsadeghi M., Zhao H., Ito A., 2019, Optical study of gasoline substitution ratio and diesel injection strategy effects on dual-fuel combustion, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 234(4), 1075-1097.

National Research Council, Division on Engineering and Physical Sciences, Board on Energy and Environmental Systems, Economy, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, 2011, Assessment of Fuel Economy Technologies for Light-Duty Vehicles, National Academies Press, Washington, USA.

Niki Y., Nitta Y., Sekiguchi H., Hirata K., 2019, Diesel fuel multiple injection effects on emission characteristics of diesel engine mixed ammonia gas into intake air, Journal of Engineering for Gas Turbines and Power, 141(6), 061020.

Stettler M. E., Midgley W. J., Swanson J. J., Cebon D., Boies A. M., 2016, Greenhouse gas and noxious emissions from dual fuel diesel and natural gas heavy goods vehicles, Environmental Science and Technology, 50(4), 2018-2026.

Synák F., Čulík K., Rievaj V., Gaňa J., 2019, Liquefied petroleum gas as an alternative fuel, Transportation Research Procedia, 40, 527-534.

Tang Y., Zhao X., Feng J., Bai S., Li G., Duan H., Zhu S., 2025, Challenges and opportunities of natural gas dual-fuel engines for marine applications, Fuel, 400, 135808.

Wang Y., Cao Q., Liu L., Wu Y., Liu H., Gu Z., Zhu C., 2022, A review of low and zero carbon fuel technologies: Achieving ship carbon reduction targets, Sustainable Energy Technologies and Assessments, 54, 102762.

Wan C., Yan X., Zhang D., Fu S., 2013, Reliability analysis of a marine LNG-diesel dual fuel engine, Chemical Engineering Transactions, 33, 811-816.

Yalong L., Bo W., Cong W., Zhi J., Binyang W., 2023, The effect of ignition diesel injection conditions on the combustion process of natural gas engine, Applied Thermal Engineering, 235, 121452.

Yip H. L., Zhai G., Rorimpandey P., Kook S., Hawkes E. R., Chan Q. N., 2024, Experimental study of laser-ignited hydrogen jet flame evolution under simulated direct-injection diesel engine conditions, International Journal of Hydrogen Energy, 93, 1060-1070.