

5G Broadband Internet in US Rural Areas: Impacts, Challenges, and Future Roadmap

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Abstract—This article examines how 5G broadband technology can transform connectivity issues in rural America. It points out the major gaps in internet access between rural and urban areas. Rural residents deal with higher costs, fewer provider options, and poor infrastructure. The study shows how limited connectivity affects education, healthcare, business productivity, and overall quality of life. Through detailed analysis, the article explores how 5G could change rural industries, especially agriculture, through precision farming, automation, and real-time data use. It reviews federal programs like BEAD, Community Connect, and the Tribal Broadband Connectivity Program. It suggests strategies such as infrastructure sharing, digital skills training, and public-private partnerships to expand rural 5G access. Despite challenges like high costs and geographic barriers, the article argues that with coordinated investments and support from policies, 5G can promote digital fairness, create economic opportunities, and help rural communities fully engage in the digital economy.

Keywords— 5G Deployment: Rural Broadband Access: Digital Divide: Precision Agriculture: Infrastructure Policy.

I. INTRODUCTION

1.1 Background

Broadband access is increasingly acknowledged as vital infrastructure in the contemporary economy. Broadband access facilitates connections for citizens and enterprises to economic opportunities across the nation. Nonetheless, rural America has fallen behind metropolitan areas in broadband investment. This lack of progress has intensified economic inequities between rural and urban regions. The absence of connectivity has impeded rural areas' participation in the 21st-century digital economy. However, broadband access may exert the most substantial influence on rural regions in terms of accessing economic prospects. Recent initiatives have broadened rural broadband connectivity. However, these initiatives can only serve as a transformative instrument for rural economic growth and resilience when extensively employed and efficiently harnessed [1].

Despite ongoing efforts, the U.S. continues to experience disparities between rural and urban communities. This creates a situation that may improve with investments from the Infrastructure Investment and Jobs Act (IIJA). Rural communities continue to experience significant delays in broadband deployment due to the perceived lack of profitability for ISPs in investing in local infrastructure. The Federal Communication Commission (FCC) has indicated that rural areas experience significantly lower access to broadband infrastructure compared to urban areas. Numerically, there

exists a deficit of 54 percent in fixed broadband availability relative to urban and suburban regions. Nineteen percent of rural Americans have access to multiple broadband options. The absence of competition may result in elevated prices. It is important to note that low-density population areas incur, on average, 37 percent higher costs than urban regions [2].

Due to physical distancing practices and constraints during the COVID-19 epidemic, the usage of telehealth and digital health platforms has increased. In response to the pandemic threat, telehealth was rapidly developed, implemented, and utilized. This was done to ensure continuity of care through multi-purpose technology platforms also called telehealth facilities [3]. The pandemic resulted in a swift incorporation of technology within educational settings. Prior to the COVID-19 pandemic, numerous educational institutions were gradually adopting digital technologies. The transition to remote learning in March 2020 compelled educational institutions to rapidly adopt Learning Management Systems (LMS), Zoom, and various educational software [4].

1.2 Problem Statement

A significant number of Americans residing in rural regions continue to experience a lack of access to high-speed internet services. The Federal Communications Commission (FCC) reports that numerous rural households experience slow or absent connectivity [5]. The "digital divide" constrains economic growth, limits access to essential services, and places rural communities at a disadvantage. Conventional broadband infrastructure faces significant barriers in accessing remote areas, primarily due to financial constraints and geographic obstacles. 5G provides a more efficient and scalable solution, enabling rural America to engage fully in the digital economy.

Reliable internet access is crucial for businesses to remain competitive in the contemporary global economy. 5G enables rural businesses to utilize cloud computing, e-commerce platforms, and real-time data transfers, thereby enhancing efficiency and competitiveness. High-speed connectivity has the potential to attract advanced manufacturing, precision agriculture, and logistics industries that may otherwise disregard rural areas.

1.3 Research Objectives

Following are the research objectives of this article.

- Explore the feasibility and impact of 5G in U.S. rural areas
- Identify 5G deployment challenges

- Recommend strategies for expanding 5G deployment in rural America

II. 5G BROADBAND INTERNET LANDSCAPE

2.1 Barriers And Challenges

1) Internet Access in Rural Black and Native American Communities

According to the current broadband definition, rural areas exhibit markedly lower access to broadband internet across all technology types compared to urban areas. Only 65 percent of rural residents have access to broadband internet in contrast to 97 percent of urban residents. Cable broadband, a prevalent broadband technology, is accessible to 93.8 percent of individuals in urban areas. However, only 36.7 percent of those in rural areas have access to the same technology [6]. Fiber optic technology is accessible to about 50% of urban residents, whereas only 25% of rural residents have access [7]. Studies indicate that individuals residing in low-income rural areas generally have limited options for broadband Internet Service Providers (ISPs). In low-income and rural Native American households, 68.3 percent lack any access [7]. Low Earth orbit satellite internet services and fixed wireless internet are becoming more accessible in these regions [8].

2) Persistent Subscription Gaps in Rural High-Speed Internet Access

Subscription rates for internet services are lower in rural regions. According to a report by The Pew Research, in-home fixed internet subscriptions are most prevalent in suburban areas at 86 percent. Urban and rural areas show significantly lower rates at 77 percent and 73 percent, respectively [9]. Furthermore, individuals residing in rural regions are more inclined to depend on wireless subscriptions and satellite connections [10]. These connections are generally less reliable compared to wired connections. Despite the decreasing costs of satellites, the expense of connectivity remains prohibitive in many rural areas. This is particularly true in geographically remote regions where only costly satellite or mobile plans are accessible. Challenging landscapes, including mountainous regions, along with sparse population distribution, can significantly increase the expenses related to wired broadband infrastructure (such as cable or fiber). Such a situation renders dependable wired services excessively costly [6].

Research demonstrates that differences in infrastructure access contribute to the adoption gap between rural and non-rural areas. Factors linked to decreased adoption rates encompass income and age. Low-income households and older individuals demonstrate a lower propensity to subscribe to available internet services [11]. These groups constitute a substantial segment of rural populations. This trend provides a potential explanation of the lower adoption rates noted in these regions. Racial characteristics act as a predictor for subscription disparities in specific rural regions. A prior study found that census tracts with greater proportions of Black residents had lower broadband adoption rates than those with higher proportions of white residents. This trends was particularly visible in geographically isolated rural areas. Studies show that areas with the lowest broadband adoption

rates are predominantly found in rural regions with substantial populations of Black and Native American individuals [11].

3) Rural Students Struggle and Home Internet Access

Children residing in rural areas demonstrate reduced internet access relative to their peers in other regions. In 2021, the National Center for Education Statistics indicated that 15 percent of families with children in metropolitan areas did not have internet access at home. This is compared to 18 percent of families living outside these regions [6]. At the beginning of the 2023–24 academic year, a survey of 4,000 school leaders and administrators indicated that rural schools were less likely to provide internet-access support for students needing home internet services in comparison to the national average.

4) Lack of High-Speed Internet and Rural Business Productivity

High-speed broadband internet infrastructure is vital for rural communities to participate in the technology economy and is crucial for technology-driven economic development. Without it, rural communities will encounter difficulties in achieving local wealth generation and securing high-quality technological employment. Studies suggest that the implementation of broadband infrastructure could improve agricultural productivity [12].

2.2 5G-enabled Opportunities

1) Smart Farming

Multiple critical factors are influencing the challenges associated with food production in the 21st century. In 2019, the estimated cost of farming in the United States reached \$350 billion. This represents a 1.1% increase from 2018, with projections suggesting continued growth. The demand is rising concurrently with the depletion of natural resources. The rising threat of climate change to food security is becoming more and more serious. Greenhouse gas emissions have a significant impact on crops. These emissions increase global temperatures, intensify pest and weed infestations, and alter precipitation patterns. These challenges may lead to reduced crop yields [13]. Two years into the pandemic, grocery prices have risen due to inflation, increased consumer demand, and disruptions in the supply chain. The U.S. Department of Agriculture forecasted a 1.5–2.5% increase in supermarket item prices for 2022. The processed fruits and vegetables were expected to rise by 2–3%. The expense associated with dining out was anticipated to rise as restaurants and hotels adapt to persistent service disruptions resulting from COVID-19 [13].

5G is poised to transform agriculture significantly. Companies are developing smart farming systems that utilize 5G, AI, and edge computing technologies. The integration of 5G with other technologies will improve precision in agriculture through the implementation of tailored, data-driven strategies for farm management. This approach departs from conventional, uniform approaches related to crop yield, water and pesticide application, and waste management. The integration of 5G technology in autonomous tractors is anticipated to improve precision in agriculture and decrease labor intensity. Autonomous tractors can function effectively in both expansive and confined areas, executing tasks

including spraying, mowing, and disking. The conversion of current tractor fleets into robotic, data-driven systems can substantially improve productivity, reduce dependence on manual labor, decrease human error, and lower both equipment and production costs. Autonomous tractors protect farmers from harmful chemical exposure, potential accidents, and various occupational hazards [14].

The implementation of 5G technology in rural areas will yield direct benefits for farmers and stimulate local economic development by attracting investment and facilitating the modernization of rural communities. By giving people in rural areas access to online learning resources and training programs, high-speed internet access improves educational possibilities. The challenges are significant; however, the potential advantages of 5G implementation in rural regions are considerable. Infrastructure investment, combined with cooperation between governments, businesses, and local communities, increases the viability of 5G technology in rural areas, fostering the growth and sustainability of the agricultural sector and rural communities [21].

Digital inclusion enables the active participation of rural communities in the digital economy. High-speed internet access allows rural residents to engage in entrepreneurship, e-commerce, and teleworking, thereby increasing their income generation potential. Implementing 5G in rural areas poses significant challenges; however, it is important to recognize the opportunities this technology provides. The beneficial effects of high-speed connectivity on economic development, education, innovation, and quality of life in rural areas highlight the need for investment and action to tackle these issues for sustainable regional progress.

Collaboration between public and private sectors, along with local community involvement, is crucial for tackling the challenges associated with infrastructure, costs, and opposition to 5G deployment. Strategic planning and targeted investment can convert these challenges into opportunities, promoting digital and economic progress in rural regions. The implementation of 5G introduces several technical and economic obstacles, especially in rural areas marked by vast geographic coverage and inadequate connectivity infrastructure [15]. The advantages of 5G implementation in rural regions are significant.

The implementation of 5G technology facilitates high-speed connectivity in rural areas, thus broadening opportunities for these regions. Precision agriculture, a notable benefit of 5G technology, allows farmers to leverage sensor data for the monitoring and application of targeted techniques across different areas of their land. This includes the operation of agricultural machinery, management of livestock, monitoring of crops, and comprehensive soil analysis. The improved connectivity enabled by 5G can transform agricultural practices by promoting informed and efficient decision-making, which may result in notable enhancements in crop productivity and quality.

5G-enabled agricultural automation significantly reduces costs, improves operational efficiency and sustainability, and facilitates the development of innovative agricultural practices. 5G technology enhances connectivity, enabling the

development of digital agriculture applications that leverage artificial intelligence and machine learning, thus offering new opportunities for innovation and growth in the agricultural sector [16]. The implementation of 5G technology in rural areas will yield direct benefits for farmers and stimulate local economic development by attracting investment and facilitating the modernization of rural communities. By giving citizens in rural areas access to online learning materials and training programs, high-speed internet access improves educational opportunities. This enhances agricultural practices for local farmers and promotes personal and professional development for all community members [22].

2.3 The Impact of 5G on Rural Life

The future of 5G in rural areas could markedly improve daily life through enhanced connectivity, efficiency, and sustainability. High-speed internet access allows rural communities to improve healthcare through telemedicine, enhance educational opportunities via e-learning, and increase efficiency in agricultural and business operations. This connectivity supports remote work, which may counteract rural depopulation trends by allowing individuals to live in rural areas while preserving career opportunities. The deployment of 5G technology in rural areas offers a substantial opportunity to enhance rural connectivity and address ongoing challenges related to the digital divide. Despite significant challenges, collaboration among governments, telecommunications providers, and communities, coupled with supportive policies, can promote a connected and inclusive future. 5G has the potential to enhance internet access in rural areas, thereby creating previously unavailable opportunities.

III. EXPANDING 5G BROADBAND INTERNET IN RURAL AMERICA: OPPORTUNITIES AND SOLUTIONS

3.1 Policy Interventions

Recent policy interventions are improving digital opportunities for rural communities by investing in digital access, adoption, and skill development.

3.1.1 The Broadband Equity, Access, and Deployment (BEAD) Program

The program, created under the Infrastructure Investment and Jobs Act of 2021 and overseen by the National Telecommunications and Information Administration (NTIA), designates \$42.45 billion in block grants to states and territories for planning, infrastructure deployment, and adoption initiatives. BEAD seeks to address the digital divide by prioritizing broadband deployment in areas with insufficient internet access, especially in rural regions. The first instance of federal funding specifically targeted at states to meet these goals is represented by BEAD. Funding enables the deployment and enhancement of infrastructure, facilitates broadband data collection and planning, provides devices to improve broadband adoption, supports digital equity initiatives, and offers reduced-cost internet access for multifamily housing units. The program is in the initial stages of implementation, with states and eligible grantees processing

their multistage application packages. Following the approval of initial proposals by the NTIA, applicants may request access to at least 20 percent of their allocated funds to initiate implementation activities [6].

3.1.2 The USDA Community Connect Program

This program seeks to support rural communities in improving infrastructure access in regions where broadband service may not be commercially feasible, but can greatly improve individual quality of life and business viability. The program provides financial assistance via grants to enhance broadband service, thereby fostering economic growth and improving outcomes in education, health care, and public safety. Research demonstrates that the program has significantly enhanced broadband speeds, showing an average increase of 45 percent in download speeds in areas that benefited [17].

3.1.3 The Tribal Broadband Connectivity Program

This program allocated \$3 billion to tribal governments to improve the quality of life for Native and tribal communities through investments in broadband deployment, adoption, and digital training and opportunities. Resources may be designated for the deployment of broadband, telehealth services, distance learning initiatives, affordability of broadband, and efforts to promote digital inclusion on tribal lands. Proposals featuring workforce development initiatives and strategies for enhancing digital capacity have been prioritized for funding. As of November 2024, all awards were in various stages of implementation [6].

3.2 Strategies for Effective 5G Deployment

Numerous methods have demonstrated their effectiveness in enhancing the accessibility, uptake, and productive application of digital technology in rural areas.

1) Subsidized subscriptions and devices

Subsidized subscriptions and devices improve the economic sustainability of wired infrastructure and elevate subscription rates. Connect Humanity, a nonprofit impact investment fund, provides investments and strategic guidance to support communities in the development of internet infrastructure. The organization allocates resources to community-oriented ISPs to meet the requirements of underserved populations, with the objective of reducing backhaul expenses and improving device accessibility. The initiative prioritizes assistance for rural, low-income, and communities of color, designating 75 percent of its investments to minority- or women-led Internet Service Providers (ISPs) [6].

2) Combined workforce and digital skills training programs

Initiatives targeting rural communities can efficiently address workforce and industry requirements while improving prospects for digital skill acquisition. The Rural LISC Digital Navigator pilot program enhances economic, social, and community engagement for individuals residing in rural areas. The initiative facilitates access to subscriptions and devices, provides training for digital service utilization, improves

digital competencies, and links users to resources for online courses and further opportunities. The program aims to augment the training services currently provided by various organizations, including Community Action Agencies, financial opportunity centers, affordable housing organizations, and human services agencies, instead of duplicating them [20].

3) Public Wi-Fi in Anchor Community Institutions

Community facilities with public Wi-Fi, like schools and libraries, improve connectivity for rural citizens and companies that don't have access to high-speed internet at home. Research demonstrates that improving community-level connections, such as providing Wi-Fi in community rooms of affordable rental housing and promoting interactions at individual residences, can enhance connectivity (Harris, Judge, and Burger 2022). Schools can improve student connectivity and success by allowing access to campus before and after school, extending the coverage of school-provided Wi-Fi to parking lots, and installing Wi-Fi hotspots on school buses. These investments improve students' digital access and reduce the time needed to complete online assignments, thus supporting the success of students in households with limited or no in-home connectivity (Evans 2019). Libraries are essential in addressing digital divides and fostering digital literacy through improved digital connectivity [17].

4) Mobile Wi-Fi Lending Programs

Mobile Wi-Fi lending programs enhance internet access for individuals who lack sufficient infrastructure or encounter connectivity issues in their residences. These programs may offer considerable benefits for individuals living in rural areas. Students participating in Montana State University's hot-spot lending program, aimed at improving internet access for individuals encountering obstacles like cost or availability, reported that the initiative had a beneficial impact on their academic performance and involvement in additional programs [18].

5) Infrastructure Sharing and Public-Private Partnerships (PPPs)

The financial feasibility of rural 5G deployment is often undermined for individual telecom providers due to low population density and high infrastructure costs. By bringing together public subsidies with private sector knowledge and investment, public-private partnerships (PPPs) successfully close this gap. Infrastructure sharing, such as the use of existing utility poles, towers, and fiber backbones, significantly lowers deployment costs and accelerates market entry. Microsoft's Airband Initiative collaborates with local ISPs and electric cooperatives to provide broadband and wireless technologies to rural regions via shared infrastructure [19] [6].

6) Citizens Broadband Radio Service (CBRS) Spectrum

A feasible solution entails the use of the Citizens Broadband Radio Service (CBRS) spectrum, offering a cost-effective and efficient alternative to traditional carrier cell towers. Policymakers must prioritize rural connectivity,

recognizing that closing the digital divide is essential for economic growth, social equity, and national competitiveness [19].

7) *Financial Incentives and Regulatory Support*

Federal and state subsidies, such as the Rural Digital Opportunity Fund (RDOF), ReConnect Program, and the Broadband Equity, Access, and Deployment (BEAD) program, allocate significant financial resources for the expansion of broadband and 5G services. Streamlining permitting, reducing regulatory delays, and providing tax incentives are crucial for accelerating rollouts. The FCC's RDOF program designates up to \$20.4 billion in subsidies over ten years to improve broadband infrastructure in underserved areas [19].

IV. CONCLUSION

The growth of 5G broadband infrastructure in rural America is crucial for closing the digital gap and promoting economic and social development. Rural communities face ongoing challenges. These include limited internet access, a shortage of broadband providers, high service costs, and old infrastructure. These issues lead to lower adoption rates, educational disadvantages, limited healthcare access, and less competitiveness for rural businesses and farms. However, 5G technology provides a strong solution. It has the potential to transform agriculture through smart farming, support remote education and telehealth, and enable rural entrepreneurs and telework. Federal and state initiatives, such as the Broadband Equity, Access, and Deployment (BEAD) Program, the USDA Community Connect Program, and the Tribal Broadband Connectivity Program, are starting to tackle these problems. Additional strategies like public-private partnerships, shared infrastructure, subsidized devices, and training in digital skills can further speed up the rollout and impact of 5G in rural areas. For rural communities to succeed in the digital economy, careful investment, inclusive planning, and community involvement are vital. By taking advantage of 5G's capabilities, rural America can improve its resilience, encourage innovation, and secure a fair and prosperous future. Ensuring reliable, affordable, and fast internet access is not just a technological goal. It is a national necessity for social and economic justice.

REFERENCES

[1] CORI. (2024). Report: The role of broadband in rural economic growth and resilience. <https://ruralinnovation.us/resources/reports/report-the-role-of-broadband-in-rural-economic-growth-and-resilience/>

[2] FCC. (2021). Fourteenth Broadband Deployment Report | Federal Communications Commission. <https://www.fcc.gov/reports-research/reports/broadband-progress-reports/fourteenth-broadband-deployment-report>

[3] Bouabida, K., Lebouché, B., & Pomey, M.-P. (2022). Telehealth and COVID-19 Pandemic: An Overview of the Telehealth Use, Advantages, Challenges, and Opportunities during COVID-19 Pandemic. *Healthcare*, 10(11), 2293. <https://doi.org/10.3390/healthcare10112293>

[4] Brookings Institute. (2024). Rewiring the classroom: How the COVID-19 pandemic transformed K-12 education. <https://www.brookings.edu/articles/rewiring-the-classroom-how-the-covid-19-pandemic-transformed-k-12-education/>

[5] Newsmatics. (2025). Bridging Rural America's Digital Divide Through 5G. <https://www.wjbf.com/business/press-releases/cinpresswire/789127523/bridging-rural-americas-digital-divide-through-5g/>

[6] Junod, A. N., Scally, C. P., Sawo, M., & Ferrara, L. (2025). Expanding Digital Opportunity: A Framework and Road Map for Strengthening Digital Inclusion. Urban Institute. <https://www.urban.org/research/publication/expanding-digital-opportunity>

[7] Garnett, Paul, Alexander Jeffrey, and David Johnson. 2024. "Achieving Internet for All: Socioeconomics and Fixed Broadband Availability in the U.S." Washington, DC: Vernoburg Group.

[8] Shayea, Ibraheem, Ayman A. El-Saleh, Mustafa Ergen, Bilal Saoud, Riad Hartani, Derya Turan, and Adnan Kabbani. 2024. "Integration of 5G, 6G and IoT with Low Earth Orbit (LEO) Networks: Opportunity, Challenges and Future Trends." *Results in Engineering* 23. <https://doi.org/10.1016/j.rineng.2024.102409>.

[9] Gelles-Watnick, R. (2024, January 31). Americans' Use of Mobile Technology and Home Broadband. Pew Research Center.

[10] Boik, Andre. 2017. "The Economics of Universal Service: An Analysis of Entry Subsidies for High Speed Broadband." *Information Economics and Policy* 40: 13–20. <https://doi.org/10.1016/j.infoecopol.2017.04.004>.

[11] Zahnd, Whitney E., Nathaniel Bell, and Annie E. Larson. 2024. "Geographic, Racial/Ethnic, and Socioeconomic Inequities in Broadband Access." *PubMed Journal of Rural Health* 38 (3): 519–26. <https://doi.org/10.1111/jrh.12635>.

[12] LoPiccolo, Katherine. 2022. "Impact of Broadband Penetration on U.S. Farm Productivity: A Panel Approach." *Telecommunications Policy* 46 (9): 102396. <https://doi.org/10.1016/j.telpol.2022.102396>.

[13] Verizon. (2022, March 3). 5G in agriculture: How smart farming is transforming the oldest industry. <http://corpweb-api.verizon.com/about/news/5g-in-agriculture-smart-farming-transforming-industry>

[14] Rehman, W. ur, Koondhar, M. A., Afridi, S. K., Albasha, L., Smaili, I. H., Touti, E., Aoudia, M., Zahrouni, W., Mahariq, I., & Ahmed, M. M. R. (2025). The role of 5G network in revolutionizing agriculture for sustainable development: A comprehensive review. *Energy Nexus*, 17, 100368. <https://doi.org/10.1016/j.nexus.2025.100368>

[15] van Hilten, M., & Wolfert, S. (2022). 5G in agri-food—A review on current status, opportunities and challenges. *Computers and Electronics in Agriculture*, 201, 107291. <https://doi.org/10.1016/j.compag.2022.107291>

[16] Tang, Y., & He, Y. (2023). Application of 5G Communication Technology in Precision Agriculture. In *Encyclopedia of Digital Agricultural Technologies* (pp. 70–75). Springer, Cham. https://doi.org/10.1007/978-3-031-24861-0_95

[17] Goldstein, Joshua, and John Pender. 2024. "Impacts of the USDA Community Connect Broadband Program on Broadband Speeds in Rural Areas." SSRN. <https://dx.doi.org/10.2139/ssrn.4851189>

[18] Wang, Chen, and Li Si. 2024. "The Intersection of Public Policy and Public Access: Digital Inclusion, Digital Literacy Education, and Libraries." *Sustainability* 16 (5): 1–22. <https://doi.org/10.3390/su16051878>.

[19] Salisbury, Meghan, and Mary Anne Hansen. 2022. "Bridging the Digital Divide: Wi-Fi Hot Spots as a Means of Digital Equity." *Portal: Libraries and the Academy* 22 (1): 199–219.

[20] US Congress. (2025). The Universal Service Fund and Related FCC Broadband Programs: Overview and Considerations for Congress [Legislation]. <https://www.congress.gov/crs-product/R47621>

[21] Dawson, D. (2021). *The Rural Broadband Industry*. Palm Beach Gardens, FL: CCG.

[22] Evans, Julie A. 2019. "Digital Learning: Peril or Promise for Our K-12 Students. National Briefing Paper -- Speak Up 2018/19." Irvine, CA: Project Tomorrow.

[23] Harris, Kathy, Naila Judge, and Chris Burger. 2022. "Learning from Each Other: A Partnership Between an Affordable Housing Organization and a Digital Literacy Research Organization." *Adult Literacy Education* (Fall): 28–33. <https://doi.org/10.35847/KHarris.NJudge.CBurger.4.3.27>.

[24] N. Kawasaki, "Parametric study of thermal and chemical nonequilibrium nozzle flow," M.S. thesis, Department of Electronic Engineering, Osaka University., Osaka, Japan, 1993.