**BEFORE**
**THE OHIO POWER SITING BOARD**

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| In the Matter of the Application of Duke Energy | ) | |
| Ohio, Inc., for a Certificate of Environmental | ) | Case No. 16-0253-GA-BTX |
| Compatibility and Public Need for the C314V | ) | |
| Central Corridor Pipeline Extension Project | ) | |

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**DIRECT TESTIMONY OF JEAN-MICHEL GULDMANN ON BEHALF OF NOPE - NEIGHBORS OPPOSED TO PIPELINE EXTENSION, LLC**

**PUBLIC VERSION**

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**Q. Please state your name and business address.**

My name is Jean-Michel Guldmann. My business address is 237 Knowlton Hall, The Ohio State University, 275 West Woodruff Avenue, Columbus, Ohio 43210.

**Q. Please describe your education and job credentials.**

I have a Master's Degree in Industrial and Systems Engineering, Ecole des Mines, Nancy, France (1970), specializing in operations research and industrial management. I also have a PhD in Urban and Regional Planning from the Israel Institute of Technology (1977), specializing in quantitative planning methods, urban economics, and environmental management. I have taught at The Ohio State University (OSU) from 1977 to 2012, rising from the rank of Assistant Professor to Full Professor. I have taught classes in regional planning, population and economic forecasting, statistical and optimization methods, as well as introductory and advanced classes in energy planning.

From 1978 to 1988, I served as a Senior Faculty Associate at the National Regulatory Research Institute at OSU, where I conducted several regulatory research projects related to natural gas distribution and funded by the Public Utilities Commission of Ohio (PUCO), the U.S. Department of Energy, and the National Association of Regulatory Utility Commissioners (NARUC). In the area of natural gas systems modeling, I have also served as consultant to the following organizations: U.S. National Bureau of Standards (1981-1982), the Information Science Division of Argonne National Laboratory (1987-2012), the Enron Corporation (1982), and the President's Commission on Critical Infrastructure Protection (1998). Since 2017, I have served as consultant to a California Energy Commission-funded project investigating the vulnerability of Northern California Natural Gas Energy System to climate change.

I have published 15 peer-reviewed articles on natural gas systems modeling, involving both econometric and optimization methods, including in flagship journals such as

Management Science, Operations Research, Resources and Energy, and European Journal of Operational Research. I have also authored and co-authored 15 research reports on natural gas issues. For more details, please see my Curriculum Vitae, which is attached as Exhibit JMG-1.

**Q. What are your professional certifications and credentials?**

I am a member of the following organizations: American Economic Association, Regional Science Association, International Association for Energy Economics, and INFORMS (Operations Research/Management Science).

**Q. On whose behalf are you providing expert testimony in this proceeding?**

My testimony is on behalf of the following intervenors: Neighbors Opposed to Pipeline Extension ("NOPE"), the City of Cincinnati ("City"), and Hamilton County ("County").

**Q. Have you testified as an expert witness before in any PUCO proceeding?**

Yes. In 1979, I provided testimony to the PUCO regarding whether East Ohio Gas Company and Columbia Gas of Ohio should be allowed to resume natural gas hookups.

**Q. Please describe the purposes of your testimony?**

The purposes of my testimony are to (1) assess whether current and future market conditions support the C314V project, (2) assess whether the C314V project achieves the objectives stated by Duke Energy Ohio, Inc. ("DE-Ohio"), and (3) offer possible alternatives for network capacity expansion that would be much less disruptive and improve overall system reliability.

**Q. What documents did you review in preparation for your testimony?**

I have reviewed DE-Ohio's Application and Amended Application, information and documents produced by DE-Ohio in discovery, and other related reports and materials, and Staff's reports.

## I. MARKET DEMAND ANALYSIS

**Q. What aspects of market conditions are you focusing on?**

I will first review recent trends in the residential, commercial-industrial, and electric generation markets for natural gas of DE-Ohio and Duke Energy Kentucky, Inc. ("DE-Kentucky") (collectively, "Duke Energy" or "DE"). Second, I will review forecasts of future markets, including the population of the Cincinnati Metropolitan Area ("CMA"), the power generation market, and the CNGV ("Compressed Natural Gas Vehicles") market. Third, I will review several estimates of market growth and peak deliveries prepared by DE or other organizations on DE's behalf. Finally, I will assess whether all this information supports the need for the C314V project.

**Q. What is your assessment of recent market trends?**

All pipeline and distribution companies are required by the U.S. Energy Information Administration ("EIA") to file Form EIA 176 on an annual basis. This publicly-available data provides aggregate annual supplies and deliveries. Because of data consistency, this form is an ideal data source for analyzing multi-year patterns. The table in **Exhibit JMG-2** is a condensed form of the information for DE over the period 2010-2016 (the information about 2017 was not yet available). I provide data for DE-Ohio and DE-Kentucky, which are treated as separate companies for regulatory purposes. However, I focus below on both companies (i.e., DE), the sum of Ohio and Kentucky data. The discussion below is wholly based on the data in Exhibit JMG-2.

The total supply volume is the sum of the interstate pipeline deliveries (receipts at city gates) and supplemental gaseous fuels (primarily the output of the propane-air plants). The total supply has decreased from 94,305 mmcf ("Million cubic feet") in 2010 to 92,476 mmcf in 2016, or a decline of about -2%, or -0.33% per year). The peak supply in 2014 was due to a particularly cold year.

The number of residential consumers has grown from 467,083 in 2010 to 477,729 in 2016, at an overall rate of +2.28% , or +0.32% per year. The consumption per residential consumer has declined from 81.1 mmcf in 2010 to 67.6 mmcf in 2016, or -16.7 % (-2.6% per year). This decline is consistent with other data, pointing to a weak/declining residential market.

The number of commercial consumers has declined from 44,232 in 2010 to 43,169 in 2016, at an overall rate of -2.4%, or -0.4% per year. The consumption per commercial consumer has declined from 663.5 mmcf in 2010 to 610 mmcf in 2016, or -8.06 % (-1.2% per year), pointing to a declining commercial market.

While the number of industrial consumers has steadily decreased from 1829 in 2010 to 1704 in 2016, the average consumption per industrial consumer has increased from 10,603 mmcf in 2010 to 13,406 mmcf in 2016, or an overall growth rate of +26.4%, or +3.4% per year. This suggests that smaller consumers have left the market and have been replaced by much larger consumers. As a result, the total industrial volume has grown from 19,393 mmcf in 2010 to 22,844 mmcf in 2016. It would be instructive to find out the consumptions and locations of the larger industrial consumers, as these may have serious implications for the need for network capacity expansion. Unfortunately, such data were not available to me.

The electric power market has grown from 19 mmcf in 2010 to 390 mmcf in 2016, and the corresponding number of consumers has grown from 1 to 2. While the growth has been strong, this is still a very small market as compared to the industrial market. As I discuss below, any additional growth is unlikely to benefit from the Central Corridor Project ("Project" or "C314V").

In order to keep the above market changes in perspective, it is important to note the volume shares in 2016: Residential: 39.5%; Commercial: 32.2%; Industrial: 27.9%; Electric power: 0.4%. The shares in numbers of customers are: Residential: 91%; Commercial: 8%; Industrial: 0.3%.[1]

In summary, there has been a strong decline in the average gas usage per customer in the residential and commercial sectors due to energy conservation efforts, a decline in the number of commercial customers, and a very weak growth in the number of residential customers. These weaknesses have been, in part, compensated by the volume growth of the industrial and power markets. However, the whole market has been in decline, as indicated by the trend in total supply volume.

**Q. What is your assessment of future residential and commercial market trends?**

Population is the primary driver of the residential and commercial markets, and also indirectly impacts the industrial and power markets. There are several available population forecasts for the CMA. There may be slight variations in the definition of the boundary of the area considered, and therefore direct comparisons across different population forecasts may not be useful. However, a meta-analysis of the forecasted growth rates is appropriate.

Consider first the forecasts over 2010-2040 prepared by the Ohio-Kentucky-Indiana ("OKI") Metropolitan Planning Organization ("MPO"), as presented in Table 1. These forecasts are inputs to the 2040 OKI Regional Transportation Plan.[2]

For the whole OKI Region, the population would grow by 219,257 people over 2010-2040, or an average annual growth rate of 0.35%. This annual rate is reduced to 0.32% over 2020-2040. While all the other counties experience some growth, both Hamilton and Campbell counties are expected to see their populations decline. Hamilton County, by far the largest county in terms of population in the OKI Region, represents the core of DE's service area.

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[1] *See* JMG-2.

[2] *See* 2010 Census; 2020-2040 projections by the Ohio Development Services (2013 Edition), Kentucky State Data Center (2011 Edition) and Indiana Business Research Center (2012 Edition). See: https://2040.oki.org/demographics/

Table 1 OKI Population Forecasts

| | **2010** | **2020** | **2030** | **2040** |
|---|---|---|---|---|
| **Butler** | 368,130 | 390,110 | 410,960 | 430,360 |
| **Clermont** | 197,363 | 208,330 | 214,090 | 216,190 |
| **Hamilton** | 802,374 | 790,600 | 785,900 | 786,090 |
| **Warren** | 212,693 | 225,770 | 235,640 | 239,060 |
| **Boone** | 118,811 | 153,933 | 190,270 | 224,687 |
| **Campbell** | 90,336 | 91,642 | 90,731 | 88,012 |
| **Kenton** | 159,720 | 168,458 | 174,699 | 177,963 |
| **Dearborn** | 50,047 | 53,482 | 55,655 | 56,369 |
| | | | | |
| **OKI Region** | **1,999,474** | **2,082,325** | **2,157,945** | **2,218,731** |

The Urban Institute (Washington, D.C) has a forecasting model that indicates that the Greater Cincinnati population will grow from 2,069,055 in 2010 to 2,252,872 in 2030, hence a growth of 8.88% or an annual average growth rate of 0.43%.[3]

Data from the American Community Survey ("ACS") of the U.S. Bureau of the Census point to the following historical data for the Cincinnati MSA:[4]
1990: 1,832,284
2000: 1,994,818 - Annual growth rate 1990-2000: 0.85%
2010: 2,114,686 - Annual growth rate 2000-2010: 0.58%
2016: 2,165,139 - Annual growth rate 2010-2016: 0.39%

The Open Data Network provides historical data and short-term forecasts (2017-2021):[5]
2010: 2,110,398
2013: 2,122,940 - Annual growth rate 2010-2013: 0.19%
2016: 2,146,410 - Annual growth rate 2013-2016: 0.36%
2020: 2,162,696 - Annual growth rate 2016-2020: 0.19%
2022: 2,166,677 - Annual growth rate 2020-2022: 0.09%

In summary, all the above forecasts are consistent with a weak population growth for the CMA. The annual population growth rate has declined over 2010-2016, and forecasts beyond 2020 point to annual growth rates ranging from +0.10% to +0.50%. Of particular concern is the expected population decline in Hamilton County, the core of DE's service

[3] Mapping America's Future, Urban Institute, available at: http://apps.urban.org/features/mapping-americas-futures/ (last accessed Mar. 26, 2019).

[4] https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

[5] Cincinnati Metro Area Demographics, Open Data Network, available at: https://www.opendatanetwork.com/entity/310M200US17140/Cincinnati_Metro_Area_OH_KY_IN/demographics.population.count?year=2017 (last accessed Mar. 26, 2019).

area, at the rate of -2.03% over 2010-2040, or -0.07% per year. These population forecasts could lead to declines in the numbers of residential and commercial gas customers. Conservation efforts, prodded by technological innovations, are likely to intensify, leading to further declines in residential and commercial gas deliveries.

I also note that the decreasing per-customer energy consumption is further confirmed nationwide by the U.S. Energy Information Administration in its State Energy Data System ("SEDS") information release of January 28, 2019, namely: "U.S. energy intensity, or energy consumption per unit of real gross domestic product (GDP), equaled 5.8 thousand Btu per chained 2009 dollar, a 2% decrease from 2015 and the lowest level since at least 1997, the earliest year for which SEDS has data".[6]

**Q. What is your assessment of future electric power market trends?**

This market would involve the conversion to natural gas of coal-fired power plants located along the Ohio River. DE has made the following peak-hour projections for three power plants:[7]
- Miami Fort: 2,000 mcfh (thousand cubic feet per hour)
- Stuart: 408 mcfh
- Zimmer: 2400 mcfh

However, The Dayton Power & Light Company ("DP&L") retired Stuart, due to economic and environmental challenges, and the plant ceased electricity generation in 2018.[8]

Miami Fort, located in Miami Township, Hamilton County, has 2 coal-fired units with total capacity of 1,020 MW, and 4 oil-fired facilities with total capacity of 56 MW.[9] The oldest unit, which has been retired, dates back to the late 1940s, and it is possible that retirement may be a more economical strategy. In any case, this plant is not close to the existing DE pipeline network system, and the construction of C314V would not help in this regard. However, the alternative western scenario (W-1), proposed by Lummus Consultants in their planning report to DE, would greatly facilitate this hookup. This scenario is extensively discussed further on in my testimony.

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[6] https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_sum/html/rank_use_gdp.html&sid=US

[7] Gas System Master Plan Study 2015-2035. Report prepared by Lummus Consultants International for Duke Energy Corporation. January 2015.

[8] *See In the Matter of the Application of The Dayton Power and Light Company to Establish a Standard Service Offer in the Form of an Electric Security Plan*, Case No. 16-395-EL-SSO, Opinion and Order, p. 38 (Oct. 20, 2017). *See also* DPL Inc. Announces the Retirement of the J.M. Stuart and Killen Station Power Plants (May 31, 2018), available at https://www.businesswire.com/news/home/20180531005754/en/DPL-Announces-Retirement-J.M.-Stuart-Killen-Station.

[9] U.S. Energy Information Administration, Form EIA-860, 2017 data, spreadsheet 3_1_Generator_Y2017.xlsx, available at https://www.eia.gov/electricity/data/eia860/

Finally, Zimmer, located near Moscow, Ohio, was originally intended to be a nuclear power plant.[10] When it was nearly 97% completed, Zimmer was converted to coal burning, and was completed in 1991. It is possible that this plant could be better served directly by high-pressure interstate transmission pipelines.

Because the electric power generation market is in flux throughout the U.S. due to recent expansion of renewable technologies (e.g., wind, solar, etc.) in response to the impacts of climate change, it would be imprudent for local gas distribution companies to commit significant new network infrastructure to serve the power market, except in cases where there is a clear short-term payoff, such as serving the Miami Fort plant.

In any case, if new electric power generation units were to be connected to and served natural gas by DE's system, these new units would most likely be interruptible customers who would not add requirements at peak time. Therefore, such growth, if any, should not impact the peak-hour firm send-out.

**Q. What is your assessment of future compressed natural gas vehicle ("CNGV") market trends?**

According to the Energy Information Administration,[11] less than 3% of U.S. natural gas consumption is for transportation: in 2017, 2.66% was for natural gas transmission and distribution, and 0.18% (or 48,658 mmcf) for the CNGV national market, with California the leading state with 22,096 mmcf or about 50% (other leading states being NY – 4,428 mmcf, TX – 4,486 mmcf, AZ - 2,861 mmcf). CNGV customers in Ohio consumed 993 mmcf in 2017. CNGV adoption in North America is much lower than on other continents. The major reasons for low adoption include, among others, inefficient mileage compared to gasoline-powered cars, significantly higher prices due to bulky storage tanks, and a paucity of fueling stations. Compressed natural gas ("CNG") is more feasible for centrally fueled/operated fleets with private refueling infrastructure.[12] In addition, this small market may be strongly impacted by the future competition of electric vehicles.

According to DE, a major hindrance to the expansion of this market within its service area is the mixing of propane gas with natural gas on peak days. However, CNGV fleet customers could easily adapt to this situation by expanding their on-site CNG storage capability to deal with this infrequent occurrence. As of April 20, 2017, DE had six propane-intolerant customers that are notified when the propane plants are in operation. These may include both industrial and CNGV customers. DE finds it difficult to project propane-intolerant market growth.[13]

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[10] *See City of Cincinnati v. Pub. Util. Comm.*, 67 Ohio St.3d 523, 1993-Ohio-79, 620 N.E.2d 826.

[11] https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm

[12] Transitions to Alternative Vehicles and Fuels. The National Academic Press, 2013, pp. 34, 35, 40, 63.

[13] CITY-INT-01-005, CITY-INT-01-006, CITY-INT-01-007.

In addition, new CNGV fleet customers would most likely be interruptible customers, as their on-site storage capability would enable them to take advantage of interruptible tariffs. Therefore, the CNGV market growth, if any, would not add to the peak-hour firm send-out.

**Q. Please summarize the market assessment DE is relying on to support its Project.**

In its Amended Application, DE indicates that it supplies up to 43,000 mcfh (i.e., daily peak hour flow) to approximately 525,000 current customers in the combined Ohio and Kentucky service territories, including 91% residential customers using 50% by volume, 8% commercial customers using 20% by volume, and less than 1% industrial customers using about 10% by volume.[14] Based on the timing of the filing of the Amended Application, this data appears to be as of 2016 or earlier, though DE never explicitly states as much in the Amended Application.[15] The scenarios involving (1) the construction of C314V, and (2) the elimination of the propane-air plants, assume a peak hour flow of 45,500 mcfh. There is no information in the Amended Application that supports the increase of the peak hour flow from 43,000 mcfh to 45,500 mcfh (or +5.8%), nor any indication of the time horizon of the forecast. The Amended Staff Report of Investigation ("Staff Report") notes: "Staff has found that the proposed project fits into regional expansion plans. The Applicant has also identified several areas of its service territory where it anticipates growth. The proposed project could accommodate anticipated system growth of up to 45,000mcfh…"[16] However, aside from general statements regarding CNGV and power generation market expansions, neither the Amended Application nor the Staff Report provide any quantified and geographically-specific information.

If the increase of the peak-hour flow from 43,000 mcfh to 45,500 mcfh (or +5.8%) is assumed to take place over 10 years (2017-2027), this would translate into an annual growth rate of 0.56%, which is outside and above the range (0.10%-0.50%) that was derived from the earlier analyses of CMA population forecasts, and is not consistent with the forecast of a 0.07% rate of decline for the population of Hamilton County, the core of DE's service territories.

**Q. Are there other documents that might clarify DE's market assessment?**

Yes. As specifically identified below, certain documents filed with the PUCO refer to DE-Ohio's service territory while other documents pertain to both service territories of DE-Ohio and DE-Kentucky. The most relevant ones are reviewed below, with a focus on market and deliveries information.

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[14] Amended Application for a Certificate of Environmental Compatibility and Public Needs for the C314V Central Corridor Pipeline Extension Project ("Amended Application"), p. 3-1.

[15] *Compare* Application, p. 3-1 (Sept. 2016) (approx. 525,000 customers, with percentages) *to* Amended Application, p. 3-1 (unchanged from 2016).

[16] Amended Staff Report, p. 27.

1. <u>Audit Reports</u>[17,18]

Exeter Associates, Inc. (hereafter "Exeter") was commissioned by the PUCO to audit the purchasing practices and policies of DE-Ohio. I have reviewed both the 2015 and the 2019 Exeter audit reports, with a focus on DE-Ohio's model for forecasting peak-day demands. A design-day forecast is prepared annually by DE-Ohio's Load Forecasting Department.[19]

In the 2015 Exeter Report, Exeter notes that DE-Ohio relied on monthly historical data over 30 years to relate total send-out to weather variables such as current-day and prior-day heating degree-days ("HDD") and average wind speed with an econometric model.[20] Monthly peak estimates would then be downscaled to peak-day send-out, and, ultimately, peak-hour send-out. Hourly demands vary with time of day and season of the year. Demand is lower at night and on weekends. Weather is a big factor, as gas consumption increases due to the use of space heating.[21] DE-Ohio uses the peak-day flow, and converts it to a peak-hour flow. For instance, on Jan. 6, 2014, the daily flow was 820,862 Dth, which, when using the 2014 natural gas content of 1.033 Btu/cf, yields a flow of 847,950 mcfd. This number, when divided by 24, yields an average hourly flow of 38,618 mcfh. The actual peak hour flow on that day was 42,358 mcfh, hence a peaking factor of 1.20 (i.e., ratio of peak over average hourly flows).[22] <u>Using data on several cold days in 2014, DE found out that the peaking factor</u> [redacted].[23] This factor is then used to convert a forecasted maximum daily firm gas consumption to a forecasted peak-hour flow to be used in the Synergi model. The estimation of the peak-day flow is based on a forecast of peak-day temperature, which is then converted to HDD. The model was solved using a temperature of -14°F, corresponding to the 1% tail-end of the distribution of temperatures from 1947 to the present. Exeter highlighted the need to use only historical <u>daily</u> data to estimate a more accurate model that would enable a meaningful comparison of actual and projected peak-day send-outs.[24]

In the 2019 Exeter Report, Exeter indicates that DE-Ohio has developed a new model based on a regression analysis of daily send-out and weather data beginning in 1995.[25]

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[17]Management and Performance Audit of Gas Purchasing Practices and Policies of Duke Energy Ohio. Report prepared by Exeter Associates, Inc. for the PUCO. December 2015 (2015 Exeter Report").

[18] Management and Performance Audit of Gas Purchasing Practices and Policies of Duke Energy Ohio. Report prepared by Exeter Associates, Inc. for the PUCO. January 2019 ("2019 Exeter Report").

[19] 2015 Exeter Report, p. 38.

[20] 2015 Exeter Report, p. 38.

[21] 2015 Exeter Report, p. 38.

[22] 2015 Exeter Report, pp. 11, 41, 51.

[23] Lummus Report, p. 48.

[24] 2015 Exeter Report, pp. vii, 47.

[25] 2019 Exeter Report, pp. 4-22.

HDD is now computed with a basis of 59°F (instead of 65°F), and the model includes, in addition to current-day and prior-day HDD, dummy variables for the day of the week and for holidays. A comparison of actual and projected firm peak-day demands is presented below (Table 11 in the 2019 Report), with units in decatherms ("Dth"):[26]

| Date | Actual | Projected | Difference |
|---|---|---|---|
| [redacted] | | | |

Exeter states that DE-Ohio has incorrectly used the model, which is [redacted] invalid, resulting in inflated forecasts.[27] However, this discovery comes too late as far as the C314V application is concerned. Indeed, it is likely that DE has also used the model incorrectly for estimating the peak-hour send-out for the DE-Ohio service territory. As a similar model is used for DE-Kentucky,[28] the over-forecasting most likely applies to the entire DE territory. If we assume an error of [redacted], the 45,500 mcfh target send-out would be reduced to [redacted] This over-forecasting raises serious doubts about the validity of the 45,500 mcfh target.

The responsibility for DE design-day forecasts has been recently transferred to a newly created Pipeline Services Department, which has created a new model that uses data over the recent 5-year period, thus reflecting recent conservation efforts. Exeter deems this new model more appropriate, but believes usage data should be limited to the most recent three-year period.[29] In any case, this model was not available at the time Duke filed its Amended Application, and Duke has not updated its Amended Application to include a valid forecast.

2. Lummus Consultants Planning Report

Lummus Consultants International ("Lummus") prepared a report to DE dated February 24, 2015, titled *The Gas System Master Plan Study 2015-2035* ("Lummus Report").[30] While its focus concerns various options for system expansion, the Lummus Report provides market information and forecasts to support DE's planning analyses. DE provided Lummus the historical data and projections, as well as other information, that formed the basis of the Lummus Report. [redacted]

[26] 2019 Exeter Report, pp. 4-24 to 4-25. Note that 1 Dth =1 MMbtu (Million British Thermal Units). The heat content of natural gas delivered in DE-Ohio's territory = 1,076 Btu/cf. Hence, 1 DTH = 0.93 mmcf.

[27] 2019 Exeter Report, pp. 4-25 to 4-26.

[28] NOPE-POD-03-016 CONFIDENTIAL.

[29] 2019 Exeter Report, pp. ES-4, 4-26.

[30] CITY-POD-1-002 CONF Attachment 2, attached as Exhibit JMG-7.

Of greater interest are the seasonal gas load shape and peak flow data. Lummus reviewed the seasonality of DE's demand, [redacted] of other local distribution companies ("LDCs"), including large demand peaks in the winter heating season and much lower demand during the shoulder and summer months.[31] Figure 10 on page 19 of the Lummus Report depicts the actual load curve in 2014 and the projected load curves for various horizons (e.g., 2020, 2025, 2030, 2035). [redacted].

Lummus further reports peak-day and peak-hour flows, including actual data for 2014 and projections to 2035[33] in Table 11 (Duke Peak-Day Flow Projections) and Table 12 (Firm Gas Peaking Factors Table). Lummus reports that the actual peak-day flow in [redacted] Next, in Table 13, the firm peak-hour gas flow at 1% exceedance was estimated to be [redacted] and would suggest that the existing 2014 system is able to satisfy a target of 45,500 mcfh, as used in the Amended Application. Further, the projection of the 1% flow to 2035 is [redacted][37]

While the load shape data suggest [redacted] in the peak January flow from 2014 to 2035, the peak-day and peak-hour projections [redacted]. The difference appears to reflect DE's assumptions of market growth from 2014 to 2035. This implicit growth assumption is not justified based on my earlier analysis of population forecasts. However, even if this growth assumption were to be accepted, the data suggest that the current DE system would be able to handle the corresponding hourly peak flow with 1% exceedance.

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[31] Lummus Report, pp. 18-19.

[32] Lummus Report, p. 19.

[33] Lummus Report, pp. 46-48.

[34] *Id.*, p. 47.

[35] *Id.*

[36] *Id.*, p. 49.

[37] *Id.*

**Q. Does the previous information support DE's claim of the need for C314V based on market demand and growth?**

Future natural gas demand, whether expressed on an annual, monthly, peak-day, or peak-hour basis, depends on the number and type of customers (residential, commercial, etc.), the average usage of gas per customer, customer sensitivity to weather (space heating), and expected future weather/temperatures. Projections of the peak-hour flow are particularly critical, because they determine the need for distribution network capacity expansion. The peak-hour flow represents the peak-hourly requirement of all firm customers, whether sales (i.e., buying their gas from DE) or transportation (i.e., buying their gas from third parties but using DE's network to transport the gas to their premises). Interruptible customers, who benefit from lower tariffs by agreeing to be curtailed at peak time, are not accounted for in peak flow projections. As I indicated earlier, this would likely be the case for new power generation and CNGV markets.

Based on the above considerations and the various data presented above, the peak-hour flow target used by DE in its Amended Application is grossly overestimated. First, the annual 0.56% growth rate it implies is not a reasonable population forecast for the CMA. Any growth in firm customers is very likely to be linked to population growth. Second, the 2019 Exeter Report raises serious doubts about the calculation of the peak flow and suggests an overestimation by about [redacted]. Third, the data and projections included in the Lummus Report suggest that the existing system may very well be able to handle short- and mid-term growth in the peak requirement.

I recommend that DE conduct a new comprehensive market and peak deliveries analysis, presenting clearly the data used and the estimated models. In doing so, DE should keep in mind that (1) the historical distributions of temperatures may not reflect future ones in light of climate change and warming, and (2) past conservation efforts may not reflect future efforts.

## II. THE C314V LINE WILL NOT ACHIEVE DE'S STATED OBJECTIVES FOR THE PROJECT.

**Q. Could you provide an overview of the C314V line extension and DE's rationale?**

First, I will first provide a description of the gas supply infrastructure that feeds into DE's system. Next, I will describe DE's system. Finally, I will describe the C314V extension (i.e., the Project).

**Q. Please describe DE's gas supply infrastructure.**

DE interconnects with five interstate pipelines: (1) to the north, Texas Gas Transmission ("TGT"), Texas Eastern Transmission ("TET"), ANR Pipeline, and Columbia Gas Transmission ("TCO"); (2) to the south, TCO (serving a very small and isolated market through the Brown County citygate station) and Kentucky-Ohio Transmission ("KOT"), supplying gas through the Foster citygate station. KOT is a fully owned subsidiary of DE-Ohio and is supplied primarily by Columbia Gulf Transmission ("CGT") and TCO. These interconnections are illustrated on the system map presented in **Exhibit JMG-3**.[38] All these interstate pipelines link southern production areas to the major markets in the northern and northeastern U.S., but also access the Marcellus Shale in the Appalachian Basin. Several of these pipelines converge at the Lebanon supply hub.

There are 21 northern citygate stations, with supply from TGT, TET ANR, and TCO, and 2 southern citygate stations, with supply from CGT and TCO. In the north, TGT supplies gas at the following locations/stations: Harrison, Fernald, Venice, Liberty, Butler, Mason, and Route 63. The Liberty station serves exclusively the Woodsdale power plant. TET supplies gas at the following stations: Millville, Trenton, Dicks Creek Plant, Union Road, and Springboro. ANR supplies gas at the Springboro station. TCO supplies gas at the Springboro and Red Lion stations in the north. Note that Red Lion (about 3.5% of total send-out) supplies a small distribution system that is not interconnected with the rest of DE distribution system. In the south, TCO supplies the Brown County station, and CGT supplies the Foster station through KOT pipeline.[39]

**Q. Please describe DE's network system.**

In the following, DE refers to the whole gas transmission/distribution integrated network system serving the CMA. This system is subdivided, for regulatory purposes, into two subsystems: DE-Ohio and DE-Kentucky. These two systems interconnect at three stations located along the Ohio River: Anderson Ferry, Front & Rose, and Eastern Avenue (a.k.a. East Works and Cavern). Northern and southern supplies flow through these stations to DE-Kentucky and DE-Ohio, respectively.

DE does not use compression to deliver gas to its distribution system, and it does not own/operate underground natural gas storage facilities. Natural gas stored elsewhere is delivered to DE at the same citygates as other interstate supplies. DE has access to propane gas stored at two plants: Erlanger ("ERL") and East Works ("EW").[40]

DE system is made of (1) 700 miles of transmission and high-pressure pipelines with varying Maximum Allowed Operating Pressure ("MAOP") and diameter, and (2) low-pressure lateral and smaller-diameter distribution pipelines, all designed to bring natural gas to customers in the central core of Hamilton County. The focus here is on the first category of pipelines, which have all been constructed over the last 50 years. The system includes six Ohio River crossing stations: Anderson Ferry ("AF"), Front & Rose ("FR"), East Works ("EW"), California ("CA"), Bracken County ("BKC"), and Brown County ("BRC"). The system was built to distribute gas from the south to the north, initially from manufactured gas sites along the Ohio River. The backbone system includes:

- Line A running north to south through central neighborhoods in Hamilton County;

[38] *See* 2015 Exeter Report, p. 5.

[39] 2015 Exeter Report, pp. 5-7.

[40] *Id.*, pp. 7, 30.

- Line V (20’’) running east to west;
- Various Lines AM conveying gas from Foster to points in OH and KY.[41]

Detailed characteristics of DE’s existing and planned transmission lines are further described in **Exhibit JMG-4**.[42] The gas flow directions are as follows: (1) South-to-North is the predominant flow direction across the river; (2) North-to-South flow is only possible at AF, EW, and CA stations; (3) with the exception of gas flow northward from the Norwood and CA stations, all other flows in the northern area are generally southward on the peak day.

Line A, which is related to the C314V expansion, is further described here. It currently consists in a mixture of 18”, 20”, and 24” diameter pipes, with an overall length of 201,700 feet. It links Butler station (where it receives gas from ANR and TGT) in the north to Norwood station on Line V. The MAOP varies from 150 pounds per square inch (“psig’) for the south section to 225 psig for the north section. Actual peak operating pressures have been very close to the MAOP, with average operating pressures for the past 5 years equal to135 psig in the south and 200 psig in the north. Lateral pipelines that branch from Line A supply residential and industrial customers in the central area. Line A was constructed between 1950-1960, and will need to be upgraded or replaced. Any future replacement will likely be 20” pipes, which would provide additional capacity. Line A was constructed of carbon steel through open trench or bore installation methods. DE planned for the repair, replacement, upgrade, or improvement of two segments of Line A in 2018, at a cost of $1.2 million, and in 2024 (cost unknown at this time).[43] In the summer, gas typically flows south through Line A.[44] At peak periods, gas generally flows north from Norwood and south from Butler.[45] The upgrades of Line A would increase diameter and/or pressure, so that gas could flow in either direction, based on customer demand and various systems operations.[46]

Historically, the flow balance over 2006-2014 has been 40% from the north and 60% from Foster.[47] In 2015, the ratio was 45%/55%.[48] Note that without the flow from Foster, [redacted].[49] DE states that its current design peak demand is 43,000 mcfh, with the P-A plants able to serve up to 10% of the peak design load, i.e., 4,300 mcfh.[50]

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[41] Amended Application, p. 2-3.

[42] 2017 Long-Term Forecast Report for Gas Demand, Gas Supply, and Facility Projections, Case No. 17-1317-GA-FOR, Report submitted by DE-Ohio to the PUCO (“LTFR”).

[43] LTFR, p. 5-14.

[44] AV-INT-02-006.

[45] *Id.*

[46] AV-INT-02-007.

[47] NOPE-INT-02-007

[48] *Id.*

[49] CITY-POD-01-017 CONFIDENTIAL.

[50] NOPE-INT-02-011, NOPE-INT-02-014.

The peak-hour system capacity of the DE system is 45,000 mcfh, including the P-A plants.[51]

The two operational P-A plants overseen by DE are: 1) East Works ("EW") located in Ohio, and 2) Erlanger ("ERL") located in Kentucky. On the historical total peak send-out of 43,250 mcfh on January 6, 2014, the total output of these two plants was around 5,600 mcfh.[52]

**Q. What are the major characteristics of the C314V pipeline extension project?**

DE served, on May 26, 2017 (or about 5 months after submitting its application), about 525,000 customers, 427,000 in Ohio and 98,000 in Kentucky.[53] In response to a data request, DE has indicated that it has 538,195 gas customers as of December 2018.[54] However, this information is not broken down by sectors, nor does it include delivery volumes, making it impossible to derive growth implications for the Project. DE has proposed to construct a pipeline (20" diameter, MAOP 500 psig, operating pressure 400 psig) linking the WW Feed station (which will become the Highpoint Park station, including the existing WW Feed and the new equipment for C314V) to the V Line.[55] The WW Feed is located at the intersection of Hamilton, Warren, and Butler counties.

The WW Feed station is the southern terminus of the line C314 pipeline (24'' diameter, MAOP 670 psig). C314 receives gas at the Mason station from TGT at 670 psig, and was designed to assist with Line A deliveries as well as to support points to the east served by Line WW. Prior to the operation of C314, DE struggled to maintain pressures above 100 psig in Line A, thus increasing potential pressure drops for customers fed by Line A in the central core of the service area. DE argues that Line A has reached maximum capacity, and, without upgrades, is not capable of supplying additional gas on peak days at its current maximum pressure (i.e., 150 psig). Line A was built between 1940 and 1960, and does not meet current regulatory standards. In the current system, there is a notable pressure drop from 600 psig to 150 psig where C314 connects with WW Feed. This pressure reduction limits the capability of Line C314 to bring greater quantities of gas into the heart of the pipeline system from the north. DE claims that the extension of C314 into C314V has been part of DE's long-term plan for the system. DE claims C314V will bring increased volumes and pressures into the system from the north, eliminating some of the existing system constraints. The new station on Line V will further reduce pressure at the connection with Line V.

**Q. What are DE's stated objectives for the C314V pipeline extension project?**

[51] NOPE-INT-02-019.

[52] NOPE-INT-02-012.

[53] NOPE-INT-01-027.

[54] Staff DR-19-003.

[55] Amended Application, pp. 2-1 to 2-2.

DE has identified three goals for the C314V pipeline project:

(1) Retire the two operating P-A peaking plants (claimed by DE to have reached the end of their useful lives).
(2) Provide a better balanced system supply from north to south.
(3) Support inspection, replacement, and upgrading of aging infrastructure.[56]

**Q. How did DE select the Central Corridor Project?**

DE has used the proprietary Gas Synergi Version 4.7 model, originally developed by Stoner Associates, to model each conceived system expansion at peaking time, in order to determine the system's ability to fulfill long-range objectives. The Synergi model is widely used in the natural gas industry, and simulates both flows and pressures throughout the network. It accounts for demographics, regions of concentrated demand growth, and contemplated pipeline replacement or pressure changes. DE claims to have evaluated a wide variety of solutions to its system issues, including no action, replacement in place of the existing backbone (Line A from Line WW to Line V), and a variety of system improvements. However, no details were provided in the Amended Application on these replacements and improvements. In addition, DE's flow studies have shown that the propane-air mixture can travel extensively throughout the system.[57]

**Q. What scenarios did DE test using the Synergi model?**

The Amended Application indicates that the Synergi model was run for a design-day peak demand of 45,500 mcfh, with a 1% (0.01) probability of exceedance.[58] [redacted].[59] However, in its Amended Application, DE does not provide any information about these forecasts and factors, and one can only speculate as to the time horizon to which they apply. Three scenarios were tested:

1. P-A plants retired – C314V not constructed (Fig. 3.5)
According to the Synergi model, DE's current system cannot maintain sufficient pressure to serve all customers. Increasing flow from the northern gates is not possible without C314V and flow from Foster would be maximized. Approximately 50,000 customers would not be served.[60] However, this conclusion is contingent upon the validity of the 45,500 mcfh target, which I have demonstrated earlier is not valid.

2. P-A plants retired – C314V constructed – Foster flow maximized (Fig. 3.6)

[56] Amended Application, p. 2-1. *See* Direct Testimony of Gary J. Hebbeler, pp. 8-14.

[57] Amended Application, p. 3-6, Figs. 3.3 and 3.4.

[58] NOPE-INT-01-042.

[59] CITY-INT-01-022 CONFIDENTIAL.

[60] Amended Application, pp. 3-6 to 3-7.

The system could serve all customers, with the following major peak supplies:
Foster: 23,057 mcfh – maximized;
Fernald: 4,200 mcfh;
Mason:7,727 mcfh (including 4,600 mcfh to C314V); and
Other northern gates: 10,516 mcfh.
The Foster/northern gates flow ratio ("F/N") would then be: 51%/49%.[61]

3. <u>P-A plants retired – C314V constructed – C314V flow maximized (Fig. 3.7)</u>

The system could serve all customers, with the following major peak supplies:
Foster: 18,835 mcfh;
Fernald: 4,900 mcfh;
Mason: 11,736 mcfh (including 8,400 mcfh to C314V); and
Other northern gates: 10,029 mcfh.
The F/N would then be: 41%/59%.[62]

The above analyses indicate that Foster would supply natural gas in the range of 18,835 - 23,057 mcfh, with the balance supplied by the northern gates. Also noteworthy is the increase in flow from Fernald to 4,200-4,900 mcfh, thus including 1,800 mcfh to help replace the eliminated P-A flow.

**Q. What other Synergi data does DE provide in the Amended Application?**

In addition to the above three cases with a design-day peak demand of 45,500 mcfh, DE also mentions a Base Case System ("BCS") configuration, with a design-day peak demand of 43,000 mcfh, with the P-A plants in operation and interruptible customers curtailed.[63] Although DE does not expressly state it, BCS is clearly a depiction of the existing system in 2017. The results, which included a network map with flows at key city gates and a data table listing pressures at nodes, were provided under separate cover to Ohio Power Siting Board ("OPSB") Staff. In discovery, DE provided peak-hour flow data for the BCS.[64] The flow from Foster is 21,700 mcfh, and the sum of the flows from the 21 northern gates is 35,030 mcfh (including the flow from Fernald at 4,565 mcfh). In addition, the total flow from the P-A plants is 4,325 mcfh.

**Q. Has Duke shown they need the C314V line if the P-A plants are retired?**

Summing all the BCS flows above yields 62,412 mcfh, which is about 50% more that the design flow of 43,000 mcfh. This discrepancy might be due to the interruptible customer flows being supplied, or because all the 21 northern gates flows are not independent

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[61] *Id.*, pp. 3-8 to 3-9.

[62] *Id.*, pp. 3-9 to 3-10.

[63] *Id.*, p. 3-10.

[64] NOPE-INT-01-039.

(which of course would negate the basic definition of city gate). In any case, the data +would suggest that the 43,000 mcfh demand could be supplied without the P-A plants.

**Q. Are there other factors leading DE to select the C314V line?**

A likely important factor for DE to select the Project is the connection to C314, taking advantage of its unused capacity. In answer to an interrogatory,[65] DE provides the following design-day peak flows in the Base Case System from C314 into:
- Line WW westward: 1,222 mcfh
- Line WW eastward: 1,774 mcfh

These values indicate a throughput of 2,996 mcfh over C314. With C314V installed and its flow maximized (see above), the total flow from Mason over C314 would be 11,736 mcfh, including 8,400 mcfh into C314V. Thus, the planned peak flows from C314 into Line WW would be 3,336 mcfh, just about 10% larger than in the Base Case. Assuming that 11,736 mcfh is close to the capacity of C314, then this capacity is probably only used currently at a 25% rate. So, if DE's goal is to maximize the use of C314 capacity, C314V is a rational choice. However, this goal was not stated as a basis of need in the Application, and is not consistent with other evaluation factors, as will be discussed further below.

**Q. What routes did Duke select for the C314V Project?**

DE indicates that 28 route variants of C314V were evaluated, with a scoring system reducing them to 3 primary routes.[66] It proposed two routes in its Amended application: (1) the Preferred Route ("PR"), ending at the Fairfax station on the V line, and (2) the Alternate Route ("AR"), ending at the Norwood station and also called the Green Route.[67] The project would involve expansions of the WW Feed and Norwood stations, or the construction of a new station at Fairfax (i.e., if the PR is selected). DE states that the PR would provide better pressure distribution in the eastern part of the Hamilton County system, both east and west on Line V.[68] It would also provide more pressure and flow towards the California station, providing the ability to more directly offset flows from Foster through the pipeline AM04.[69] As a result of the OPSB Staff recommendation that the AR route be selected,[70] DE has subsequently submitted to the OPSB a slightly modified version of the AR in April 2018, involving 7 adjustments to the original AR.[71] Land-use and other major characteristics of both routes in their final

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[65] NOPE-INT-02-042.

[66] Amended Application, p. 2-5.

[67] *Id.*, pp. 2-5 to 2-8.

[68] *Id.*, p. 2-7.

[69] *Id.*

[70] Staff Report of Investigation – Duke Energy Ohio C314V Central Corridor Pipeline Extension Project. Ohio Power Siting Board. May 2017.

[71] C314V Central Corridor Pipeline Extension Project – Supplemental Information. Report prepared by CH2M for Duke Energy. April 2018.

forms are presented in **Exhibit JMG-5.** Note that the total capital costs ($128.2 Million for AR and $111.7 Million for PR) do not include the costs for decommissioning the P-A plants.

**Q. Will the C314V project achieve DE's stated goal of improving north to south flow across the system?**

No. While the proposed pipeline would allow additional natural gas to be obtained from northern gates and moved southward through the system to serve customers, thus reducing the demand from Foster, this improvement would be minimal and would add minimal reliability. Under the "C314V flow maximized" scenario, the system would still rely on Foster for 41% of its supply at peak time.[72] An outage at Foster would still jeopardize much of DE's market. This is dramatically illustrated in Figure 3.7 of the Amended Application, where the geographical reach of the flow from Foster is delineated. DE's discovery responses[73] recognize that 1) "the proposed 20" pipeline is expected to reduce reliance from 55% to 45% from Foster" and 2) "the need to balance supply will no longer be fully met". In addition, DE recognizes that the Green or Alternate Route would reduce the reliance on Foster only from 55% to 50%.[74] As demonstrated below, there are other options that Lummus developed for DE that would nearly eliminate DE's reliance on Foster.

**Q. Has Duke adequately shown the need to retire the PA plants?**

No. The propane Duke uses is purchased, delivered by truck, and stored underground in mined rock caverns near the Ohio River. Descriptions of these facilities are available in the Lummus Report.[75] The Lummus Report indicates [redacted]

The P-A plants were built in the early 60's. The retirements of the two plants figure prominently among the reasons for building C314V. However, when DE filled its original application with a 30" pipeline in 2016, the P-A plants did not appear to be the emergency now claimed by DE.

In the Amended Staff Report, the only apparent basis for the conclusion that the P-A plants have reached the end of their useful lives was from the 2015 Exeter Report, which states: "The Company's Dicks Creek Plant propane facility is no longer operational due to a geological failure at the Todhunter Propane Cavern. The Eastern Avenue and Erlanger Plant propane facilities are presently operational. However, the potential exists

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[72] Amended Application, pp. 3-9 to 3-10

[73] STAFF-DR-12-001; NOPE-INT-01-035.

[74] NOPE-INT-02-009

[75] Lummus Report, pp. 79-83.

[76] Lummus Report, pp. 51, 52.

for these facilities to also become unavailable. DE-Ohio should assess the potential for this to occur and evaluate and determine the Company's optimal interstate pipeline capacity portfolio if this were to occur."[77] [redacted].[78]

In addition, in response to Staff asking how many winter seasons does DE expect to continue using the P-A plants, DE replied: "After the Central Corridor Pipeline is in service and depending on the current system usage, we expect that the propane-air peaking plants will continue to be operational for several years before decommissioning as demand and system configurations are adjusted."[79] This reply certainly does not carry any sense of urgency regarding the retirement of the two plants, but is in contradiction with DE's statements that "the propane facilities are currently at the end of their useful lives" and that the ERL plant would be operable for another three to four years beyond 2013.[80] Further, DE has been active in carrying capital improvement projects over 2017-2018: [redacted].[81] This would confirm that DE plans to continue using the plants.

In any event, DE could replace these plants by new P-A plants with modern technology short periods (a few days per year) of extreme demand the necessary send-out increment, which would have to be otherwise secured, at additional cost, as a peak-day demand reservation from interstate pipelines. The numbers of days when the P-A plants were used in recent years are: 10 in 2015, 13 in 2016, 9 in 2017, and 13 in 2018, mostly in January, with a few additional days either in December or February.[82] The P-A problems of CNGV customers could be solved by increasing CNG storage capacity at customer sites. It is also likely that these customers would use lower interruptible tariffs. Alternatively, the plants could be replaced by a new LNG plant, or by increasing pipeline peaking service. The Lummus Report provides (a cost comparison of these options, assuming 85,000 Dthd of peaking capacity:[83]

| Option | Investment ($ Million) | Operation ($ Million) |
|---|---|---|
| [redacted] | [redacted] | [redacted] |

The continued operation of the P-A plants is the most economical option. A new LNG plant would face siting issues (land area, proximity to population), and the only feasible

[77] 2015 Exeter Report, p.48.

[78] CITY-INT-01-004 HIGHLY CONFIDENTIAL.

[79] STAFF-DR-18-002.

[80] STAFF-DR-01-001.

[81] STAFF-DR-19-001 CONFIDENTIAL.

[82] STAFF-DR-19-004 SUPPLEMENTAL.

[83] Lummus Report, p. 94, Table 21.

alternative would be increasing peaking services. As discussed earlier, it is clear that DE is planning to increase the peak flow from Fernald by 1,800 mcfh under both scenarios of "Foster flow maximized" and "C314V flow maximized". However, this incremental peak flow is independent of the construction of C314V, and does not require new investment on the line from Fernald. This suggests that there is unused capacity on this line, and this might be the case for other lines linked to the northern gates. Unfortunately, the dearth of data provided by DE does not allow for further analysis of this issue.

In summary, there is no current need in retiring the P-A plants. I recommend that DE further assess the costs of upgrading the two P-A plants with modern technology, as well as the feasibility of additional peaking service flows while using existing available capacity from the northern gates.

**Q. Is the C314V Project necessary to support inspection, replacement, and upgrading of aging infrastructure?**

The C314V Project is not necessary to achieve this goal. DE intends, as it should, to conduct regular maintenance and upgrades on its existing lines. DE intends to replace sections of Line A over the next 20 years. Sections of Line EE were scheduled to be replaced in 2018 and 2021, i.e., before the scheduled start of C314V. Line V is scheduled for replacements in 2022 and 2023. While C314V could provide 1) alternative feeds to the south end of Line A via Line V, 2) an alternative feed to Line V when segments are disconnected, and/or 3) an alternate feed to Line V and the north section of Line EE when disconnected, DE admits[84] that lines A, EE, and V can be upgraded and/or replaced without operating C314V.

## III. DE APPEARS TO HAVE BETTER ALTERNATIVES TO THE C314V PROJECT THAT REQUIRE FURTHER CONSIDERATION.

**Q. Do you think there are better alternatives to the C314V proposal?**

Yes. First, as explained above, credible projections indicate that there will be limited growth of natural gas demand in DE service territory. With continued conservation efforts and the possible effects of climate change, notwithstanding the occasional polar vertex, it is likely that the current system, even without the P-A plants, could serve the peak-day demand for the foreseeable future. At the very least, market growth should be re-assessed.

Second, C314V does not achieve the goal of re-balancing the supply system from the south to the north, with Foster still supplying natural gas within the range 18,835 - 23,057 mcfh out of the hypothesized total peak demand of 45,500 mcfh (or 41% to 51% of the total supply). Therefore, C314V does not materially improve the reliability of the overall

[84] NOPE-RFA-01-001.

system, and it leaves DE customers exposed to the consequences of a Foster supply interruption.

Third, even if capacity expansion is ultimately deemed necessary, there are better options that would reduce population exposure to a new line and improve overall reliability. In order to describe such options, it is necessary first to describe the expansion scenarios prepared and analyzed by Lummus.

**Q. Please describe the expansion scenarios presented in the Lummus Report.**

The Lummus Report [redacted][85]

[redacted]

[redacted]

[redacted]

[redacted]

[85] Lummus Report, p. 51-52

[86] Lummus Report, p. 61.

[87] Lummus Report, p. 35.

[88] *Id.*

[89] *Id.*, p. 62.

[redacted]

[redacted]

[redacted]

[redacted]

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[90] *Id.*, p. 72.

[91] *Id.*, pp. 62-63.

[92] *Id.*, p. 72.

[93] *Id.*, pp. 63-64.

[94] *Id.*, p. 72.

[95] *Id.*, pp. 64-65.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[96] *Id.*, p. 72.

[97] *Id.*, pp. 65-66.

[98] *Id.*, p. 72.

[99] *Id.*, pp. 66-67.

[100] *Id.*, p. 72.

[101] *Id.*, pp. 67-68.

[102] *Id.*, p. 72.

[103] *Id.*, pp. 68-69.

T[redacted]

[redacted]

**Q. How does Lummus evaluate these scenarios?**

Lummus proposed [redacted]

[redacted]

[redacted]

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[104] *Id.*, p. 72.

[105] *Id.*, pp. 69-70.

[106] *Id.*, p. 72.

[107] *Id.*, p. 91.

[108] *Id.*

[redacted]

[redacted][10]

**Q. Did Duke obtain other route evaluations?**

There are more variants for C314V routing. TRC Pipeline Services (“TRC”) analyzed [redacted]

[redacted]

[redacted]

[109] *Id.*

[110] *Id.*

[111] Route Evaluation Report – Duke C314V. Report prepared by TRC Pipeline Services for Duke Energy. February 2016, p. 2 (CITY-POD-01-004 CONF attachment), attached as Exhibit JMG-8.

[112] *Id.*

[113] *Id.*, pp. 10-14.

[114] *Id.*, p. 6.

[redacted]

The PIR would be 308.6 feet for the final specification of C314V (d=20", MAOP=500 psig). Note that while DE estimates the number of residences within two buffers of width 200 feet and 2,000 feet (see Exhibit JMG-5), it does not show how many residences are with the PIR of 308.6 feet for the PR and AR. [redacted] However, the TRC analysis and Lummus Report demonstrate that there are other available route options within and outside the Central Corridor with lower residential impact than the AR and PR routes selected by DE.

**Q. If network expansion is ultimately necessary, what are the better alternatives to the proposed C314V line?**

The line W-1 (or its minor variant W-2) proposed by Lummus presents the best option by far, both in terms of population exposure and ability to provide a good north-south flow balance as described below. Moreover, DE has not fully explored options in and near the Central Corridor that might be less disruptive in view of its dense urban population. The Eastern Route delineated by TRC is but one example, while another example would be looping/upgrading lines WW and A, although these are not my preferred options as explained below.

**Q. Could you describe the looping/upgrading alternative?**

First, network capacity expansion may take different forms such as pipe replacements, pressure upgrades, line looping, compression, and/or new pipelines over new routes. DE

[115] *Id.*, p. 9.

[116] *Id.*, pp. 10-15.

[117] *Id.*, p. 11.

selected the last option. As an alternative, looping existing lines eliminates disruption of new population and activities.

In its Amended Application, DE presents two scenarios (A and B) as illustrated on Figures 3.6 and 3.7 respectively, wherein the P-A plants are retired and C314V is in operation. The peak design flow is 45,500 mcfh.

<u>Scenario A</u>: Foster = 23,047 mcfh; Fernald = 4,200 mcfh; Mason = 7,727 mcfh. Mason would send 4,600 mcfh through C314V, and the balance into Line A via Line WW west.

<u>Scenario B</u>: Foster = 18,835 mcfh; Fernald = 4,900 mcfh; Mason = 11.736 mcfh. Mason would send 8,600 mcfh through C314V, and the balance into Line A via Line WW west.

DE claims the difference between 45,500 and the sum of the above flows, in each scenario, is due to the other gate stations.[118] This difference is 6,000 mcfh for Scenario A, and 1,500 mcfh for Scenario B.

Combining the maximum supplies from both scenarios, excluding the flow into C314V, and reinstating the peak flows from the P-A plants, we obtain the following:
Foster: 23,057
Fernald: 4,900
Mason: 11,736 – 8,600 (C314V) = 3,136
Other gates: 6,000
P-A plants: 4,325
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Total: 41,418 mcfh

While the above flow is close to the design flow of 45,500 (which may be significantly overestimated), additional gas between 3,136 and 11,736 mcfh can be brought in from Mason. This could be done by upgrading/looping line WW west and Line A south of the interconnection with WW west. This additional gas could flow south to Norwood and feed the high-pressure loop, and north to customers linked to Line A. Alternatively, these customers could be fed from the north at the Butler station. This upgrading/looping option has not been explored by DE as an alternative to C314V. Using the same ROW, this option could be more economical and much less controversial. DE claims in its Amended Application that, "due to the current status of residential and commercial development around the existing pipelines extending from the north line V", there is not enough ROW width to replace Line A, extending from Line WW to Line V.[119] However, there is no supporting data for this claim. DE simply states that Line A has a variety of easement widths.[120] By using upgrading and looping, this alternative, which is located in the same area as C314V and makes use of gas brought in from Mason, would be much

[118] STAFF-DR-08-005; STAFF-DR-08-006.

[119] Amended Application, p. 4-3.

[120] CITY-INT-01-019.

less disruptive to population and economic activities. However, this option would not improve the overall system reliability and over-dependence on Foster supplies.

**Q. Could you describe the W-1 alternative?**

As described earlier, the W-1 western scenario involves [redacted] over the split with C314V, thus ensuring increased reliability and less potential exposure to a supply interruption at Foster. This line would also increase potential access to other interstate suppliers. Finally, a variant of W-1, described as Scenario W-2, [redacted]. Such market growth would not be possible with C314V.

**Q. Did the Amended Staff Report reference western options?**

Yes. In the Amended Staff Report, the OPSB Staff states the following: "The Applicant considered three western options ….in the Gas System Master Plan. The Applicant found that the western options did not allow for retirement of the propane-air peaking plants or improve reliability in the central core area. Additionally, these western options did not allow pipeline inspection and replacement work to be conducted as needed in the central core area."[121]

**Q. How do you respond to this statement in the Amended Staff Report?**

There are several important considerations in response to this assertion.

First, [redacted] Thus, the W-1 and W-2 alternatives allow for retirement of the propane-air peaking plants.

Second, the W-1 scenario achieves a F/N split of [redacted], thus improving the reliability of the central core area by reducing the importance of the Foster supply.

Third, the Amended Application does not include any analysis of the western options.

Fourth, the target peak-hour flow in the Amended Application is 45,500 mcfh, which is in excess of 3,000 mcfh compared to the Lummus Report scenarios, likely providing the basis for the incorrect claim that P-A plants cannot be retired. However, to reach such a conclusion, the Synergi model would have to be run for the scenario W-1 under the 45,500 mcfh target. It is quite possible that an increased capacity for the new Harrison-Anderson Ferry line, as well as increased flows from other northern gates could provide

[121] Amended Staff Report, p. 28.

for the 3,000 mcfh gap. It is not clear that any such new scenario has been simulated by Synergi.

Fifth, the problems related to inspection and replacement work in the central core area would have to be demonstrated through a new simulation of scenario W-1. DE admits that lines A, EE, and V can be upgraded and/or replaced without C314V.[122] While C314V could provide 1) alternative feeds to the south end of Line A via Line V, 2) an alternative feed to Line V when segments are disconnected, and 3) an alternate feed to Line V and the north section of Line EE when disconnected, it is not clear why, under Scenario W-1, additional gas injected into the loop at the Anderson Ferry station and flowing towards line V would not be able to provide the same support for maintenance/upgrade as new gas flowing from C314V into line V at Norwood or Fairfax.

Finally, as referenced earlier, both the need to retire the P-A plants and the need for a 45,500 mcfh target are doubtful. In sum, the W-1 scenario is fully viable in terms of satisfying possible increased gas needs and of strongly improving the reliability of the system.

**Q. What analysis have you performed with respect to the W-1 route?**

In addition to the above considerations, I have carried out a detailed geographical analysis of the W-1 line to assess its possible impacts on people and economic activities located close to the line. Detailed maps and data tables are available in **Exhibit JMG-6.** The possible layout is illustrated in Figure 1 of Exhibit JMG-6, [redacted]. This layout has first been set on a Google Earth image, and then analyzed with a Geographical Information System ("GIS"). As drawn, the line has a length of [redacted]. Figure 2 presents the jurisdictional boundaries of nearby cities and municipalities. Figure 3 presents the boundaries of a line buffer 2000 ft. wide (i.e., 1000 ft. on each side of the line), together with the boundaries of the Census blocks crossed by the line and its 2000 ft. buffer. Identifying these Census blocks makes it possible to use data from the 2010 Population and Housing decennial Census, namely population, households, and housing units in each block. The population of each block appears on Figure 3. Two distinct analyses and comparisons with DE's estimates have been carried out: (1) population-residence, and (2) land uses.

<u>Population Analysis</u>

The goal of the population analysis is to estimate the total numbers of people, households, and housing units located within two buffers along the line: 200ft wide (Buffer A) and 2000 ft. wide (Buffer B). Buffer A cannot be graphically represented on the maps due to the map scale. However, it is of course fully represented within the GIS. Each block is then divided into two areas: $A_1$ = area of the block within the buffer, and $A_2$ = area of the block outside the buffer. The population-related variables are then

[122] NOPE-RFA-01-001.

assigned to the buffer in proportion to the area of the buffer in the block. If $P_T$ is the total block population, the population in the buffer, $P_B$, is estimated as:

$$P_B = P_T * [A_1/(A_1 + A_2)] \qquad (1)$$

This area-proportional allocation is a standard approximation procedure in GIS when using different boundary systems. The results are presented in Table 1 of Exhibit JMG-6, where each block crossed by the line in [redacted] is identified, together with its area, population, number of households, and number of housing units. The table also shows the area of each block within the two buffers, and the resulting allocations of the population, households, and housing units. The estimated total population, households, and housing units are indicated at the bottom of the table:

Buffer A: population = 182; Households = 52; Housing units = 64
Buffer B: population = 1706; Households = 479; Housing units = 598

A second method of allocation is based on the land cover composition derived from the 2011 U.S. National Land Cover Database ("NLCD"), as presented in Figure 4 of Exhibit JMG-6. Figure 5 of Exhibit JMG-6 expands Figure 4 by including block boundaries, and corresponding population. I have used the total developed area (sum of low-intensity, medium-intensity, and high-intensity developments) within a block as the allocation factor. Using such developed area allows for a more precise pinpointing of where people live. $A_1$ represents, for each block, the developed area within a buffer, and $A_2$ the developed area outside the buffer. Formula (1) is then applied, and the results are presented in Table 3 of Exhibit JMG-6. The estimated total population, households, and housing units are indicated at the bottom of the table:

Buffer A: population = 102; Households = 30; Housing units = 38
Buffer B: population = 1460; Households = 407; Housing units = 512

A third method of allocation is based on the land-use composition derived from data from [redacted], as presented in Figure 6 of Exhibit JMG-6. Figure 7 of Exhibit JMG-6 expands Figure 6 by including block boundaries and corresponding population. The allocation method is similar to the one based on NLCD data, but uses exclusively residential areas. Formula (1) is then applied, and the results are presented in Table 5 of Exhibit JMG-6. The estimated total population, households, and housing units are indicated at the bottom of the table:

Buffer A: population = 121; Households = 35; Housing units = 44
Buffer B: population = 1509; Households = 420; Housing units = 532

The estimates obtained with the three methods have similar orders of magnitude. The third approach, based on residential land use, is probably the most accurate, and is used in the following comparison with DE impact estimates, as presented in **Exhibit JMG-5**. DE does not provide estimates of population and households. Therefore, I can only compare the above estimates with DE's numbers of residences within the two types of buffer. In Buffer A (200 ft. wide), DE reports the number of residences at 115 in the preferred route (PR) and 182 in the alternate route (AR). These numbers must be compared with 44 housing units for the W-1 line or a reduction of 62% in the PR case and 76% in the AR case. In Buffer B (2000 ft. wide), DE reports the number of residences at 3153 in the preferred route and 2186 in the alternate route. These numbers must be compared with 532 housing units for the W-1 line or a reduction of 83% in the PR case and 76% in the AR case. I conclude that the population exposure to a new pipeline would be considerably lower in the case of Line W-1 compared to the C314V line. It should be further emphasized that the layout of the W-1 line could be improved to further reduce population exposure, but such detailed analysis was not feasible within the framework of the research for this testimony.

<u>Land-use Analysis</u>

Table 2 of Exhibit JMG-6 presents the land cover composition of the two buffers, as derived from the NLCD data (Figure 4), including both total areas and shares (%). Table 4 of Exhibit JMG-6 present similar data in the case of the land uses in Figure 6. The focus here is on Buffer B (2000 ft. wide), as DE reports land-use data only for this buffer corridor (see Exhibit JMG-5).

Table 2 indicates that the share of all developed land covers is around 6%, while forests represent 35.4%, cultivated land about 36.1%, open space about 6.9%, and water (Ohio River and other water bodies) about 15.5%. DE's data suggest that built areas (total minus woodlots and parks/recreation) represent around 70% of the C314V buffer for PR and 80% for AR.

Table 4 indicates that woodlots represent 19.3% of the W-1 buffer, to be compared with 14.1% for PR and 11.9% for AR. Commercial-industrial land uses represent 6.5% of the W-1 buffer, to be compared with 37.4% for PR and 40.2% for AR. Park/recreation represents 4.3% of the W-1 buffer, to be compared to 14.5% for PR and 6.8% for AR. It is not clear how to compare DE's paved areas with the data in Table 4.

Overall, the above comparisons indicate that the W-1 line would impact built land-uses and populations much less than the C314V line.

**Q. Why is this difference in impact important?**

Accidents regularly occur along pipelines, due to excavation or malfunctioning, and may result in explosions. The less people in the proximity of the pipeline, the safer. 20-year trend data on serious incident occurrences have been compiled by the Pipeline and Hazardous Materials Safety Administration ("PHMSA").[123] The data show that, over the period 1999-2018, there have been 775 serious pipeline incidents in the U.S., involving 305 fatalities and 1,273 injuries. As an example, on December 5 2017, an accident

[123] *See* https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends

resulted from third party excavation at a depth of approximately 4 feet which ruptured a 20 inch high pressure natural pas pipeline, with two people killed.[124] This accident occurred in a rural area, hence the low number of casualties. Would it have happened in a high-density urban area, the results would have been catastrophic. In this respect, C314V is a risky project, and the W-1 scenario is a much safer option.

**Q. What are the conclusions of your testimony?**

Based on all the previous analyses, I recommend the following:

First, the C314V application should be denied by the OPSB, because 1) the project is not justified by market growth and related peak requirements; 2) the project does not materially improve the north-south balance and reliability of the system; 3) the need for retirement of the P-A plants is not clearly justified; and 4) the risks involved in operating the pipeline through a high-density populated area are not acceptable.

Second, DE must reassess its market and peak send-out forecasts by 1) re-analyzing long-term growth prospects in light of very recent trends and other information, such as energy conservation; and 2) revising its peak send-out estimation methodology and its use of temperature data in light of likely trends due to global warming.

Third, DE should conduct detailed socio-economic, land-use, and environmental impact analyses of either scenarios W-1 or W-2, as delineated in the Lummus report.

[124] *See* https://www.phmsa.dot.gov/safety-reports/pipeline-failure-investigation-reports

**Exhibit JMG-1**

Curriculum Vitae of Jean-Michel Guldmann

Curriculum Vitae

**JEAN-MICHEL GULDMANN**

Professor Emeritus and Academy Professor
The Ohio State University


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| **BUSINESS ADDRESS** | City and Regional Planning Section<br>Austin E. Knowlton School of Architecture<br>237 Knowlton Hall<br>The Ohio State University (OSU)<br>275 West Woodruff Avenue, Columbus, Ohio 43210-1138, U.S.A.<br>Phone: (614) 202-9989, Fax: (614) 292-7106<br>E-Mail: guldmann.1@osu.edu |


**EDUCATION**

Master's Degree in Industrial and Systems Engineering,
Ecole des Mines, Nancy, France, 1970
Specialization: Operations Research, Industrial Management.

Ph.D. in Urban and Regional Planning, Technion - Israel Institute of Technology, 1977
Specialization: Quantitative Planning Methods, Urban Economics, Location Theory, Mathematical Models of Land Use, Transportation Systems, and Environmental Management.

**ACADEMIC TEACHING POSITIONS**

| | |
|---|---|
| October 2018 | Visiting Professor, Department of City and Regional Planning, Gazi University, Ankara, Turkey. Intensive course in Regional Economics and Decision Analysis, Thesis Workshop, and Seminar. |
| November 2013 – June 2016 | Visiting Professor, College of Resources, Environment, and Tourism, Capital Normal University, Beijing, China. Seminars: Decision Analysis Methods; Optimization Methods and Applications. |
| July 2012 – | Professor Emeritus of City and Regional Planning, The Ohio State University. |

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|---|---|
| October 1987 - June 2012 | Full Professor of City and Regional Planning, The Ohio State University<br>Graduate Courses Taught at OSU: Introduction to Quantitative Methods, Applications of Quantitative Methods, Urban Planning Data and Forecasting, Static Optimization, Dynamic Optimization, Decision Analysis, Introduction to Analysis of Energy Factors, Seminar on Mathematical Models of Energy Management and Planning, Regional Planning Studio, Outlines of Regional Planning. |
| October 1985 - August 1986 | Berman Visiting Professor, Institute of Urban and Regional Studies, The Hebrew University of Jerusalem, Jerusalem, Israel<br>Seminars on optimization methods and energy planning. |
| October 1982 - September 1987 | Associate Professor of City and Regional Planning, The Ohio State University |
| October 1977 - September 1982 | Assistant Professor of City and Regional Planning, The Ohio State University |
| May-June 1977 | Adjunct Lecturer, Ecole Nationale Superieure des Mines de Paris, Paris, France.<br><u>Course</u>: Methodology for Air Pollution Control and Industrial Location in Urban Areas - graduate level (one quarter). |
| 1975-1976 | Adjunct Lecturer at the Louis Pasteur University, Strasbourg, France.<br><u>Courses:</u> The Environment in the Process of Urban and Regional Planning<br>(undergraduate - two semesters) - Models of Environmental Management (graduate - one semester). |
| 1972-1973 | Teaching Assistant in the Program of Urban and Regional Planning, Technion-Israel Institute of Technology. <u>Courses</u>: Quantitative Methods (two semesters) and Mathematical Models of Urban Structure (one semester). |
| 1969-1970 | Teaching Assistant in Mathematics at the Department of Mathematics,<br>University of Nancy, France, Undergraduate level (one semester). |

**ACADEMIC ADMINISTRATIVE POSITION**

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|---|---|
| October 1, 2005 - August 31, 2007 | Interim Director, Austin E. Knowlton School of Architecture, The Ohio State University. |

**ACADEMIC RESEARCH POSITIONS**

| | |
|---|---|
| 1978-1988 | Senior Faculty Associate, The National Regulatory Research Institute, The Ohio State University. Regulatory modeling research |

on various natural gas distribution issues.

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| November 1975 - January 1976 | Research Associate, Center for Urban and Regional Studies, Technion – Israel Institute for Technology. Ford Foundation Research Grant: Economic Costs of Environmental Quality. |
| 1974-1975 | Research Associate, Louis Pasteur University, Strasbourg, France. Research project: Natural Resources and Regional Land Use Planning in Alsace. |
| 1971-1973 | Senior Research Assistant, Center for Urban and Regional Studies, Technion - Israel Institute of Technology. |

**NON-ACADEMIC PROFESSIONAL POSITIONS**

| | |
|---|---|
| 2017-2019 | Consultant to California Energy Commission-funded project "Investigating Climate-Change-Induced Vulnerability of the California Northern Natural Gas Energy System and Identifying Resilience Options". |
| 2017-2019 | Consultant to Fair Shake Environmental Legal Services – Research and testimony related to Duke Energy's application for pipeline extension. |
| 2007 | Consultant to ACP – Visioning and Planning. Population forecasting for a large university town. |
| 1998 | Consultant to the President's Commission on Critical Infrastructure Protection (PCCIP). R&D planning for the U.S. natural gas infrastructure. |
| 1995-1996 | Consultant to the Centerior Energy Corporation, Cleveland, Ohio. Transmission lines projects evaluation. |
| 1992 | Consultant to the Enron Corporation, Houston, Texas. Spot and long-term natural gas pricing assessment. |
| 1987- 2012 | Consultant to the Information Science Division, Argonne National Laboratory, Argonne, Illinois: (1) Analysis of the random factors in sulfur dioxide emissions and air quality; (2) Studies of natural gas delivery infrastructure; (3) Development of a GIS/MIS for the natural gas industry, (4) Study of natural gas hubs. (Works sponsored by NAPAP, U.S. Department of Energy, Joint Program Office for Special Technology Countermeasures.) |
| 1981-1982 | Consultant to the U.S. National Bureau of Standards, Washington, D.C. Development of the rate-making component of the Gas Analysis Modeling System. |

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|---|---|
| 1978 | Consultant to Contract Research Corporation, Belmont, MA. Development and programming of a location-allocation model for the location of Small Business Administration agencies in the U.S. |
| 1976-1977 | Senior Planner, Regional Planning Agency for Alsace (O.E.D.A.), Strasbourg, France. Principal investigator in the field of environmental management: design of a regional environmental data bank; development of water quality models for the evaluation of wastewater treatment strategies; evaluation of the impact on air quality of alternative industrial site developments; design of solid waste treatment strategies at the regional level; assessment of the impacts of different siting alternatives for nuclear power plants in the Rhine Valley. |
| 1976-1977 | Consultant to the Commission of European Communities, Bruxelles, on the project: Ecological Mapping of the European Community. |
| 1976-1977 | Consultant to the French Ministry of the Environment, Paris, for the preparation of a Handbook for the Design of Regional Environmental Planning Strategies. |
| 1972 | Consultant to the Urban Renewal Authority, Ministry of Housing, Jerusalem, Israel. Data processing and analysis for a large-scale survey over two depressed neighborhoods in the City of Tiberias. |
| 1970-1971 | Transportation Planning Engineer. Haifa Area Transportation Planning Agency, Haifa, Israel. Public transportation planning and urban network analysis. |

**AWARDS**

| | |
|---|---|
| 1974 | Sagorski Prize, for outstanding thesis in the Social Sciences, Technion - Israel Institute of Technology |
| 1979 | Haifa Municipality Technology Prize, for the study "Centralized Air Pollution Treatment and the Optimal Location of Industries." |
| 1982 | Engineering Research Award, College of Engineering, The Ohio State University. |
| 1985-86 | Berman Visiting Professorship–The Hebrew University of Jerusalem. |
| 1986 | Local Government Scientific Research Prize, for the book "Industrial Location and Air Quality Control: A Planning Approach" - 8th National Congress on Local Government and Administration, Ministry of the Interior, Jerusalem. |

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|---|---|
| 1991 | Ameritech Prize, Graduate School, Ohio State University. |
| 2001 | Lumley Research Award, College of Engineering<br>The Ohio State University. |
| 2014 | Member, Emeritus Academy, The Ohio State University. |

**MEMBERSHIP IN PROFESSIONAL SOCIETIES**

American Economic Association
Regional Science Association
International Association for Energy Economics
INFORMS (Operations Research/Management Science - full member)

**PRESENTATIONS IN CONFERENCES, CONGRESSES, AND SYMPOSIA**

Sixth Annual Conference of the British Section of the Regional Science Association, London, England, August 1973. Presentation: A Model of Air Quality Impact on Industrial Land Use Allocation, (with D. Shefer).

Fourteenth European Congress of the Regional Science Association, Karlsruhe, West Germany, August 1974. Presentation: Indivisibilities, Economies of Scale and Air Quality Management, (with D. Shefer).

Committee on Urban Economics, U.S.A. Annual Conference, Santa Fe, New Mexico, March 1976. Presentation: Dynamic Planning of Industrial Location and Design of Central Regional Air Pollution Control Systems (with D. Shefer).

Optimization Days, Ecole Polytechnique, Montreal, May 1978. Presentation: Visual Impact and the Location of Activities: A Combinatorial Optimization Methodology.

NARUC Biennial Regulatory Information Conference, Columbus, Ohio, October 1978. Presentation: Regulatory Simulation Model (RSM) for Gas Distribution Utilities, (with D.Z. Czamanski).

Twenty-fifth North American Meeting of the Regional Science Association, Chicago, November 1978. Presentation: Evaluation of Natural Gas Allocation Policies in Consuming Regions with a Simulation Model, (with D.Z. Czamanski).

Twenty-sixth North American Meeting of the Regional Science Association, Los Angeles, November 1979. Presentation: Solar Energy and Access to Sunlight: An Optimization Model of Energy Supply and Land-Use Design.

Canadian Regional Science Association Meeting, Montreal, June 1980. Presentation: A Chance-Constrained Programming Model for Air Quality Control and Locational Decisions.

Twentieth Regional Science Association European Congress, Munich (W. Germany), August

1980. Presentation: Modeling the Interactions Between Geothermal Energy Use and Urban Structure

V. Symposium Uber Operations Research, Koln (W. Germany), August 1980. Presentation: Meteorological Variability and Air Quality Management: A Stochastic Optimization Approach.

ORSA/TIMS Joint National Meeting, Colorado Springs, November 1980. Presentation: The Optimal Location of Vegetated Buffer Zones in Urban Areas as a Means for Air Quality Management.

Twelfth Annual Modeling and Simulation Conference, Pittsburgh, May 1981. Presentation: Econometric Modeling of Electricity Distribution Capacity Costs and Implications for Marginal Cost Pricing.

Twenty-eighth North American Meeting of the Regional Science Association, Montreal, November 1981. Presentation: Impacts of Market Size and Mix, Population Density, and Climate on Gas Distribution Networks Investments in Urban Areas.

ORSA/TIMS Joint National Meeting, Detroit, MI April 1982. Presentation: A Marginal Cost Pricing Model for Gas Distribution Utilities.

NARUC Biennial Regulatory Information Conference, Columbus, Ohio, September l982. Presentation: The Allocation of Gas Distribution Plant Costs Based on Marginal Costs by Customer Class, (with C. Aki and K. Lee).

Twenty-ninth North American Meeting of the Regional Science Association, Pittsburgh, PA November 1982. Presentation: Modeling the Structure of Electricity Distribution Costs in Urban Areas.

Twenty-third European Congress of the Regional Science Association, Poitiers (France), August 1983.
Presentation: A Structural Framework for the Design of Integrated Environmental and Land-Use Planning Optimization Models.

Thirtieth North American Meeting of the Regional Science Association, Chicago, November 1983. Presentation: The Dynamics of Utility Systems at the Urban Fringe.

Fifteenth Annual Modeling and Simulation Conference, Pittsburgh, PA April 1984. Presentation: A Chance-Constrained Dynamic Model of Air Quality Management.

Twenty-fourth European Congress of the Regional Science Association, Milan (Italy), August 1984. Presentation: Econometric Modeling of the Vintage Structure and Dynamics of Urban Gas and Electric Distribution Systems, (with Y.W. Lee).

Colloque de l'Association de Science Regionale de Langue Francaise (ASRDLF), Lugano (Switzerland), September 1984. Presentation: Couts et Tarification d'un Service Public Urbain: le Cas de la Desserte Gaziere.

Thirty-third North American Meetings of the Regional Science Association, Columbus, Ohio, November 1986. Presentation: Cross-Subsidizations in the Provision of Urban Utility Services.

ORSA/TIMS Joint National Meeting, Washington, D.C., April 1988. Presentation: Optimal Gas Contract Portfolio Selection Methodologies.

Twenty-eighth European Congress of the Regional Science Association, Stockholm (Sweden), August 1988. Presentation: Modeling the Cost Structure of Local Telephone Networks.

Telecommunications Costing in a Dynamic Environment Conference, San Diego, April 1989. Presentation: Disaggregate Capital and Operating Cost Functions for Local Exchange Companies. (Paper also presented at the CAST symposium Alternative Methods for Telecommunications Regulation: Price Caps?, The Ohio State University, June 1989).

Eleventh Annual North American Conference of the International Association for Energy Economics, Los Angeles, October 1989. Presentation: Optimal Capacity Expansion and Peak Load Pricing: A Case Study of the New England Gas Market (with D.A. Hanson).

Symposia on Marginal Cost Techniques for Telephone Services, Seattle, July 1990, and Columbus, August 1990. Presentations: (1) Disaggregate Capital and Operating Marginal Costs for Local Exchange Companies, and (2) Point-to-Point Marginal Costs for the Switched Network.

Thirtieth European Congress of the Regional Science Association, Istanbul (Turkey), August 1990. Presentation: Spatial Interaction Models of Sectoral Telecommunication Flows.

Thirty-second European Congress of the Regional Science Association, Louvain-la-Neuve (Belgium), August 1992. Presentation: Input-Output Modeling of Regional Telecommunication Flows.

Thirty-fourth Annual Meeting of the Association of Collegiate Schools of Planning, Columbus (Ohio), October 1992. Presentation: Assessing the Regional Economic Impacts of the Clean Air Act Amendments of 1990.

1993 National Telecommunications Forecasting Conference, Washington, D.C., June 1993. Presentation: Analysis of Intersectoral Business Telecommunications Demand: A Combined Input-Output/Gravity Model Approach.

Thirty-fourth European Congress of the Regional Science Association, Groningen (The Netherlands), August 1994. Presentation: Telecommunications, Information Exchange, and Spatial Interaction: Theoretical Framework and Empirical Results.

Forty-first North American Meeting of the Regional Science Association International, Niagara Falls (Canada), November 1994. Presentation: A Spatial Equilibrium Model for City Size, Urbanization Ratio and Rural Structure (with Fahui Wang).

Forty-second North American Meeting of the Regional Science Association International,

Cincinnati,
November 1995. Presentation: Simulating Urban Population and Employment Densities with a Garin-Lowry Model (with Fahui Wang).

Thirty-sixth European Congress of the Regional Science Association, Zurich (Switzerland), August 1996. Presentation: Urban Transportation Network Design, Traffic Allocation, and Air Quality Control: An Integrated Optimization Approach (with W.S. Kim).

Forty-fourth North American Meeting of the Regional Science Association International, Buffalo, New York, November 1995. Presentation: Hub-and-Spoke Network Design: A General Model and Numerical Results (with Guoqiang Shen).

Thirty-eighth European Congress of the Regional Science Association, Vienna (Austria), August 1998.
Presentation: Competing Destinations and Intervening Opportunities Interaction Models of Inter-City Telecommunication Flows.

Fortieth European Congress of the Regional Science Association, Barcelona (Spain), August 2000.
Presentation: Spatial Interaction Models of International Telecommunication Flows.

Forty-first European Congress of the Regional Science Association, Zagreb (Croatia), August 2001.
Presentation: Impacts of Telecommunication Infrastructure on Rural Development.

Forty-second European Congress of the Regional Science Association, Dortmund (Germany), August 2002. Presentations: (1) International Water Resources Allocation and Conflicts - The Case of the Euphrates and the Tigris (with M. Kucukmehmetoglu), and (2) Spatial Interaction Modeling of Interregional Commodity Flows (with M. Celik).

American Geophysical Union (AGU) Chapman Conference on Ecosystem Interactions with Land Use, Santa Fe, New Mexico, June 14-18, 2003. Presentation: Development of the Optimal Land-Use Pattern with Minimal Non-point Source Pollution (with I. Yeo and S.I. Gordon).

Fiftieth North American Meeting of the Regional Science Association International, Philadelphia, Pennsylvania, November 2003. Presentation: Geography and the Cost of Network Infrastructure: The Case of Local Telephone Systems (with M. Cubukcu).

American Geophysical Union (AGU) Annual Fall Meeting, San Francisco, California, December 10-14, 2003. Presentation: Hierarchical Regression Approach to the Global Optimal Solution (with I. Yeo and S.I. Gordon).

Forty-Sixth Annual Meeting of the Association of Collegiate Schools of Planning, Portland (Oregon), October 2004. Presentation: Land Use Optimization for Nonpoint Source Water Pollution Control (with I. Yeo and S.I. Gordon).

Forty-Fifth European Congress of the Regional Science Association, Amsterdam (The Netherlands), August 2005. Presentations: Multi-Objective Programming for the Allocation of Trans-Boundary Water Resources - The Case of the Euphrates and the Tigris (with M.

Kucukmehmetoglu).

ASCE/EWRI Watershed Conference, Williamsburg, VA, July 2005. Presentation: Multistage Hierarchical Optimization for Land Allocation to Control Nonpoint Source Water Pollution (with I. Yeo and S.I. Gordon).

Mid-Continent Regional Science Association Conference, Indianapolis, June 2006. Presentation: Estimating Suppressed Data in Regional Economic Databases: A Goal-Programming Approach
(with S. Zhang).

Forty-Seventh Annual Meeting of the Association of Collegiate Schools of Planning, Fort Worth (Texas), November 2006. Presentation: Impacts of Urban Containment Policies (Urban Growth Boundaries, Urban Service Areas, and Greenbelt) on the Regional Economy (with M. Woo).

Annual Meeting of the Association of American Geographers, San Francisco, CA, April 2007. Presentation: Analysis of Urban Spatial Structure under Urban Containment Land Use Policies (with M. Woo).

Forty-Eighth Annual Meeting of the Association of Collegiate Schools of Planning, Milwaukee (Wisconsin), October 2007. Presentation: Urban Air Pollution, Traffic Volumes, and Road Congestion (with Y. Kim).

American Geophysical Union Conference, San Francisco (CA), December 2007. Presentation:
Is the Relationship Between Peak Runoff Discharge and Land-Use Patterns Convex? Numerical Experiment with the IHLUO Model (with I. Yeo).

Energy Systems Modeling Symposium, The Ohio State University, December 2007. Presentation:
Natural Gas Infrastructure Modeling: From Local Distribution to Trans-boundary Networks.

Annual Meeting of the Association of American Geographers, Boston, MA, April 2008. Presentation: Urban Vegetation: Is It Really Helpful for Air Pollution Mitigation? (with Y. Kim and Y.T. Leem).

ACSP-AESOP 4th Joint Congress, Chicago, IL, July 6-11, 2008.Presentation: No Driving for a Day per Week: Collective Actions for Urban Traffic Congestion (with Y. Kim).

Seventh Annual CMAS Conference, Chapel Hill, NC, October 2008. Presentation: Impacts of Traffic Volumes and Wind Directions on Air Pollution Concentrations in Seoul, Korea (with Y. Kim and H-M Ra).

Forty-Eighth Annual Meeting of Western Regional Science Association, Napa, California, February 2009. Presentation: Accessibility, Diversity, and Dynamics of Locations of Jobs and Population (with S. Zhang).

Third World Conference of Spatial Econometrics, Barcelona, July 8-10, 2009. Presentation: Modelling the Spatial Dependence of Shopping Center Trade Areas (with B. Ozuduru).

Thirty-Ninth Annual Meeting of the Urban Affairs Association: Contesting and Sustaining the City: Neighborhood, Region, or World, Chicago, Illinois, March 2009. Presentation: Incorporating College Population into Cohort-Component Population Forecasting (with S. Zhang).

UKC2009, Korean-American Scientists and Engineers Association (KSEA) Conference, Raleigh, North Carolina, July 16-19, 2009. Presentation: Three-Dimensional City Model Based on Data Fusion for Virtual Environments (with B. Chun).

Fiftieth Annual Meeting of the Association of Collegiate Schools of Planning, Crystal City, Virginia, October 2009. Presentation: Reduced Traffic During The Weekend: Is It Good for Urban Air Quality? (with Y. Kim).

Annual Meeting of the Association of American Geographers, Washington, DC, April 2010. Presentation: Relationship Between High-rise Building Patterns and Land Values, using LiDAR, GIS, and Appraisal Data (with B. Chun).

Fifty-First Annual Meeting of the Association of Collegiate Schools of Planning, Minneapolis, Minnesota, October 2010. Presentation: Two- and Three-Dimensional Urban Core Determinants of the Urban Heat Island: A Statistical Approach (with B. Chun).

Fifty-First Annual Meeting of the Association of Collegiate Schools of Planning, Minneapolis, Minnesota, October 2010. Presentation: A Computable General Equilibrium Model of the City: Impacts of Locational Restrictions and Zoning (with C. Olwert).

Fifty-Second Annual Meeting of the Association of Collegiate Schools of Planning, Salt Lake City, Utah, October 2011. Presentation: Urban Core Determinants of the Urban Heat Island: Spatial Statistical Approach (with B. Chun).

Ohio Transportation Engineering Conference (OTEC), Columbus, Ohio, October 2011. Presentation: Transportation Trends: How Do We Explain VMT? (with G. Akar).

Transportation Research Board 91st Annual Meeting (TRB), Washington, D.C., January 2012.
Presentation: Another Look at VMT: Determinants of Vehicle Use in Two-Vehicle Households (with G. Akar).

Fifty-Third Annual Meeting of the Association of Collegiate Schools of Planning, Cincinnati, Ohio, November 2012. Presentation: A Spatial Panel Modeling Approach for the Assessment of Seismic Losses and Land-Use Planning (with C.-H. Wang).

Transportation Research Board 92nd Annual Meeting (TRB), Washington, D.C., January 2013.
Presentation: Do your Neighbors Affect your Mode Choice: A Spatial Probit Model for Commuting to The Ohio State University (with C.-H. Wang and G. Akar).

Fifty-Second Annual Meeting of the Western Regional Science Association (WRSA), Santa Barbara, California, February 2013. Presentation: Macro-Level Analysis of the Impacts of Urban Factors on Traffic Crashes: A Case Study of Central Ohio (with D. Lee and B. Von Rabenau).

Beijing Forum 2013, Beijing, China, November 1-3, 2013. Invited presentation: Urban Heat Island Reduction through Urban Design and Planning Decisions: Combining Spatial Statistics and Simulation Models.

Sixtieth Annual North American Meeting of the Regional Science Association International (RSAI), Atlanta, Georgia, November 2013. Presentation: A Spatial Analysis of the Impact of Urban Environment Factors on Age-related Crashes in the Central Ohio Region (with D. Lee and B. Von Rabenau).

Sixtieth Annual North American Meeting of the Regional Science Association International (RSAI), Atlanta, Georgia, November 2013. Presentation: A land-use allocation optimization model to mitigate potential seismic losses (with C.-H. Wang).

Sixtieth Annual North American Meeting of the Regional Science Association International (RSAI), Atlanta, Georgia, November 2013. Presentation: Solar Energy Access and Complex Urban Cores Three-Dimensional Morphology: A Spatial Statistical Approach (with B. Chun).

Fifty-Fourth Annual Meeting of the Association of Collegiate Schools of Planning (ACSP), Philadelphia, PA, October 2014. Presentation: Driver Demographics and Car Crashes: Implications for Urban Planning (with D. Lee and B. von Rabenau).

Fifty-Fourth Annual Meeting of the Association of Collegiate Schools of Planning (ACSP), Philadelphia, PA, October 2014. Presentation: Statistical Modeling and Simulation of Parcel-Level Land Development Dynamics (with E. Tepe).

INFORMS 2014 Annual Meeting, San Francisco, November 2014. Presentation: Optimization of Roof and Ground Greening Strategies to Mitigate the Urban Heat Island (with B. Chun).

INFORMS 2014 Annual Meeting, San Francisco, November 2014. Presentation: A Chance-Constrained Optimization Model of Urban Land-Use Allocation under Seismic Hazard (with C.-H. Wang).

Fourth Forum of Chinese Energy and Resources Economics and Management (CEREM), Xuzhou, China, July 2015. Invited keynote presentation: Optimization of Green Roof and Green Space Allocation to Mitigate the Urban Heat Island.

Fifty-Fifth Annual Meeting of the Association of Collegiate Schools of Planning (ACSP), Houston, TX, October 2015. Presentation: Impact of Driver Demographics, Built Environment, and Road Conditions on Crash Severity: A Logit Modeling Approach (with D. Lee and B. von Rabenau).

Fifty-Fifth Annual Meeting of the Association of Collegiate Schools of Planning (ACSP), Houston, TX, October 2015. Presentation: Mitigation of the urban heat island with greening strategies: a nonlinear programming model (with B. Chun).

Sixty-Second Annual North American Meeting of the Regional Science Association International (RSAI), Portland, Oregon, November 2015. Presentation: Parcel-Level Land

Development Dynamics: A Spatial and Temporal Autologistic Model (with E. Tepe).

Fifty-Eighth Annual Meeting of the Association of Collegiate Schools of Planning (ACSP), Buffalo, NY, October 2018. Presentation: Interregional Virtual Water Trading: Implications for Regional Economic Development Under Climate Change (with M.G. Bhatia).

Fifty-Eighth Annual Meeting of the Association of Collegiate Schools of Planning (ACSP), Buffalo, NY, October 2018. Presentation: Characterizing Long-term Changes in Urban Green Infrastructure: A Comparative Study of the Columbus and Atlanta Metropolitan Areas (with Y. Park).

**INVITED LECTURES**

Environmental Data Banks, Environmental Modeling, and Regional Planning: The Case of Alsace. Lectures given at the Seminar of Applied Ecology, organized by the Ecole Nationale du Genie Rural,
des Eaux et des Forets at Bandol, France (May 26, 1977; November 18, 1976; May 30, 1976).

Pollution Standards and Optimal Location of Activities in a Metropolitan Area: The Particular Case of Air Pollution. Lecture given at the Transportation Research Center, University of Montreal (Nov. 19, 1976).

Natural Resources and Regional Planning in Alsace. Lecture given at the Colloquium Architecture, Landscape and the Environment in Alsace, Institut Qualite Alsace (June 8, 1977), Strasbourg, France.

Technical and Environmental Problems of Using High-Sulfur Coal. Lecture given at the Department of City and Regional Planning, The Ohio State University, Columbus (April 12, 1977).

Where to Put the Collector: Land-Use and Planning Implications of Solar Energy. Lecture given at The Ohio State University Union, Solar Seminar Series (November 17, 1980).

Evaluation of Expansion and Pricing Policies for a Gas Distribution Utility -Simulation and Mathematical Programming Approaches. Lecture given at the Transportation Research Center, University of Montreal (December 17, 1980).

The Use of Mathematical Models in Environmental Quality Management and Land Use Planning. Lecture given at the Department of Geography, Tel-Aviv University (November 12, 1985).

Statistical Models for Urban Infrastructure Planning. Lecture given at the Department of Geography, Haifa University (January 23, 1986).

A Stochastic Approach to the Interactions between Meteorological Variability, Location of

Pollution Sources, and Air Quality Control. Lecture given at the Department of Geography, Ben Gurion University of the Negev (March 23, 1986).

Chance-Constrained Models for Air Quality Management. Lecture given in The Environmental Economics Seminar, Policy and Economic Analysis Group, Argonne National Laboratory (April 24, 1987).

Research on the Gas Industry - A Regulatory Perspective. Lecture given at the ANR Pipeline Company Annual CD-1 Meeting, Scottsdale, Arizona (May 14, 1987).

Natural Gas supply in the 1990s: Contracting, Reliability, and Pricing Issues. Lecture given at the Ohio Energy Strategy Forum, Public Utilities Commission of Ohio, Columbus, Ohio (January 13, 1992).

Uncertainty and Randomness in Environmental Planning Optimization Models. Lecture given at the ORSA Roundtable, Department of Industrial and Systems Engineering, The Ohio State University, Columbus, Ohio (February 3, 1992).

Modeling Inter-industry Telecommunications Flows: Spatial Equilibrium Framework and Empirical Estimates. Lecture given at the Geography Graduate Colloquium, Northern Illinois University, DeKalb, Illinois (April 1997).

Telecommunications and the Regional Economy. Lecture given at the Faculty Colloquium, Faculty of Architecture and Town Planning, Technion - Israel Institute of Technology, Haifa, Israel (December 20, 1999).

Telecommunications Flows in a Regional Economy: A Geographical Perspective. Lecture given at the Departmental Seminar, Department of Geography, The Hebrew University of Jerusalem, Jerusalem, Israel (December 22, 1999).

Statistical Models of Urban and Regional Air Quality: The cases of Ozone and Carbon Monoxide. Lecture given at the Departmental Seminar, Department of Geography, University of Haifa, Haifa, Israel (December 30, 1999).

Modeling Telecommunications Infrastructure and Usage in Rural Areas. Lecture given at the Center for Urban and Regional Analysis (CURA), The Ohio State University (January 18, 2002)

An Empirical Analysis of Shopping Center Locations in Ohio. Lecture given at the DAAP School of Planning Ph.D. Program Colloquium, University of Cincinnati (November 28, 2006).

Optimal Allocation of Stormwater Pollution Control Technologies in a Watershed. Lecture given at the School of Urban and Public Affairs, University of Louisville, Louisville, Kentucky (September 9, 2009).

Spatial Statistical Modeling of the Urban Heat Island in Urban Centers and Suburban Environments. Lecture given at: (1) College of Resources, Environment and Tourism, Capital Normal University, Beijing, China, July 2, 2013; (2) School of Management, Xi'an University of Architecture and Technology, Xi'an, China, July 9, 2013.

Data Mining: Optimization Methods to Estimate Missing Data in Regional Economic Databases. Lecture given at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China, July 4, 2013.

Solar Energy Access and Urban Morphology in Complex Central Core Urban Areas. Lecture given at the Institute of GIS and Remote Sensing, Peking University, Beijing, China, July 8, 2013.

Urban Heat Island Mitigation through Urban Planning: Combining Spatial Regression and Simulation, Center for Urban and Regional Analysis (CURA), The Ohio State University, October 2, 2014.

Spatial Modeling of Earthquake Impacts and Damage Minimization through Land-Use Planning, College of Resources, Environment and Tourism, Capital Normal University, Beijing, China, October 10, 2014.

Optimal Allocation of Land Uses to Minimize Earthquake Damages: Application to Taichung, Taiwan. Lecture given at: (1) Institute of GIS and Remote Sensing, Peking University, and (2 Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China, October 2014.

Green Roofs and Green Spaces for the Mitigation of the Urban Heat Island in High-Density Cities. Department of City and Regional Planning, Faculty of Architecture, Middle East Technical University, Ankara, Turkey, October 8, 2015.

Quantitative Methods in Planning: (1) The Urban Heat Island and Green Spaces, and (2) Earthquake Mitigation and Land Use. Lecture given at: (1) Department of City and Regional Planning, Gazi University, Ankara, Turkey, October 9, 2015; (2) Department of City and Regional Planning, Dokuz Eylul University, Izmir, Turkey, October 12, 2015; and (3) Department of City and Regional Planning, Istanbul Technical University, Izmir, Turkey, October 14, 2015. Presentation at Gazi University available at: https://www.youtube.com/watch?v=c4xJlaP5Gbs

Mitigation of the Urban Heat Island with Greening Strategies: An Optimization Model. Chinese Academy of Sciences, Institute of Geographic Sciences and Natural Resources Research, State Key Laboratory of Resources and Environmental Information Systems, Beijing, China, May 27, 2016.

Creating 3D City Models with Building Footprints and LiDAR Point Cloud Classification: A Machine Learning Approach. Department of City and Regional Planning, Gazi University, Ankara, Turkey, October 19, 2018.

Impacts of Greenery, Water, and Imperviousness on the Urban Heat Island in Beijing's Olympic Area: Spatial and Uncertainty Analyses. Department of City and Regional Planning, Gazi University, Ankara, Turkey, October 25, 2018.

## PUBLICATIONS

### A. Book

Industrial Location and Air Quality Control: A Planning Approach. (Co-author: D. Shefer). John Wiley and Sons, New York, 1980.

### B. Chapters in Books

1. Air Quality Control, Industrial Siting and Fuel Substitution: An Optimization Approach, in Advances in Environmental Science and Technology, Vol. 10, pp. 301-367, 1980, Wiley (with D. Shefer).

2. Spatial Interaction Models of International Telecommunication Flows. In Spatially Integrated Spatial Science: Examples in Best Practice, M.F. Goodchild and D.G. Janelle (eds.), Oxford University Press, pp. 100-119, 2004

### C. PEER-REVIEWED Articles Published/In Press

1. Mathematical Models of Industrial Plant Location and Pollution Abatement Strategies, Environment and Planning, Vol. 5, No. 5, 1973, pp. 577-588 (with D. Shefer).

2. A Model of Air Quality Impact on Industrial Land Use Allocation, London Papers in Regional Science, Vol. 5, 1975, pp. 66-83, Pion, London (with D. Shefer).

3. Beit-Shemesh as a Central Place, Its Sphere of Influence and Possible Means of Extending It, Regional Studies, Vol. 9, 1975, pp. 193-202 (with D. Shefer and H. Shear).

4. Stack Height as a Means for Air Quality Control: A Mathematical Programming Approach, Journal of Environmental Management, Vol. 4, No. 3, 1976, pp. 241-249 (with D. Shefer).

5. Optimal Plant Location and Air Quality Management Under Indivisibilities and Economies of Scale, Socio-Economic Planning Sciences, Vol. 11, No. 2, 1977, pp. 77-93 (with D. Shefer).

6. Centralized Air Pollution Treatment and the Optimal Location of Industries, Environment and Planning A, Vol. 9, No. 10, 1977, pp. 1121-1142 (with D. Shefer).

7. Industrial Location, Air Pollution Control and Meteorological Variability: A Dynamic Optimization Approach, Socio-Economic Planning Sciences, Vol. 12, No. 4, 1978, pp. 197-214.

8. Urban Land Use Allocation and Environmental Pollution Control: An Intertemporal Optimization Approach, Socio-Economic Planning Sciences, Vol. 13, No. 2, 1979, pp. 71-86.

9. Visual Impact and the Location of Activities: A Combinatorial Optimization Methodology,

Socio-Economic Planning Sciences, Vol. 13, No. 2, 1979, pp. 47-70.

10. The Analysis of New Gas Hook-ups in Ohio, Bulletin of Business Research, Vol. 54, No.3-4, March-April 1979 (with D.Z. Czamanski).

11. Solar Energy and Access to Sunlight: An Optimization Model of Energy Supply and Land-Use Design, Environment and Planning A, Vol. 12, 1980, pp. 765-786.

12. A Simulation Model of Market Expansion Policies for Natural Gas Distribution Utilities, Energy, Vol. 5, No. 10, 1980, pp. 1013-1043 (with D.Z. Czamanski).

13. A Mathematical Experiment in Landscape Planning, Environment and Planning B, Vol. 7, 1980, pp. 379-398.

14. Modeling the Interactions Between Geothermal Energy Use and Urban Structure, Energy, Vol. 6, 1981, pp. 351-368 (with B.D. Rosenthal).

15. A Chance-Constrained Programming Approach to Natural Gas Curtailment Decisions, Resources and Energy, Vol. 3, 1981, pp. 133-161.

16. Supply, Storage, and Service Reliability Decisions by Natural Gas Distribution Utilities: A Chance-Constrained Approach, Management Science, Vol. 29, No. 8, 1983, pp. 884-906.

17. Modeling the Structure of Gas Distribution Costs in Urban Areas, Regional Science and Urban Economics, Vol. 13, No. 3, 1983, pp. 299-316.

18. Modeling the Location of Greenbelts as a Means for Air Quality Control, Socio-Economic Planning Sciences, Vol. 17, No. 4, 1983, pp. 217-224.

19. An Econometric Model of Electricity Distribution Systems in Urban Areas, Environment and Planning A, Vol. 16, 1984, pp. 793-806.

20. Une Taxonomie de Modeles Integres d'Amenagement et de Gestion de l'Environnement, Revue d'Economie Regionale et Urbaine, Vol. 6, 1984, pp. 321-346.

21. Extending Gas and Electric Lines at the Urban Fringe: A Statistical Analysis, Journal of Environmental Systems, Vol. 14(1), 1984, pp. 77-91.

22. A Further Note on the Structure of Gas Distribution Costs in Urban Areas, Regional Science and Urban Economics, Vol. 14, No. 4, 1984, pp. 583-588.

23. A Disaggregate Econometric Analysis of Electricity Distribution Capital Costs, Energy, Vol. 10, No. 5, 1985, pp. 601-612.

24. Economies of Scale and Natural Monopoly in Urban Utilities: The Case of Gas Distribution, Geographical Analysis, Vol. 17, No. 4, 1985, pp. 302-317.

25. A Logit Analysis of Telecommunication Network Bypass Decisions, Socio-Economic

Planning Sciences, Vol. 19, No. 5, 1985, pp. 349-356 (with J. Racster and M.D. Wong).

26. A Structural Framework for the Design of Integrated Environmental and Land-Use Planning Optimization Models, Mathematical Modelling, Vol. 7, No. 1, 1986, pp. 61-81.

27. Interactions Between Weather Stochasticity and the Locations of Pollution Sources and Receptors in Air Quality Planning : A Chance-Constrained Approach, Geographical Analysis, Vol. 18, No. 3, 1986, pp. 198-214.

28. A Marginal Cost Pricing Model for Gas Distribution Utilities, Operations Research, Vol. 34, No. 6, 1986, pp. 851-863.

29. Cost Reallocation as a State Regulatory Policy Option in Natural Gas Distribution Pricing, Energy Systems and Policy, Vol. 10, No. 4, 1987, pp. 373-404.

30. A Chance - Constrained Dynamic Model of Air Quality Management, Journal of Environmental Engineering - ASCE, Vol. 114, No. 5, 1988, pp. 1116-1135.

31. Land Use, Market Mix, and the Allocation of the Investment Costs of Electricity Distribution Networks, Socio-Economic Planning Sciences, Vol. 22, No. 5, 1988, pp. 201-212.

32. Capacity Cost Allocation in the Provision of Urban Public Services: The Case of Gas Distribution, Growth and Change, Vol. 20, No. 2, 1989, pp. 1-18.

33. Economies of Scale and Density in Local Telephone Networks, Regional Science and Urban Economics, Vol. 20, No. 4, 1990, pp. 521-535.

34. Natural Gas Market Expansion and Delivery Infrastructure Costs: The Case of New England (with D.A. Hanson), Resources and Energy, Vol. 13, No. 1, 1991, pp. 57-94.

35. Modeling Residential and Business Telecommunications Flows: A Regional Point-to-Point Approach, Geographical Analysis, Vol. 24, No. 2, 1992, pp. 121-141.

36. Input-Output Analysis of Regional Telecommunications Flows, Information Economics and Policy, Vol. 5, No. 4, 1993, pp. 311-329.

37. Cross-Subsidization in the Telephone Industry: Empirical Evidence from the Pre-Divestiture Era, Socio-Economic Planning Sciences, Vol. 28, No. 2, 1994, pp. 101-112.

38. Reliability Pricing of Electric Power Service: A Stochastic Production Cost Simulation Approach (with Y. Hegazy), Energy-The International Journal , Vol. 21, No. 2, 1996, pp. 87-97.

39. Simulating Urban Population Density with a Gravity-Based Model, Socio-Economic Planning Sciences, Vol. 30, No. 4, 1996, pp. 245-256 (with F. Wang).

40. A Spatial Equilibrium Model for City Size, Urbanization Ratio and Rural Structure, Environment and Planning A, Vol. 29, 1997, pp. 929-941 (with F. Wang).

41. Intersectoral Point-to-Point Telecommunication Flows: Theoretical Framework and Empirical Results, Regional Science and Urban Economics, Vol. 28, No. 5, 1998, pp. 585-610.

42. Population and Employment Density Functions Revisited: A Spatial Interaction Approach, Papers in Regional Science , Vol. 77, No. 2, 1998, pp. 19-41 (with F. Wang).

43. Optimizing The Natural Gas Supply Mix of Local Distribution Utilities, The European Journal of Operational Research , Vol. 112, 1999, pp. 598-612 (with F. Wang).

44. Competing Destinations and Intervening Opportunities Interaction Models of Inter-City Telecommunication Flows, Papers in Regional Science , Vol. 78, 1999, pp. 179-194.

45. Modeling Air Quality in Urban Areas: A Cell-Based Statistical Approach, Geographical Analysis , Vol. 33, No. 2, 2001, pp. 156-180 (with H.Y. Kim).

46. GIS in Coal Transportation Modeling: Case Study of Ohio, Geographic Information Sciences, Vol. 7, No. 1, 2001, pp.24-34 (with H. Tu).

47. International Water Resources Allocation and Conflicts - The Case of the Euphrates and the Tigris, Environment and Planning A, Vol. 36, No. 5, 2004, pp. 783-802 (with M. Kucukmehmetoglu).

48. Optimizing Patterns of Land Use to Reduce Peak Runoff Flow and Non-point Source Pollution with an Integrated Hydrological and Land-Use Model, Earth Interactions, Vol. 8, No. 6, 2004, pp. 1-20 (with I.-Y. Yeo and S.I. Gordon).

49. Vehicle Characteristics and Emissions: Logit and Regression Analyses of I/M Data from Massachusetts, Maryland, and Illinois, Transportation Research Part D , Vol. 11, No. 1, 2006, pp. 59-76 (with M. Beydoun).

50. Spatial Interaction Modeling of Interregional Commodity Flows, Socio-Economic Planning Sciences , Vol. 41, No. 2, 2007, pp. 147-162 (with M. Celik).

51. Land-Use Optimization for Nonpoint Source Water Pollution Control, Environment and Planning B , Vol. 33, No. 6, 2006, pp. 903-921 (with I. Yeo).

52. A Hierarchical Optimization Approach to Watershed Land-Use Planning, Water Resources Research Vol. 43, WO9420, doi:10.1029/2005WR004731, 2007 (with I. Yeo and S.I. Gordon).

53. Estimating Suppressed Data in Regional Economic Databases: A Goal-Programming Approach, European Journal of Operational Research Vol. 192, No. 2, 2009, pp. 521-537 (with S. Zhang).

54. Geography and the Cost of Network Infrastructure: The Case of Local Telephone Systems, Annals of Regional Science , Vol. 42, No. 4, 2008, pp. 821-842 (with M. Cubukcu).

55. Multi-Objective Allocation of Trans-Boundary Water Resources: The Case of the Euphrates and Tigris, Journal of Water Resources Planning and Management , Vol. 136, No. 1, 2010, pp. 95-105 (with M. Kucukmehmetoglu).

56. Accessibility, Diversity, Environmental Quality and the Dynamics of Intra-Urban Population and Employment Location, Growth and Change, Vol. 41, No. 1, 2010, pp. 85-114 (with S. Zhang).

57. Global Spatial Optimization with Hydrological Systems Simulation: Application to Land-Use Allocation and Peak Runoff Minimization, Hydrological and Earth System Sciences, Vol. 14, 2010, pp. 325-338 (with I. Yeo).

58. Impacts of Urban Containment Policies on the Spatial Structure of Metropolitan Areas, Urban Studies, Vol. 48, No. 16, 2011, pp. 3511-3536 (with M. Woo).

59. Impact of Traffic Flows and Wind Directions on Air Pollution Concentrations in Seoul, Korea, Atmospheric Environment, Vol. 45, 2011, pp. 2803-2810 (with Y. Kim).

60. A Computable General Equilibrium Model of the City: Impacts of Technology, Zoning, and Trade, Environment and Planning A, Vol. 44, No. 1, 2012, pp. 237-253 (with C. Olwert).

61. Impact of Multi-Dimensional Isovists on Commercial Real Estate Values in the CBD Area Using GIS, Seoul Studies, Vol. 9, 2011, pp. 17-32 (with B. Chun and W. Seo).

62. Landscape Ecology, Land-Use Structure, and Population Density: Case Study of the Columbus Metropolitan Area, Landscape and Urban Planning, Vol. 105, 2012, pp.74-85 (with J. Lu).

63. Two- and Three-Dimensional Urban Core Determinants of the Urban Heat Island: A Statistical Approach, Journal of Environmental Science and Engineering, Vol. B1, No. 3, 2012, pp. 363-378 (with B. Chun).

64. Costs of Abandoned Coal Mine Reclamation and Associated Recreation Benefits in Ohio, Journal of Environmental Management, Vol. 100, 2012, pp. 52-58. (with S. Mishra, F. Hitzhusen, B. Sohngen)

65. Another Look at VMT: Determinants of Vehicle Use in Two-Vehicle Households, Transportation Research Record – Journal of the Transportation Research Board, Vol. 2322, 2012, pp. 110-118 (with G. Akar).

66. Spatial Analysis of the Urban Heat Island Using a 3-D City Model, Journal of the Korea Spatial Information System Society , Vol. 20 (4), 2012, pp. 1-16 (with B. Chun).

67. Analytical Strategies for Estimating Suppressed and Missing Data in Large Regional and Local Employment, Population, and Transportation Databases, WIREs Data Mining and Knowledge Discovery, Vol. 3, 2013, pp. 280-289.

68. A Regression-Constrained Optimization Approach to Estimating Suppressed Information Using Time-Series Data: Application to County Business Patterns 1999-2006, International Regional Science Review, Vol. 38(2), 2015, pp. 119-150 (with S. Zhang).

69. Land-Use Planning and the Urban Heat Island, Environment and Planning B, Vol. 41, 2014, pp. 1077-1099 (with J-P. Kim).

70. The Urban Heat Island in High-Density Central Cities: A Multi-Scale Spatial Statistical Analysis, Landscape and Urban Planning, Vol. 125, 2014, pp. 76-88 (with B. Chun).

71. Urban Containment Policies and Urban Growth, International Journal of Urban Sciences, Vol. 18(3), 2014, pp. 309-326 (with M. Woo).

72. Retail Location and Urban Resilience: Towards a New Framework of Retail Policy, S.A.P.I. E.N.S., Vol. 6 (1), 2014, pp. 1-12 (with B. Ozuduru).

73. Employment Distribution and Land-Use Structure in the Columbus Metropolitan Area, Journal of Urban Planning and Development – ASCE, published online: September 26, 2014, DOI: 10.1061/(ASCE)UP.1943-5444.0000234. (with J. Lu).

74. Do Your Neighbors Affect Your Bicycling Choice? A Spatial Probit Model for Bicycling to The Ohio State University, Journal of Transport Geography Vol. 42, 2015, pp. 122-130 (with C.-H. Wang and G. Akar).

75. Land-Use Regression Panel Models of $NO_2$ Concentrations in Seoul, Korea, Atmospheric Environment, Vol. 107, 2015, pp. 364-373 (with Y. Kim).

76. A Land-Use Allocation Optimization Model to Mitigate Potential Seismic Losses, Environment and Planning B, Vol. 42, 2015, pp. 730-753 (with C.-H. Wang).

77. A Spatial Panel Approach to the Statistical Assessment of Seismic Impacts and Economic Damages: Case Study of Taichung, Taiwan, Computers, Environment and Urban Systems, Vol. 57, 2016, pp. 178-188 (with C.-H. Wang).

78. Geography and the Capital Costs of Urban Energy Infrastructure: The Case of Electricity and Natural Gas, METU Journal of the Faculty of Architecture, Vol. 33(1), 2016, pp. 61-86 (with M.A. Senyel).

79. Spatial and Temporal Modeling of Parcel-Level Land Dynamics, Computers, Environment and Urban Systems, Vol. 64, 2017, pp. 204-214 (with E. Tepe).

80. Interactions Between the Built and Socio-Economic Environment and Driver Demographics: Spatial Econometric Models of Car Crashes in the Columbus Metropolitan Area, International Journal of Urban Sciences, Vol. 22(1), 2018, pp. 17-37 (with D. Lee and B. von Rabenau).

81. Spatial Regression Models of Park and Land-Use Impacts on the Urban Heat Island in Central Beijing, Science of the Total Environment, Vol. 626, 2018, pp. 1136-1147 (with Z. Dai and Y. Hu).

82. Joint Costs in Electricity and Natural Gas Distribution Infrastructures: The Role of Urban Factors, Urban Science, 2, 35, 2018 (with M.A. Senyel).

83. Impacts of Greening on the Urban Heat Island: Seasonal Variations and Mitigation Strategies, Computers, Environment and Urban Systems, Vol. 71, 2018, pp. 165-176 (with B. Chun).

84. Spatio-Temporal Multinomial Autologistic Modeling of Land-Use Change: A Parcel-Level Approach, Environment and Planning B: Urban Analytics and City Science, Online July 6, 2018, DOI: 10.11.77/2399808318786511 (with E. Tepe).

85. Influence of Trees on the Outdoor Thermal Environment in Subtropical Areas: An Experimental Study in Guangzhou, China, Sustainable Cities and Society, Vol. 42, 2018, pp. 482-497 (with S. Zheng, Z. Liu, and L. Zhao).

86. Thermal Impacts of Greenery, Water, and Impervious Structures in Beijing's Olympic Area: A Spatial Regression Approach, Ecological Indicators, Vol. 97, 2019, pp. 77-88 (with Z. Dai and Y. Hu).

87. Creating 3D City Models with Building Footprints and LiDAR Point Cloud Classification: A Machine Learning Approach, Computers, Environment and Urban Systems, Vol. 75, 2019, pp. 76-89 (with Y. Park).

## D. WORKING PAPERS UNDER REVIEW OR REVISION

1. Modeling of Shade Creation and Radiation Modification by Four Tree Species in Hot and Humid Areas: Case Study of Guangzhou, China (with S. Zheng, Z. Liu, L. Zhao, J. Wang).

2. The Sky View Factor and Urban Morphology: A Spatial Regression Approach (with B. Chun).

3. Interregional Virtual Water Trading: Implications for Regional Economic Development under Climate Change (with M. Bhatia).

4. Chinese Urban Energy Consumption Structure and its Determinants: A Dynamic Shift-Share Analysis (with Z. Li and Z. Hu).

.

5. Optimal Allocation of Stormwater Pollution Control Technologies in a Watershed (with W-B Chen and S.I. Gordon).

6. County-Level Empirical Analysis of Shopping Center Locations in Ohio (with B. Ozuduru).

7 Urban Transportation Network Design, Traffic Allocation, and Air Quality Control: An Integrated Optimization Approach (with W.S. Kim and S. Zhang).

8. Spatial Analysis of Telecommunication Flows: Literature Review and Conceptual

Framework.

9. Modeling Telecommunications Infrastructure and Usage Decisions in Rural Areas.

## E. CONFERENCE PROCEEDINGS

Regulatory Simulation Model (RSM) for Gas Distribution Utilities, Proceedings of the First NARUC Biennial Regulatory Conference, 1978, pp. D3-D14 (with D.Z. Czamanski).

Meteorological Variability and Air Quality Management: A Stochastic Optimization Approach, Methods in Operations Research, Vol. 41, 1981, pp. 153-156, Oelgeschlager, Gunn and Hain Publishers, Cambridge, MA.

Econometric Modeling of Electricity Distribution Capacity Costs and Implications for Marginal Cost Pricing, Modeling and Simulation, Vol. 12, 1981, pp. 893-897.

The Allocation of Gas Distribution Plant Costs Based on Marginal Costs by Customer Class, Proceedings of the Third NARUC Biennial Regulatory Conference, 1982, pp. 476-488 (with C. Aki and K. Lee).

A Chance-Contrained Dynamic Model of Air Quality Management, Modeling and Simulation, 1984, Vol. 15, pp. 495-499.

Disaggregate Capital and Operating Cost Functions for Local Exchange Companies, Proceedings of the Bellcore-Bell Canada Conference on Telecommunications Costing, 1989, pp. 717-749.

Multistage (Top-Down) Optimization Approach To Watershed Conservation to Control Nonpoint Source Water Pollution. Proceeding of Watershed Management Conference 2005, the Environmental & Water Resources Institute of the American Society of Civil Engineers, 2005 (with I. Yeo and S.I. Gordon).

## F. BOOK REVIEWS

Review of "Energy Development in the Western United States - Impact on Rural Areas" by S.H. Murdock and F.L. Leistritz, and "Energy Conservation and Public Policy" edited by J.C. Sawhill. Environment and Planning A, Vol. 8, 1982, pp. 408-410.

Review of "Geothermal Energy Development: Problems and Prospects in the Imperial Valley of California" by E.W. Butler and J.B. Pick. Environment and Planning A, Vol. 16, 1984, pp. 558-559.

Review of "Energy, Planning and Urban Form" by S. Owens. Geographical Analysis, October 1988, pp. 348-350.

## G. RESEARCH REPORTS

Forecasting the Demand for Employment, Capital and Land of the Industries in the Haifa Region with a Regional Input-Output Model, May 1974, pp. 120 (in Hebrew, summary in English). Center for Urban and Regional Studies, Technion - Israel Institute of Technology (with D. Shefer, Y. Frishman, H. Shalev).

Economic Costs of Environmental Qualities: The Optimal Spatial Configuration of Industrial Plants in a Growing Urban Region, June 1976. Final Report to the Ford Foundation, Center for Urban and Regional Studies, Technion - Israel Institute of Technology (with D. Shefer).

Methodologies d'Integration des Ressources Naturelles dans les Decisions d'Amenagement du Territoire. Final Report to the French Ministry of the Environment, November 1975, pp. 150 (in French), Louis Pasteur University, Strasbourg, France.

Evaluation d'Impacts sur l'Environnement et Analyse Economique: Trois Applications Regionales. Final Report to the French Ministry of the Environment, October 1975, pp. 175 (in French), Louis Pasteur University, Strasbourg, France.

Atlas de l'Environnement-Alsace, September 1975, pp. 50 (Set of 25 commented maps on various aspects of regional environmental quality and problems). Louis Pasteur University, Strasbourg, France.

The Allocation of Increasing Gas Supplies in Ohio. Three-volume report to the Public Utilities Commission of Ohio, October 1978 (with D.Z. Czamanski).

Optimal Policies of Gas Purchases and Storage Operations and Expansion. The National Regulatory Research Institute (NRRI), April 1979.

Optimal Gas Curtailment Policies. NRRI, May 1979.

Extension of the Regulatory Simulation Model: RSM User's Manual. NRRI, March 1979 (with R.E. Kurth, D.Z. Czamanski, and E. Snijders).

Budget Billing Plans for Electric and Gas Utilities: An Analysis and Some Recommendations for Change. NRRI, January 1980 (with K.A. McDermott).

Marginal Cost Pricing for Gas Distribution Utilities: Preliminary Analyses and Models. NRRI, Report No. 80-12, November 1980.

Marginal Cost Pricing for Gas Distribution Utilities: Further Analyses and Models. NRRI, Report No. 81-9, December 1981 (with W. Pollard and R.A. Tybout).

A Marginal Cost Pricing Model for Gas Distribution Utilities. NRRI, Occasional Paper No. 5, December 1982.

State Regulatory Options for Dealing with Natural Gas Wellhead Price Deregulation. NRRI, Report No. 83-7, August 1983 (with others).

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**Exhibit JMG-2**

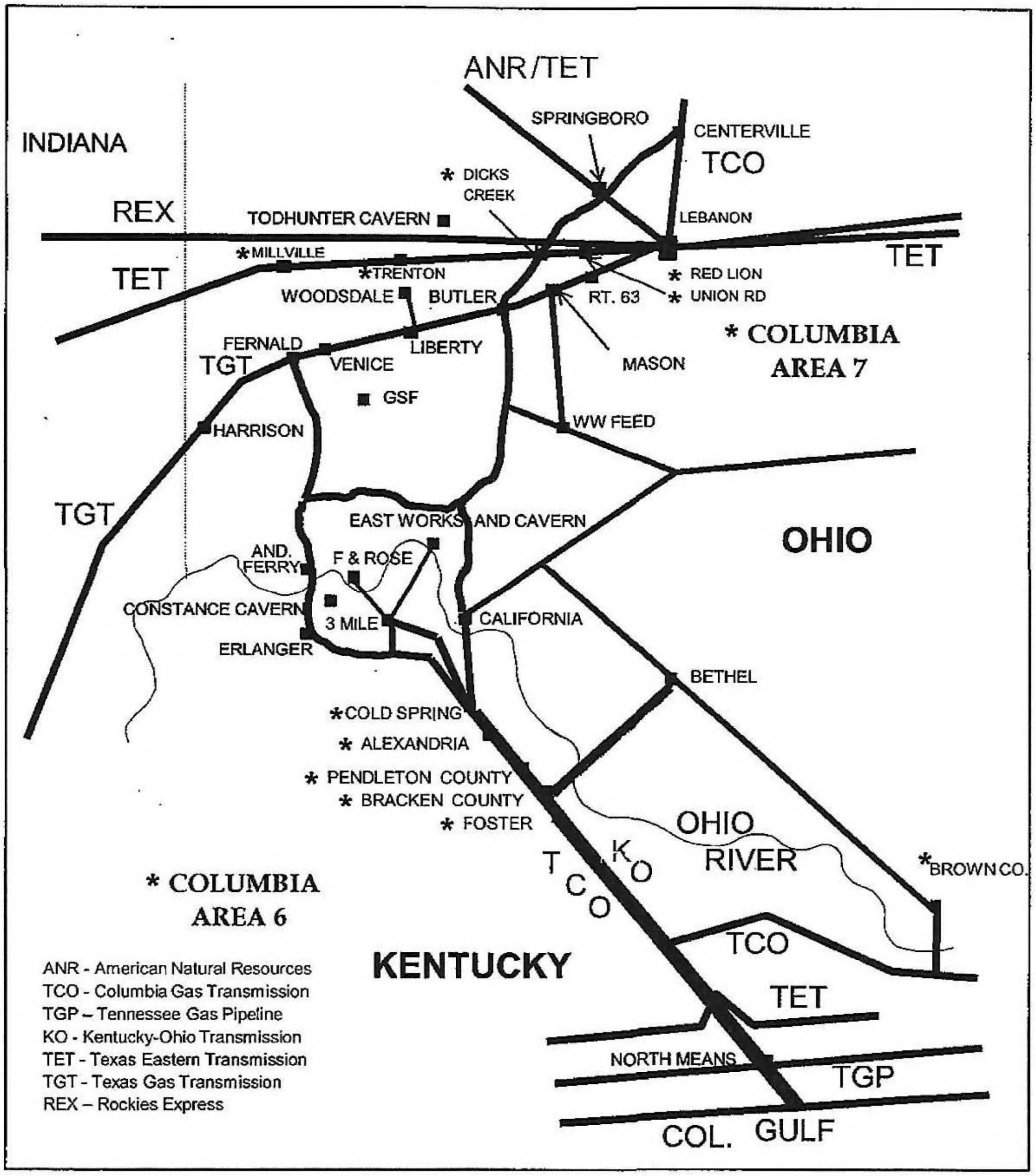
Data from EIA Form 176

| Volumes and Consumers - Duke Energy - 2010-2016 Source: Form EIA 176 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Item | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| | | | | | | | | |
| Receipts at Citygate Volume | KY | 19826073 | 21606614 | 19605514 | 22162978 | 22435927 | 20489042 | 22295737 |
| Total Supply Volume | KY | 19831543 | 21614743 | 19606201 | 22192242 | 22487842 | 20539795 | 22360766 |
| Residential Volume | KY | 6531587 | 6043620 | 5230077 | 6483794 | 6847088 | 5945448 | 5410586 |
| Residential Consumers | KY | 87260 | 87316 | 87883 | 88282 | 88731 | 89195 | 89990 |
| Commercial Volume | KY | 4615627 | 4393883 | 3977527 | 4589505 | 5027511 | 4403981 | 4178528 |
| Commercial Consumers | KY | 7489 | 7427 | 7448 | 7408 | 7512 | 7531 | 7564 |
| Commercial Sales Consumers | KY | 7429 | 7371 | 7389 | 7343 | 7448 | 7467 | 7498 |
| Commercial Sales Volume | KY | 3570316 | 3303471 | 2919794 | 3462828 | 3876357 | 3347311 | 3046517 |
| Industrial Volume | KY | 2380062 | 2396479 | 2458337 | 2629720 | 2704500 | 2761188 | 2831350 |
| Industrial Consumers | KY | 258 | 260 | 259 | 259 | 259 | 260 | 258 |
| | | | | | | | | |
| Receipts at Citygate Volume | OH | 68597481 | 62758916 | 60297252 | 68772542 | 73969827 | 64639383 | 60530748 |
| Total Supply Volume | OH | 74473349 | 71436182 | 68257919 | 76819460 | 81571814 | 71856896 | 70114904 |
| Residential Volume | OH | 31332756 | 29262577 | 25780309 | 31467942 | 32833445 | 29093625 | 26893900 |
| Residential Consumers | OH | 379823 | 379527 | 380689 | 381605 | 384208 | 385647 | 387739 |
| Commercial Volume | OH | 24733773 | 23500276 | 22053492 | 24293455 | 25651737 | 22676383 | 22153102 |
| Commercial Consumers | OH | 36743 | 36384 | 36120 | 35994 | 35979 | 35768 | 35605 |
| Industrial Volume | OH | 17013381 | 17351460 | 18187428 | 19649617 | 20211619 | 19643190 | 20012682 |
| Industrial Consumers | OH | 1571 | 1554 | 1517 | 1493 | 1479 | 1454 | 1446 |
| Electric Power Volume | OH | 18978 | 28942 | 33821 | 144299 | 424774 | 576311 | 390340 |
| Electric Power Transport Consumers | OH | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| | | | | | | | | |
| Receipt at City Gate Volume | DE | 88423554 | 84365530 | 79902766 | 90935520 | 96405754 | 85128425 | 82826485 |
| Total Supply Volume | DE | 94304892 | 93050925 | 87864120 | 99011702 | 104059656 | 92396691 | 92475670 |
| Residential Volumes | DE | 37864343 | 35306197 | 31010386 | 37951736 | 39680533 | 35039073 | 32304486 |
| Residential Consumers | DE | 467083 | 466843 | 468572 | 469887 | 472939 | 474842 | 477729 |
| Residential Volume per Consumer | DE | 81.1 | 75.6 | 66.2 | 80.8 | 83.9 | 73.8 | 67.6 |
| Commercial Volume | DE | 29349400 | 27894159 | 26031019 | 28882960 | 30679248 | 27080364 | 26331630 |
| Commercial Consumers | DE | 44232 | 43811 | 43568 | 43402 | 43491 | 43299 | 43169 |
| Commercial Volume per Consumer | DE | 663.5 | 636.7 | 597.5 | 665.5 | 705.4 | 625.4 | 610 |
| Industrial Volume | DE | 19393443 | 19747939 | 20645765 | 22279337 | 22916119 | 22404378 | 22844032 |
| Industrial Consumers | DE | 1829 | 1814 | 1776 | 1752 | 1738 | 1714 | 1704 |
| Industrial Volume per Consumer | DE | 10603.3 | 10886.41 | 11624.87 | 12716.52 | 13185.34 | 13071.4 | 13406.12 |
| Electric Power Volume | DE | 18978 | 28942 | 33821 | 144299 | 424774 | 576311 | 390340 |
| Electric Power Consumers | DE | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| Electric Power Volume per Consumer | DE | 18978 | 28942 | 33821 | 72150 | 212387 | 288156 | 195170 |
| Total Delivery Volume | DE | 86626164 | 82977237 | 77720991 | 89258332 | 93700674 | 85100126 | 81870488 |
| | | | | | | | | |
| Volume Losses Whole Company | DE | 7678728 | 10073688 | 10143129 | 9753370 | 10358982 | 7296565 | 10605182 |
| Rate of loss % | DE | 8.1 | 10.8 | 11.5 | 9.9 | 10.0 | 7.9 | 11.5 |

Volume: mcf; Consumers: #; Volume losses = Total supply volume – Total delivery volume
Rate of loss = (Volume Loss/Total supply volume)*100

**Exhibit JMG-3**

Supply Infrastructure Network




Source: 2015 Exeter Report, p. 5.

**Exhibit JMG-4**

Transmission Lines in DE Network

Existing transmission lines [Doc 44]
- Line A: Centerville Sta. No. 9 to Norwood Sta. No. 36; 20’’; 225psi, 150 psi; 112,872+88,236 feet length;
- Line D: California Sta. No. 7 to East Works Sta.; 24”; 200, 388, 175 psi; length = 23,766 feet;
- Line V: Line D to Norwood; 20”; 200, 175 psi; 45,116 feet;
- Line AA: Anderson Ferry Sta. to North Bend Road Sta.; 20-24”; 175 psi;86,588 feet;
- Line EE: California Sta. to Line V: 24”; 200 psi; 25,481 feet;
- Line CG07: Butler Sta. to Dicks Creek Sta.; 10, 12, 16”; 400, 438, 800 psi; 25,443 feet;
- Line LP2: Dicks Creek Sta. to Line A: 20”; 225, 438, 800 psi; 1,524 feet;
- Line LP5: Dicks Creek Sta. to AK Steel Back-up Sta.: 8, 12”; 538 psi; 4,371 feet;
- Line C210: Princeton Road to Woodsdale Plant: 16, 24”; 670, 500 psi; 24,359 feet;
- Line CG04: Line AA to Livingston Road: 20”; 175 psi; 20, 754 feet;
- Line C314: Mason Rd. Sta (@Texas Gas) to F/L WW on Fields Ertel Rd.; 24”; 670 psi; 56,303 feet;
- Line C338: Ohio River to Bethel Sta. #760: 12”; 535 psi; 86,967 feet;
- Line C340: Sta. #759 (Bracken Co., KY) to F/L C338 on Ohio shore; 12”; 535 psi; 3,699 feet;
- Line C251: STA 137 Minton Rd. to Miami Western Dr.; 8”; 360 psi; 38,387 feet;
- Line CG63: LP02 Tap to Sta 311 & 181: “; 438 psi; 582 feet.

Planned transmission lines [Doc 44]
- Existing Line C314 to Lebanon Hub (Warren Co.):48,000 feet; 24”; 720 psi; loop current pipeline to increase capacity for system load growth and provide greater operational alternatives; timing: 2023;
- Existing Line C338 at Bethel to Blanchester (Clermont Co.): 12”; 650 psi; 132,000 feet; loop current pipeline to increase capacity for system for future industrial growth; timing: 2024;
- Replacements for D000b, A000b, EE00, CG07b;
- Several retrofits.

**Exhibit JMG-5**

Land and Population Impacts of the Preferred (PR) and Alternative (AR) Routes for C314V

| Variable | PR | AR |
|---|---|---|
| Length (miles) | 13.9 | 12.9 |
| # properties crossed by the construction ROW | 723 | 471 |
| Proposed construction ROW (acres) | 135 | 125 |
| Land uses within 2000 feet corridor (%) | | |
| Industrial and commercial | 37.4 | 40.2 |
| Paved areas | 27.5 | 36.8 |
| Parks & recreation | 14.5 | 6.8 |
| Woodlots | 14.1 | 11.9 |
| Number of land-use features within 100 feet | | |
| Historic Structures | 31 | 4 |
| Residences | 115 | 182 |
| Number of land-use features within 1000 feet | | |
| Historic Structures | 230 | 116 |
| Residences | 3153 | 2186 |
| Pipeline length in feet (%) crossing land uses | | |
| Residences | 2581 (3.5%) | 82 (0.1%) |
| Parks & recreation | 10,808 (15.7%) | 4,582 (6.7%) |
| Industrial and commercial | 27,557 (37.4%) | 28,365 41.6%) |
| Capital costs ($ Million) | | |
| Total | 128.2 | 111.7 |
| Land & land rights | 26.8 | 19.6 |
| Structures & improvements | 5.2 | 0.9 |
| Pipes | 87.2 | 82.4 |
| MR equipment | 8.7 | 8.7 |
| ROW clearing | 0.3 | 0.1 |
| Property tax revenues ($ Million) | 3.3 | 2.9 |

**Exhibit JMG-6**

Impacts of Scenario W-1 - Redacted

**Exhibit JMG-7**

Lummus Report – Redacted

**Exhibit JMG-8**

TRC Route Evaluation Report – Redacted

4837-0895-4513, v. 1

## CERTIFICATE OF SERVICE

I certify that the foregoing was filed electronically through the Docketing Information System of the Public Utilities Commission of Ohio on this 2nd day of April, 2019. The PUCO's e-filing system will electronically serve notice of the filing of this document on all parties of record.

/s/ *James F. Lang*
One of the Attorneys for City of Cleveland and
Board of Commissioners of Hamilton County