METHANE EMISSIONS FROM U.S. GAS PIPELINE LEAKS

August 2023

Renee McVay
Scientist, Environmental Defense Fund

Acknowledgments
Thank you to the following individuals for their contributions to this report: Daniel Zavala-Araiza, Jack Warren, Erin Murphy, Peter Zalzal and Edwin LaMair.

Environmental Defense Fund
Environmental Defense Fund is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

Cover photo: John Rae

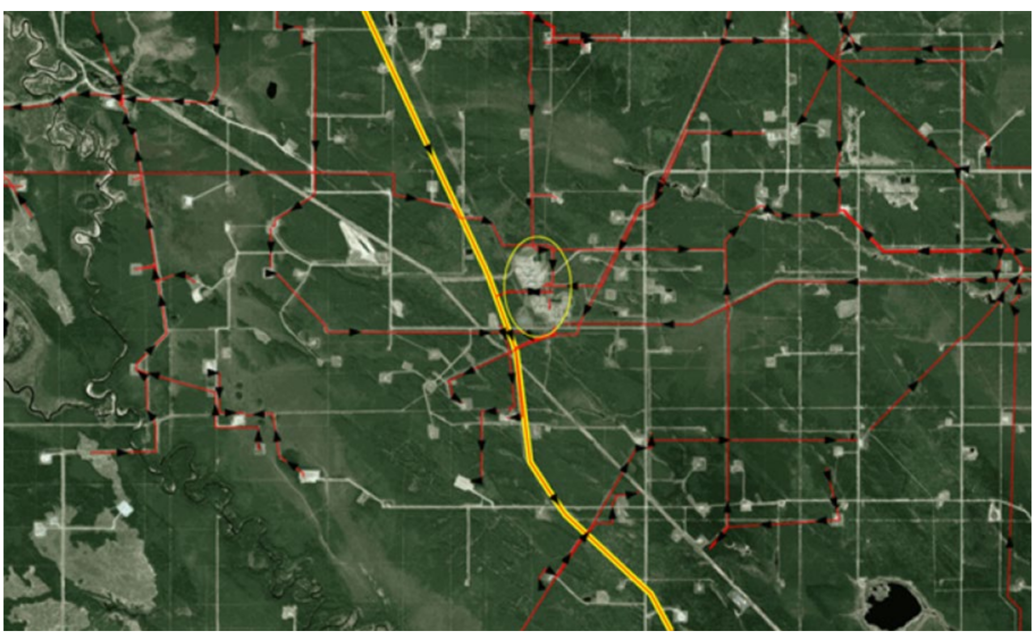
TABLE OF CONTENTS

INTRODUCTION

Methane is a potent greenhouse gas with a warming potential 84 times greater than carbon dioxide (CO2) over a 20-year period and 30 times greater over a 100-year period.[1] Natural gas is primarily composed of methane, meaning that all leakage from natural gas pipelines contributes to harmful climate pollution. EDF analysis, using the latest research, finds that U.S. natural gas pipelines are leaking between 1.2 million and 2.6 million tons of methane per year.

Peer-reviewed research demonstrates that rapid implementation of all methane mitigation measures could slow the rate of near-term warming by 30% and avoid 0.25°C of additional warming by midcentury. Given the urgent global need to reduce greenhouse gas emissions to mitigate the climate crisis, cutting methane emissions from pipelines is an important strategy to limit the rate of current warming. Pipeline methane leaks also pose safety risks due to the possibility of fires or explosions caused by ignition of the natural gas, which can cause significant harm to people and property.

The United States has an extensive network of over 3 million miles of pipelines to transport natural gas, infrastructure that is on average 40-50 years old. Leaks on pipelines must be addressed to reduce methane pollution and improve safety.



Gas Gathering and Transmission Pipelines in Alberta, Canada

Gathering pipelines in red, transmission pipeline in yellow, gas processing facility is within the yellow circle. Note that comparable maps of pipeline infrastructure in the US are not publicly available.

Source: Highwood Emissions Management, Report, p15

GAS PIPELINE INFRASTRUCTURE

There are three major types of natural gas pipelines, varying based on their role in the supply chain and general size and pressure levels.

Pipeline type	U.S. miles	Description
Gathering	~435,000	Gathering pipelines transport unprocessed gas from well sites to processing facilities or transmission pipelines. These were historically small diameter, low pressure lines, but bigger lines have become more prevalent with the expansion of hydraulic fracturing. The unprocessed gas transported in gathering lines is comprised of 60-90% methane, with the remainder consisting of volatile organic compounds (VOCs) and other health harming pollutants.[2] PHMSA recently expanded oversight of gathering lines, but most of this infrastructure is still federally unregulated. Only ~30,000 miles are currently subject to federal leak survey standards.
Transmission	~300,000	Transmission pipelines are large diameter, high pressure pipelines that transport natural gas long distances from production areas to city gates and large end users, like power plants. Transports pipeline-grade gas (95% methane; source)
Distribution	~2,330,000	Distribution pipelines are generally small diameter, low pressure pipelines that transport gas in local networks to end users such as residential and commercial buildings, industrial users, and power plants. This infrastructure is located in neighborhoods and communities, making Transports pipeline-grade gas (95% methane; source)

Pipelines Are Leaking More Methane Than Previously Estimated

According to EDF's analysis, natural gas pipelines nationwide are leaking as much as 2.6 million tons of methane each year, which has the same climate impact as nearly 50 million passenger cars driven for a year on near-term warming scales. Through established data collection methods and technologies, researchers have been able to improve understanding of methane leakage from natural gas pipelines. EDF's analysis, based on published field survey data and known characteristics of U.S. pipeline infrastructure, indicates that methane emissions from gas pipeline leaks are significantly higher than current estimates by the U.S. Environmental Protection Agency's Greenhouse Gas Inventory ("GHGI"). Measurement and quantification of methane emissions from oil and gas infrastructure is continuously improving as state-of-the-art technologies and analytical approaches are developed and deployed.

ANNUAL METHANE EMISSIONS FROM U.S. PIPELINE LEAKS (IN METRIC TONS)		
	EDF Analysis	EPA 2022 GHGI
Gathering	482,000 – 1,890,000	127,000
Transmission	6,400	3,300
Distribution	761,000	203,000
TOTAL	1,250,000 – 2,660,000	333,000

To develop accurate emissions estimates using publicly available data, EDF relies on emission factors from recent peer-reviewed research that present methane measurements from extensive field survey campaigns of pipeline infrastructure. The research includes analysis of over 4,000 leak indications on distribution pipelines and over 500 emission sources on gathering pipelines.[3] EDF estimates that U.S. onshore gas pipeline methane leakage is between 3.75 times and 8 times greater than estimated by EPA.

EDF estimates that U.S. onshore gas pipeline methane leakage is between 3.75 times and 8 times greater than estimated by EPA

In the EPA GHGI, pipeline leakage estimates for gathering, transmission, and distribution segments are based on leak rate data from only two small studies in the distribution segment. For distribution pipelines, the GHGI emissions rates are taken from a study of only 230 leaks in that segment. For gathering and transmission pipelines, leak rates are based on a 1996 study detailing measured emissions from just 64 leaks in distribution main pipelines. Constructing emissions estimates for the vast nationwide network of pipelines from such a small number of measurements of exclusively distribution pipelines can be expected to lead to significant inaccuracies. Furthermore, the assumption that leak rates will be similar across gathering, transmission, and distribution pipelines is not substantiated by research. The details of the EDF analysis, in comparison with the EPA GHGI approach, are discussed further in the Methodology section below.

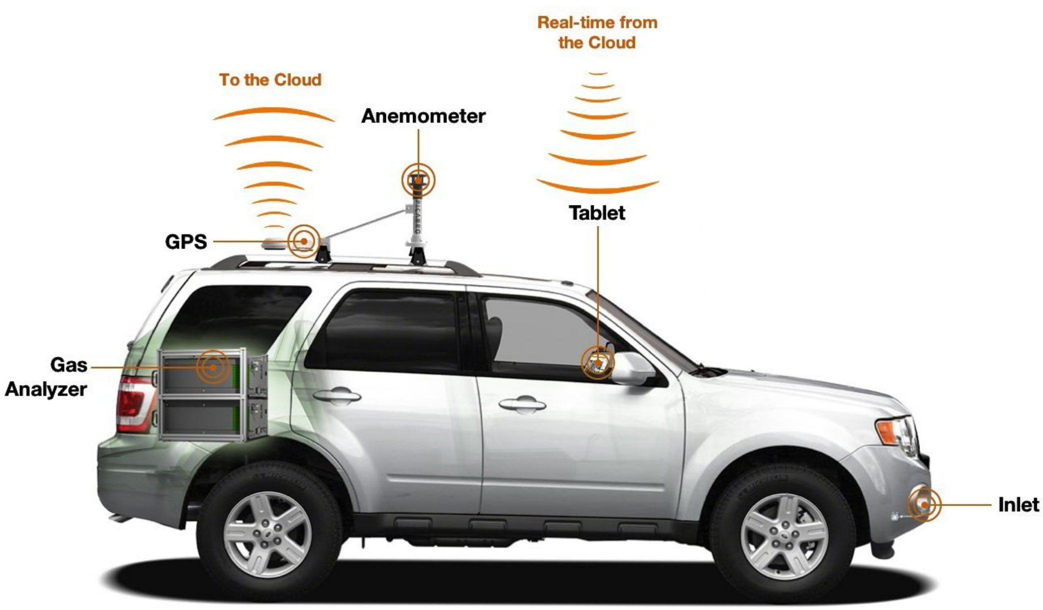
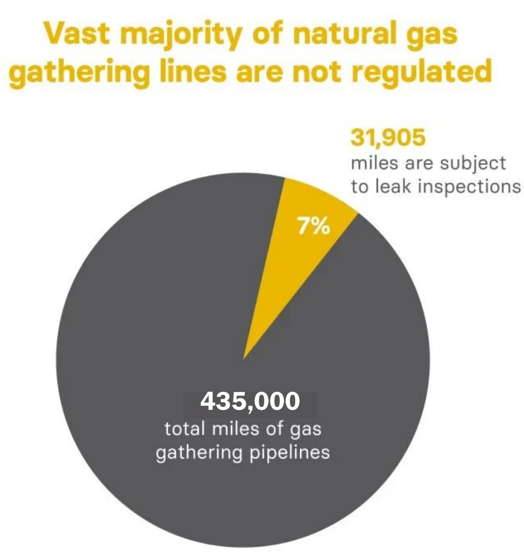


Diagram of vehicle-based advanced leak detection used for distribution systems. Source: Picarro

As methane detection technologies have become more widely available and effective in recent years, researchers are able to continue to improve quantification of emissions from pipeline leaks. Pipeline operators can also deploy these advanced leak detection technologies to find and fix more leaks on their systems.

POLICY RECOMMENDATIONS TO REDUCE LEAKAGE FROM PIPELINES

The Biden-Harris Administration has adopted strong goals to reduce U.S. greenhouse gas emissions 50-52% by 2030 (below 2005 levels), and to specifically reduce methane emissions 30% by 2030 (below 2020 levels). To achieve this goal, one necessary component of a national methane strategy will be to develop federal protections to address methane leaks on pipelines. The U.S. Methane Emissions Reduction Action Plan identifies the importance of addressing pipeline methane emissions through a series of actions by the Pipeline and Hazardous Materials Safety Administration (PHMSA), the pipeline oversight agency within the U.S. Department of Transportation. Congress also recently recognized the importance of rapidly reducing methane emissions from the oil and gas sector by enacting the Methane Emissions Reduction Program as part of the Inflation Reduction Act.[4] That program places a charge on the most excessive emissions from large polluters in certain industry segments and was designed to complement regulatory action.



Current federal standards only require operators to fix pipeline leaks if they pose an immediate safety hazard. Thus, many large leaks that are a major source of climate pollution—and could pose a safety risk—are allowed to persist on pipelines for years because they are not classified as imminently hazardous. Furthermore, many pipeline operators are still using legacy leak survey methods despite the commercial availability of advanced leak detection technology, which has been proven to identify more gas leaks.

A priority action that will address this gap is a rulemaking to improve oversight of pipeline methane leaks. In the PIPES Act of 2020, Congress directed PHMSA to act quickly to set standards requiring gas pipeline operators to use advanced leak detection ("ALD") to more effectively find and fix leaks. With U.S. natural gas pipelines leaking as much as 2.6 million tons of methane per year, a strong advanced leak detection rule is urgently needed to protect the environment and improve safety. PHMSA issued a proposed rule in May 2023 that calls for more frequent pipeline leak surveys, more leaks to be repaired more quickly, and more modern technologies to be used to find pipeline leaks.[5]

METHODOLOGY

This section summarizes typical approaches to estimating methane emissions from pipeline infrastructure and presents the detailed approach and data sources for this analysis. Emissions quantifications are often referred to as "bottom-up," referring to the traditional emission inventory approach that relies primarily on component-level emission factors and engineering equations, or "top-down," referring to the use of atmospheric measurements to estimate emissions at larger spatial scales.[6] The EPA GHGI and many quantification programs use a bottom-up approach to estimate pipeline emissions. For this approach, generally an emission rate (methane emissions per leak per year) is multiplied by an activity factor (leaks per mile of pipe material) and multiplied by the number of miles of each pipeline material. This equation yields an estimate of the annual methane emissions from a defined mileage of pipelines. Such calculation-based methane emission inventories have been found to underestimate real emissions.[7]

Recently, in enacting the Inflation Reduction Act, Congress recognized the inaccuracies of EPA's existing emission factor-based approaches to estimating methane emissions and directed the agency to revise its methane reporting methods. Specifically, Congress directed EPA to ensure that reporting is (1) "based on empirical data," (2) "accurately reflect[s] the total methane emissions and waste emissions from the applicable facilities," and (3) allows owners of the applicable facilities "to submit empirical emissions data, in a manner to be prescribed by [EPA]."[8] EPA is currently in the process of revising its methodologies to fulfill this directive and move toward measurement-based reporting for oil and gas sources, including pipelines.

EDF is planning continued scientific analysis and direct measurement to improve the accuracy of oil and gas sector methane emissions. While those efforts are ongoing, newer studies that are not reflected in EPA's GHGI estimates shed additional light on the extensive emissions from pipeline infrastructure. These studies improve upon EPA GHGI estimates for methane leakage from pipelines, which are based on data that are outdated, tend to represent a very small sample size, and fail to appropriately characterize the heavy tail of methane emissions distributions. To develop more accurate emissions estimates, EDF relies on emission factors from recent peer-reviewed research that use methane measurements from extensive field survey campaigns of pipeline infrastructure. We expect to gain further insights based on ongoing measurement efforts that will help to further refine these estimates.

Gathering Pipelines

EPA Approach. The EPA GHGI derives its gas gathering pipeline emission factor (kg of methane / mile) from gathering pipeline mileage and leak data reported by operators through the EPA Greenhouse Gas Reporting Program ("GHGRP") Subpart W. Under GHGRP Subpart W, operators are required to calculate and report their gathering pipeline methane emissions using EPA-defined emission rates (standard cubic feet of methane / hour / mile of pipeline)—which differ based on pipeline material—applied to data about the operator's system. The emission rates set by EPA for GHGRP Subpart W are from an EPA/GRI 1996 study [9] based on a small sample of measured data obtained from distribution mains (only 64 leaks), and an EPA-generated estimate for the number of leaks per mile of gathering pipelines by material. Thus, GHGI emission estimates for gathering pipeline leaks are not based on any direct leak measurement of gathering lines. Instead, EPA GHGI rely upon a circular estimate that derives an emission factor based on EPA-provided emission rates and operator reported pipeline mileage by material.

EDF Analysis. Gathering line leak emissions are estimated using emission factors ("EF") calculated in Yu et al. 2022.[10] As part of the PermianMAP project, oil and gas infrastructure was surveyed in four aerial campaigns during 2019-2021 using aircraft equipped with a sensor capable of imaging and quantifying large plumes of methane. The flights surveyed more than 10,000 miles of gathering pipelines in each campaign, identifying hundreds of high-emitting pipeline sources.

Our analysis identifies a range of possible emissions estimates from gathering lines depending on how broadly we apply estimates from Yu 2022. The lower bound estimate applies the Yu 2022 EF of 2.7 MT/km, the most conservative EF from 2021 in the study, to the mileage of gathering lines located in the Permian Basin, estimated using information from the Enverus database, and otherwise applies the EPA GHGI EF to the remaining mileage of US gathering lines. Due to the reliance on GHGI EF's for outside the Permian, this lower-bound estimate is likely conservative since typical inventory approaches often underestimate total methane emissions (Alvarez et al 2018). The higher estimate applies the Yu 2022 EF of 2.7 MT/km to the mileage of all US gathering lines. A multi-basin aerial study, Cusworth et al. (2022) finds significant gathering line emissions in regions beyond the Permian.[11] For example, their gathering line observations in regions like the Marcellus are similar to those in the Permian, though regions like the Denver-Julesburg basin have proportionally few gathering pipeline emissions sources in this study. Because the majority of nationwide gathering lines are located in Texas, the same local regulatory environment as the Permian, and lower-emitting areas such as the Denver-Julesburg have a small fraction of gathering lines, it is possible that the upper-bound is not a significant overestimation nationally. More empirical assessments of pipelines across other basins are needed to fully assess if current measurements are presentative of gathering pipelines nationally.

Transmission Pipelines

EPA Approach. The EPA GHGI uses the same EPA/GRI 1996 study for emission factors for gas transmission pipelines. Similar to the approach for gathering pipelines, this study uses the same small sample of measured data from distribution mains and incorporates number of leaks in transmission pipelines, by pipeline material, derived from walking surveys of transmission pipelines. This approach makes the explicit assumption "that the leak rates from transmission pipelines are identical to leak rates from distribution mains."

EDF Analysis. To estimate transmission pipeline leakage in the absence of transmission pipeline data, EDF uses the same analytical approach used in the EPA GHGI, but with more up-to-date emission factors. The Weller et al. 2020 paper found higher emission rates from leaks in distribution main pipelines than the EPA/GRI study, based on extensive field surveys across the country using advanced leak detection technology and analytics.[12] Since the EPA/GRI study assumed that distribution main emission rates per leak were equivalent to transmission pipelines emission rates per leak, EDF used Weller et al. emissions rates per leak to update transmission pipeline emission factors in a similar fashion.

Additional data can help to improve understanding of emissions from transmission pipelines, as reflected in both the EPA GHGI approach using the EPA/GRI 1996 study protocol, and the updated EDF analysis using Weller et al. 2020 emission factors within the same protocol. Thus, although the best available estimates appear to indicate that leakage is lower on transmission pipelines compared to gathering and distribution pipelines, improved leak survey and reporting requirements could help to shed light on the scale of leakage from this extensive infrastructure.

Distribution Pipelines

EPA Approach. The current EPA GHGI estimate of fugitive methane emissions from local distribution systems is based on two studies: the EPA/GRI 1996 study referenced earlier and one conducted by Lamb et al. in the early 2010s. The GHGI derives emission rates (scf/leak/hour) for distribution mains and services from the Lamb et al study (based on direct measurements of 230 leaks). For activity data (leaks per mile of pipeline material), the EPA relies on the GRI/EPA 1996 study, which is based on historic leak repair data and reported leak data provided by a small subset of companies. Two limitations of this approach are the missing characterization of the upper tail of leak emission rates and the reliance on activity data derived from traditional leak survey approaches. Several studies[13] have shown that a small number of emission sources, so-called "super-emitters", account for a significant amount of emissions across the natural gas supply chain. A large sample size is necessary to adequately observe these infrequent but significant emission events in order to develop accurate emission rates. Additionally, studies[14] have indicated that advanced mobile leak detection (methane analyzers on vehicles) are better able to identify leaks than traditional walking surveys, which means traditional approaches would result in an underestimation of leaks in natural gas distribution systems.

EDF Analysis. For the EDF Analysis, the methane emission estimates for distribution mains pipelines are sourced from Weller et al. 2020,[15] which developed emission factors based on a significant number of leak data points (over 4,000) and applied them to nationwide pipeline material data for distribution mains. The Weller 2020 emission factors were developed based on a survey of local natural gas distribution systems conducted using high-sensitivity methane sensors placed in Google Street View cars, deployed in twelve U.S. metropolitan areas. The study used the data collected during these surveys from four U.S. urban areas where pipeline GIS information was also obtained, allowing for incorporation of additional information about the installed pipeline segments including the pipe material, installation date, pipe diameter, and operating pressure. The emissions estimates for distribution services pipelines are taken from the GHGI, in the absence of more recent data.

NOTES

1 IPCC AR6, WG 1, The Physical Science Basis at 7-125.

2 U.S. EPA, Analysis of Average Methane Concentrations in the Oil and Gas Industry Using Data Reported Under 40 CFR part 98 Subpart W, (April 9, 2020), https://www.regulations.gov/document/EPA-HQ-OAR-2017-0757-2682.

3 There are currently no peer-reviewed studies or other publicly available datasets focused on identifying and quantifying methane leaks on gas transmission pipelines.

4 42 U.S.C. § 7436.

5 U.S. Dep't of Transportation, PHMSA, Proposed Rule: Pipeline Safety: Gas Pipeline Leak Detection & Repair, 88 Fed. Reg. 31890 (May 18, 2023).

6 EDF, Hitting the Mark: Improving the Credibility of Industry Methane Data at p10 (Feb. 2020), https://storage.googleapis.com/edfbiz_website/Oil%20Gas%20Methane/Hitting-the-Mark.pdf.

7 Alvarez et al., Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain, 361 Science 186 (2018), https://science.sciencemag.org/content/361/6398/186; Rutherford et al., Closing the Methane Gap in US Oil and Natural Gas Production Emissions Inventories, 12 Nature Comms. 4715 (2021),

8 42 U.S.C. § 7436(h).

9 EPA Research & Development, National Risk Management Research Laboratory & Gas Research Institute, Report: Methane Emissions from the Natural Gas Industry, Vol. 2: Technical Report (June 1996), https://www.epa.gov/sites/default/files/2016-08/documents/2_technicalreport.pdf ["EPA/GRI 1996 Study"].

10 Yu et al., Methane Emissions from Natural Gas Gathering Pipelines in the Permian Basin, Environ. Sci. Technol. Lett. 2022, 9, 11, 969–974, https://doi.org/10.1021/acs.estlett.2c00380

11 Cusworth et al., Strong methane point sources contribute a disproportionate fraction of total emissions across multiple basins in the United States, PNAS 119 (38) e2202338119 (2022), https://doi.org/10.1073/pnas.2202338119.

12 Weller et al., A National Estimate of Methane Leakage from Pipeline Mains in Natural Gas Local Distribution Systems, Environ. Sci. Technol. 2020, 54, 8958−8967, https://pubs.acs.org/doi/pdf/10.1021/acs.est.0c00437.

13 A.R. Brandt, Methane Leaks from North American Natural Gas Systems, Vol 343, Issue 6172, p733-735 (2014), https://www.science.org/doi/10.1126/science.1247045; Zimmerle et al., Methane Emissions from the Natural Gas Transmission and Storage System in the United States, Environ. Sci. Technol. 2015, 49, 15, 9374–9383, https://doi.org/10.1021/acs.est.5b01669; Hendrick et al., Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments, Vol. 213, p710-716, 2016, https://doi.org/10.1016/j.envpol.2016.01.094.

14 Weller et al., Vehicle-Based Methane Surveys for Finding Natural Gas Leaks and Estimating Their Size: Validation and Uncertainty, Environ. Sci. Technol. 2018, 52, 20, 11922–11930, https://pubs.acs.org/doi/10.1021/acs.est.8b03135.

15 In the recent Subpart W rulemaking, EPA acknowledges the Weller et al. study and proposes to update GHGRP reporting requirements based on aspects of that study. For distribution mains, EPA proposes to continue to use leak rates (scf/hr/leak) from the Lamb et al. study and to update to use leak frequency (leak/mile-yr) from the Weller et al. study. EPA asserts that the quantification of advanced leak detection from Weller et al. does not appear to be as accurate as the standard measurement method used in Lamb et al. EPA solicits feedback on this combined approach and whether it is preferable to relying exclusively on one of those two studies. While there is significant uncertainty in the quantification of individual leak indications, the Weller et al. approach is a robust approach to quantifying emissions from a population of leak indication (e.g., local distribution network within a city). Maazallahi et al. performed additional work comparing methods in Hamburg, Germany, and showed the importance of Weller et al. approach to identify leaks and provide robust estimate of emissions from population of leaks. Since the development of the approach from Weller et al., a similar method has been applied to several other cities around the world: Hamburg and Utrecht, Bucharest, and Paris.