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Environmental, public health, and safety assessment of fuel pipelines and other freight transportation modes

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HIGHLIGHTS

- Externalities are examined for pipelines, truck, rail, and barge.
- Safety impact factors include incidences of injuries, illnesses, and fatalities.
- Environmental impact factors include CO_2eq emissions and air pollution disease burden.
- Externalities are estimated for constructing and operating a large domestic pipeline.
- A large pipeline has lower cumulative impacts than other modes within ten years.

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ABSTRACT

The construction of pipelines along high-throughput fuel corridors can alleviate demand for rail, barge, and truck transportation. Pipelines have a very different externality profile than other freight transportation modes due to differences in construction, operation, and maintenance requirements; labor, energy, and material input intensity; location and profile of emissions from operations; and frequency and magnitude of environmental and safety incidents. Therefore, public policy makers have a strong justification to influence the economic viability of pipelines. We use data from prior literature and U.S. government statistics to estimate environmental, public health, and safety characterization factors for pipelines and other modes.

In 2008, two pipeline companies proposed the construction of an ethanol pipeline from the Midwest to Northeast United States. This proposed project informs our case study of a 2735-km $3.5 billion pipeline (2009 USD), for which we evaluate potential long-term societal impacts including life-cycle costs, greenhouse gas emissions, employment, injuries, fatalities, and public health impacts. Although it may take decades to break even economically, and would result in lower cumulative employment, such a pipeline would likely have fewer safety incidents, pollution emissions, and health damages than the alternative multimodal system in less than ten years; these results stand even if comparing future cleaner ground transport modes to a pipeline that utilizes electricity produced from coal. Monetization of externalities can significantly enhance the value of a pipeline to society. In this study, a pipeline with a construction cost of $1.37 million/km in 2014 USD and a NPV of revenue over 22.2 years of $1.85 million/km would be associated with $0.5–$1.3 million/km in avoided negative externalities—the majority of which are expected from avoided air pollution-related deaths ($0.26–$1.0 million/km) and avoided GHG emissions ($0.12–$0.19 million/km).

1. Introduction

In the United States, much of the new biofuel and unconventional fuel production capacity is being developed in central regions of the country, while demand for fuels is greatest along the densely populated coasts. Liquid fuel transportation by rail has been growing rapidly in recent years, including from the Midwest to East Coast of the United States [1], with accidents and congestion concerns often making headlines. Meanwhile, proposals to construct new pipelines often meet vocal public resistance. In light of the increasing need to transport large quantities of fuels

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hundreds of kilometers to fuel terminals and retail stations, this analysis provides an objective evaluation of the strengths and weaknesses of each mode to foster long-term thinking on pipeline development.

Construction of new pipelines may enable transportation of fuels at a lower cost [2]—with fewer negative social and environmental impacts—than alternative transportation modes. Nonetheless, all modes have their strengths and weaknesses: trucks are faster and more widely available than other modes, but impractical for transporting large quantities of liquids; rail is relatively fast and can be cost-competitive with even large-diameter pipelines for fuels such as oil sands (which require the addition of diluent and heat to facilitate pumping [3]); and maritime transportation is often priced competitively with pipelines, but is limited to available waterways and is typically slower than rail and truck transportation.

Several recent publications report estimated costs and benefits of building pipelines for the transportation of oil [4], biofuels [5], natural gas [6], and carbon dioxide (CO_2) [7,8]. These models are useful for estimating and optimizing the life-cycle costs of pipeline projects, but there remains a need to understand and compare life-cycle costs of each mode, including externalities such as environmental, public health, and safety impacts. Life-cycle assessment (LCA) has long been used to inform energy system design and management tradeoff decisions, often yielding counterintuitive results on the externalities associated with alternative processes or products [9]. A recent LCA study highlighted that the greenhouse gas (GHG) emissions intensity of a pipeline relative to other modes depends largely on the same criteria that impact a project's economic viability: location; length and diameter of the pipeline; type and volume of fuel transported; utilization rate and lifespan of the pipeline; and existence of nearby competing alternatives [10].

As pipelines essentially enable the electrification of fuel transportation, this study complements research on externalities associated with the electric grid and electrification of freight and passenger transportation. Reductions in the GHG intensity of electric grids can contribute to meeting other environmental objectives, like reducing criteria air pollutants (CAP) that adversely impact human health [11,12]. When monetized, human health benefits of U.S. carbon [13] (and specifically renewable energy [14]) policies could offset a substantial fraction of the cost of implementation. Electrification of transportation does not always lead to reductions in both GHG and CAP emissions. As one example, life-cycle SO_x emissions would increase substantially if freight rail is electrified [15]; however, emissions alone are not indicative of impacts, as public health impacts depend on the quantity, type, and location of emissions [16]. In evaluating the impacts of electrifying school buses, public health outcomes were estimated to be comparable in value to GHG emission reductions—together valued at close to $1,000/year per bus [17].

This paper contributes an evaluation of the externality profiles of the major fuel transportation modes, and presents a framework for evaluating new infrastructure projects against existing alternative options. Previous literature on the economics, environmental, public health, and occupational safety impacts of different modes of freight (or specifically fuel) transportation, and sector-specific industry statistics from U.S. government databases, inform our characterization of life-cycle impacts from large-diameter pipelines and other modes for transporting liquid fuels. Through the generation of characterization factors for each mode, we evaluate the average externality impacts of fuel transportation modes in the United States per unit of functional activity. These factors are then applied to a location-specific case study in which the status quo method of transporting biofuels—rail, truck, and barge—is compared to the short- and long-term impacts associated with constructing and operating a new long-distance pipeline.

As a preview of results, we find that under our most conservative set of assumptions, after 22.2 years of operating (at which point the pipeline becomes marginally profitable for the private operator), the pipeline would result in less than half as many GHG emissions, less than 27% as many air pollution related fatalities, 32% as many construction and operation related injuries and illnesses, 29% as many construction and operation related fatalities, and 37% as much employment as the status quo surface transportation system. We find that the pipeline would enable the avoidance of more than $1.2 billion in monetized externalities, mostly driven by the reduction in air pollution that results from shifting the source of combustion emissions from trucks and locomotives to electricity production sources.

2. Methodology

The methods for characterizing the externalities associated with each mode draw upon previous literature on life-cycle assessment for estimating GHG emissions of construction and operation of transportation systems; air pollution dispersion and exposure modeling to estimate the public health disease burden of criteria air pollutant emissions; and economic input–output analysis to parameterize employment, occupational injuries, illnesses, fatalities, and hazardous material spills from the transportation/industrial sectors. Each of these metrics, other than hazardous material spills, were monetized using previous estimates from the economics literature. For all scenarios modeled, GHG emissions were valued using the social cost of carbon as reported by the US Federal Government Interagency Working Group on the Social Cost of Carbon (IAWG). We use their reported average values using a 3% discount rate, which range from $39 to $63 in 2014 USD for emissions in 2014–2037 [18]. We further discount the future values back to 2014, also at 3%, to arrive at present values for the emissions for each scenario, resulting in discounted GHG values ranging from $33 to $39 per t CO_2eq in 2014 USD from 2010 to 2033, which can be found in Table A8. After estimating the marginal increase in disease burden attributed to air pollution, the value of human lives lost is monetized by following methods used by the U.S. government's regulatory agencies; occupational fatalities are also valued according to this method. Non-fatal occupational injuries and illnesses are valued by synthesizing literature on the average financial and personal burdens imposed on society from injuries and illnesses (that are not fully borne by industry). These methods—which are explained in more detail in the following sections—allow pipelines and other modes to be characterized in a manner that enables consistent comparison.

2.1. Pipeline construction, maintenance, and (pumping) operations

We estimate the GHG emissions intensity of pipeline construction, maintenance, and operations following the methods of Strogen et al. [10]. Annual emissions and costs associated with maintenance are assumed to be equal to 3% of the initial construction emissions and costs, respectively. Pipeline pump stations are assumed to be electrically powered and operate continuously 90% of the time (and are down for maintenance 10% of the time); pumping power requirements are a function of pipeline geometry, fluid properties, and velocity. In order to assess the economic viability of a pipeline project, the net present value (NPV) of earnings before taxes, depreciation, and amortization is estimated by discounting future cash flows in the equation adapted from Strogen et al. [10], $NPV = (R_t - C_{O\&M})/r * [(1+r)^{-nc} - (1+r)^{-(nc+no)}] - C_C$, which accounts for annual transportation tariff revenues (R_t); annual operation and maintenance costs ($C_{O\&M}$); the construction period, in years, between initial investment and commencement