Geospatial, temporal and economic analysis of alternative fuel infrastructure: The case of freight and U.S. natural gas markets

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Executive summary

The recent emergence of natural gas as an abundant, inexpensive fuel in the United States has the potential to prompt a momentous shift in the level of natural gas utilized in the transportation sector. Natural gas is already a popular fuel for short-haul, urban municipal and fleet vehicles such as garbage trucks, transit buses, and taxis. Long distance freight could be the next logical place for natural gas to expand penetration. We choose natural gas as a proxy for alternative fuels to highlight factors other than relative fuel cost which is often the focus of alternative fuels modeling. Natural gas requires new fueling infrastructure and vehicle stocks like many alternative fuels but the fuel itself is less expensive than the oil-based incumbent - diesel fuel- and natural gas engine and fuel dispensing technologies are already proven. This allows researchers to consider more directly the variables influencing the adoption rate of alternative fuels other than fuel cost or technological risk.

Previous studies on alternative fuels have employed techniques such as optimization models which solve for generalized optimal supply chain configurations but do not take into account the competitive pressures of existing infrastructure or the spatial analysis of a specific application or location. Additional studies have contributed spatial models which identify optimal station configurations from a spatial perspective of a specific application or location in light of existing infrastructure, but do not account for the entire supply chain requirements and costs necessary to support those station locations. In our methodology, we combine the two which allows for direct comparison of economic factors in the context of optimal spatial configurations. This approach allows us to expand the types of inference and conclusions that can be compared.

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We add to the literature by utilizing an optimization solution that is able to consider both spatial and temporal aspects of alternative fuel adoption within a framework that simultaneously considers the economic competitiveness of its full supply chain against the full depreciated supply chain of the incumbent fuel. Our optimization solution further contributes to existing modeling science by applying network analysis to reduce the number of potential candidate locations for new infrastructure from infinitely many to a finite number of reasonable choices given. We combine and augment these approaches in our study to take into account spatial data of existing infrastructure as well as the economic and technological requirements of the supply chain and to evaluate inter-temporally a buildout solution over a multi-period time horizon. Our methodology allows for the comparison of supply chain cost considerations against spatial criteria to reveal the most important determinants of alternative fuel refueling development. This comparison was not possible with the generalized mathematical optimization method or spatial analysis method used alone. Our aim is to determine the most profitable transportation networks and locations for natural gas flows into transportation markets nationwide.

Using this new methodology, our paper demonstrates that flow rates take precedence over proximity to surplus resources. We find that the level of profitability of alternative fueling infrastructure, in the case of natural gas, is more highly correlated with access to a high volume of traffic flows of freight movements than with the locus of surplus fuel feedstock supplies such as the shale formations in Texas or Oklahoma. Our results show that for natural gas trucks, California, the Great Lakes region, and the Mid-Atlantic are superior areas for natural gas refueling development because of large traffic flows and high diesel prices. These implications hold for other alternative fuels such as hydrogen because these characteristics are not specific to natural gas, rather they identify regions that could offer the largest potential economies of scale and highly priced incumbent fuel against which an alternate can more easily compete.

Keywords natural gas, spatial optimization, alternative fuels, fuel infrastructure.

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