Future US Ethanol Transportation Network Design and Performance

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ABSTRACT

In this paper, alternative future U.S. ethanol transportation networks including ones with ethanol pipelines are compared. The network is modeled as a cost-minimizing, transportation problem with a linear objective function and linear constraints. The network includes nodes, locations where ethanol is imported, exported, produced and consumed, for each state, Canada, Mexico, Brazil, and the rest of the world. Nodes are connected by capacitated arcs that correspond to existing or potential truck, rail, barge, or pipeline connections. Ethanol production and use by state data is taken from the Energy Information Administration, US ethanol imports and exports by port is taken from the Census Bureau, and transport prices are available from public and private sources. Solutions to the linear program provide understanding of the feasibility and advantages of alternative ethanol transportation networks. Simulation is used to estimate the impact of varying transport costs, and quantities supplied and demanded on network performance including the flexibility of networks to address short- and long-term market conditions. Interpretation of shadow prices and slack variables are used to gauge the sensitivity of solutions. Scenarios including growth in state, domestic, and international ethanol production and consumption; and state or federal mandates, such state low carbon fuel standards or advanced biofuel use mandates are considered.

KEYWORDS

Ethanol, transportation, network economics

1. INTRODUCTION

Transportation of ethanol in the United States has increased dramatically in the last decade as the Renewable Fuel Standard supported the development of the domestic corn-ethanol industry and import of Brazilian sugar cane-ethanol. Currently, interstate transportation of ethanol is dominated by rail, followed by truck and barge (Citation), with each mode having unique attributes and advantages in terms of cost, flexibility, and reliability for different trips.

Despite claims otherwise, ethanol can and is being moved by pipeline. In Brazil, an ethanol pipeline has been in use since 2013 connecting interior ethanol refineries with the Port of Santos and global markets (citation). While an ethanol pipeline is technically feasible in the United States and a project to move ethanol from Midwest biorefineries to the East Coast by pipe have been under consideration for a decade (citation), no projects are currently under development.

In this paper, alternative future U.S. ethanol transportation networks including ones with ethanol pipelines are compared. The network is modeled as a cost-minimizing, transportation problem with a linear objective function and linear constraints. The network includes nodes, locations where ethanol is imported, exported, produced and consumed, for each state, Canada, Mexico, Brazil, and the rest of the world. Nodes are connected by capacitated arcs that correspond to existing or potential truck, rail, barge, or pipeline connections.

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2. METHODS AND DATA

2.1. Network Model

The network consists of nodes: corn ethanol refineries, CER_i, and customers, C_j, of various types including refineries, wholesale racks, retailers with blend pumps, export terminals. Arcs connecting these nodes are highway, railroad, inland waterway, and pipeline networks. It is assumed that trips do not span one at most.

$$Max\ p_{zj} \sum_n z_{nj}$$

$$- \left[\sum_i \sum_k c_{ik} x_{ik} + \sum_i \sum_l c_{il} x_{il} + \sum_k \sum_l c_{kl} x_{kl} + \sum_l \sum_m \sum_t c_{lmt} y_{lmt} \right.$$

$$+ \sum_l \sum_n \sum_t c_{lnt} y_{lnt} + \sum_m \sum_n \sum_t c_{mnt} y_{mnt} + \sum_n \sum_j \sum_t c_{njt} z_{njt}$$

$$+ \sum_k c_k \left(\sum_i x_{ik} \right) + \sum_l c_l \left(\sum_i x_{il} + \sum_k x_{kl} \right) + \sum_m c_m \left(\sum_l x_{lm} \right)$$

$$\left. + \sum_n c_n \left(\sum_l x_{ln} + \sum_m x_{mn} \right) \right]$$

St

$$\sum_k x_{ik} + \sum_l x_{il} \leq a_i \ for\ all\ i$$

$$\sum_l x_{kl} \leq \sum_i x_{ik} \ \ for\ all\ k$$

$$\sum_m y_{lm} + \sum_n y_{ln} \leq g \left(\sum_i x_{il} + \sum_k x_{kl} \right) for\ all\ l$$

$$\sum_j z_{nj} \leq h \left(\sum_l y_{ln} + \sum_m y_{mn} \right) \ for\ all\ n$$

$$d_j \leq \sum_n \sum_t z_{njt} \ \ for\ all\ j$$

$$\sum_i x_{ik} \leq c_k \ for\ all\ k$$

$$\sum_{l} x_{il} + \sum_{l} x_{kl} \leq c_l \; for \; all \; l$$

$$\sum_{l} x_{lm} \leq c_m \; for \; all \; m$$

$$\sum_{l} y_{ln} + \sum_{m} y_{mn} \leq c_n \; for \; all \; n$$

Cij is the cost of transporting a unit of material from node i to node j (arc ij)

Xij is the units of material moved from node i to node j

G conversion factor from primary biomass to intermediate product

H conversion factor from intermediate product to final product

Consider backhaul

Added transportation option 1 or 2 for truck or rail to final customer.

Pzj is the price of product z in market j

Ck is the cost of piling or processing at node k (or l or m or n)

---Multiple feedstocks, multiple products.

2.2. Data

Ethanol production and use by state data from 2014 is taken from SEDS, the Energy Information Administration US ethanol imports and exports by port is taken from the Census Bureau, and transport prices are available from public and private sources.

2.3. Simulation

Vary production and demand proportionally by consumption by state.

Increase exports.

3. RESULTS

4. FINDINGS

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