MODELING NATURAL GAS LIQUID INFRASTRUCTURE IN THE UNITED STATES

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INTRODUCTION

Since 2007, the United States has seen a large increase in the production of natural gas from shale formations[1]. In addition to the methane produced at gas wells, natural gas liquids are also produced in large quantities during shale gas production. Natural gas liquids (NGLs) are composed of ethane, propane, butane, and pentane. All of these components can be separated from the methane and used as raw materials for the chemical industry. Ethane is of particular interest because it can either be used in ethylene crackers (chemical plants which produce ethylene) or rejected into the residential and commercial natural gas infrastructure.

This project will develop a model to visualize the spatial distribution of ethane production and consumption around the U.S.

As a result of the increase in natural gas and NGL production, the domestic chemical industry (specifically the use of ethane) has begun to change dramatically. By representing different components of the ethane industry, we can use the model to provide stakeholders with information about possibilities for changes in the industry as natural gas production (and consequently ethane production) increases in the U.S.

This model will be used for two applications for this project:
1) Design an optimum pipeline configuration to minimize the cost of transporting ethane to the chemical plants that use it as a feedstock.
2) Locate fractionation centers in optimal locations to serve demand

The first application involves transporting the ethane in the existing natural gas pipeline infrastructure from a supply node to a demand node. When ethane is transported in a natural gas pipeline (mixed in with methane), it must be separated from the methane stream at a fractionation center and then be sent to a demand node (chemical plant that uses ethane). The second application uses the model and an optimization algorithm to locate a small number of fractionation centers around the U.S. in the most economical manner to serve demand.

MOTIVATION

Currently, ethylene crackers use a heavier, petroleum-based feedstock (i.e. naphtha) instead of ethane. Because ethane is becoming more readily available in the U.S., there is an opportunity to displace petroleum feedstock use with ethane. This model will show a visual representation of the transportation requirements to get ethane to those demand locations.

Another motivation is the desire to direct development of NGL infrastructure in the most economical way. Right now, 75% of new NGL production will go to Mont Belvieu, Texas for fractionation[2]. Identifying new

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[1] http://www.eia.gov/dnav/ng/ng_prod_shalegas_s1_a.htm
[2] Smith, C. "US NGL infrastructure expansions follow shale development," Oil and Gas Journal, 3 Jun 2013

transportation opportunities could enable fractionation in different locations. Facilitating other parts of the country to receive NGLs would relieve some of the bottlenecks recently experienced in Mont Belvieu.[3, 4]

The recent announcement of new dedicated ethane transportation projects[5] totaling over 335,000 barrels per day demonstrates the large potential for uses of ethane. By understanding and utilizing a model, policy makers, pipeline operators, chemical companies, and others can gain information about the smartest way to expand infrastructure.

MODEL FORMULATION

SUPPLY AND DEMAND NODES

Production of ethane and other natural gas liquids from shale plays are expected to increase through 2035[6]. The location of domestic shale plays and the assessment of total barrels of NGLs are shown in Figure 1.
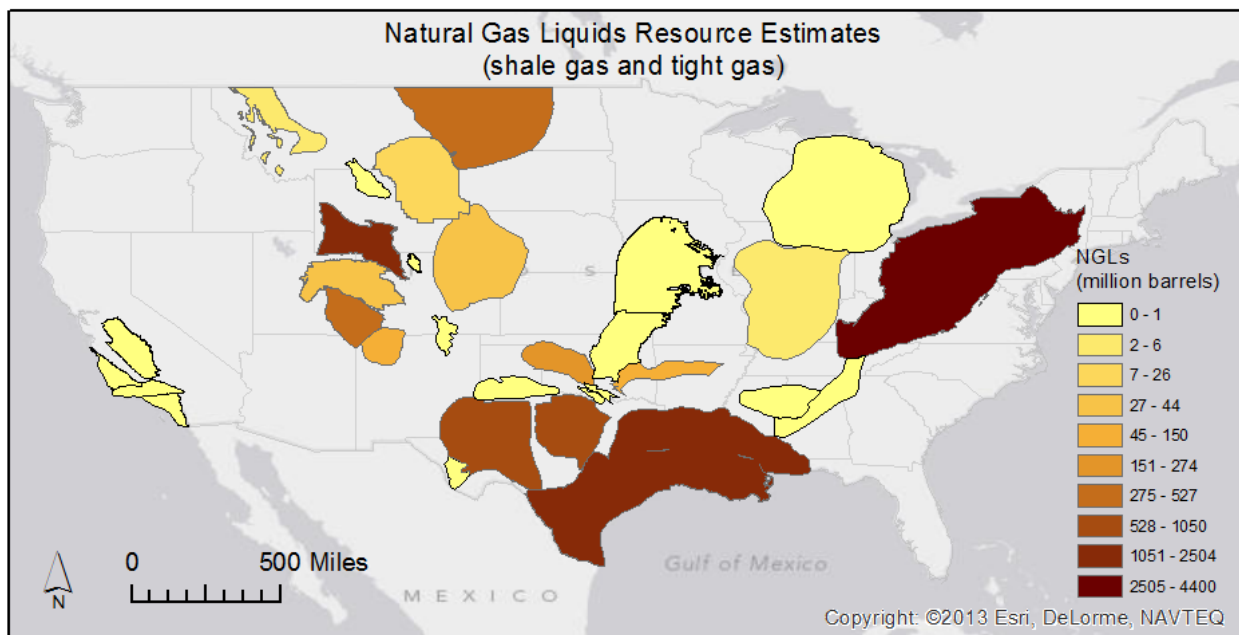
Figure 1: Shale plays in the United States. Shading shows million barrels of NGL resources (shale gas and tight gas, as estimated by USGS[7]).

[3] Fasullo, P. "Reshaping the NGL value Chain: Challenges and Opportunities," Annual GPA Convention, San Antonio, TX, 9 April 2013

[4] Smith, C. "US NGL infrastructure expansions follow shale development," Oil and Gas Journal, 3 Jun 2013

[5] Mariner West pipeline (65,000 bpd) from Pennsylvania to Sarnia; Mariner East pipeline (40,000 bpd) Pennsylvania to export terminal; Vantage pipeline (40,000-60,000 bpd) Bakken to Edmonton; ATEX pipeline (190,000 bpd) Marcellus to U.S. Gulf Coast; from Smith, C. "US NGL infrastructure expansions follow shale development," Oil and Gas Journal, 3 Jun 2013

[6] Paper #1-13 Natural Gas Liquids, National Petroleum Council, North American Resource Development Study, 2011
http://www.npc.org/Prudent_Development-Topic_Papers/1-13_NGL_Paper.pdf

The model will be constructed as connections between supply nodes (shale plays where ethane is produced) and demand nodes (chemical production facilities that require ethane). Supply nodes are placed at the center of each one of the 32 shale plays in the U.S., calculated using the ArcMap tool *Feature to Point*. Demand nodes are placed at the location of the 30 ethylene crackers in the United States[8]. The locations of the supply and demand nodes in relation to shale basins are shown in Figure 2.
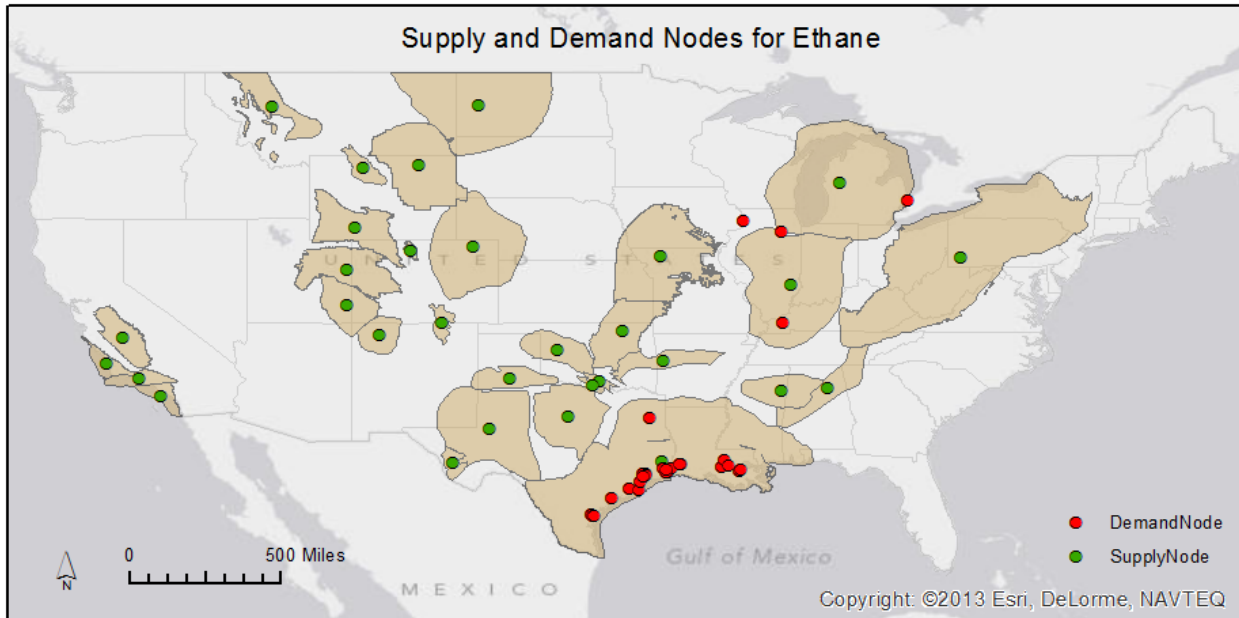
Figure 2: Supply nodes (green) and demand nodes (red) for the United States. Shale basin boundaries are also shown.
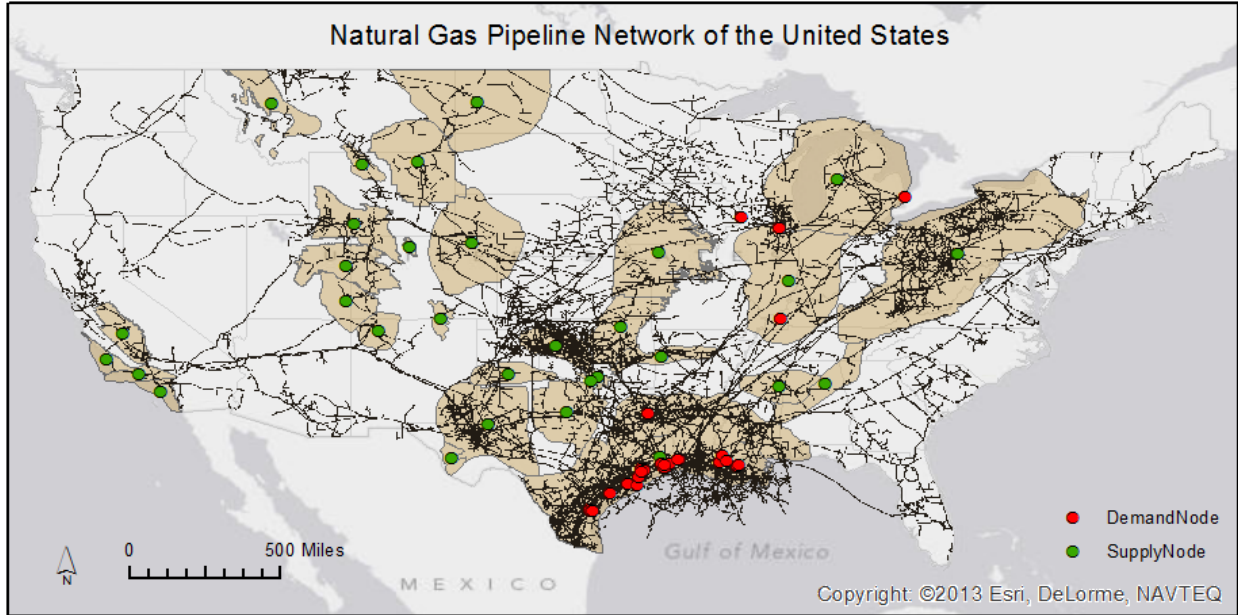
TRANSPORTATION

Ethane can be transported through the current natural gas pipeline infrastructure, so the connections between the supply and demand nodes are existing natural gas pipelines. Generalized pipeline routes are imported from ESRI[9] and converted to a raster using the ArcMap tool *Feature to Raster* with a cell size of 5000, as shown in Figure 3.

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[7] http://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment.aspx#.Uopp7Pmsim6
[8] Locations are from the IHS Directory of Chemical Producers http://www.ihs.com/products/chemical/companies/producers.aspx
[9] http://www.arcgis.com/home/item.html?id=c577ea2ee5e249f0b29eb8937e5363d7

**Figure 3:** Natural gas pipelines in the U.S. Supply/Demand nodes and shale basin boundaries are also shown.

APPLICATIONS

ROUTE CALCULATION

The network of pipelines is used to analyze the least cost path between each supply node and the closest demand node. To determine the best path, a series of Spatial Analyst tools are used. The pipeline routes are represented as a cost raster – cells that contain a pipe segment have a low cost and cells that do not have a pipe segment have a higher cost. Routes will be calculated to satisfy the constraint of minimizing accumulated cost, which will serve to minimize distance. Representing current pipelines as low cost will force any calculated route to travel where an existing pipeline is located[10].

The cost raster and demand nodes are inputs to the ArcMap tool *Cost Distance*, which provides a distance and backlink raster as outputs. For each cell, the backlink raster identifies the neighboring cell that has the lowest accumulative cost path. These rasters and the supply node locations are inputs to the ArcMap tool *Cost Path*, which provides a raster output representing the lowest cost path from each supply node to the closest demand node. Figure 4 shows the chosen pipeline routes.

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[10] The pipelines are generalized with a 5 km buffer, so exact pipeline locations are not represented by this model. The intent is to represent general pipeline locations and ethane movement.
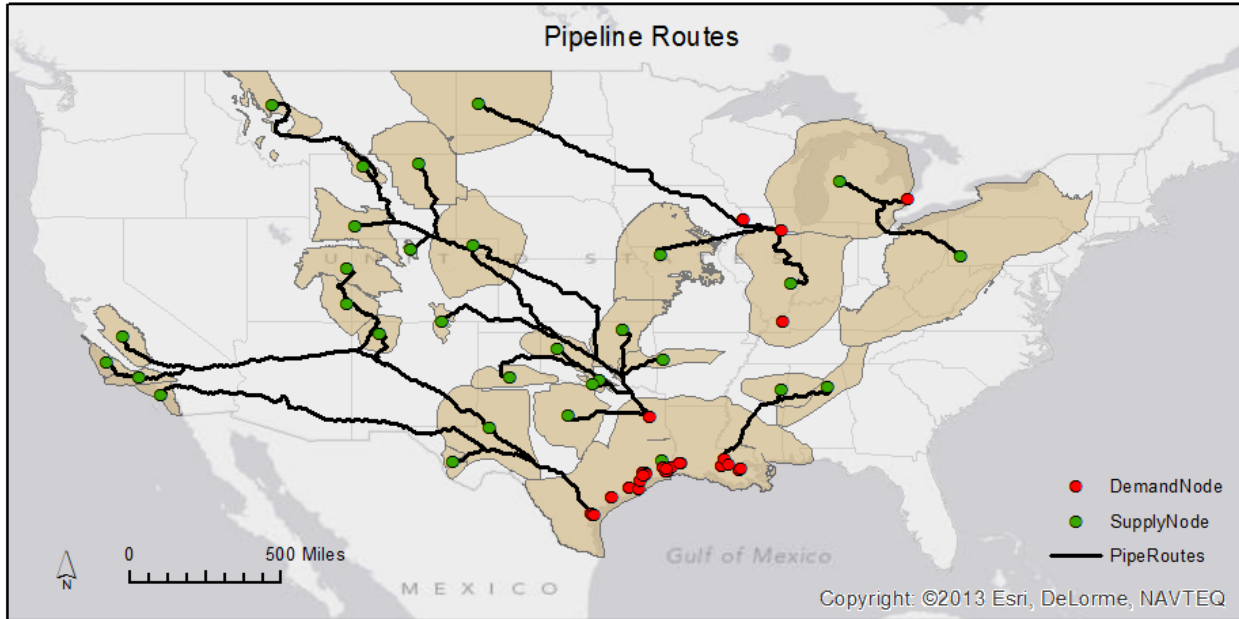
Figure 4: Pipeline routes that minimize cost while connecting each supply node to a demand node.

FRACTIONATION CENTER LOCATIONS

If ethane is to be transported in a methane stream in a natural gas pipeline, the ethane must be separated out before it can be used at a chemical plant. This separation is done at a fractionation center. Fractionation centers can service multiple demand points, so a small number of fractionation centers will be located around the country to reduce capital costs. The constraint on placement of fractionation centers is to minimize transportation cost of the separated ethane from the fractionation center to the demand point. Distance will be used as the proxy for transportation cost. So chosen locations must minimize the sum of the distance from each demand point to the closest fractionation center. To enable this calculation in ArcMap, a network of pipelines is created and then a Location-Allocation analysis is run in Network Analyst.

To create the network, the original pipeline raster of all natural gas pipelines in the U.S. is converted to polylines using the ArcMap tool *Raster to Polyline*. A new Network Dataset is created and the network is built with the demand locations on the network junctions. Figure 5 illustrates an example of the network around Houston, TX.
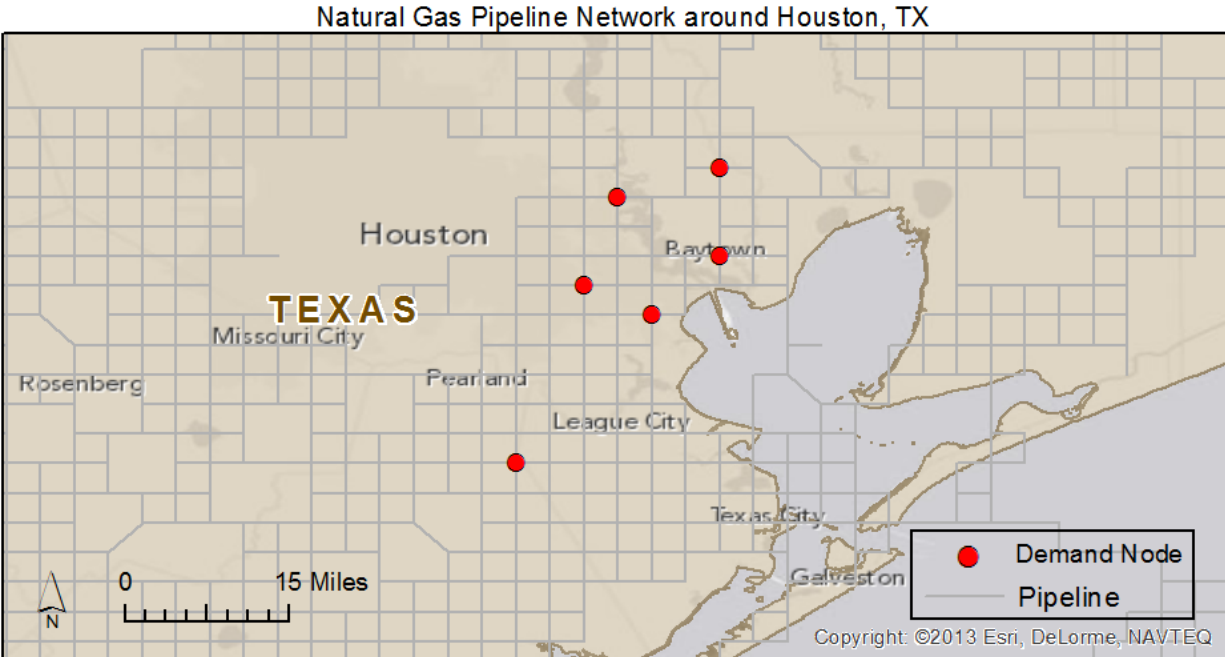
Figure 5: Houston, TX pipeline network with demand nodes.

To calculate the optimum location of the fractionation centers, a Location-Allocation layer is created with the pipeline polylines (network edges) added as Lines and the demand nodes added as Demand Points. The candidate facility locations are the network junctions within the extent of the demand node coverage area.

Eight facility locations will be chosen to account for the existing six major fractionation centers in the U.S.[11] and two additional options. The result of the Location-Allocation analysis is eight facility locations that minimize the total travel distance between every demand node and the closest fractionation center. The placement is shown in Figure 6 and the location data in Table 1.

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[11] Sarnia, Chicago, Conway, West Texas, Mt. Belvieu/Texas Gulf, and Mississippi River; from Paper #1-13 Natural Gas Liquids, National Petroleum Council, North American Resource Development Study, 2011 http://www.npc.org/Prudent_Development-Topic_Papers/1-13_NGL_Paper.pdf
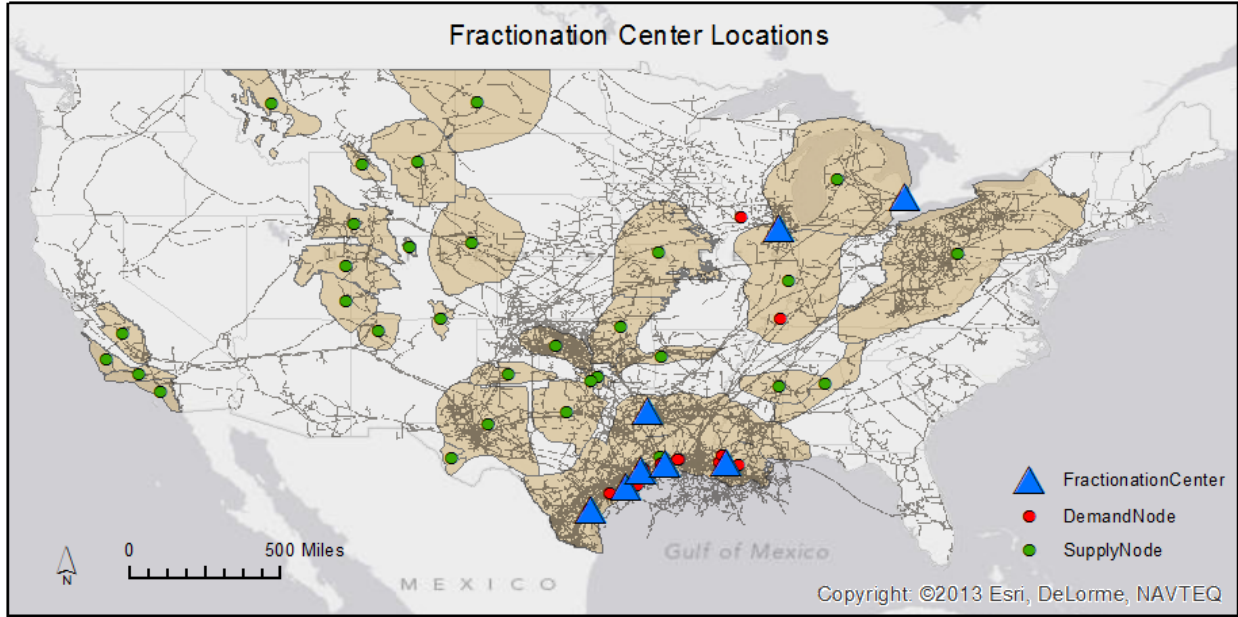
Figure 6: Fractionation center locations as determined by Location-Allocation analysis.

Table 1: Coordinates of fractionation center locations.

| Facility Number	Longitude	Latitude
1	-95.772226	28.941048
2	-97.521651	27.840595
3	-95.056229	29.722282
4	-93.931515	30.077155
5	-91.012860	30.114032
6	-94.738554	32.573793
7	-88.450838	41.410232
8	-82.432902	42.845360

Any route to transport ethane from a supply node to a demand node must travel through one of these fractionation centers to separate the ethane from the natural gas stream. With this optimal configuration of fractionation centers, the added transportation cost of routing streams through the centers is minimized.

ANALYSIS

The selection of the pipeline routes connecting supply and demand nodes (Figure 4) shows the corridors of ethane transportation that emerge around the country. These corridors are visualized in Figure 7.
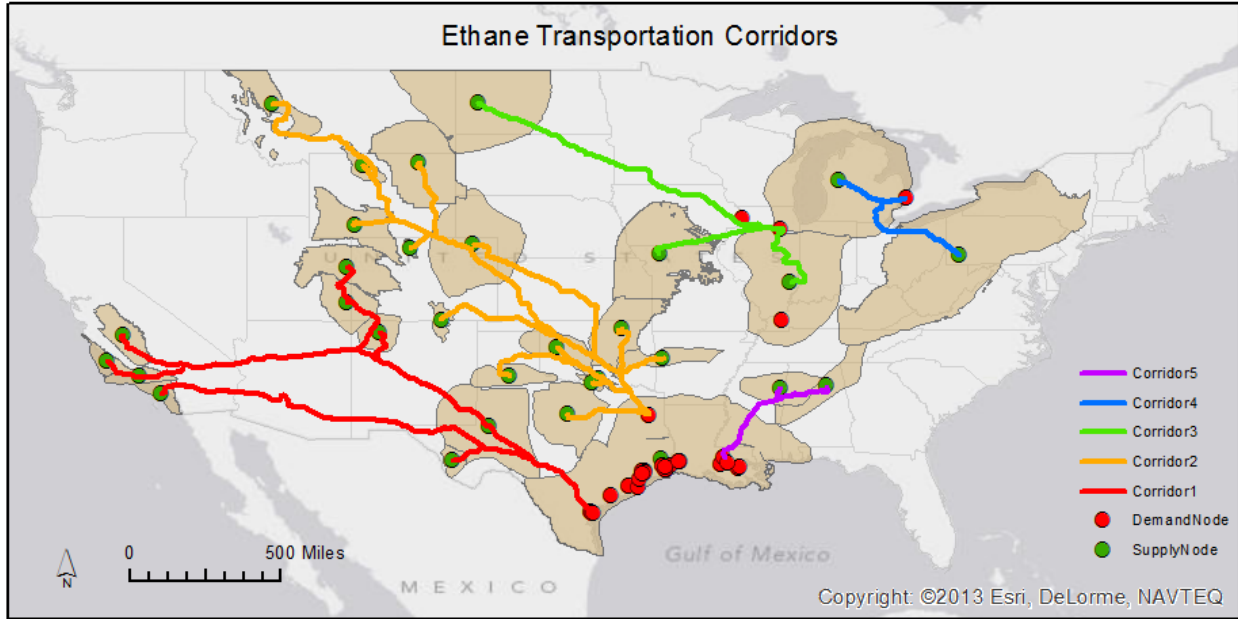
Figure 7: Emergence of transportation corridors for ethane, grouped by basin and pipeline infrastructure.

The natural flow of the orange corridor in Figure 7 terminates at the demand node located at Longview, Texas. Identifying these end points provides insight into which demand facilities have potential to expand capacity to best utilize the ethane supply. As ethane production increases, Longview, Texas is a potential location to build new facilities that will use ethane as a feedstock. Similarly, route junctions in other corridors also have the potential for expansion of ethane use.

FUTURE WORK

To combine results from both applications, a next step would be to alter the chosen pipeline routes to travel through a fractionation center before going to a demand node. This would enable a complete representation of ethane flows from supply through fractionation centers to demand. However, a method of forcing the chosen routes through a location has not been found. Even giving the cell containing the fractionation centers an extremely low cost in the cost raster is not sufficient to force their inclusion in the calculated routes. Making costs at those points negative could be a solution, but the Spatial Analyst tools that calculate route cannot handle negative costs.

The calculated pipeline routes to transport ethane are based only on distance. When actually transporting ethane, capacity is also a parameter necessary to calculate routes. First, pipeline capacity must be respected as the limit on volume of flow at any given time. When one pipeline has reached the maximum amount of flow, that pipeline cannot be used anymore and an alternate route must be chosen. Second, demand capacity must be incorporated. Each demand location has a maximum amount of ethane it can receive and the demand at each

location must be met. In the future, the optimum pipeline routes should be chosen with the constraints of pipeline capacity and satisfying all demand nodes.

This model can be expanded beyond ethane and applied to all natural gas liquids. With the addition of demand locations and capacities for propane, butane, isobutane, and pentanes, many of the raw materials for the entire petrochemical industry can be represented, presenting a complete picture of the natural gas liquid infrastructure in the U.S.

CONCLUSION

Locations of ethane supply across the U.S. (shale basins) are connected to demand nodes (chemical facilities that utilize ethane as a raw material) by natural gas pipelines. By representing these features in ArcMap, connections and pathways can be visualized. Pipeline routes that connect supply nodes to demand nodes by the shortest distance are discovered using Spatial Analyst tools. These pathways provide insight into the best regions to utilize ethane supply (based on the emergence of transportation corridors). Also, Network Analyst tools enable siting of fractionation centers to best serve the demand locations. With these analyses coupled, a very clear picture of ethane production, transportation, and use can be constructed for the United States. When this model is applied to all NGL components, the pipeline routes can provide valuable information about the distribution and use of natural gas liquids around the country.

ACKNOWLEDGEMENT