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Analysis of Liquid Natural Gas as a Truck Fuel - A System Dynamics Approach

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Purpose of Analysis

The purpose of this analysis is to evaluate the potential for growth in use of liquid natural gas (LNG) fueled trucks. . A system dynamics model was constructed for the analysis and a variety of scenarios were investigated. The analysis considers the economics of LNG fuel in the context of the trucking industry to identify barriers to the increased use of LNG trucks and potential interventions or leverage points which may overcome these barriers.

Overview of Results

The use of LNG in trucks is not yet economically attractive. The operating savings which come principally from fuel costs are currently outweighed by the added capital costs of LNG trucks and fueling facilities relative to diesel.

This conclusion is based on model scenarios using reasonable numbers for LNG trucking equipment, fuel costs, etc. which reflect the current situation in the trucking industry. There may be exceptions where diesel fuel costs are high and LNG costs are particularly low making the economics of LNG trucks locally attractive. In our analysis we considered several ways to increase the number of LNG trucks and, thereby, achieve the reduction in LNG truck capital costs resulting from manufacturing economies of scale and improved technology maturity.

Several avenues for improving the attractiveness of LNG trucks were considered in the analysis. An obvious one is the differential between diesel and LNG fuel prices. As the differential increases, the savings from using LNG fuel increase. Another possibility is to reduce the capital cost necessary for initial LNG truck operation. This might happen if truck purchases were underwritten. LNG fuel station initial costs are $300,000 for a fleet station. If fuel stations are provided which serve fleets, the costs could be spread over a larger number of trucks than one fleet would have. The capital outlay would be unnecessary for fleets but the cost of LNG would be slightly higher to pay for the fueling station capability.

Another possibility is that LNG truck purchases might be mandated due to environmental rather than economic considerations. Such short-term mandates could have the long-term effect of providing economy of scale and technology maturity benefits that cause LNG trucks to become more economically attractive.

Another leverage point is the potential economic, rather than environmental, benefit of LNG as a clean fuel. Clean fuel reduces engine wear as evidenced by the clean oil seen today when changing LNG truck oil. Reduced engine wear could lead to lower maintenance costs and longer warranties. Increased warranty periods could have a significant impact on the economics of LNG trucks because the capital costs would be offset by longer operation and increased savings due to operating costs.

System Dynamics

System dynamics is a discipline which considers societal issues as systems whose behavior can be understood as a function of time. In developing a system dynamics model of the use of LNG in trucking, key variables and their influence on one another are identified. These influences are quantified and implemented in a computer model. Developing a system dynamics model is best done as a team effort involving both subject area experts and modellers.

Some elements of such a model are clearly quantifiable, such as the current capital costs of diesel and LNG trucks. Other relationships between model variables, such as the decision process of a fleet owner considering new technology, are more difficult to quantify. These relationships are determined from interactions with experts in the area being modeled.

The results of system dynamics models can sometimes be compared with past history for model validation. However, for LNG in trucking, there is little or no past history for comparison. We do know that today, in 1996, there is no growth in LNG trucks. Using today's values in the model should and does show no growth.

Equipment Issues

In this analysis we considered the use of LNG for the largest class of trucks. These trucks have engines of 400-450 horsepower and generally achieve high annual mileage. This class of trucks is considered a potential market for LNG because the principal economic advantage of LNG is fuel cost. Trucks which have high annual mileage benefit more from fuel savings than low mileage vehicles.

In the class of trucks under consideration in this analysis, LNG is considered in competition with diesel trucks and so the differences between diesel and LNG were identified. A principal economic issue with LNG is the extra cost of LNG trucks. LNG tanks are a major component of the extra cost relative to diesel. The extra cost of LNG tanks is approximately $9,000 of the approximately $20,000 additional cost for an LNG truck.

LNG is a cryogenic liquid. Therefore the tanks which hold LNG are vacuum insulated to keep it cold. As a result, LNG tanks are larger and cost and weigh more than equivalent diesel tanks. Also, the energy content in LNG by volume is 2/3 that of diesel fuel. This means that to produce comparable range for a truck, LNG fuel requires more tank volume. Full LNG tanks weigh a few hundred pounds more than diesel. The tank weight difference is somewhat offset because LNG is lighter than diesel fuel. In the analysis, the weight difference of a few hundred pounds was not considered to have a significant economic effect on trucks with a load of 80,000 pounds or more.

Another issue with LNG tanks is how long the temperature of the fuel can be maintained. Current tanks can maintain the required temperature for several days but not indefinitely. Eventually, the fuel heats up and pressure increases causing relief valves to operate. This is not a problem except when mechanical problems idle a truck for an extended period. This does not seem to be a major issue for high mileage trucks and has not been included in the analysis.

LNG tank failures can have significant economic effects. An LNG tank is currently an uncommon truck component. It also is more complex than a diesel tank. Instrumentation failures, loss of vacuum, and other failures can put a tank and therefore a truck out of service until a replacement tank is obtained. Having the truck out of service has a large,

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immediate financial impact. Diesel tanks are simpler and can be more quickly fixed or replaced.

LNG fueled engines require a spark for ignition or use some diesel fuel with compression ignition. Spark ignited engines can run on pure LNG but this requires substantial changes from diesel systems. Dual fuel, compression ignited engines have the advantage that they can run on diesel when LNG is unavailable but also require two on-board fuel systems. Differences in engines are not modeled explicitly in the model. We believe such major differences in design show the lack of maturity in the technology i.e. one type of engine will eventually win out if LNG use in trucks grows. The engine effects in the model show in the extra capital cost of LNG trucks and in fuel mileage figures.

Fuel delivery for LNG requires investment in a fueling station by truck fleets or by an independent supplier. While fueling stations exist today, there are not a sufficient number yet to support industry growth. The simulation includes the cost of a fueling station as part of the capital cost of beginning to use LNG trucks or treats the fueling station cost as an increase in the per gallon cost of fuel. Differences in the mechanics of fuel delivery between diesel and LNG do not provide barriers to use of LNG other than the initial capital cost.

For the current simulation, we have assumed that reliability costs and maintenance costs for LNG trucks and associated equipment are the same as for diesel trucks.

Truck Industry Issues

A variety of potential scenarios were considered for the simulation of LNG in the trucking industry. Certain sectors or route structures within the industry appear to be more likely candidates for the introduction of LNG. The long haul and point to point segments of the industry were not considered for the simulation due to the lack of LNG availability. Although dual fuel engines are available, the lack of LNG fueling stations would necessitate the use of diesel for the majority of the miles traveled and the capital cost of extra LNG tanks would appear to eliminate this option. The lack of LNG stations could be possibly overcome by a fixed route corridor strategy. However, it is unclear whether there would be sufficient volume, especially for a single fleet, to justify the construction of multiple stations. A corridor strategy may naturally result once a number of LNG fueling stations are available but this has not been considered for the simulation.

The analysis and simulation has concentrated on a centrally fueled, fixed location fleet structure. This structure can be found in the less than truckload (LTL) industry segment, retail distribution systems delivering goods from a distribution center to retail stores, and manufacturing logistics transporting products between manufacturing locations. However, a major advantage of LNG results from lower fuel costs which implies higher mileage applications will benefit most from LNG. The pick-up / delivery of LTL may result in insufficient mileage to benefit significantly from LNG. Full truckloads to maximize mileage on fixed routes appear to be the most promising segment for the introduction of LNG and was the segment initially considered for the analysis.

Diesel trucks modeled in the analysis retail for $100 - 110K and trailers are an additional 15 - 30 K. The most prominent buyers for new trucks are larger fleets with more than 100 trucks. A common practice of these fleets is to lease trucks. The trucks have a manufacturer 5 year, 1M mile warranty. The average annual mileage for a truck is approximately 125,000. When a truck reaches 350,000 - 450,000 (approximately 3 years into the warranty), they are returned for resale. A used truck with 2 years left on the warranty sells for $50 - $60K. These trucks are generally resold to smaller fleets or independent owner / operators. After the warranty ends trucks may be overhauled and receive a new, shorter warranty such as 200,000 miles. Such trucks are usually purchased by farmers, construction companies, or other companies that need a large capacity truck but not for a large number of miles.

With the current mode of purchase/lease operations, an LNG truck has little resale market value due to the type of fleets buying used trucks. A small fleet owner / operator who does not have access or own a LNG fueling station would not buy an used LNG fueled truck. Until the LNG trucking industry is cost effective for the small owner / operator businesses, LNG trucks will need to be converted back to diesel in order to find a significant resale market.

Economic Issues

Currently, the overriding economic issue is the federal excise tax placed on LNG. The Internal Revenue Service has ruled that LNG is to be taxed as a liquid fuel like diesel rather than treated like alternate fuels such as compressed natural gas. This excise tax of 18 cents per gallon of LNG reduces the savings due to fuel price. It severely limits the market for LNG engines.

There is currently no economic benefit from the environmental benefits of using LNG in trucks. There has been discussion of financial credits for reduced emissions but nothing has been implemented that would affect decisions to buy trucks. Also, in trucking, the environmental benefits would be spread across the area covered by the truck routes rather than concentrated where air quality is a problem. Thus, it is difficult to quantify a localized benefit for which a truck owner might be rewarded.

Simulation

The model consists of a fixed number of fleets (100) which operate a fixed number of trucks (200 per fleet). The simulation is driven by the differential cash flow of operating LNG and diesel fueled trucks under similar conditions. Based on the cash flow differences, which includes the difference in capital costs, a fleet with an LNG fueling station will determine to purchase LNG fueled trucks. The greater the cash flow differential, the greater the number, if any, of LNG fueled trucks up to a maximum percentage determined by the potential LNG market share. Only a given percentage of a fleet route structure is assumed to be suitable for LNG fueled trucks and hence a maximum percentage of trucks purchased will be LNG fueled. The percentage of the overall market available to LNG fueled trucks is also assumed to increase as the number of fleets with LNG fueling increases.

The decision for a fleet to purchase a fueling stations is based on the payback period of the fueling station and is based on fueling station cost, a minimum initial purchase of LNG trucks, assumed to be five trucks, and differential cash flow over the life of the LNG truck. The shorter the payback period, the more likely a fleet will purchase a fueling station. The maximum payback period before a fleet is likely to purchase a fueling station is five years.

Figure 1 shows a top level view of the simulation structure. The arrows indicate influences, e.g., "LNG Fueling Availability" has an impact on "Potential Market Share".

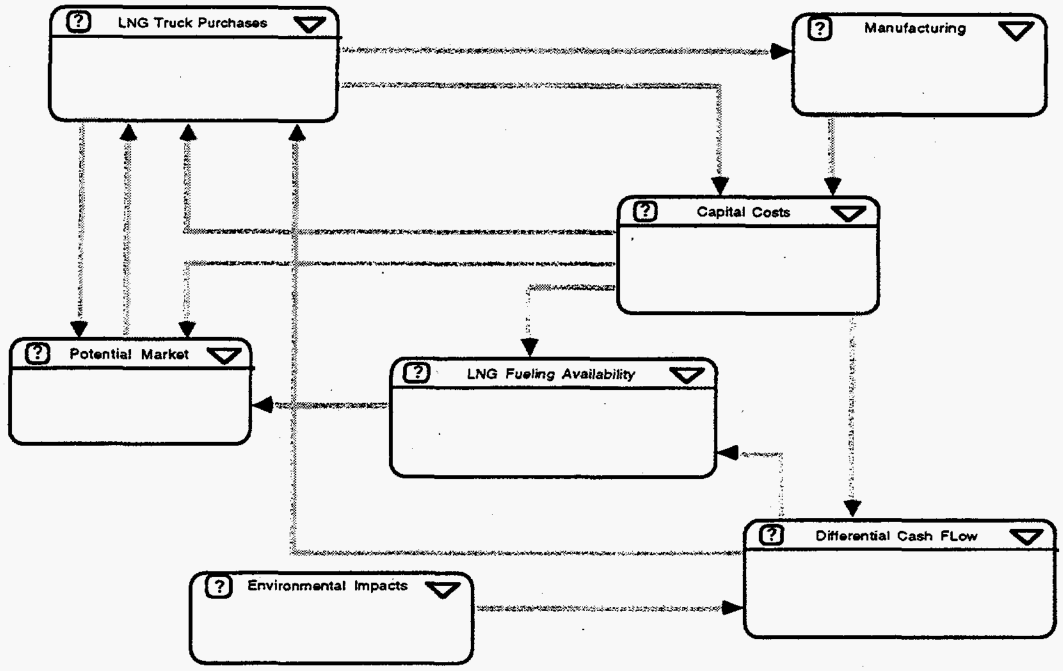

Figure 1. Simulation Top Level

As the number of LNG trucks increases, the difference in capital costs between diesel and LNG will decrease due to increase in the maturity of LNG technology and manufacturing economies of scale. This increases the differential cash flow between LNG fueled trucks and diesels increasing the likelihood that more LNG fueling stations and more LNG trucks will be purchased.

The model also includes an environmental sector. This sector currently has no impact on the model results as there is currently no economic return for environmental benefits of LNG fuels. The model does not consider non-economic environmental benefits such as public perception or goodwill.

Some Simulation Results

The results of the simulation are driven by the underlying assumptions. The following are the base case assumptions used in the model:

- Both LNG and diesel trucks are operated for four years for 125,000 miles per year and have the same resale value.
- All nonfuel operating expenses are the same for both diesel and LNG.
- The initial difference in purchase costs between LNG and diesel is $20,000.
- The purchase cost of an LNG fueling station is $300,000.
- Diesel: 7 mpg, LNG 3.8 mpg

- There are a total of 20,000 trucks in the simulation as there might be in a single large metropolitan area.
- Simulation covers 25 years.

The basic assumption used in the first simulation is that all LNG fueled trucks, both currently and for the foreseeable future, are centrally fueled from a fleet owned LNG fueling station. Initially only 2 of the 100 fleets in the model have LNG fueling stations and run a minimal number (~10) of LNG fueled trucks to reflect the experimental nature of LNG use in the trucking industry.

The differential cash flow between LNG and diesel trucks is based on the difference in capital costs and the price differential between diesel and LNG. Figure 2 displays the results of four simulation runs where the difference in LNG and diesel fuel costs are: curve 1: 60 cents per gallon, curve 2: 70 cents per gallon , curve 3: 80 cents per gallon, curve 4: 90 cents per gallon. As is clearly evident, there must be a significant difference in fuel costs before an appreciable number of LNG trucks are purchased.

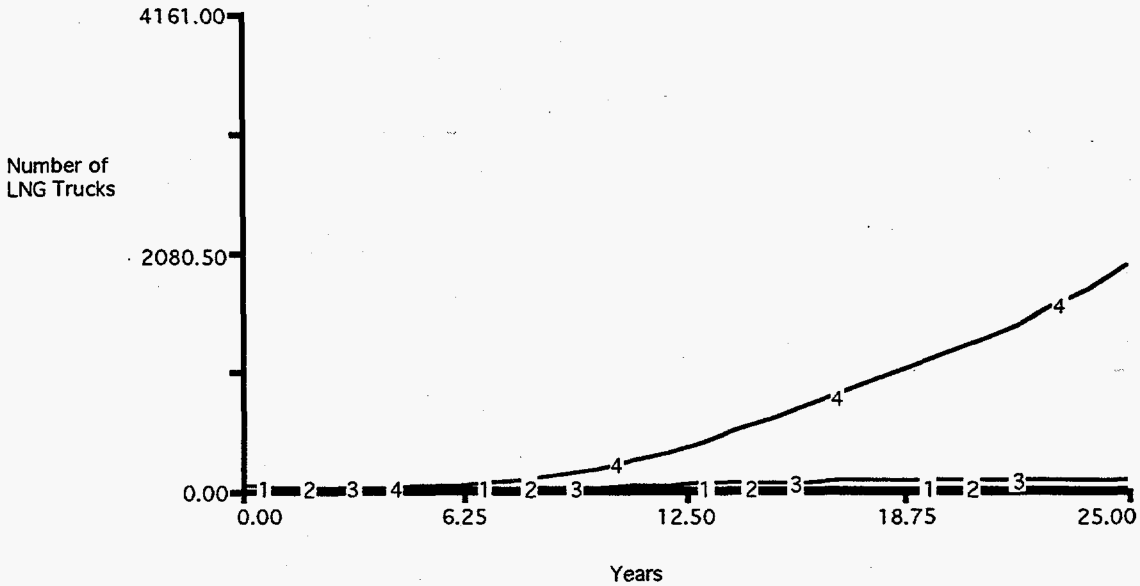

Figure 2. Diesel LNG Price Differential

Although LNG trucks provide a positive differential cash flow relative to diesels, the previous graph shows the payback period for LNG stations and trucks is too long to result in the purchase of significant numbers of LNG trucks unless the price of diesel is significantly greater than LNG. Another run was made where the service life, for the original owner, of LNG trucks was increased to 6 years while the service life of diesels remained at 4 years. The assumption was also made that the manufacturer's warranty for LNG trucks was also increased so the resale value for LNG trucks after 6 years was the same as diesels after 4 years. This run assumed 70 cents per gallon difference in the cost of diesel and LNG, the same as curve 2 in Figure 2. The results are shown in Figure 3. Curve 1 assumes an LNG truck service life of 4 years and curve 2 assumes an LNG service life of 6 years. This represents the potential benefit of longer truck service due to using a clean fuel.

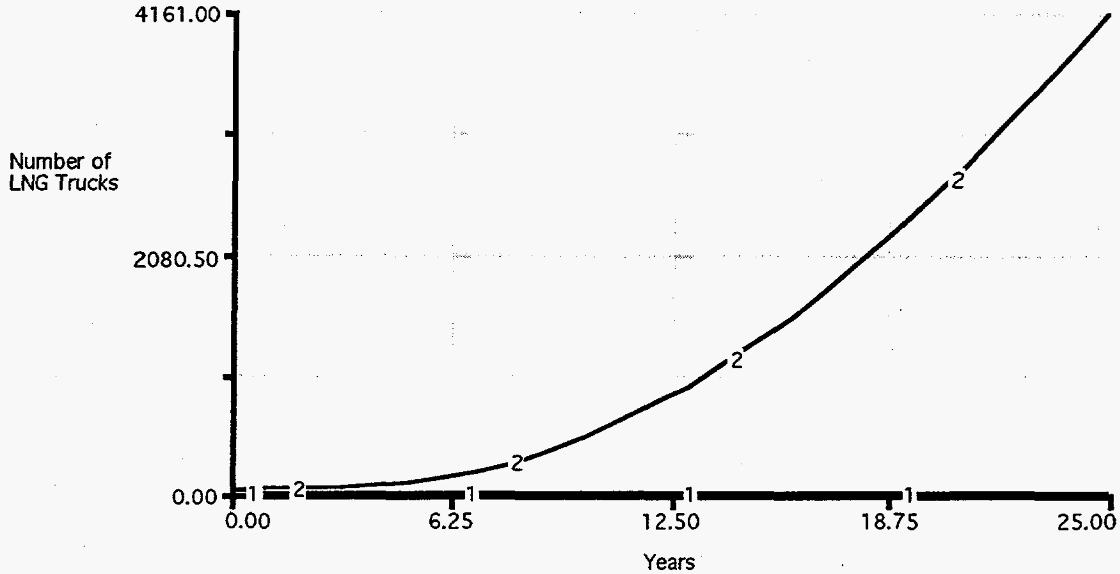

Figure 3. LNG Extended Service Life

The results of these simulations indicate although LNG vehicles may be more economic to operate, the additional capital costs of LNG trucks and the fueling station are not paid back quickly enough to suggest LNG trucks will increase significantly under current conditions. This results holds even though the simulation assumptions generally favor LNG, e.g., the existence of a comparable resale market, etc. The immediate conclusion is that it will be necessary to decrease the additional capital costs, especially for the fueling station, consider a longer payback period through longer operation of the trucks, or assume an increase in the LNG diesel fuel price differential before LNG will become a significant factor in the trucking industry.

To investigate the impact of the fueling station costs, a simulation was run under the assumption that LNG fueling was available at no capital cost. This is equivalent to an assumption of public LNG stations. Figure 4 displays the results of four runs where the difference in LNG and diesel fuel costs are: curve 1: 60 cents per gallon, curve 2: 70 cents per gallon , curve 3: 80 cents per gallon, curve 4: 90 cents per gallon. LNG trucks become a viable option at a smaller LNG/diesel fuel price differential when the purchase of fueling stations is not required. Also note that the number of LNG trucks reach a maximum number due to the predefined LNG maximum market share currently built into the model. If public stations became widely available, this market share and hence the number of LNG fueled trucks would likely increase beyond the limits currently in the simulation. In a situation of public fueling station, the cost of the fueling station would show up as an increase in LNG fuel price and a reduction in the cost advantage differential between LNG and diesel. If one assumes a fueling station costs $300,000 and can serve 50 trucks which travel 125,000 miles per year each at 3.5 mpg of LNG, the $300,000 capital cost could be recovered in 5 years by increasing LNG price by $0.04 per gallon.

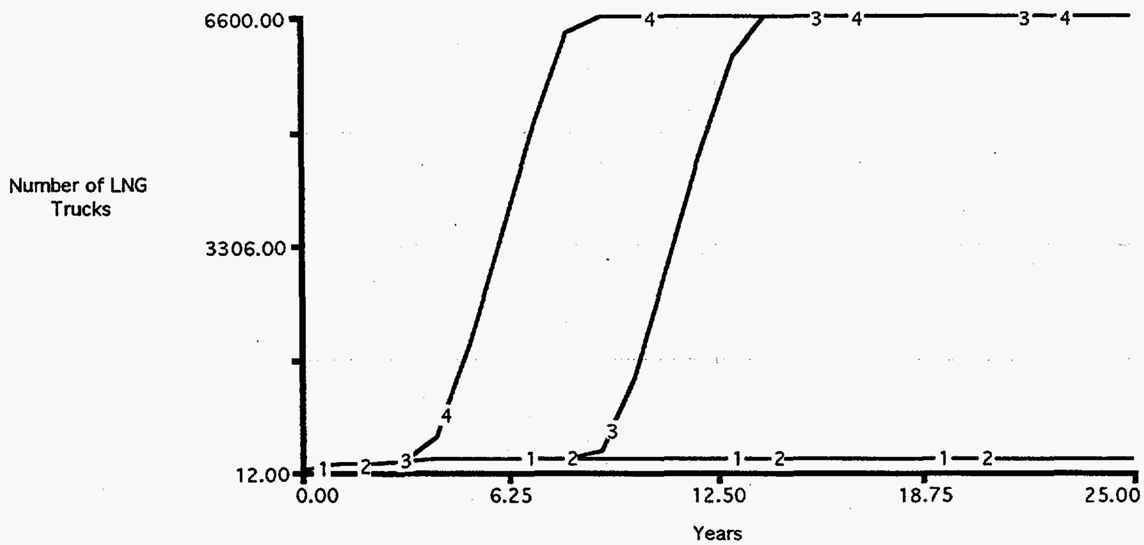

Figure 4. Public LNG Stations

The potential of government mandates for LNG fueled trucks was also investigated. The assumption was made that, starting in year 4, 10% of all trucks purchased must be LNG. A consequence of this assumption is that either LNG fueling is available or, equivalently, the capital cost of the fueling station is eliminated from the purchase decision to acquire LNG truck because LNG purchases are mandated. Hence, this scenario is equivalent to the public station scenario with the additional mandated purchases. The results are shown in Figure 5.

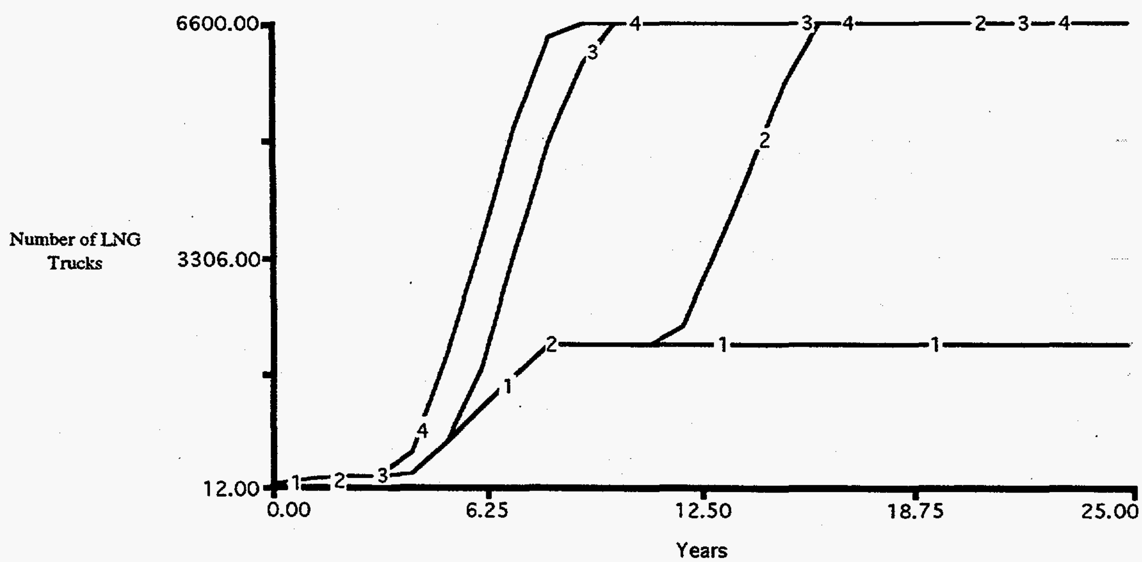

Figure 5. Mandates

Figure 5 displays the results of four simulation runs where the difference in LNG and diesel fuel costs are: curve 1: 60 cents per gallon, curve 2 70 cents per gallon , curve 3: 80 cents per gallon, curve 4: 90 cents per gallon. As in the previous case, the removal of fueling station costs from economic consideration results in LNG trucks being purchased at lower LNG diesel cost differentials. Additionally the mandate forces the number of LNG trucks to be purchased to a level that the impact of manufacturing economies of scale reduce the difference in capital costs of diesel and LNG trucks sufficiently that LNG trucks become economically viable at a 70 cents a gallon fuel cost differential.

It should be noted that in Figures 3 - 5, LNG becomes a viable fuel option at smaller diesel LNG fuel price differentials. The reason is that once sufficient numbers of LNG trucks are being manufactured, the manufacturing economies of scale decrease the capital cost differential between diesel and LNG trucks. This decrease in truck capital cost differential, together with either the longer payback period in Figure 3 or the elimination of fueling station capital costs in Figures 4 and 5, enable the lower operating costs of LNG to make the use of LNG economically attractive relative to diesel.

Conclusions

Today, LNG use in trucks is not yet economically viable. A large change in the savings from fuel cost or capital cost is needed for the technology to take off. Fleet owners have no way now to benefit from the environmental benefits of LNG fuel nor do they benefit from the clean burning nature of the fuel.

Changes in the fuel cost differential between diesel and LNG are not a research issue. However, quantifying the improvements in reliability and wear from the use of clean fuel could support increased maintenance and warranty periods.

Many people involved in the use of LNG for trucks believe that LNG has the potential to occupy a niche within the larger diesel truck business. But if LNG in trucks can become economic, the spread of fuel stations and technology improvements could lead to LNG trucks becoming the dominant technology. An assumption in our simulation work is that LNG trucks will be purchased when economically attractive. None of the simulation results show LNG becoming economic but then only to the level of a niche market.