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16. Abstract Planning for growth in freight transportation throughout Texas has become a significant challenge, particularly along the Interstate 35 corridor. Reasonably, the expected construction and maintenance expenses required to accommodate this growth led to a four-year research project to investigate the technical and economic feasibility of using a freight-conveying pipeline to reduce highway truck traffic on I-35. This report summarizes the findings of research performed in the first three years and discusses the advantages and disadvantages of employing such a system with regard to the participation of both public and private sectors. Recommendations are then made for an innovative system that integrates the favorable aspects of this concept into the Texas Department of Transportation's plans for new statewide freight corridors. Substantial emphasis is given to presenting the need for attracting private investors and creating attractive shipping alternatives for the transportation industry, and to the challenges presented by both alternative and traditional transportation fuels.					
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**YEAR 4 REPORT ON THE TECHNICAL AND ECONOMIC
FEASIBILITY OF A FREIGHT PIPELINE SYSTEM IN TEXAS**

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CHAPTER 1 – PROJECT RATIONALE AND SCOPE

INTRODUCTION

The 1998 Transportation Efficiency Act for the 21st Century (TEA-21) legislation allocated funds to the Texas Transportation Institute (TTI) to investigate the feasibility of developing a freight pipeline system in Texas for the purpose of reducing roadway construction and maintenance costs, and to reduce the pollution and congestion problems attributed to truck traffic. Funding for this four-year project has been administered by the Texas Department of Transportation (TxDOT) through the Federal Highway Administration (FHWA), wherein TxDOT has provided a 20 percent match to federal funds.

This report is the fourth in a series of research reports documenting TTI's investigation into the technical and economic feasibility of an underground freight transportation system. The research proceeded from the outset with the goal of developing an implementable transportation alternative to intercity trucking. Employing a systems engineering approach, TTI established the need for such a system and the parameters within which they would meet the need. The need for an alternative to intercity movement of freight by truck is well established. The impact of this mode of transportation is increasingly felt in terms of diminished highway safety, pavement life, and air quality, and in certain corridors, dramatic increases in congestion levels. In the wake of September 11, 2001, there is also increased awareness of the need for improved security within the freight transportation industry.

The parameters established for the alternative system included the following:

- subterranean transport of freight,
- high capacity,
- high performance,
- low cost, and
- highly reliable, continuous (24/7) operations.

In addition to these criteria, the research sought to develop a system that provides a positive benefit for all of the key stakeholders: the citizens of Texas, shippers, the existing freight transportation industry, and the Texas Department of Transportation. In as much, the research effort focused on developing a system that would benefit the state by removing a *significant volume* of trucks from the highway system, while attracting investment and operational participation by the private sector. Systems that lacked this set of attributes were rejected from the outset as ineffectual. So too were system concepts that attempted to position themselves as competitive to existing transportation modes, particularly those that were seen as competitive with the trucking industry. Rather, the research strove to develop a system that served as an extension of the existing freight transportation industry, with trucking interests serving as the principal customer base.

PROJECT SCOPE

This project was undertaken to define the parameters for which a freight pipeline in Texas would be deemed feasible, including the following:

- transport technology,
- freight characteristics,
- corridor locations,
- economics, and
- political framework.

TTI worked with TxDOT to establish their overriding issues and the venue within which a freight pipeline system would be a potentially valuable adjunct to the existing freight transportation systems. Given that the research project was “conceptual” in nature – that is, there would be no actual system or sub-system prototypes constructed – the physical setting for the evaluation was important only for establishing:

- potential utilization rates for the alternative system,
- the suitability of construction a subterranean system through the selected corridor,
- the minimal distance over which a pipeline would offer a preferred service to the trucking industry, and
- the location of a pipeline that would address TxDOT’s most critical needs.

Once the above conditions were established, the venue defined what the problem, the magnitude of the design and operating challenge, and the type of solution required. These elements provided TTI with the parameters needed to design a system, assess its cost and performance, and ultimately, determine its feasibility – technically, economically, and politically.

As the review of prior reports on this project will reveal, TTI selected the Interstate 35 corridor from Laredo to Dallas as the test case. This corridor is the most adversely impacted in the state by North American Free Trade Agreement (NAFTA) truck traffic and hence safety, security, congestion, and capacity are of tremendous concern to the local sponsor. The I-35 corridor between Laredo and Dallas is approximately 450 miles in length, providing the opportunity to improve upon the transit time offered by over-the-road trucking. Additionally, because of the geographical location of Texas and its proximity to Mexico, the number of trucks using the corridor from origins and destinations outside of Texas indicated that vehicles from elsewhere were consuming much of the state’s roadway capacity under what could be considered a subsidy from Texas’ citizens.

The freight pipeline was seen as a way to maintain and even increase trade with Mexico, while conserving scarce roadway resources and limiting the financial burden associated with hosting international trade-related truck traffic. Therefore, the scenario that was tested proposed a means by which truck drivers could:

- drive to Dallas, off load Laredo-bound cargo, load cargo arriving from Laredo, and return with new freight to the U.S. interior,
- reduce trucking costs by paying a fee lower than the per mile cost now incurred by the trucking industry, and
- increase his or her productivity (the return load would allow the trucker to move two freight loads at the same time – one load through the freight pipeline and the second, return load, effectively doubling production for the period of time that both loads were in transit).

By providing a meaningful role and location for the freight pipeline along with a business model that facilitated modal shift, TTI was able to develop a conceptual design of an underground

system that accomplished the stated objectives of the system – removing trucks from Texas highways in numbers sufficient to have a discernable impact. Furthermore, the scenario and setting provided a venue of substantial magnitude within which the economies of scale associated with development, construction and revenue growth could provide a robust evaluation. Construction costs plus estimated operational and maintenance costs were contrasted in the final analysis against the revenues and social benefits projected from initial freight pipeline traffic levels and plausible traffic growth rates.

Of important consideration was the benefit derived from avoiding the key social costs that result from truck traffic (degraded safety levels, traffic congestion, pavement damage, air pollution, etc.). In the culminating evaluation, the nature of avoided future costs had a significant impact on the assessment of system feasibility. The fact that avoided social costs represent benefits “on paper” only, rather than being transformed by the beneficiaries (the public) into some tangible remuneration to compensate the benefactors (investors), substantially affected the recommended outcome. In other words, a portion of the benefit stream associated with avoided social costs is inaccessible as real compensation to those contributing to the avoidance. This basic inequality between what is considered a benefit versus what can be offered as compensation to those providing the benefit (i.e., avoiding a social cost) creates real challenges for public-private ventures whose viability is predicated on social welfare or the avoidance of detrimental social impacts.

CHAPTER 2 – CONCEPT DEVELOPMENT AND EVALUATION

INTRODUCTION

External costs, as described by Griffin and Steele, occur when “the private calculation of benefits or costs differs from society’s valuation of benefits or costs” (1). In the absence of full restitution from the trucking industry for damage and deterioration imparted to Texas roadways, such costs are being borne by the traveling public in the form of increased congestion and reduced ride quality throughout the state. At their current level, passenger fuel tax revenues are incapable of supporting the growth in passenger vehicles and the subsidy of trucking infrastructure concurrently. This reality is reflected in public funding levels that cannot meet the need for additional roadway capacity, and which postpones many needed maintenance and rehabilitation projects. While the imposition of additional trucking taxes could increase levels of highway funding, the subsequent increase in prices of shipped goods is economically undesirable. Alternatively, a more efficient means of transporting freight throughout the state should be developed that both lessens the demand on public infrastructure and improves the performance of the trucking industry. One proposed solution to this dilemma is to construct freight pipelines that transport solid freight within Texas to reduce truck traffic on the highway system.

The potential social benefits of using pipelines to transport solid freight have been recognized for several years (2). The advantages of using such facilities arise from the removal of trucks from the highway system, resulting in benefits such as:

- reduced highway congestion,
- reduced pavement damage,
- reduced air pollution,
- energy conservation, and
- improved transportation productivity.

A generally accepted implementation strategy has been to entice private investors to build and operate freight pipelines, thereby saving transportation departments large portions of the money currently used in the construction and maintenance of roadways. When this is

the case, an economic analysis from the private investor's perspective must be included to determine concept feasibility. Some past research on freight pipelines has focused on this criterion, while other work has not. However, the project documented herein has been performed with the intention of reviewing all relevant aspects of the freight pipeline concept, including the feasibility of attracting private investment. The final recommendations on implementing this concept were to incorporate the most favorable of all findings.

This chapter briefly reviews previous research on freight pipelines, followed by a summary of Years 1-3 of this four-year TTI study.

Previous Freight Pipeline Research

The idea of transporting goods through freight pipelines can be traced as far back as 1827; even then they thought speeds as fast as 99 miles per hour to be possible (3). In fact, this type of pipeline has been used to some degree since 1861, albeit in smaller applications than would be required to displace significant numbers of trucks from roadways. Examples of operations that have incorporated pneumatic pipeline systems include:

- post offices,
- manufacturing plants,
- hospitals, and
- minerals extraction.

In addition to pneumatic pipelines, methods such as coal slurry and coal log pipelines have been implemented; however, these transport freight considered to be bulk cargo. In terms of research, solid freight pipelines have been investigated for their suitability in long distance operations, including the:

- City of Leiden, The Netherlands (4),
- State of Minnesota (5),
- Chicago to New York corridor (6),
- City of Tokyo, Japan (7),
- Ruhr-area, Germany (8), and

- State of Texas (9).

Obviously, the previous research prepared on the feasibility of a freight pipeline in Texas was of the most interest to the current four-year study. The assumptions and findings of this previous investigation are described below.

Previous Work on Freight Pipelines in Texas

TTI first became involved in freight pipeline research in 1998 when Goff et al. investigated the feasibility of constructing a privately owned, 2-meter pipeline between San Antonio and Dallas/Fort Worth along the Interstate 35 corridor (9). This study mainly addressed the economic feasibility of “tube freight,” although some information on the technical and institutional feasibility was included. As explained by Goff, combination trucks in Texas pay only 50 percent of the direct costs they impose on the state’s highways, which prevents proper roadway capacity or quality from being achieved. The cost of the alternative system was estimated to be \$1.5 billion and assumed that linear induction motors would serve as the propulsion system. The report reasoned that such a facility was institutionally and technically feasible since personnel could be readily trained to operate the pipeline of expectedly high reliability. However, the researchers found that the potential volume of freight captured by a pipeline of this capacity was insufficient to make the concept profitable to investors.

YEAR 1 INVESTIGATION OF THE FREIGHT PIPELINE

The intent of this research project was not to develop new technology for application to the transport of freight in Texas, but rather to find the best combination of existing technology that provides a realistic alternative to shipping freight by truck. Therefore, research was begun with a preliminary assessment of past and current practices in the operation of freight pipelines to determine the extent of available technology. From this, the project was directed toward a detailed examination of each facet of the freight pipeline concept.

Background Research

With exception to the transport of liquids, freight pipeline technology has been essentially confined to (10):

- Slurry pipelines – bulk commodities (such as coal) are transported in a pulverized form in water, followed by the removal of water once the freight reaches its destination.
- Hydraulic capsule pipelines – buoyant forces are relied upon to transport units of freight on top of moving water.
- Pneumatic capsule pipelines – these require either suction or positive pressure to propel freight capsules through the pipeline.

Of these concepts, researchers thought the pneumatic capsule concept held the most promise for transporting freight throughout Texas corridors.

Pneumatic Capsule Technology

Pneumatic capsules are operated either by using suction to pull capsules through the pipeline, or by using positive pressure to push the capsules through the pipeline. Suction or positive pressure forces are generally developed using a fan or blower, which can provide considerable moving capacity for freight of limited size and weight. With regard to effective transport distances, suction systems are limited to approximately 200 meters, but pressure systems can transport material over one mile. In pneumatic capsule pipelines, the properties of the transporting fluid (air or inert gas) limit the application of this technology to relatively small-diameter pipelines carrying lightweight commodities.

A variation of the pneumatic pipeline approach proposes that linear induction motors be employed as the propulsion system. In this embodiment, some of the limitations cited above may be overcome with power systems that use the pipeline and the freight-conveying capsule as the two principal elements of the motor. However, the size of the system (a diameter of 2 meters) and its circular configuration significantly limits both the size (height) and quantity of freight the system could conceivably transport.

A system design that employs prefabricated circular conduits for underground transport of freight necessarily employs capsules of modest length to enable the capsule to negotiate vertical and horizontal curvatures within the tube. The capacity limitation that results would require a tube-freight system to employ between six and nine capsules for each truck load of material

removed from highway operations. When coupled with the requirement to alter the standard pallet configuration used throughout the trucking industry to meet size limitations, the material handling and terminal operations challenge was judged too burdensome to realistically overcome.

Research on the Application of Freight Pipelines in Texas

A well-conceived technical and strategic approach to the implementation of a freight pipeline system was envisioned to offer several advantages, including improvements in:

- cost effectiveness,
- system reliability,
- energy efficiency,
- system performance,
- cargo security,
- pollution reduction,
- infrastructure durability, and
- effective land use.

With these benefits in mind, research in Year 1 was performed in several areas; namely, the identification of:

- potential transportation corridors,
- type of freight,
- policy concerns,
- technical design concepts, and
- aerodynamic effects.

Potential Transportation Corridors

The feasibility of using freight pipelines to solve transportation problems in Texas was judged by selecting an existing highway corridor so that the technical challenges and financial viability of the system could be evaluated. The criteria upon which this selection was based included the:

- potential to improve existing and future conditions within the highway corridor,
- ability of the pipeline to access other freight modes, and

- potential for expansion or extension of the pipeline facility.

For the application of these criteria, it was first recognized that the various corridor options can be characterized as an:

- intracity corridor,
- intercity corridor, or
- trans-Texas corridor.

Intracity corridors were not considered to be likely candidates for freight pipeline operations due to the extensive underground construction through urban areas laden with existing underground infrastructure. Furthermore, this concept does not accommodate the dynamic shipping and relocation practices of local businesses, or the extensiveness of the required shipping network. Alternatively, intercity corridors carry substantial amounts of truck traffic that could be transferred to a primarily rural freight pipeline system, which would consist of one continuous underground facility between cities. However, the additional modal shift (trans-loading) required in this instance by the freight pipeline makes the concept noncompetitive with the shipping speeds of trucks.

Application of the freight pipeline concept to a trans-Texas corridor became the preferred scenario for several reasons. First, the speed and reliability of a freight pipeline compensates for the additional time required by modal shifts as shipping distances increase. Furthermore, the potential benefits that could accrue by removing trucks from long distance, high-volume corridors would offer the greatest improvements to existing and future highway conditions. This scenario also offers the most comprehensive solution to projected increases throughout NAFTA corridors.

Of all trans-Texas corridors, the Interstate 35 corridor between Laredo and Dallas was determined to be in most need of alternative transportation solutions. This corridor carries a significant amount of NAFTA truck traffic that contributes to tremendous volumes of traffic through the cities of San Antonio, Austin, and Dallas/Fort Worth. Other corridors were considered, such as the Beaumont-Houston-El Paso and Laredo-Houston-Beaumont corridors,

but these routes contribute less to metropolitan-area traffic that does the I-35 corridor. Therefore, research was directed toward determining the feasibility of constructing a freight pipeline along the Interstate 35 corridor.

Type of Freight

The conceptual design of the freight pipeline was developed with consideration to the type of freight that would most likely be shipped, based on need and economics. This approach differs substantially from the study prepared by Goff et al. in that the previous work assumed a 2-meter pipeline facility, based the economic evaluation upon the volume of goods that could be shipped through a system of this size. Alternatively, this current project sought to identify the type of freight that would provide the greatest benefit to the State of Texas (i.e., reductions in congestion, pavement construction, energy consumption, pollution, etc.) while minimizing costs. The three types of freight considered in this research were:

- manufacturers' packaging (boxes, etc.),
- aggregated packaging (pallets), and
- containers.

The likelihood of truck cargo being converted to single-package shipments was considered to be very low since material handling and time requirements would be excessive; not to mention the fact that this burdensome process would have to be reversed as packages exit the system. Also, containerized cargo, while conducive to modal shift, comprises a relatively low portion of interstate traffic and requires the greatest capital investment in pipeline construction.

As part of this research, a study was performed in cooperation with the Texas Department of Public Safety that surveyed northbound trucks on I-35 near Devine, Texas (about 35 miles south of San Antonio). Among the findings of this investigation were:

- Approximately 76 percent of traffic was transported in enclosed trailers.
- Approximately 40 percent of traffic was palletized and bound for Dallas.
- Laredo-Dallas palletized freight exceeded 1,000 trucks per day.

Based on the methodology described, and as determined from analysis, palletized cargo was found to be the most suitable form of freight for which conceptual designs should be developed.

Therefore, research in Years 1-3 was devoted to a thorough investigation of the feasibility of transporting palletized cargo through a freight pipeline.

Policy Concerns

A freight pipeline can be successful only if the trucking industry values its contribution to shipping operations. Without industry's willingness to make modal shifts at Laredo and Dallas, the facility would fail in terms of economics and purpose. Therefore, the concept must be designed with the intention of providing industry with an attractive alternative to existing shipping practices by reducing costs and improving performance.

In addition to the needs of trucking companies, the needs of the State must also be reconciled by providing a stream of benefits that warrant investing in a freight pipeline project – whether this investment is in the form of construction costs, regulatory oversight, or operations. Each of these issues were identified as policy concerns that needed to be considered when preparing conceptual designs of the freight pipeline and terminals.

Technical Design Concepts

The selection of a trans-Texas corridor and type of suitable freight, together with the policy concerns described earlier, were incorporated into several design and operational guidelines for the freight pipeline concept; namely, to:

- provide an alternative transportation system for moving palletized freight between Laredo and Dallas;
- conceptually design a system that uses existing, proven technology, and is fully automated;
- produce a marginal cost of operation that is competitive with current trucking costs;
- minimize conflicts with other transportation modes and land uses by constructing the system below grade;
- provide a high-speed (approximately 60 mph), high capacity system, with 24-hour service; and
- use automated material handling technology at terminals.

Figure 1 outlines the sequence of decisions that led to the development of these guidelines. As this figure shows, the scope of research was refined so that the investigation of technical concepts could begin. As a result, the remainder of Year 1 research was devoted to research in each of these technical design areas, each of which are summarized in the following sections.

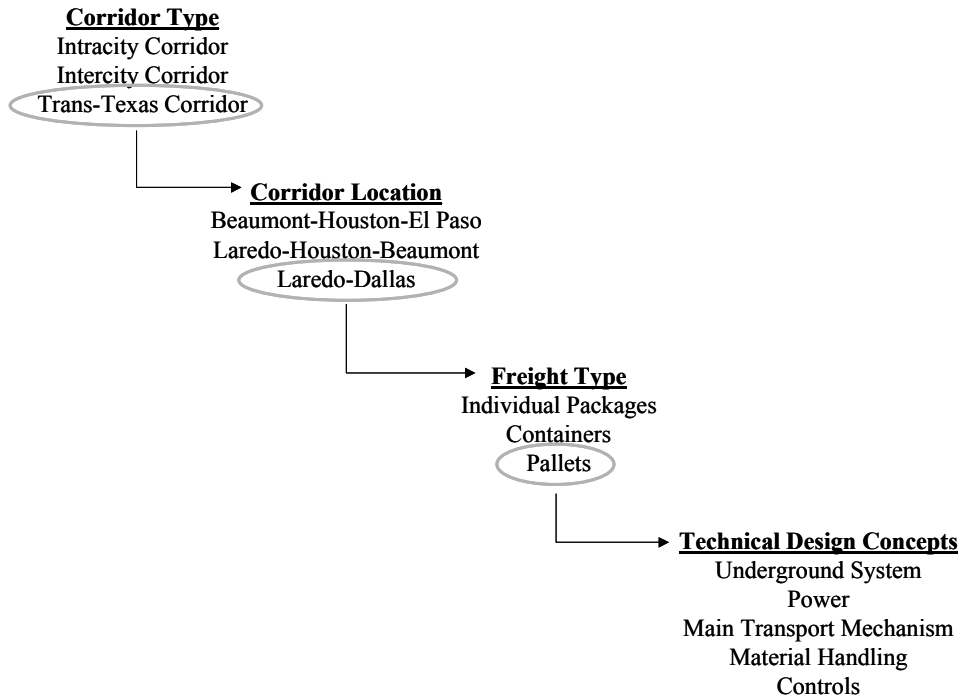


Figure 1. Development of the Freight Pipeline Concept in Year 1.

Underground System

Alternatives to the design of the underground system (conduit) were begun by first establishing a series of design requirements that are of significance to pipeline construction, such as material selection, pipeline size, and cost. However, the main benefit of this methodology was to identify any factors that would prevent completion of the project. Of course, the greatest deterrents to construction of the facility were expected to be the cross-sectional size of the pipeline and the geologic conditions throughout the corridor. These factors were investigated more thoroughly in Year 2 research.

Power System

The concept of a continuously operated, fully automated freight pipeline was assumed to require a reliable and extensive source of power generation. With this thought in mind, research was performed to identify the power requirements and potential power sources for sustained pipeline operations. Of significant concern was the potential need to build additional power generating infrastructure to support these operations.

The analysis to develop the energy requirements for the system conservatively shows that 130 kW of peak electric load capacity (50 tons on 30 percent incline at 60 mph requires 127 kW plus 3.4 kw per foot of rise, see Eq. 21, p. 85, Research Report 1519-2) would be the maximum required for a truck equivalent of freight in a fully loaded MTM, 30 pallets totaling 100,000 pounds including the MTM tare weight. For the pipeline to operate at the anticipated load profile of 2,000 trucks per day from Dallas to Laredo, the maximum pipeline occupancy occurs between the hours of 9:00 am to 4:00 pm. The total number of MTM's in the pipeline during its peak hour of 4:00 o'clock in the afternoon is 1,891 units.

Assuming the maximum load of the MTM during acceleration to be 37 kW (see Eq. 34, p. 98, Research Report 1519-2) then the load will be twice this value or 74 kW since, two MTM loading docks are at each terminal. The additional load for the pipeline can be assumed to be up to 50 miles for any electric current block in the system. The electric capacity for the pipeline is not expected to be reasonably supplied by any single power source, due to physical limitations of power distribution system, including limiting capacity of power carrying equipment in the pipeline tunnel system itself. Assuming the maximum power needs for the pipeline to be the maximum occupancy of the peak period coincidence (bi-directional flows, northbound and southbound MTM's) loading for 50 miles of pipeline length, then based on four MTM's per minute being sent into the pipeline from each terminal, there can be a maximum of 400 MTM's occupying 50 miles of the system simultaneously. The research team assumes that where ever a positive gradient occurs in one direction, an equal but negative gradient occurs in the opposite direction. Further, it has been assumed no gradient is continuous, but the predominant physical aspect of the pipeline system gradient is level with an overall lift from Laredo to Dallas being equalized by the fall in the opposite direction.

Energy recovery from electric power regeneration occurs when an MTM uses the power control system to slow the MTM while going down grade is expected to be one half the efficiency losses due to the use of the linear motor drive. All the energy calculations developed for the year two report include the efficiency loss for the power consumption. However, regeneration was not discussed in that report. Assuming the electrical slip loss of the linear motor to be 50% less than the rotating traction motor, then the regeneration losses will be 50% of the recovery capacity, or only 25% of the energy input needed to maintain speed up a positive gradient for the MTM using electrical regeneration going down the gradient. Therefore for every 130 kw required to go up a gradient, only 32 kw is recovered by those going down the gradient. The ultimate balance is a cost of 100 kw, instead of a cost of 130 kw for each of the units, one up and one down.

The research team considered the potential for gradients on the route and assumed there will be no more than 10% of the entire length to have substantial gradients. The gradients were also assumed to be principally located in the northern half of the system and evenly distributed. Therefore, there will be 0.20 miles of gradient every mile in the northern half of the system. For the 50 miles of system being considered to have the maximum occupancy, it is evident that the traffic will be north of the half-way point, or in the area with gradients. A total of 10 miles of grade can be expected to be encountered in any 50 miles in the northern half. Given that the MTM distribution will be four units per mile (maximum departure rate from either terminal) in each direction, there will be 400 MTM's in the 50 mile length of concern. Since a net capacity of 100 kW per two (2) MTMs occupying a grade (one in each direction) is required, there will be 80 MTM's occupying the gradients in the 50 mile length being evaluated and thus 8,000 kW peak load capacity. The remainder of the MTM's, 320 units, are all assumed to be in level transit. In level transit, the MTM requires 2 kW (see Eq. 10, p. 82, Research Report 1519-2) to maintain its acquired speed of 60 mph. thus the remaining 320 MTM's require a load capacity from the electricity supply system of 640 kw.

The peak electric load capacity requirement for the highest occupancy 50 mile length of the system is conservatively estimated to be 9,000 kW or 9 megawatts (MW) of capacity and overall the system capacity is at most estimated to be 50 MW. Based on the current (2001) peak load

57,000 MW requirements within ERCOT and the generating capacity, 70,700 MW, the pipelines overall capacity requirement represents less than one half of one percent of ERCOT's reserve.

This preliminary work suggested that 200 kW of electrical power would be required to transport each truck equivalent of freight (30 pallets).

Main Transport Mechanism

Conceptual design of the main transport mechanism began with an investigation into: 1) function, 2) motor selection, and 3) shape and aerodynamics. The design and operational guidelines described earlier were used to initiate research on each of these issues; of which, the aerodynamic computations proved to be most difficult.

In this research, the MTM concept was developed as a means of transporting pallets between the Laredo and Dallas terminals, requiring interaction with control and power systems within the pipeline. Researchers defined the following MTM functions as part of this work:

- Secure and safely transport pallets through the pipeline.
- Provide a rigid support for cargo loads.
- Exchange information with the control system.
- Provide onboard power for the propulsion system.

Three alternatives were examined as a potential propulsion system for the MTM by considering factors such as compatibility with operating conditions, material and maintenance costs, and performance requirements. The following onboard motors were chosen for consideration:

- natural gas – powered electric motors
- linear electric motors (induction and permanent magnet), and
- rotating electric traction motors

A numerical analysis was also begun in Year 1 in order to understand MTM parameters, such as shape, tunnel clearance dimensions, and car linkage configurations that affect energy consumption. Several aerodynamic shapes were considered in the analysis to determine how these parameters could be modified to minimize drag on MTMs that navigate the pipeline. This

work emphasized the importance of having a smooth transition surface between adjacent MTMs, and the need for an aerodynamic configuration at the end of adjacent MTMs in order to reduce pressure drag. Also, the preliminary analysis suggested that a tunnel cross-section 3.3 times larger than the MTM cross-section would be needed for drag minimization.

Material Handling

Palletized freight was identified as the type of cargo most likely to be transportable through the pipeline in volumes capable of substantially reducing truck traffic on I-35. The transshipment from trucks required for pallets entering and exiting the pipeline would necessitate a highly automated, reliable material handling system that minimizes the time for this trans-loading process to occur. In consideration of this, a series of requirements for terminal operations were identified related to the logistics, identification and security of the palletized cargo. While suitable technology exists for such operations to occur, the results of this investigation were considered as the feasibility of the project's conceptual design was evaluated.

Communications, Command, and Control

The communications, command, and control system technology was addressed at the macro-system level. The general nature of the C3 system was defined to include the requirement for intelligent on board systems to be an inherent and fundamental element of each MTM control process. The control of each MTM was to be localized on the vehicle. Systems oversight functions were to be distributed across zones with a master control element at the top of the systems hierarchy (Figure 2). The estimated cost ranges for the resulting distributed C3 system was then established by examining analogous systems.

Three tiers are envisioned for the C³, the central control, a regional or block control and the local control element. The local control is at the individual MTM level. Each MTM is expected to be “smart” with an onboard computer and power control system monitoring vehicular sensor to establish speed, distance to the immediate vehicle in front of it, etc. The primary requirement of this type of system is a reliable communication system between the vehicle under control and the vehicle being monitored for controlled vehicle reaction. The research team has determined that the power supply system in the pipeline can be used to provide a feedback loop between the local control vehicle and the vehicle immediately ahead of it, being monitored for position, etc.

The regional or block control C³ is envisioned to be a monitoring control for over or under utilization of control elements within its sphere of authority. Elements it is envisioned to monitor are; localized over heating of the power distribution system the MTM's are drawing power from which, could be indicative of an MTM motor failing or substantial increased wheel/axle friction, etc. Additionally, the regional control units will be required to maintain MTM count, system speed, local power conditions, etc.

The central control stage is expected to monitor MTM entry and exit events at the terminals, maintain supervisory authority over the regional control systems and conduct traffic flow predictions for performance characterizations within the system to compare actual performance updates against a plan.

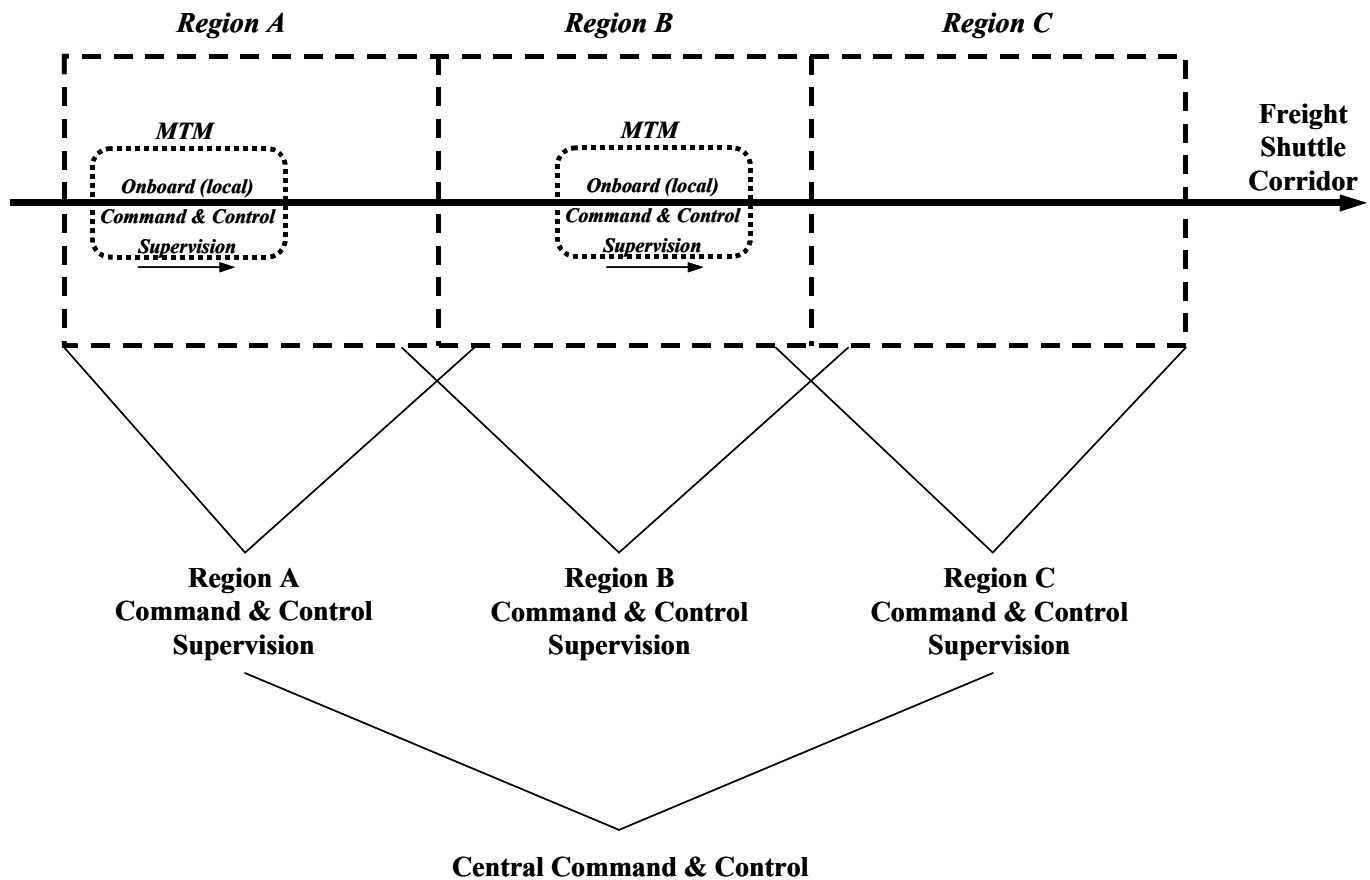


Figure 2. Communication, Command, and Control Approach

YEAR 2 INVESTIGATION OF THE FREIGHT PIPELINE

This stage of research more closely examined the technical design concepts identified as part of the work in Year 1. In addition, facility operations were incorporated into the project by developing simulation models of pipeline operations, and by refining the operational requirements of the freight pipeline concept. The general areas of research in Year 2 can be classified as:

- conceptual design of system components,
- freight movement and simulation modeling,
- energy analyses,
- preliminary geologic investigation of the I-35 corridor, and
- business and economic considerations.

System Component Design

The design and operational guidelines identified in Year 1 were used to define functional and performance specifications upon which conceptual designs would be based. A substantial portion of this work was dedicated to the conceptual design of the MTM, focusing on issues related to propulsion, suspension/running gear, fuselage, and structure. The following sections provide the investigation of these issues.

Propulsion System

As a result of this project, a linear induction motor was chosen as the propulsion system that, while less conventional than other systems, would provide benefits such as:

- absence of moving parts and the elimination of motor wear,
- reduced occurrence of electrical breakdown as compared to conventional rotating motors,
- elimination of the need for rail/wheel adhesion in the provision of tractive forces,
- liberal grade restrictions, and
- MTM speed unlimited by motor speed.

MTMs propelled by linear induction motors have the advantage of shifting the generation of power from a motor that fails to the remaining motors, thereby eliminating the potential for

forced stops within the freight pipeline. Also, MTMs can be slowed or stopped by converting the potential energy of a moving MTM into electricity, thereby allowing this energy to be transferred back to the distribution system for reuse.

Suspension/Running Gear System

MTMs must provide a ride quality that is comparable to freight traveling by truck at 60 to 70 mph, requiring a reliable and well-designed suspension/running gear system. Several running gear systems were evaluated for reliability, ride quality, and cost including the:

- mag-lev system,
- rubber tire system, and
- steel wheel/steel rail system.

Of these, preliminary investigations indicated that performance and economic criteria could best be met using steel wheel/steel rail running gear. Researchers identified suspension design issues suitable to this running gear system as:

- ride quality,
- material durability,
- required maintenance,
- capital and operating costs, and
- compatibility with wheel configuration.

The performance of both two-wheel single-axle and four-wheel bogie suspension systems were evaluated with respect to these criteria to establish a set of considerations and key issues that should be addressed in preliminary designs. An initial assessment of such issues has identified the four-wheel bogie suspension system as having substantial promise in future analyses.

Fuselage

The fuselage was conceived to encapsulate and protect the MTM cargo while enhancing aerodynamic performance of MTMs in transit. This type of system can be designed to serve as a structural component of the frame, or it can be designed to only protect cargo and improve

aerodynamic performance. Researchers identified issues associated with these alternatives so that an optimal design could be selected, including:

- reduction of MTM weight by using the fuselage as part of the structural framework,
- potential for inducing fatigue stresses during loading/unloading operations,
- limitations of a structural fuselage on loading/unloading operations, and
- ease of replacing a nonstructural fuselage.

Structure

A structural MTM frame requires a capability to withstand all static and dynamic forces throughout the design life. Based on anticipated design loads, a steel structure would be required and would weigh approximately twice the amount required for span support in order to minimize deflections, vibrations, and fatigue. The design loads of this structure, which is anticipated to be approximately 30 ft in length, are as follows:

- distributed live load of 500 lb/ft,
- frame weight of 1000 lb, and
- propulsion and control system weight of 2000 lb.

Using these loading conditions, the frame of a fully loaded MTM would be required to resist a maximum bending moment of 60 k-ft. However, the design moment should be approximately 120 k-ft (twice the maximum bending moment) in order to provide the strength required to limit deflection, vibration, and fatigue.

Freight Movement and Simulation Modeling

The feasibility of a freight pipeline depends upon the system's capacity to move cargo through the conduit in a way that provides the timely delivery of MTMs and minimizes the power required for their movement. Therefore, much of the Year 2 research consisted of continuing the aerodynamic analysis of the MTM, and on developing simulation models of system operations.

Aerodynamic Analysis

A study was performed to minimize drag on the MTMs during transport through the freight pipeline for the purpose of minimizing energy expenditures. This investigation showed that aerodynamic drag minimization is primarily associated with a reduction in skin friction and

pressure drag. Consequently, computational tools were used to perform an aerodynamic analysis of MTM configurations that would minimize these parameters. This work produced the following recommendations to minimize drag:

- Use a continuous MTM configuration with the surface of the separate MTMs blended.
- Use a rectangular MTM (in cross section) with curvature in profile. A suitable low-drag profile is formed from two circular arcs joined by a flat section.
- Blockage ratios (β) should be kept below 0.3.
- Clearance between the upper surface of the MTM and the tunnel roof should be greater than 3 ft.
- Clearance between the tunnel sidewall and the train should be greater than 3 ft.

Simulation Modeling

In addition to aerodynamic performance, researchers evaluated the freight pipeline concept was evaluated using criteria such as transportation time, system reliability, and system capacity. Year 2 research focused on the analysis of these features by modeling freight pipeline operations using *Arena* (a simulation software). The system was modeled as separate northbound and southbound pathways that link directly to the Dallas and Laredo terminals, based on initial assumptions of:

- Each MTM car transports a maximum of six standard pallets.
- MTMs travel as a set of five linked cars.
- MTMs travel at a speed of 60 mph.
- A set of five linked cars are loaded in 30 seconds.
- All MTMs are initially located in MTM storage.

In this preliminary model, results were obtained for average length and time of MTM queues, and average lengths of time in the system, by assuming a time-dependent arrival rate function. This work served as the basic model for more detailed analyses that were carried out in the third year report.

Energy Analyses

The freight pipeline concept was committed to operating on electrical energy after selecting linear induction motors as the propulsion system. Consequently, an interruption in the delivery of

electricity would prevent the system from operating and, as a result, reduce the reliability of the system. In consideration of the deregulation of the electric utilities and the California power shortages of 2001; electrical power deliverability was identified as an important area of investigation. Furthermore, this work sought to determine the electricity demands of the freight pipeline in order to offer any conclusions on the feasibility of an electrical powered propulsion system.

An inventory was prepared on the electrical generation capacity of power plants in Texas, including those completed and those being constructed or planned. The findings were:

- Power plants built since 1995 produce a total of 8,652 MW.
- Power plants being built will produce a total of 12,745 MW.
- Power plants being planned would produce 16,385 MW.

In conjunction with this assessment, research was performed to determine the amount of energy consumed by MTMs during operations. Freight transportation data obtained from pipeline simulations were applied to the energy equations developed in Year 2 so that a peak energy demand could be forecasted. Based on this approach, the freight pipeline was found to require a peak demand of no more than 5 MW, which is 0.039 percent of the generating capacity of power plants being built at the time.

Geologic Description of Corridor

Investigations into the feasibility of a subterranean freight pipeline required consideration of the extensive earthwork and subsurface features throughout the 450-mile corridor. Variations in geology from Laredo to Dallas were anticipated to be substantial, so part of the Year 2 report was comprised of a preliminary investigation into the physical characteristics of the I-35 corridor. The geologic report was comprised of technical descriptions and rankings (by county) of the following categories:

- Hydrologic Factors – climate, water table depth, and aquifer locations and recharge zones
- Topographic Factors – slope, slope continuity, landform type, and landform characteristics

- Geologic Factors – stratigraphic uniformity, slope stability, permeability, shrink-swell potential, and structural uniformity
- Soil Parameters – pH, thickness, uniformity, shrink-swell potential, stability, and accessibility

In addition to the above information, geologic descriptions of aquifers and formations that exist within the pipeline corridor were included. All of this information was prepared to provide a reasonable understanding of existing conditions, and to identify specific geologic issues that would affect the construction of a freight pipeline.

Business and Economic Considerations

As addressed in the design and operational guidelines, the system must be integrated into current business operations. The Year 2 report researched this aspect of the project by identifying the needs of the public, TxDOT, shippers, and the freight industry. This effort resulted in two important criteria by which the feasibility of the pipeline should be evaluated; namely, the pipeline should operate at a target speed of 60 mph and should operate within a cost structure that justifies a user fee of less than \$0.10 per ton-mile; these criteria were incorporated into the pipeline simulation model.

In addition to the needs of industry, a freight pipeline must also be of substantial benefit to the public for its implementation to be considered. With this in mind, research determined that reductions in the following parameters should be recognized as having value to the public and TxDOT, and should be included in the economic analysis performed in Year 3:

- air pollution,
- noise pollution,
- highway congestion,
- driving time,
- automobile accidents, and
- highway lane construction.

YEAR 3 INVESTIGATION OF THE FREIGHT PIPELINE

A preliminary conceptual design of the freight pipeline was completed in this stage of research, which allowed for an economic evaluation of public benefits to be prepared. With the intent of providing an objective and practical assessment of the proposed concept, special effort was given toward the identification of both favorable and unfavorable features of the recommended design. By following this strategy, it was possible to use the culmination of research in Years 1-3 to prepare final recommendations and concept modifications (Year 4) that would be of most benefit to the State of Texas.

Development of Facility Components

Certain aspects of the technical designs first developed in Years 1-2 were investigated further in Year 3 to provide reasonable cost estimates of the freight pipeline components. Important considerations were identified concerning the material handling system, and valuable MTM design concepts were formulated. These findings are summarized in the following two sections.

Terminals and Material Handling

Preliminary work concluded that the additional modal shift of freight between trucks and the pipeline made the relatively short distance of intercity corridors noncompetitive with the shipping speed of trucks, resulting in the selection of a trans-Texas corridor to evaluate the feasibility of a freight pipeline. While the time lost to this material handling process can be regained over the 450-mile Laredo-Dallas corridor, the validity of this assumption requires freight to be processed through each terminal in no more than 30 minutes. Therefore, material handling remained a critical issue in determining the feasibility of the pipeline, which prompted the identification of system elements that must be coordinated for the system to perform as required. These elements include:

- connector roadways,
- truck staging areas,
- truck loading/unloading zones,
- pallet inspection areas,
- pallet staging areas, and
- MTM loading/unloading areas.

Research indicated that each of these considerations could be addressed using existing technology. However, there was an expectation that system reliability would diminish as greater numbers of terminal and material handling components become interrelated. This uncertainty was considered when predicting the volume of trucks that would use the freight pipeline, as discussed in the economic evaluation.

MTM Design

While the previous year's research focused on identifying a suitable aerodynamic shape of the MTM, work in Year 3 resulted in a conceptual design of the propulsion/guidance mechanisms and structural system that would meet the performance specifications outlined in Year 2. The most feasible configuration was an MTM centered over a vertical guideway that serves both for navigation and for the relay of power to linear induction motors mounted on the MTMs. [Figure 3](#) depicts how this concept would appear in the freight pipeline and shows how the aerodynamic shape would conform to the MTM guideway.

The conceptual MTM design shown in [Figure 3](#) includes the following features:

- five identical 26-foot long cars capable of carrying six pallets each,
- front and rear of five-car assemblies enclosed with a 45-degree, non-structural aerodynamic attachment, and
- two sets of opposing 20-horsepower linear induction motors on each MTM car.

The transport of individual pallets in the MTMs required that the design of each car provide structural support for the freight. Therefore, the recommended conceptual design consists of a rigid steel structure that meets the following criteria:

- maintains required clearance tolerance for the pallet loading/unloading mechanism,
- prevents fatigue in structural and non-structural components,
- supports the linear induction motors, and
- prevents torsional load displacements.

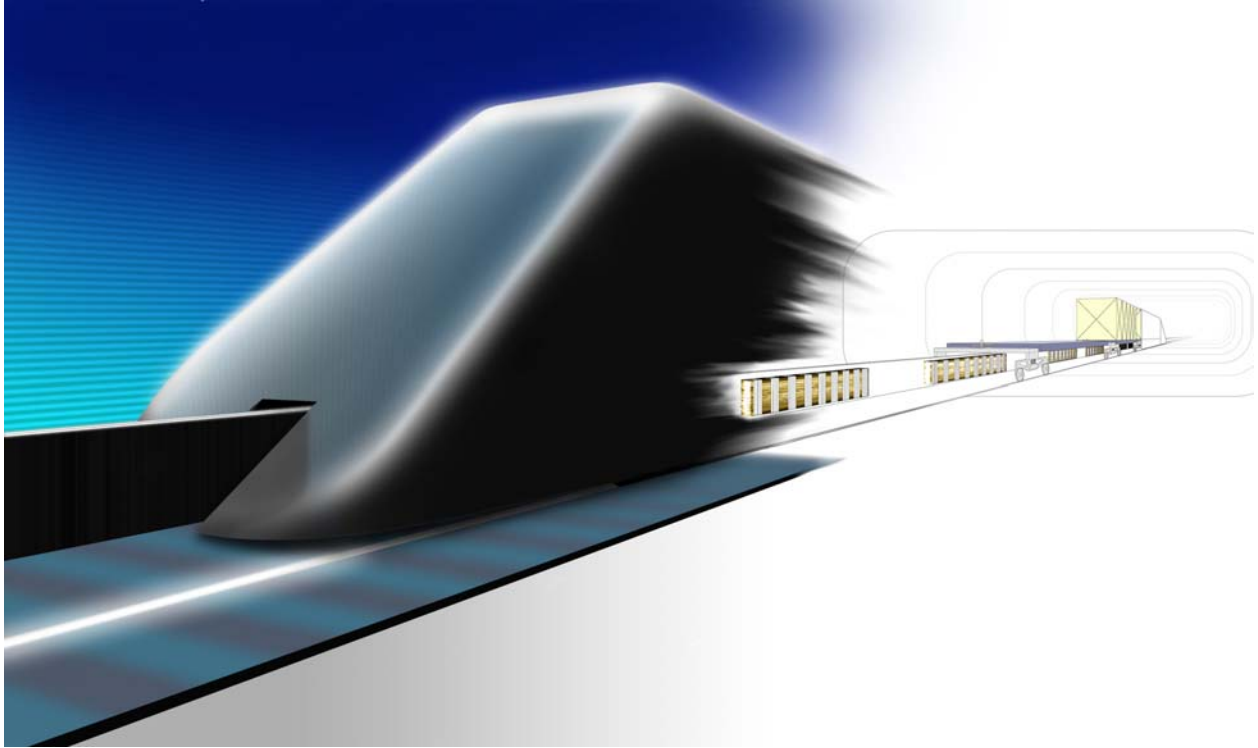


Figure 3. Conceptual Design of the Guideway-Mounted MTM.

Simulation Modeling

Work was performed in Year 3 to expand the basic model that simulated the flow of freight between terminals to include the operational performance of the truck loading/unloading docks and pallet inspection stations. By simulating operations over a five-day period, the new model made possible the assessment of:

- freight processing over a wide array of operating conditions,
- number of pallets transported,
- bottlenecks,
- queue lengths, and
- interaction of system components.

Based on the assumptions established in Year 2, the model shown in [Figure 4](#) found that 2,100 MTMs would be required to sustain pipeline operations indefinitely, and that two MTM loading/unloading docks would be needed to prevent queues from forming within the terminals. Also,

simulation of the truck loading/unloading process determined that 110 truck docks would be required to hold truck queue times to less than 15 minutes.

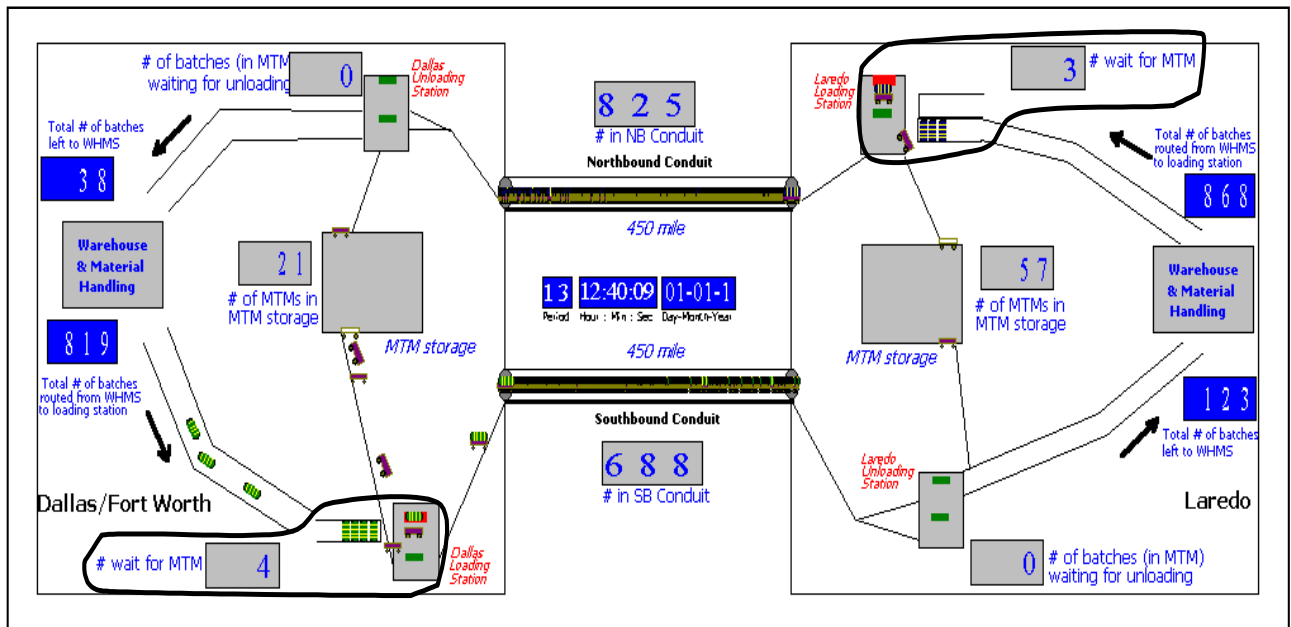


Figure 4. Simulation Model.

Economic Analysis

Research on the freight pipeline concept includes a determination of the economic worth to both the public sector and to potential private investors. Therefore, concept feasibility was to be evaluated by performing a:

- cost-benefit analysis for the public sector, and
- financial analysis for the private sector.

Work in Year 3 was dedicated to preparing the public sector cost-benefit analysis by developing an initial estimate of capital and operating costs, and then comparing those costs to the benefits accrued by the public sector through operation of the freight pipeline. Costs were based on the performance and aerodynamic requirements established in Years 1-2; namely, the operational guidelines established as part of the business model and the conduit dimensions required as determined from the aerodynamic analysis. As documented in Year 2, the design of the system attempted to balance the tradeoffs inherent in the cost associated with system size (cross section)

and the revenue-generating capability of the system associated with its capacity. A system with a large cross section would accommodate more freight, but it would also cost significantly more than smaller systems.

These initial estimates were considered to be within a degree of accuracy associated with a concept screening or feasibility study investigation, inferring that the level of uncertainty may actually be as great as –50 to +100 percent (11).

Cost Estimates

Capital cost estimates for the freight pipeline were comprised of pipeline construction, terminal construction, and the manufacture of the MTMs. Without a preliminary design, the pipeline cost was estimated by modifying the known cost of similar projects to fit the scope of the freight pipeline. Four large projects were selected to develop a preliminary cost estimate as follows:

- Texas TGV High-Speed Rail Project – preliminary engineering designs and cost estimates for the San Antonio-Dallas corridor.
- Mary Rhodes Memorial Pipeline – 101-mile, 5.5-foot diameter pipeline from Lake Texana to Corpus Christi.
- Central Arizona Project – 336-mile, 16.5-foot deep aqueduct from Lake Havasu to Tucson, Arizona.
- San Diego Aqueduct – preliminary study for a 100-mile aqueduct from the Colorado River (Arizona) to San Diego County (California).

A preliminary estimate of approximately \$4.0 billion was obtained by scaling these projects to account for the length and size of the pipeline, for anticipated track work, and for monetary changes associated with time and location. In order to estimate the cost of freight terminals, conceptual spacing requirements were developed for truck loading/unloading, pallet inspection, and MTM loading/unloading. These estimates were then used to determine the necessary terminal space, which in turn was used to calculate building and site work costs. Each terminal was estimated to cost approximately \$67 million or approximately 1.7 percent of the pipeline construction cost. Finally, the unit cost of each MTM was calculated using the estimated steel requirement from a preliminary structural design and the estimated MTM fleet volume obtained

from computer simulation of the freight pipeline system. Researchers determined this cost to be \$483 million.

The aggregated estimate for total system capital cost was therefore approximately \$4.6 billion, understanding that the confidence interval associated with the level of detail in this assessment places the possible cost range from between \$9.2 billion at the high end to \$2.3 billion at the lowest conceivable level. These estimates equate to approximately \$10.2 million per mile, with a possible range of from \$20.4 million to \$5.1 million. TTI, based on its review of major construction projects of a similar nature, considers that higher costs are a more likely outcome than lower costs.

In addition to capital costs, the Year 3 work estimated operating costs for each aspect of facility operations. These expenses included:

- labor costs,
- energy costs,
- component replacement costs, and
- loss in fuel tax revenue.

Annual costs associated with the operation of the pipeline included a \$10,000/mile maintenance cost and a personnel cost of \$6.25 million (assuming a staff of 125 people employed at an average rate of \$50,000/year). Furthermore, \$1.0 million per year was added for office and overhead expenses, resulting in a total pipeline operating cost of \$11.75 million per year. Also, a terminal maintenance cost of \$2.0 million per year was included based on an assumed unit cost of \$1.0 million per terminal per year. Other expenses included in the Year 3 cost estimate, such as energy consumption and MTM maintenance costs, were found to be small in magnitude when compared to the pipeline construction cost.

Determination of Benefits

Benefits included in the economic analysis were those benefits (i.e., avoided costs) accrued by the removal of trucks from Interstate 35, classified as follows:

- avoided marginal costs of truck traffic,

- avoided trucking industry expenses, and
- avoided highway construction costs (assumed to equal zero in this project).

The dollar value of these benefits were set equal to the marginal costs of highway use, which are listed in the Addendum to the 1997 Federal Highway Cost Allocation Study Final Report (12) and defined as:

- pavement cost – cost of repairing pavement deterioration,
- congestion cost – value of additional travel time due to small increments of traffic,
- crash cost – medical costs, property damage, lost productivity, pain and suffering associated with highway crashes,
- pollution cost – cost of premature death and illness due to vehicular emissions, and
- noise cost – change in value of adjacent properties caused by motor-related noise.

Table 1 lists both rural and urban trucking costs for 80 kip, 5-axle trucks used in this research. Also, an avoided trucking cost of \$1.40/mile-truck was used, based on statistical data published by the Federal Highway Administration (13).

Table 1. Marginal Costs of 80 kip, 5-Axle Truck Traffic on Highways.

Cost Category	Marginal Costs (2000)	
	Rural Trucking (\$/mile)	Urban Trucking (\$/mile)
Congestion	0.0223	0.2006
Collision	0.0088	0.0115
Pollution	0.0385	0.0449
Noise	0.0019	0.0304
Pavement	0.1270	0.4090

As published by the Federal Highway Administration (12).

Public Sector Net Present Value

The estimated volume of traffic captured by the freight pipeline was based in part on two corridor studies: the Effect of the North American Free Trade Agreement on the Texas Highway System (14), and the I-35 Trade Corridor Study: Recommended Corridor Investment Strategies (15). From these, it was concluded that approximately 50 percent of trucks entering Texas on I-35 at Laredo would be traveling non-stop through Dallas, with overall traffic projections

expected to reach 3,700 trucks per day by 2025. Also, Year 1 research on the freight pipeline concluded that approximately 50 percent of this traffic would be palletized and suitable for transport through the pipeline. Based on this information, and assuming that freight pipeline operations would not begin for a substantial period of time, it was concluded that 925 trucks/day, or $3,700 \text{ trucks/day} \times 50\% \times 50\%$, would be a reasonable assumption for the initial volume of trucks that would use the pipeline.

A further review of the literature indicated that, while current yearly rates of growth in international truck traffic are between 4-6 percent, long-term growth rates would decrease to a level more comparable to the expected growth in domestic trucks of 1.4 percent/year through 2010-2025 (15). Consequently, a yearly growth in I-35 truck volumes of 1.4 percent was assumed in this economic analysis. Once the traffic estimates were prepared, the net present value of the freight pipeline was computed by applying a discount rate of 3.9 percent over the 50-year project life to the following components:

- capital expenditures,
- operating expenses (for 925 trucks/day and increasing by 1.4%/year), and
- accrued benefits (for 925 trucks/day and increasing by 1.4%/year).

Based on the scenario outlined above, the net present value to the public sector was found to be \$1.1 billion, indicating that the freight pipeline concept could potentially be worthy of consideration as a solution to the transportation problems in Texas. A sensitivity analysis was also performed in order to evaluate the risk associated with errors in the estimated variables (i.e., cost estimate, initial volume of trucks, and rate of growth rate in trucks). Figure 5 shows how the net present value of \$1.1 billion is susceptible to significant change within a –50 percent to +100 percent range of error in the cost estimate. This plot, which assumes an initial 1,000 trucks/day, shows the freight pipeline to be highly infeasible at any reasonable rate of growth in trucks if the actual construction cost happens to exceed the original estimate by any appreciable amount.

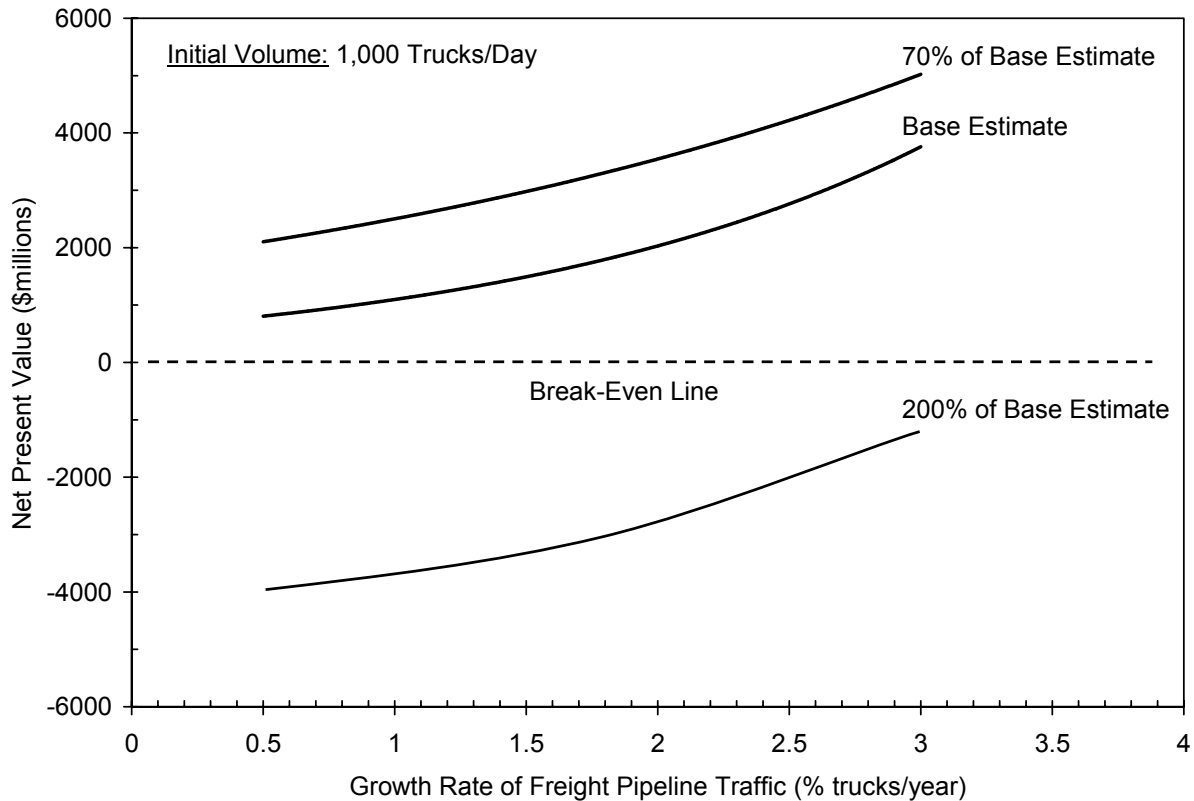


Figure 5. Effect of Cost Estimation Error on Net Present Value.

As with cost estimates, the potential exists for error in the estimate of trucks that would begin using the facility. Use of the freight pipeline would certainly diminish if material handling operations at either terminal were found to be unreliable or inadequate – a limitation of any system requiring transloading. Therefore researchers prepared, [Figure 6](#) to evaluate the risk associated with this error by plotting net present value for a series of truck growth rates and initial truck volumes. This work shows the susceptibility of project success to facility utilization rates, and indicates that actual truck volumes of approximately one-half the predicted volume would result in an unfavorable net present value. Consequently, the feasibility of the multi-billion dollar pipeline would depend a great deal on facility operations such as:

- terminal operating speed and efficiency,
- truck loading/unloading efficiency,
- truck and MTM queuing times, and
- pallet processing reliability.

In other words, while the terminals would be only a fraction of the total project cost, the performance of these facilities would greatly influence the trucking industry's willingness to divert their freight to the pipeline. This emphasized the importance of the material handling process to the economic feasibility of the freight pipeline and stressed the need to achieve high levels of performance and reliability within the freight terminals.

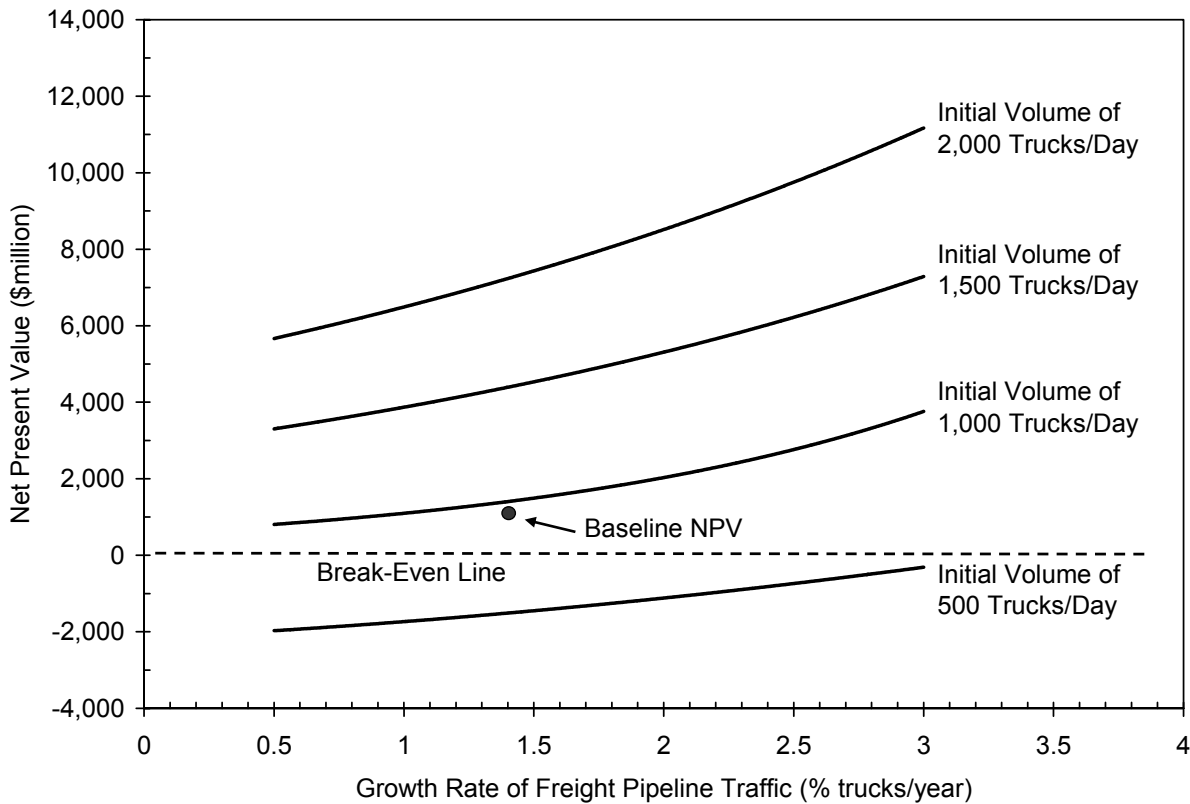


Figure 6. Effect of Initial Truck Volume Estimates on Net Present Value.

Project Financing

Cost estimates for this project indicate that no single source of funding would be sufficient, and that some combination of available resources would be required. As part of the Year 3 work, a review was made of potential funding sources for a freight pipeline, with the belief that some combination of public-private financing could be arranged using an approach similar to that of the Alameda Corridor in Los Angeles. In this project, a depressed 20-mile rail corridor was constructed to eliminate 200 at-grade rail crossings under the following financial arrangement:

- \$400 million Transportation Infrastructure Finance and Innovation Act (TIFIA) loan from the U.S. Department of Transportation,

- \$400 million investment by the Ports of Los Angeles and Long Beach,
- \$700 million from local project revenue bonds, and
- \$350 million in state and local funding.

Federal Funding

Federal legislation allows for the appropriation of funds to construct transportation corridors that significantly reduce existing truck congestion. While such legislation defines fiscal limits, the actual level of funding is established in yearly appropriations bills through programs such as:

- Designation as a Project of National Significance
- Selection as a Federal Demonstration Project
- National Corridor Planning & Development and Coordinated Border Infrastructure Programs
- TIFIA Loan

State Funding

State funding options are more limited than those at the federal level, but are often a critically important means of matching federal funds. These funding options include:

- Bonding,
- state Transportation Funds, and
- innovative Funding Methods.

Regional/Local Funding

Local entities currently assist with the funding of state transportation projects through the following sources:

- Congestion Mitigation and Air Quality funds, and
- Regional Mobility Authorities.

Private Funding

Funding by the private sector may be in the form of:

- private ownership and
- private operations.

Relocation of Existing Pipelines

The Laredo-Dallas corridor was found to contain approximately 80 existing natural gas or hazardous liquid pipelines – with an average diameter of 20 inches and a maximum diameter of 36 inches. Therefore, a thorough review was made in Year 3 to determine the level of effort that would be required to relocate these lines below the proposed 13-foot excavation for the freight pipeline. Section 192.250 of the Code of Federal Regulations requires any pipe installed underground to have at least 12 inches of clearance between the outside of the pipe and the extremity of any other underground structure (in this case, the freight pipeline), so the total depth to which any existing natural gas or hazardous liquid pipeline would have to be lowered is 14 feet. Using an optimistic scenario of an existing pipeline initially being buried with four feet of cover, researchers performed an analysis to determine the level of effort required to lower the pipeline an additional 10 feet.

Pipe diameter and grade of steel were found to be important factors in determining the trench length required to lower a pipeline while it remains in service. For example, a 20-inch pipe of grade X42 steel (42,000 psi yield strength) would require a minimum trench length of 1,000 feet in order to provide a deflection profile that prevents the pipe's longitudinal stress limit from being exceeded. Stronger steel, such as grade X52 (52,000 psi yield strength), reduces this required trench length to 832 feet; but an X42, 36-inch pipe would increase the required length to almost 1,200 feet. These findings suggested that the complexities associated with excavating and constructing an underground freight pipeline would include a significant and costly level of effort in altering the profile of the existing pipeline network.

Private Sector Financing of the Freight Pipeline

Researchers performed additional analyses to assess the viability of the freight pipeline as a purely private venture. In this assessment the capital financing and the operational and maintenance expenses were assigned to a private sector entity to determine the rate of return at differing rates of use, at different levels of cost overrun, and at a range of user fees. The findings of these analyses strongly suggest that the freight pipeline system would not be feasible for the private sector to undertake without public contributions under any reasonable scenario. Usage

rates required for a privately funded system to be profitable far exceed reasonable customer base projections used in the principal analysis.

Figure 7 presents a graphical summary of the rate of return values obtained for a freight pipeline system financed strictly by the private sector for different user fee levels and for different initial truck volume levels. As can be seen, rates of return of at least 10 percent are not possible at a user fee of \$1.00 per mile, even at truck volumes of 5000 or more per day. Moreover, increasing the user fee to \$2.20 per mile, which is almost twice the current cost of trucking, would still require more than twice the projected volume of palletized freight in order to earn a 10 percent return.

The conclusion readily reached is that, in order to even be contemplated as a strategy to move freight in densely traveled corridors, freight pipeline operations require public and private participation, with the public's involvement predicated on the benefits achieved through avoided social costs.

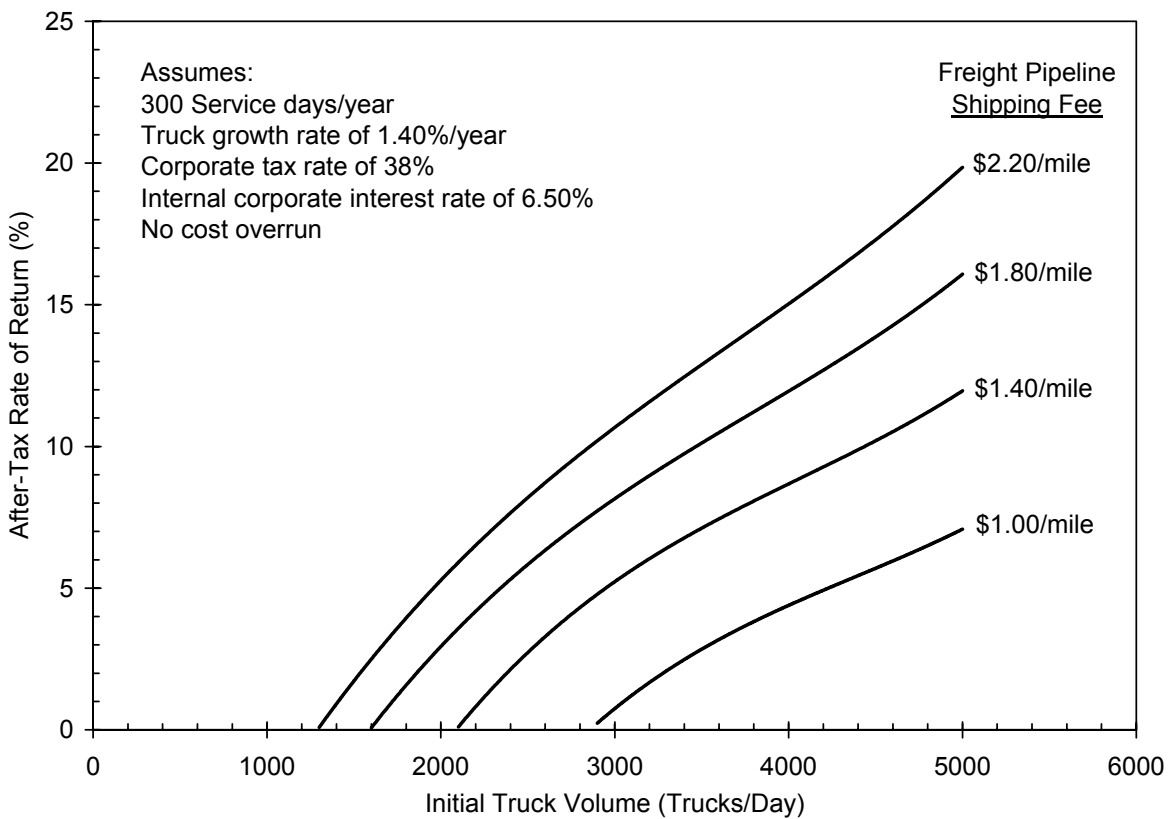


Figure 7. Private Sector Economics for the Freight Pipeline.

SUMMARY

The preceding analysis leads to the following observations:

- Based on the scenario described above, the net present value to the public sector was found to be \$1.1 billion, indicating that the freight pipeline concept could potentially be worthy of consideration as a solution to the transportation problems encountered on Interstate 35 in Texas.
- The initial estimates were considered to be within a degree of accuracy associated with a *concept screening or feasibility study*, inferring that the level of uncertainty may actually be as great as –50 to +100 percent.
- As with cost estimates, the potential exists for error in the estimate of trucks that would initially use the facility as an extension of their operations. Further, use of the freight pipeline by the trucking industry would diminish if material handling operations at either terminal were found to be unreliable or inadequate – a limitation of any system requiring transloading.
- The findings suggested that the complexities associated with excavating and constructing an underground freight pipeline would include a significant and costly level of effort in altering the profile of the existing pipeline network.
- Cost estimates for this project indicate that no single source of funding would be sufficient, and that some combination of available resources would be required.
- The net present value of \$1.1 billion is susceptible to significant change within a -50% to +100% range of error in the cost estimate. The analysis shows the freight pipeline to be highly *infeasible* at any reasonable rate of growth in trucks if the actual construction cost happens to exceed the original estimate by an appreciable amount.
- Findings from the analysis to determine the potential for a strictly private venture strongly suggest that the freight pipeline system would not be feasible for the private sector to undertake without public contributions under any reasonable scenario.

The considerations cited above suggest that, while marginally feasible, the freight pipeline concept – or any known underground system that requires transloading – would not, because of the large risk associated with its construction and operation, be an attractive investment opportunity for the private sector. Further, since many of the benefits (i.e., reductions in

pollution, roadway congestion, and vehicle collisions) are not convertible to equivalent cash flows for the investor, the user cost rate required to produce acceptable returns on investment would be significantly higher than transportation costs now incurred by the trucking industry. Consequently, the findings from this analysis shows no evidence that the freight pipeline would be an attractive investment to the private sector.

CHAPTER 3 – ADDITIONAL CONSIDERATIONS FOR THE FINAL ANALYSIS

This chapter serves to examine some of the additional factors taken into consideration by the research team as it completed its evaluation of the potential for underground freight movement to effectively and economically address the freight transportation issues evident or emerging in Texas. These issues center on the adverse social ramifications associated with over the road transport of freight by trucks – diminished safety, freight security, accelerated roadway damage, increased congestion, and increased air pollution. The appeal of underground freight movement is found in the perception that this approach to freight transport could effectively mitigate many of these social costs. The three principal elements contained in most of the technical concepts put forward as candidate approaches to underground freight movement that address these concerns are:

1. the separation of freight traffic from passenger traffic – both in grade and alignment,
2. increase freight transportation security, and
3. the potential for efficiency levels – in energy and time savings – exceeding those found with traditional systems (trucking and rail).

The freight pipeline studied in the current research embodies these principal elements, as well as providing a large enough reduction in truck traffic levels to interest policy makers – a limitation of lower capacity, tube freight systems. A point of concern with any underground system, particularly in the wake of September 11, 2001, is the potential for an explosive device to render the system inoperable for an extended period of time. Thus, rather than just providing additional security for freight (which it could still be considered to do), the system itself may also have to be protected since it could be viewed as an inviting target – and this would be difficult given the requirement to inspect thousands of individual pallets each day.

However, even given the issues associated with security, it is the marginal or qualified economic feasibility associated with underground freight transportation – attributable to the risk and uncertainty associated with excavation or tunneling – that suggests alternative systems that also embody the elements listed above may be a far more feasible way to achieve real improvements in freight transport.

The current research examined in detail the viability of alternative freight transport technologies, settling on a linear induction system supported by steel wheels and a steel running surface. The evaluation undertaken suggests that this alternative technology offers superior performance in terms of both energy and speed over current motor carrier systems. Given the potential of new technology to improve freight movement economics, there remain questions concerning how to readily achieve separation of freight from passenger traffic and how to ensure enhanced security? Focusing on these points, the final recommendation offered by TTI relative to general freight transportation, takes into consideration several additional factors not directly tied to the subterranean movement of goods. These considerations are part of the longer term freight transportation landscape – keeping freight movement inexpensive, reliable, and secure.

Transportation Technology Advancements – A Brief Historical Reference

The history of freight transportation spans the millennia. For centuries goods were moved by human and animal-powered carts and wagons. In the 19th century, the industrial revolution was marked by the introduction of motive power in the form of steam engines. For the first time in history, man-made power plants provided mechanical assistance in a form that could be tailored to the task at hand. Prior to this time, water power had provided the energy for mills and factories, but the reliance on gravity-powered water wheels limited the application to locations with available water resources. The steam engine allowed engineers to design and build both fixed and mobile machines for a wide variety of applications. Railroads, invented in England in the early 19th century, were first used in mining, but soon found their way to more generalized application in transportation. Steam technology revolutionized the transportation of people and goods and provided enormous economic benefits to the societies that used them. Railroads dominated intermediate and long-distance freight transportation beginning in the 1850s, effectively “leap-frogging” wagons and animal power to become the mode of choice for moving large quantities of freight over long distances. It remained dominate for over 100 years, until the 1950s.

Operational and Technology Challenges Facing the Railroad Industry

For all of its advancements and refinements, the modern railroad system in the U.S. would be immanently recognizable to most 19th century Americans. Long trains are still pulled by one or

more powerful locomotives. Steel wheels roll, as they always have, atop hardened steel rails. The rail itself remains set precisely four feet eight and one half inches apart and, for the most part, wooden cross ties still serve as a key structural component tying rail to the road bed. Yard operations remain at the heart of the rail network, collecting, sorting, and routing carloads to their final destination. But for all that has stayed the same, there has been an evolution in the role railroads play in the nation's transportation system. The rail industry has become a specialist in moving heavy freight over long distances – distances sufficient to overcome the otherwise metered pace of a system that finds itself constrained by the very technology that initially made it so stunningly successful.

Conventional wisdom suggests that the railroads lost their preeminence in the land-based freight industry as a result of the interstate highway system – that 40,000 mile limited access system inspired by the German's pre-World War II autobahn. The interstate system allowed trucks to expand their range and reduce their transit time to a level that the railroads found impossible to match, particularly when the dock-to-dock service also possible with trucks is added to the overall logistics. There were many other factors involved in the decline of the railroads, such as rate control, over regulation, and swollen employment levels, but trucking had perhaps the largest, most telling impact. The net effect of the interstate system pushed many railroads into bankruptcy and set into motion a series of events that ultimately led to the restructuring of the industry in 1980 through the Staggers Act. Just as railroads had provided a superior alternative to carts and animal-drawn wagons, trucking had leap-frogged the railroads to become the mode of choice for shippers. It remains so today.

Railroad Technology

Railroads are ideal for extending transportation into areas without any but the most rudimentary transportation infrastructure. The cross tie and rail combination allows railroads to penetrate even unfavorable terrain with a bare minimum of surface grading and relatively modest infrastructure. The resulting track system provided a rolling surface with great mechanical advantage and a guideway that effectively and safely directs the locomotive and rolling stock. From the historical perspective of geographic development, no other system could have offered

the speed, economy, capacity, or reliability that railroads provided. Because of these features, railroads have a central place in American history.

Putting aside strictly business issues, there is one characteristic a railroad possesses that is central to its operating success: low rolling friction and energy efficiency. The physics of the steel wheel on steel rail makes moving a massive load on land both practical and economical. Without physics on their side, the railroads would surely have gone the way of the horse and wagon – beat out by faster, more efficient competition. The energy required for a locomotive to move a load is less than one-fifth the amount required to move a similar load over the highway, with concomitant reductions in fuel use and emissions.

The elegance of rail transportation is found in simplicity: the ballast-cross tie-rail combination distributes the load more effectively with a lower rolling friction coefficient than is accomplished by 18 rubber tires on a roadway surface. However, the simplicity of the steel wheel, steel rail relationship belies an underlying technological and practical complexity that places limits on the potential for rail transportation to fill new and expanding roles in the national transportation system.

Radius of Economic Operations

Railroads collect and sort rail cars in terminals. These gathering locations are where cars with similar destinations are identified and grouped together to build a train. Also known as classification yards, or in the case of intermodal service, intermodal yards, terminals are the source of most of the delay associated with traditional railroad operations. Referred to as “dwell time,” the amount of time a railroad car is in a terminal can vary from a few hours to several days. This yard-related delay results in an inability to compete with trucking over short distances. By the time a car is sorted and added to the appropriate train “consist” (the railroad term for the cars comprising the train) a truck may well have completed its short haul – particularly if the move is within 400-500 miles. Building long trains pays dividends, however, when the destinations are more than 500-750 miles in length. Railroad statistics confirm that the average distance of a shipment made by rail exceeds 1000 miles, while the average shipment distance by truck is around 300 miles.

Figures 8 and 9 display the concept of radius of economic operations from two locations in Texas – Houston and Laredo. The implication of this characteristic of railroad operations, and a key reason that trucking dominates intercity movement of freight over short and intermediate distances, is that traditional freight rail will not be among the solutions to trucking generated highway congestion on routes of these more modest distances.

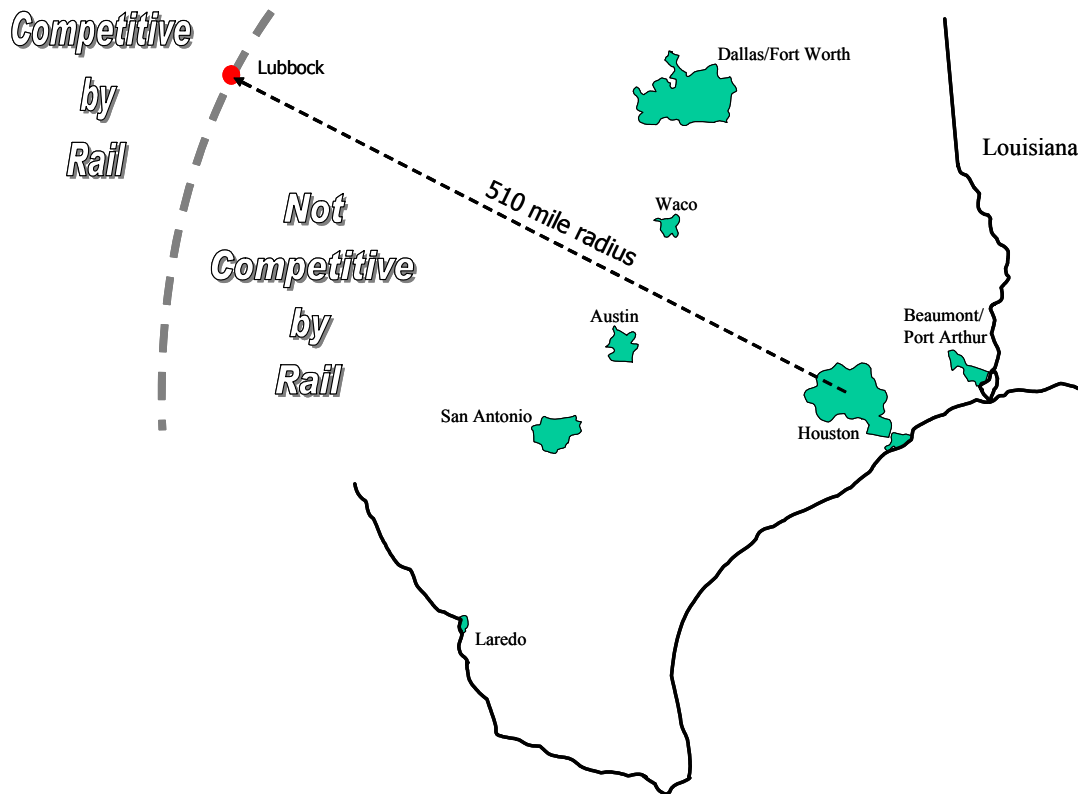


Figure 8. Radius of Economic Railroad Operations from Houston, Texas.

The railroad industry recognizes this limitation, and some carriers are seeking ways to attack the problem by partnering with the public sector to implement short-haul intermodal services designed to mitigate the delays associated with traditional rail intermodal operations. The transportation market associated with this sector is huge. Intercity movement of goods by truck represents more than 10 times the revenue base of existing railroad operations. The combination of expedited single loads and point-to-point operations makes it almost impossible for railroads to compete on price alone. The provisions proposed by advocates of short-haul rail include dedicate railroad equipment and crews, priority dispatching, strategically placed intermodal

yards, and contract relationships with trucking companies that seek the additional economies allowed by rail shipments. The prevailing thought on the subject includes participation by the public sector in the form of subsidies, grants, participation in the building and operation of new intermodal facilities, or ownership of the dedicated equipment. The benefits gained by the public sector, namely lower congestion and reduced pavement damage on over-burdened highway facilities are seen as the motivating element behind these proposed public-private partnerships.

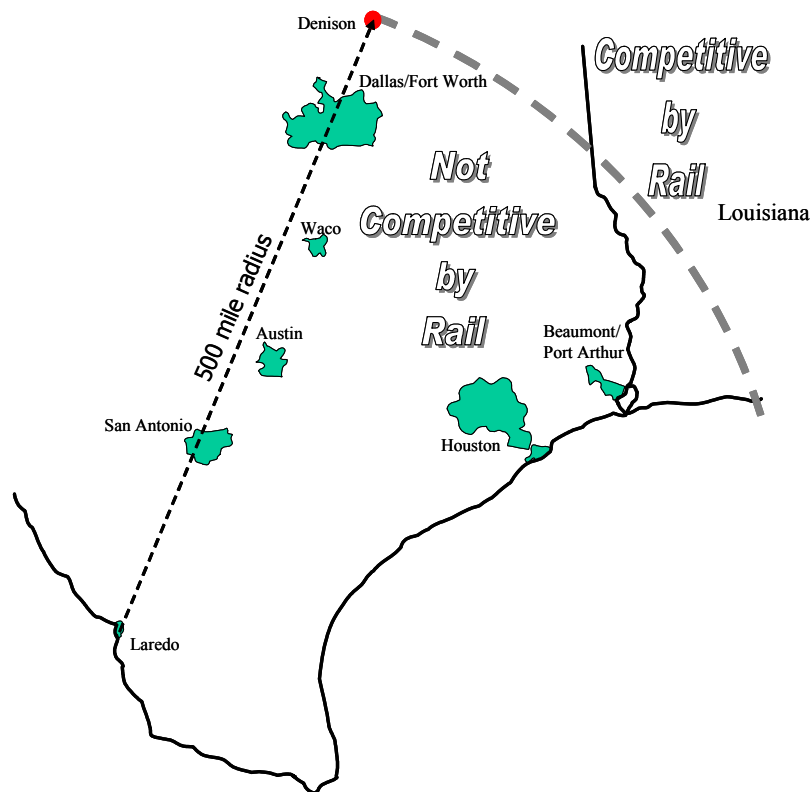


Figure 9. Radius of Economic Railroad Operations from Laredo, Texas.

The potential for partnerships between railroads and the public sector to mitigate truck traffic over certain routes is good under certain conditions. The two entities must agree on common goals and create a framework that balances private profit potential and its associated risk against the public gain. Public gains represented by avoiding significant social costs associated with trucking operations as they are carried out today. Public-private partnerships are no small challenge given the history of public sector-railroad interaction (and regulation) and the deeply engrained differences in their respective approach to benefit determination. Railroads seek profit

maximization and the control of risk while their public sector counterparts seek public benefits in the form of welfare, maximizing services and infrastructure.

Technological Issues

The very attributes that underwrote the success of railroads, steel rail and steel wheels, a fixed guideway, long trains, and heavy loads create a system complexity that limits the potential for rail to assume a greater role in the movement of freight over short and intermediate distances. The technical issues are well known and understood: rail is subject to periodic failure. Wheels fracture, bearings fail, ties deteriorate, and the resulting loss of gauge may cause a derailment. Air pressure-based braking systems are anachronistic and ineffective, requiring as much as a mile for trains to make a complete stop. Rail cars can uncouple or jump the tracks. These problems name but a few of the technological challenges facing railroads.

Since the rail system in the U.S. is part of an international network (the U.S., Canada, and Mexico routinely interchange traffic), the reality of the process where cars and other equipment are exchanged between railroads makes the introduction of new equipment configurations an exceedingly difficult and long-term proposition. This interchange process coupled with the fact that over half of the railcars currently in service on U.S. railroads are privately owned means that any significant change in the types of equipment being used on rail networks will come very slowly, if at all. The standard three-piece truck (also called bogies) that supports most of the railcars in operation today was designed in the 1920s, and while there are premium trucks on the market that offer improved steering and better ride quality, their impact on railroad economics will not be felt for many years.

These observations are important for a number of reasons. First, the railroads are constrained by their own and the Federal Railroad Administration's (FRA) operational rules and hence technological innovation is difficult. Constraints are evidenced by the slow pace of adoption of electronic braking systems, which offer shortened stopping distance and improved train handling characteristics. Second, the technological complexity described above has the dual impact of increasing the overall cost of rail transport while lowering the reliability of rail to a level that detrimentally impacts a shipper's decision when faced with a mode choice. There are huge

expenses associated with maintenance of track and rolling stock and equally large costs associated with failure to maintain these assets to a high level of operational integrity. Some derailments can cost tens of millions of dollars and have secondary impacts on rail system throughput that add additional costs. When these factors are added to the system impedance associated with terminal operations, it is no wonder that “customer service issues” remain a major hurdle for the railroads.

Third, the railroads expend considerable financial resources on research to incrementally improve their systems. Some of the research is aimed at systems designed to monitor the condition of their network. Flat-wheel detectors and hot-bearing detectors are two examples, while some of the research is targeted at more fundamental elements of railroading such as the composition of the steels used to manufacture rail and wheels. The nature of these efforts and of these expenditures, speak to an important point – railroads are seeking improvement at the margins. There is no thought given to changing the basic approach to transportation represented by the mature railroad system – a system that operates with success in the niche within which its own operational and technological constraints has placed it.

In summary, there appears to be only a limited opportunity for railroads to assume a larger role in the short-haul intercity freight (<500 miles) market. Since both the economics and the technology of traditional railroading do not lend themselves to acceptable service levels at these distances, it remains for either trucking or a new approach to intercity freight to bear the burden of ever-increasing volumes of freight.

Transportation Fuels in the 21st Century

In-depth research has been performed on this subject as part of the Year 4 research and has been included as a supplement at the end of this report.

Complacency in the United States’ ability to procure petroleum is easy to understand considering that the supply of oil has been virtually unlimited throughout the 20th Century. Perhaps a more accurate sense of history can be acquired if one realizes that the U.S. consumption of oil for transportation purposes in 1950 (approximately 100 million barrels) represents only 2.5 percent of the oil consumed by transportation in 2000 (4 billion barrels). In fact, the entire world did not

produce as much oil as the U.S. now consumes for all purposes (7.1 billion barrels/year) until 1960. Therefore, the perceived assurance of plentiful oil supplies throughout the past century and beyond is perhaps attributable to the fact that there has actually been little demand for oil until the past several decades as shown by the production curve in Figure 10. Of course, oil supply must be discussed not only in terms of consumption but in terms of oil discoveries as well. Caution seems further warranted from this perspective when considering that, with respect to the peak year of world oil discoveries in 1962 (approximately 40 billion barrels), new discoveries have declined to the point where only about 6 billion barrels were discovered in 2002. In other words, worldwide discoveries in 2002 did not replace U.S. oil consumption in this same year.

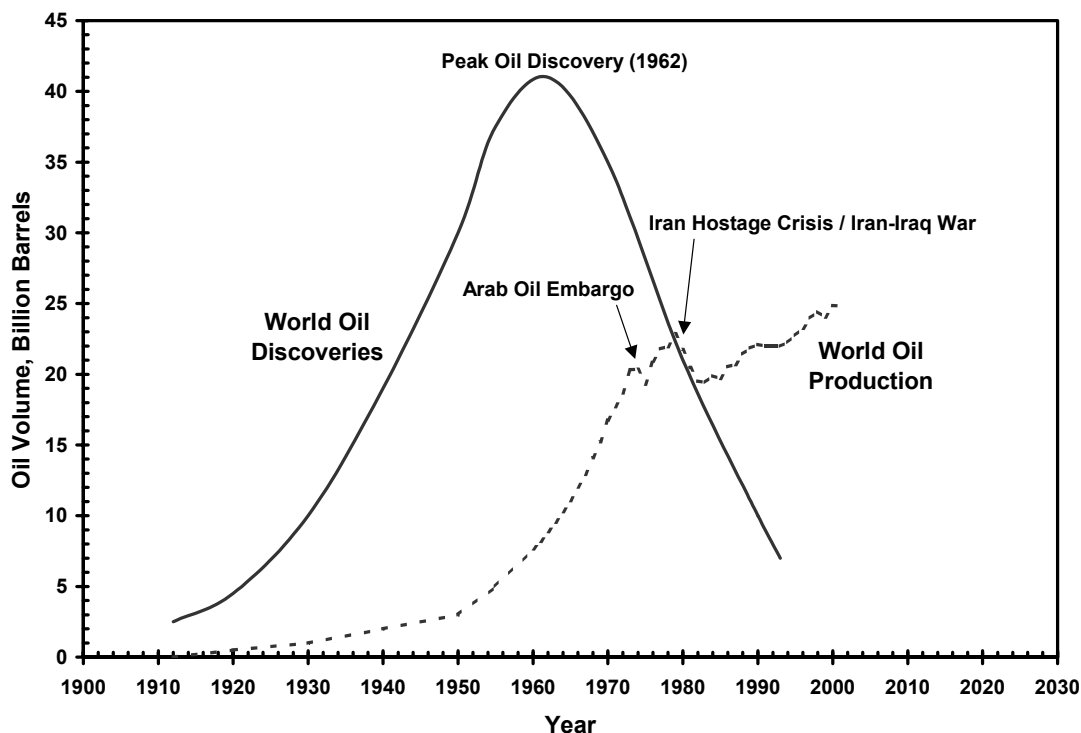


Figure 10. Comparison of Historic World Oil Discoveries and Production (after Master, Attansi and Root).

Descriptive Oil Supply Forecast

A plot of world oil production can be described graphically as: first production occurring at an initial point in history (early 1900s), ascending over an extended period of time, then at some point, descending over a similar period of time in order to return to a level of zero production. Industry and government agree that this process (the production curve) will occur over

approximately two centuries, meaning that the depletion of economic oil will not occur until near the end of the 21st Century. However, it is not final depletion that should be of interest to transportation planners, but rather the point in time when oil production reaches a plateau and then begins to slowly decline. This “production peak” is the point at which oil supply and demand begins to diverge; and once supply can no longer meet demand, fuel prices will rise and both motorists and air travelers will expect alternative transportation solutions (i.e., alternative fuels and infrastructure).

The United States Geologic Survey’s (USGS) estimate of the world’s ultimate recoverable reserves, by far the most optimistic of all forecasts, is between 2.2 trillion barrels (95 percent certainty) and 3.0 trillion barrels (mean expected). Furthermore, the USGS estimates the peak in world oil production to occur between the years 2021-2037 if production continues within rates projected by the United States Energy Information Administration. So, assuming a planning horizon of only 20 years, current infrastructure plans already extend into the era of oil supply deficits (2023), meaning that decision makers could be overlooking a critically important transportation issue.

Benefits of a Linear Induction System

In light of the long-term oil supply outlook, and given the precarious potential for hydrogen to become a main transportation fuel, there is a need for transportation planning to identify reliable freight and passenger systems that reduce our virtually complete reliance on petroleum. This four-year research project has identified a linear induction system that combines the low rolling friction of steel wheels and steel rail with an electric propulsion system as a viable alternative means of moving intercity freight within Texas. This approach provides Texas with significant future latitude given that electric power can be obtained from a variety of energy sources. Therefore, the potential for this concept to succeed, coupled with its flexibility in energy reliance, provides motivation for the identification of a suitable form of infrastructure in which this technology can be applied.

The Trans Texas Corridor

In 2002, Texas Governor Rick Perry proposed a state-wide system of multimodal corridors to provide Texas with the transportation infrastructure necessary to sustain mobility and economic

growth in the state well into the 21st Century. Called the Trans Texas Corridor (TTC), the system as conceived will provide the foundation for future travel between major metropolitan areas of the state for both freight and people. The TTC system consists of roughly 4000 miles of corridor for road and railways, pipelines, and utilities. The design concept calls for wide corridors (~ 1200 feet) to accommodate various combinations of elements. Among those initially cited are:

- highways,
- dedicated truck lanes,
- freight rail – both traditional and high-speed, and
- high-speed passenger rail.

The TTC system is to be located outside of urban areas with connections into urban centers provided by each respective metropolitan area. Offering users a grade-separated right of way, the corridor's truly radical feature is found in the plans for financing, construction, and operations. The recognition of future budget shortfalls for the maintenance and construction of transportation infrastructure has motivated TxDOT to promote the TTC as a privately financed and operated system of toll facilities. [Figure 11](#), shows the TTC in conceptual terms relative to urban areas and the existing highway system.

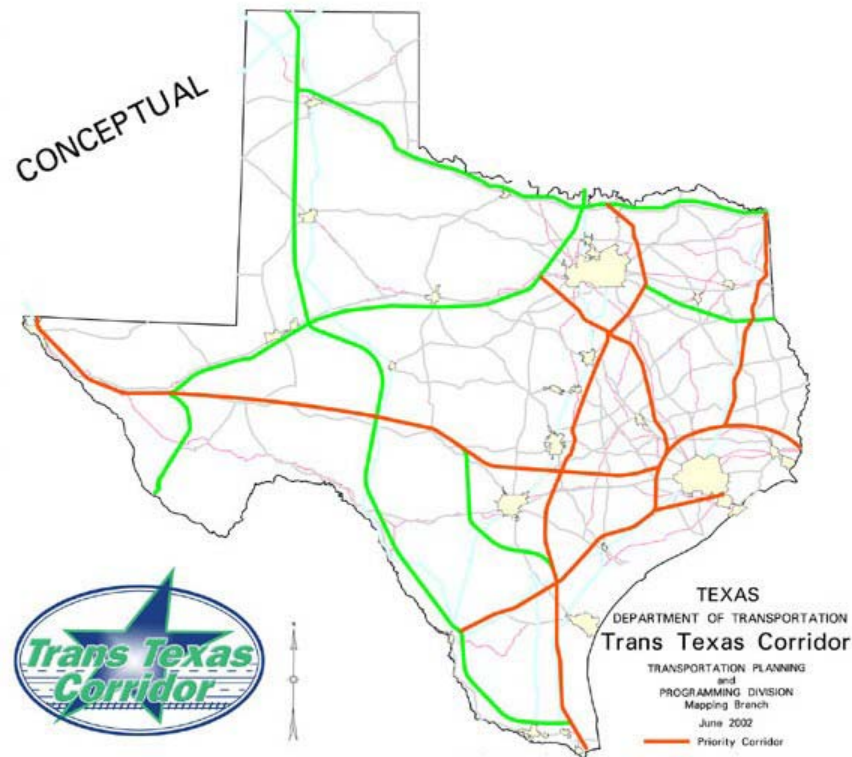


Figure 11. Conceptual Rendering of the Trans Texas Corridor.

With private sector participation, grade-separated rights of way and the opportunity to partner with the state, both financially and operationally, the TTC offers transportation planners with new opportunities and challenges. The control of corridor access could provide enhanced security for all modes and offer the opportunity to introduce innovative transportation technologies or approaches.

CHAPTER 4 – EVALUATION OF AN ALTERNATIVE CONCEPT

INTRODUCTION

The research undertaken by TTI relative to underground freight transportation has resulted in the conclusion that, due to the cost of excavation, tunneling, and related infrastructure, any system that would significantly impact the levels of truck traffic on Texas highways would be prohibitively expensive. Further, the risk of cost over-runs for projects of this type and scope plus the inability to profit directly from mitigating the social costs of truck traffic, would discourage investment by the private sector. These conclusions, in conjunction with the additional considerations examined by TTI as detailed in [Chapter 3](#), suggest that the components for a viable alternative freight transportation system may be found within a subset of the systems proposed by TTI for the underground freight transport system.

TTI has identified transloading as a major obstacle to introducing any “new” approach to freight transportation. Given the fact that a large proportion of freight moves over distances of less than 500 miles, any system that requires the cost of additional labor and time to shift and/or repackage loads between alternative conveyances is seriously handicapped. Limitations of transloading were partially overcome by positioning the freight pipeline as a NAFTA-related system that conserved Texas’ highways by facilitating trans-Texas freight movement, effectively allowing out of state trucks to interface with Mexico and vice versa, without using Texas roads.

With transloading as a major obstacle, the ideal underground system would be capable of transporting intermodal containers. The system would become a link in the already established intermodal system that includes steamship lines, rail, trucking, and even barges whereby intermodal containers are transferred between modes quickly. However, as the current research has emphasized, the excavation and tunneling costs are the principal reason for the economic infeasibility of the freight pipeline even for cases where the size of the underground structure was minimized to the fullest extent possible. It is safe to assume that a conduit of sufficient size to accommodate intermodal containers, which are roughly 10 feet high and 10 feet wide, would be prohibitively expensive. Preliminary calculations suggest that a conduit roughly 18 x 28 feet would be required to operate one track in each direction.

The Freight Shuttle

For practical purposes, the Trans Texas Corridor proposed for Texas is a surface analog to the freight tunnel investigated for this research. It offers the potential for grade and alignment separation, security, and available right of way in major Texas corridors that correspond to the demonstrated patterns of high-volume truck traffic. The potential cost savings for using a surface alignment rather than trenching or tunneling to achieve traffic separation are enormous.

By modifying the original MTM concept to handle containers rather than pallets, and by incorporating the linear induction system into TxDOT's plan for a sealed and secure TTC network, similar benefits to that of the freight pipeline are achieved. In doing so, the same levels of energy efficiency, security, and avoided trucking costs are attained, while the costs and risks associated with construction and material handling are minimized. This alternative concept reduces the need for material handling to a system that employs standard intermodal cranes that are readily available, and have known service rates and reliability measures. The required terminals can be sized to accommodate high, medium, or low volumes of traffic and be located away from urban centers.

TTI has named this freight transport technology the "Freight Shuttle." Employing the track system designed for the freight pipeline, the vehicle operates on a fixed guideway, using the vertical element of the linear induction motor for vehicle guidance. Steel wheels use a steel running surface to minimize rolling friction and the aerodynamics developed for the MTM are scaled up to minimize drag. Savings are achieved with the larger vehicle in both the linear motors (increased efficiency) and in the structural design of the Freight Shuttle. This latter savings is due to the structural soundness of the intermodal container, which can replace a portion of the structural steel included in the pallet-carrying MTM. [Figure 13](#) shows an artist's rendering of the Freight Shuttle.

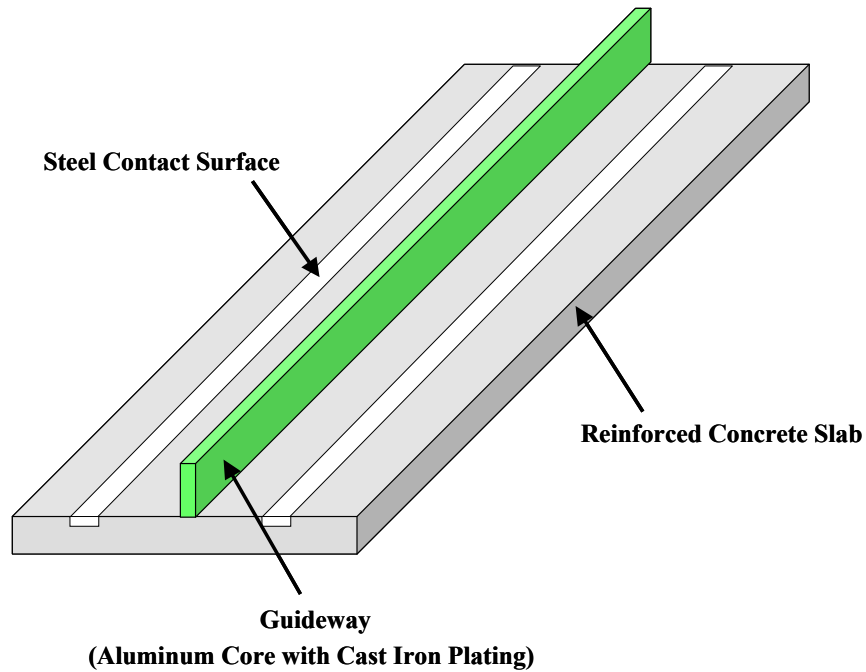


Figure 12. Illustration of Running Surface and Guideway for the Freight Shuttle.

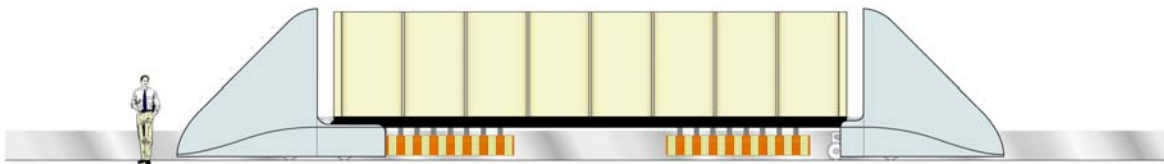


Figure 13. The Freight Shuttle.

Trans Texas Corridor Alignment

The freight shuttle concept uses the transport technology proposed in [Chapter 2](#) in aboveground alignments of the Trans Texas Corridor. This proposal would employ the isolated, sealed corridors of the TTC network to provide similar benefits to that of a buried freight pipeline without incurring the inherent costs and risks associated with massive earthwork projects. [Figure 14](#) illustrates the recommended construction strategy for the freight shuttle, which provides a direct link between truck terminals throughout Texas and eliminates the need for intercity truck

traffic to use the highway system. Depending on the trucking industry’s response to the development of the Trans Texas Corridor, these terminals may consist of a single shared facility at the city’s edge, or may consist of existing truck terminals that access the Corridor through extended belowground structures.

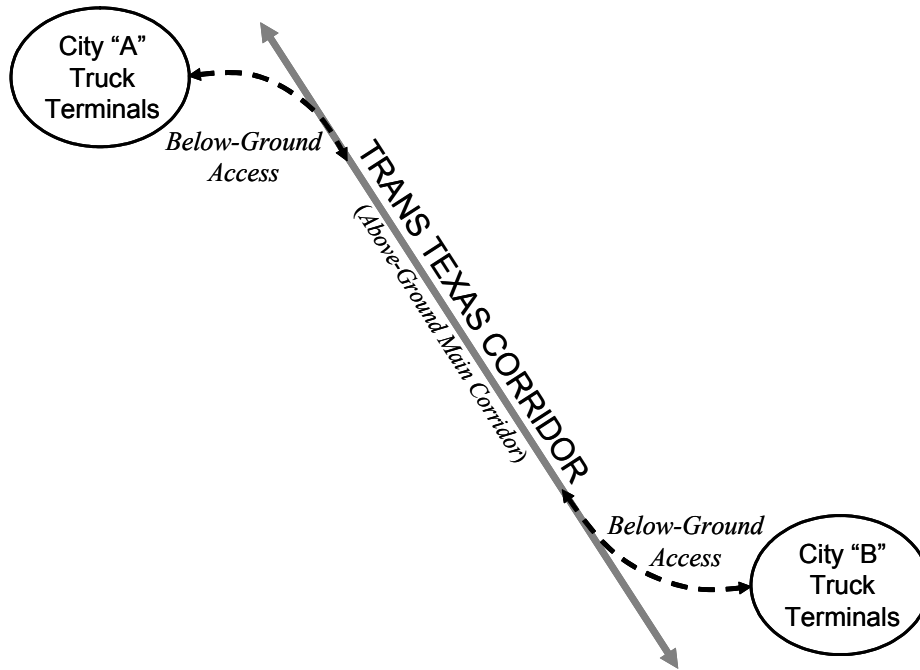


Figure 14. Construction Strategy for the Freight Shuttle System.

Accessing the Trans Texas Corridor

The freight shuttle concept includes underground access to the sealed Trans Texas Corridor, as shown in [Figure 15](#). These tunnels may simply extend to the outer limits of the corridor, or may actually extend directly into the truck terminals. This concept allows easy access to the sealed corridor, and provides a means by which even mid-sized towns along each route can connect with the freight shuttle network.

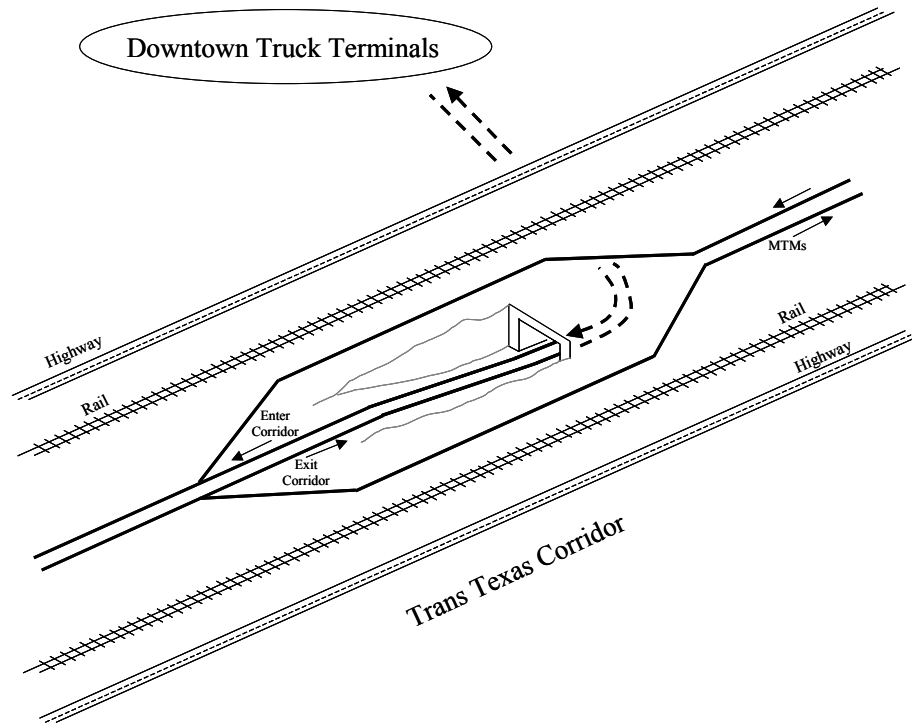


Figure 15. Freight Shuttle Access to the Trans Texas Corridor.

The original simulation model for freight pipeline operations between Laredo and Dallas was modified to determine the effectiveness of using container cranes to transfer freight (Figure 16). An analysis with this model concluded that the use of container cranes to load and unload freight (as shown in Figure 17) would be a viable means of streamlining freight shuttle operations.

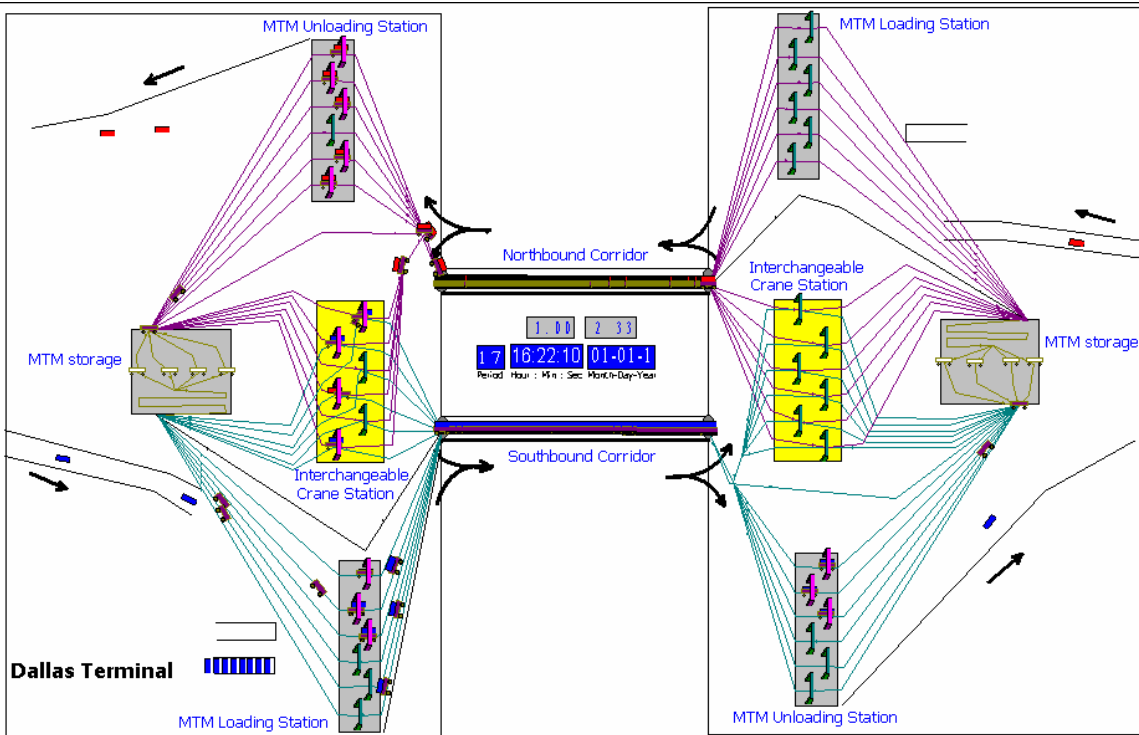


Figure 16. Simulation of Container Crane Operations



Figure 17. Transfer of Freight Shuttle Cargo Using Container Cranes.

Freight Shuttle Routes

The freight shuttle network should be constructed within all priority corridors of the Trans Texas Corridor Plan in order to both maximize social benefits to the state and to provide the transportation industry with a system that reaches all of the state's major urban centers. Figure 18 describes these corridors in terms of distance and truck traffic. These values serve as a basis for the economic analysis of the freight shuttle.

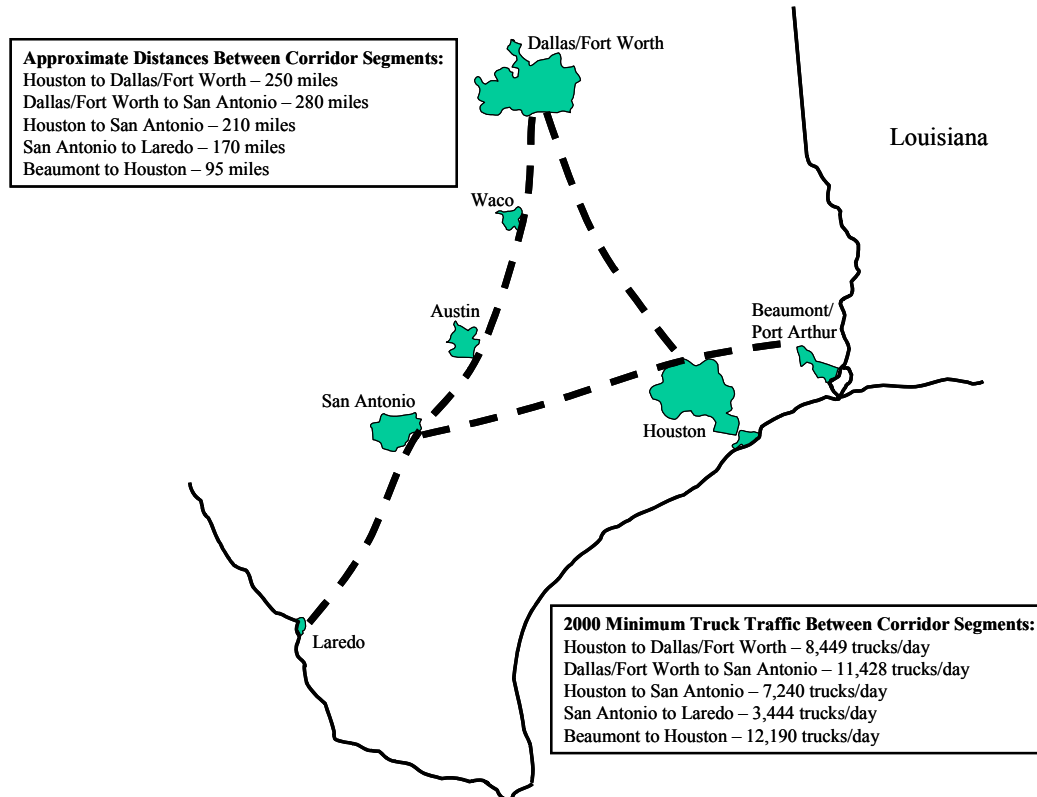


Figure 18. Recommended Freight Shuttle Corridors.

Economic Evaluation

Cost estimates for the proposed freight shuttle network were prepared using the project costs outlined within the 1991 franchise application for the Texas TGV high-speed rail system (16). The Texas TGV system, shown in Figure 19 as proposed by the Texas TGV Consortium, is comparable to the recommended freight shuttle routes as shown previously in Figure 18.

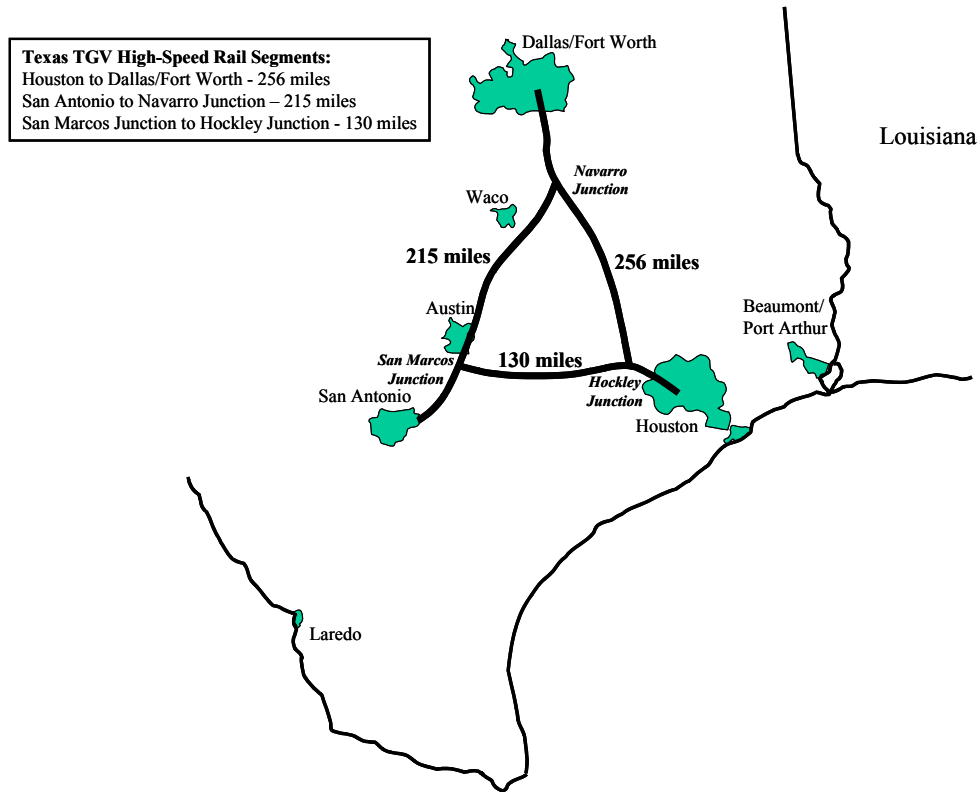


Figure 19. Texas TGV High-Speed Rail Corridors (after Texas TGV Consortium, 1991).

Description of the Texas TGV Cost Estimate

In Year 3, cost estimates for the proposed freight pipeline were based on conceptual designs, which restricted the degree of accuracy to that associated with concept screening or feasibility investigations (-50 to +100 percent) (11). On the contrary, project costs for the Texas TGV were based on preliminary plans and profiles for the entire double track system shown in Figure 19 (16). Since estimates based on civil drawings are expected to have a degree of accuracy within -10 to +15 percent, the use of these plans should provide a substantial improvement in the accuracy in estimating costs for the freight shuttle. Also, the alignment of these corridors was based on efforts by the Texas TGV Consortium to:

- minimize negative environmental impacts,
- minimize property severance,
- minimize relocation efforts,
- avoid unstable soil or foundation conditions, and
- provide the most direct route possible between terminals.

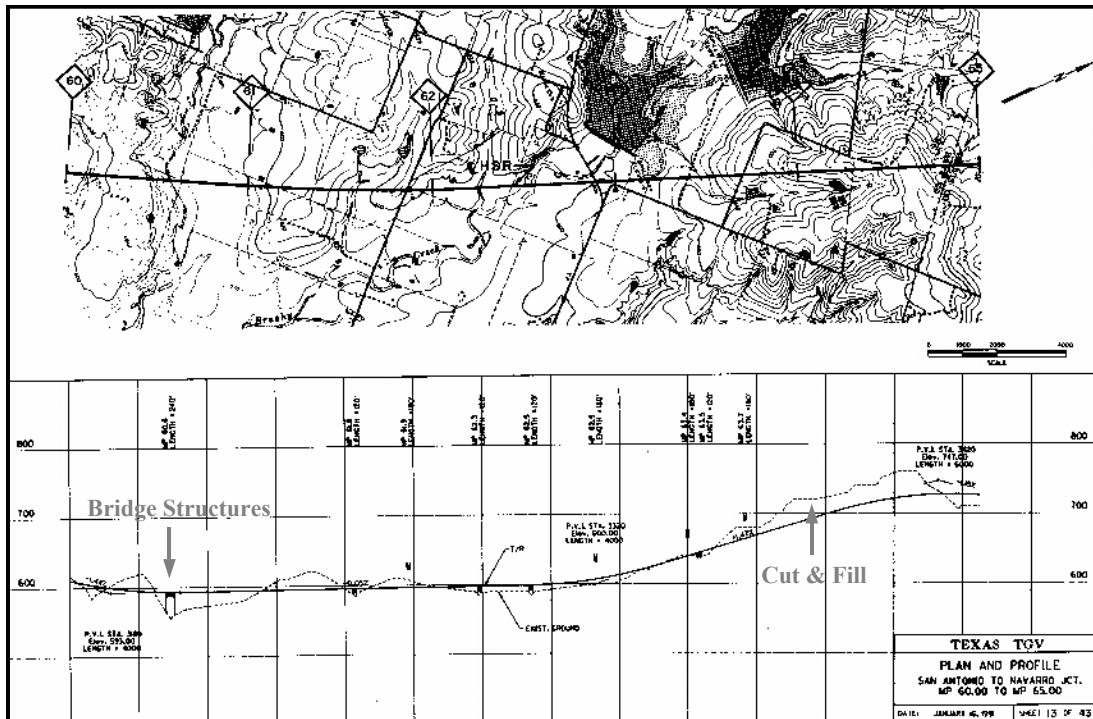
The implementation of this design strategy resulted in a detailed set of cost categories, as shown in [Table 2](#). In addition to these costs, the following general cost items were included to obtain a final cost estimate for the Texas TGV system:

- engineering/environmental/design – 7% of total construction cost
- construction management – 3% of total construction cost
- testing, startup and training – 2% of total construction cost

Table 2. Texas TGV Capital Cost Categories.

Earthwork	Structures
Grading	Bridge
Excavation	Rail Underpass
Borrow	Culvert
Soil Stabilization	Storm Drain
Landscape/Mulching	Tunnel
Fencing	Contingency (10%)
Subballast	
Sound Walls	Power/Signals
Crash Walls	Catenary
Retaining Walls	Substations
Contingency (5%)	Signal/Control
	Transmission Line
Rail	Contingency (7.5%)
Trackwork	
Contingency (3%)	Maintenance-of-Way
	Equipment
Utility Relocations	Contingency (5%)
Utility Relocations	
Contingency (10%)	Right-of-Way
	Right-of-Way
	Contingency (10%)

[Figure 20](#) shows a section of the San Antonio-Navarro Junction corridor from milepost 60.00 to milepost 65.00 in Hays County, Texas; illustrating the level of detail included in the Texas TGV cost estimate.



(Prepared by the Texas TGV Consortium, 1991; Texas State Archives)

Figure 20. Sample of Preliminary Plan and Profile for the Texas TGV High-Speed Rail System.

Using the Texas TGV to Estimate Freight Shuttle Costs

The proposed freight shuttle network is more extensive than the Texas TGV network (compare Figures 18 and 19), so a method was adopted by which the cost/mile of Texas TGV corridors were multiplied by the full length of freight shuttle corridors as appropriate. In 2003 dollars, the cost/mile of each Texas TGV corridor was found to be:

- Houston-Dallas/Fort Worth (256 miles): \$8,475,967
- San Antonio-Navarro Junction (215 miles): \$6,500,029
- San Marcos-Hockley Junction (130 miles): \$5,924,973

Researchers computed cost estimates for the major freight shuttle corridors (Figure 18) using these cost/mile values. Since the San Antonio-Laredo corridor was not included in the Texas TGV system, the San Antonio-Navarro Junction unit cost was applied over that length; likewise,

the San Marcos-Hockley Junction unit cost was applied over the Beaumont-Houston corridor length. The resulting cost estimates for the freight shuttle corridors are as follows:

- Houston-Dallas/Fort Worth: \$2.119 billion
- Dallas/Fort Worth-San Antonio: \$1.820 billion
- San Antonio-Laredo: \$1.105 billion
- Houston-San Antonio: \$1.244 billion
- Beaumont-Houston: \$0.563 billion

Freight Shuttle Economics

The economic feasibility of the freight shuttle was evaluated from the perspective of both the public and private sectors. Since the degree to which this system will remove trucks from Texas' highways is uncertain, calculations were performed over a range of displaced truck volumes from 20 to 50 percent of year 2000 corridor traffic (Figure 18). Also, the level of public investment is also uncertain, so these same calculations were made for a series of assumed government subsidies up to \$2 billion.

Public Sector

The research team calculated benefits to the public using a net present value analysis over a 25-year period, with benefits consisting of reductions in the marginal costs listed in Table 2. In this work, 10 percent of all truck traffic removed from the interstate system was assumed to be urban trucking. Figure 21 shows the public sector net present value for the various combinations of government subsidy and displaced highway traffic. As expected, net benefits to the public decrease as the size of government subsidy increase, and increases as the volume of displaced highway traffic increases. Most importantly, Figure 21 shows that the freight shuttle concept is a good investment of public money if the system captures reasonably low percentages of Year 2000 truck volumes.

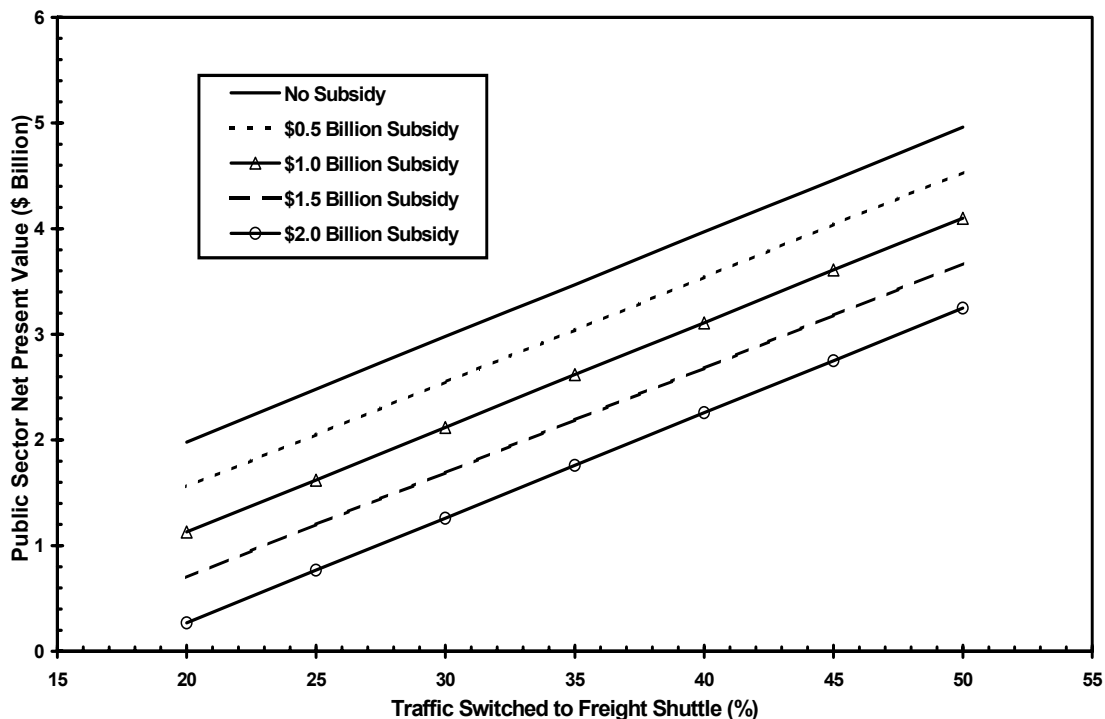


Figure 21. Net Present Value of the Freight Shuttle to the Public Sector.

Private Sector

Researchers calculated rates of return on investment to private investors based on expected cash flows over a 25-year period from construction and operation of the freight shuttle system. This analysis assumes that the project is financed equally over five years with 20-year bonds that pay 4 percent interest. Revenues earned from the project were calculated assuming a user fee of \$1.00/truck-mile. This fee is a 25 percent reduction in the current \$1.40/truck-mile cost incurred by trucking companies, which would provide considerable incentive for industry to use the freight shuttle.

Rate of return calculations were based on a 25-year investment period since the service life of all infrastructure components are expected to equal or exceed this amount of time. The service life of fixed structures (bridges, storm drains, underpasses, etc.) may exceed 100 years, and that of the rolling surface/guideway should exceed 30 years. A service life of 25-30 years should be expected for electrical components (communications, instrumentation, etc.) and site work (ditches, fencing, etc.).

Figure 22 shows the before-tax internal rate of return to investors at various levels of government subsidy and volumes of displaced highway traffic.

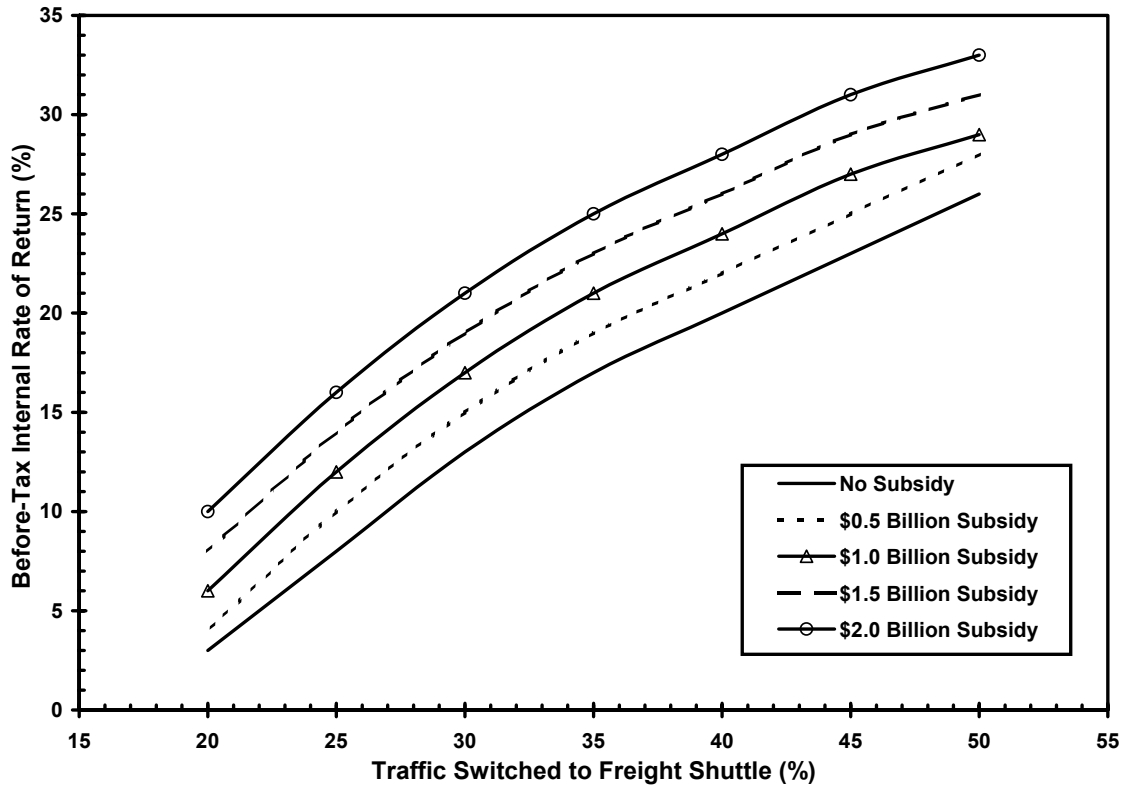


Figure 22. Return on Investment of the Freight Shuttle to the Private Sector.

Public-Private Benefits

Finally, a relationship between benefits received by both sectors (public and private) was prepared using the results of the previous analyses. Figure 23 shows a plot of return on private investment versus net public benefits for common amounts of government subsidy and displaced highway traffic.

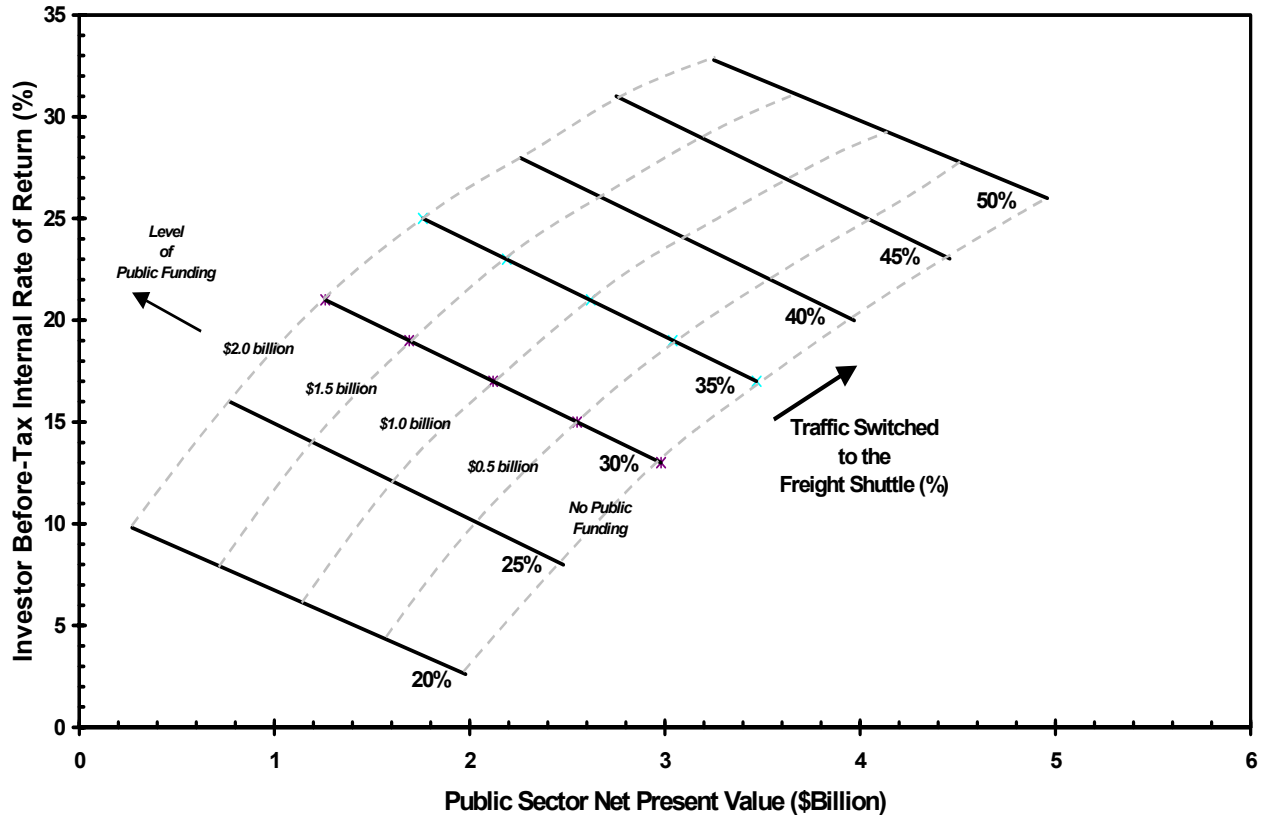


Figure 23. Relationship Between Public-Private Benefits of the Freight Shuttle.

THE USE OF URBAN DRAY VEHICLES IN CONJUNCTION WITH THE FREIGHT SHUTTLE

In conjunction with the Freight Shuttle, TTI proposes the establishment of a program that encourages the development and use of urban dray vehicles to substitute for diesel tractors in urban areas. The UDV is envisioned as an alternative fuel vehicle that would lower mobile emissions and favorably impact the air quality of urban areas.

The use of trucks for dock-to-dock delivery of freight is essential and is among the factors that have contributed to the growth and dominance of the trucking industry. The practice of using powerful diesel rigs for the intercity movement of freight as well as in local delivery roles has developed as a natural consequence of the transport of freight by trucks. However, the ability of trucking to serve both of these roles has resulted in adverse levels of mobile emissions in urban areas attributable to trucking. Were it not for the need to use trucks with sufficient power to achieve highway speeds over long distances under load, local deliveries, which could employ

lower-horsepower vehicles, could be accomplished by low-emission trucks dedicated to that role in an urban area.

The intermodal yards proposed for Freight Shuttle-borne container exchanges with trucking could serve as ideal fueling locations for a dedicated fleet of urban drays. The fleet would be equipped with intermodal container chassis and serve to pick up and deliver containers to local businesses within a limited geographic radius around the urban area. Figure 24 depicts the concept associated with the UDV-Freight Shuttle interface.

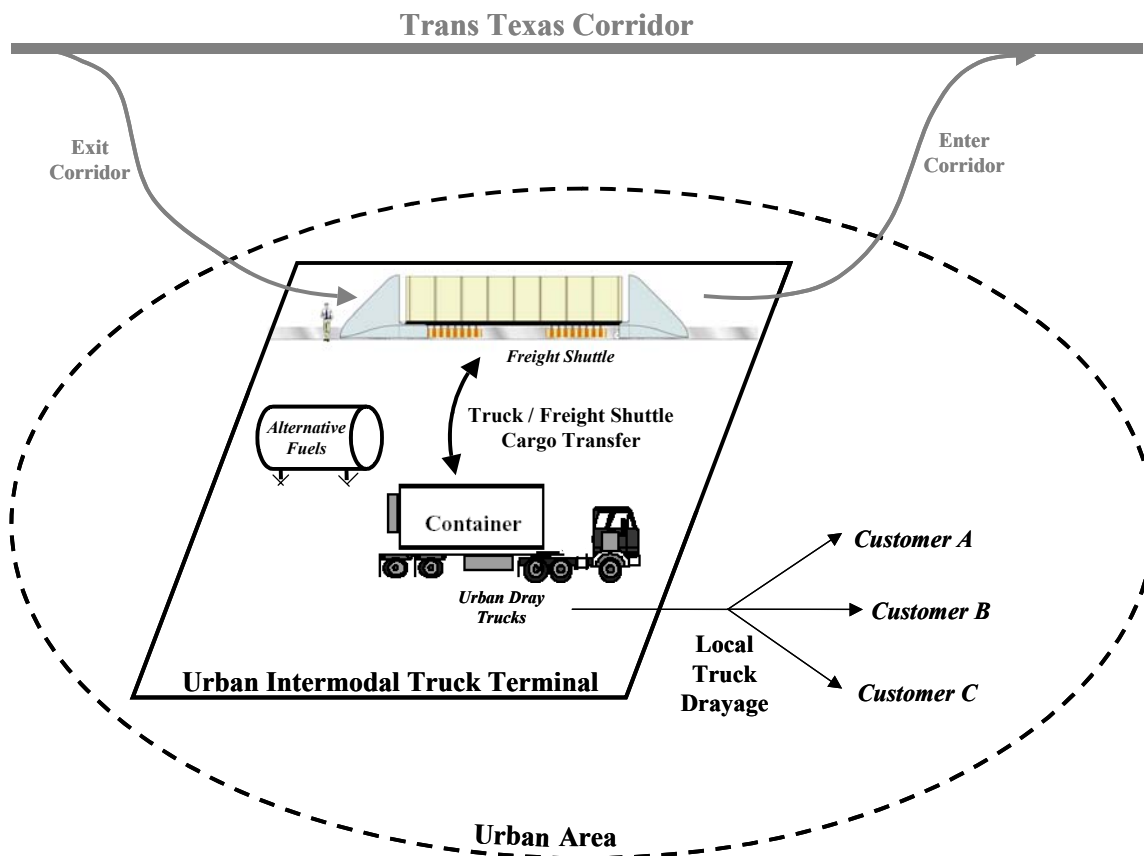


Figure 24. Proposed Strategy to Support Freight Shuttle Operations with Urban Dray Vehicles.

TTI estimates that local delivery of containers would require substantially lower horsepower engines than over the road trucks normally employ. The reduction could result in engines rated at 160-180 horsepower as contrasted to diesel engines commonly operating in the 240

horsepower range. With alternative fuels such as natural gas, UDVs could reduce emissions by as much as 50 percent over enhanced diesel truck emissions (17). The U.S. Environmental Protection Agency provides for vehicle certification to ultra low emission vehicle emission standards that produce 50 percent less emissions than provided for by the national low emission vehicle standards (18).

The negative ramifications associated with non-attainment create the conditions under which UDVs could, with appropriate public sector inducements, become an integral part of the freight transportation mix. The development of tax incentives and loan programs aimed at encouraging private sector use of UDVs in urban areas could achieve large improvements in air quality without adversely impacting the ability to ship and receive freight.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

The Texas Transportation Institute has undertaken this research project with the needs of key freight transportation stakeholders in mind. These stakeholders include:

- the citizens of Texas,
- the shipping community,
- the existing freight transportation industry, and
- the Texas Department of Transportation.

The focus on the needs of these stakeholder groups was established and maintained throughout the research to ensure that the end result was broadly beneficial and attained the highest potential for implementation and use that was possible given the highly capital intensive and structured nature of the freight transportation industry. Research results and recommendations that could have created significant dis-benefits to constituent groups were not, from the inception of this effort, considered viable and thus were consciously avoided as approaches were identified and evaluated.

The citizens of Texas have clear needs relative to freight transportation and also relative to the sometimes negative byproducts of the freight transportation systems that have evolved. Principally, citizens require the efficient and reliable transportation of goods and materials with a minimum of adverse impact on transportation safety and congestion and with a minimum of negative environmental affects. Similarly, the shipping community requires reliable, inexpensive transportation options to remain competitive in an increasingly global business economy.

Serving the needs of the existing freight transportation community, particularly trucking and rail, was also seen as essential so that any new approach to freight movement was considered to be an extension of the systems already in place. The development of a new system of freight transport will require what is referred to as “seamless connectivity” in that the existing modes must substantially form the principal customer base. The business model put forth throughout this

research has been predicated on providing positive economics for both trucking and railroad interests.

TxDOT, the non-federal sponsor of this work, is responsible for providing safe and efficient transportation for both people and goods. These goals are becoming an increasingly difficult challenge to meet. The needs of passengers are often different from the requirements of freight carriers. The sheer volume of trucking is overwhelming and when combined with the impacts of truck traffic on safety, infrastructure, mobility, and air quality the department's task is becoming truly monumental. TTI recognized that a quantum leap was necessary to achieve real and significant gains against the array of issues facing TxDOT and proceeded in this research effort with an achievement of that magnitude in mind.

Underground Freight Movement

The viability of underground freight movement, which was investigated in exhaustive detail in Years 1-3 of this work, appears marginal at best. The sheer cost of excavation and tunneling, particularly when it is required over a significant distance, makes attaining profitable operations at reasonable levels of traffic unlikely. It should be noted too that many states and Texas in particular, have ample open spaces – particularly between urban areas. Objectively, one must ask if it is necessary to go to the added expense of placing infrastructure underground for the sole sake of grade and alignment separation when these can be achieved at lower costs above ground.

Further, given the events of September 11, 2001, the security *provided by* a freight movement system must be weighed against the issue of security *for* a freight movement system. The recognition that a ballistic event occurring inside a freight tunnel could create significant damage to the system and require extensive repair and down time suggests that other approaches may be more secure and provide a less inviting target. This serious consideration adds significantly to the challenges associated with material handling by requiring careful inspection of every pallet load – at meaningful traffic levels this equates to several thousand per day. The task is greatly simplified when intermodal containers are the unit of transfer.

When transloading is figured into the assessment, material handling soon becomes another major obstacle to viability. The economic calculations based on costs and revenues suggest that the underground system designed by TTI – which strove to attract meaningful levels of truck-borne material and minimize the task of handling standard pallets – was only feasible when the avoided social costs associated with the adverse impacts of trucking were considered. Given that freight transportation is a private, for profit undertaking in this country, suggesting that the public sector substantially underwrite the financing and construction of such a massive system would likely have limited political appeal and be hard to justify to those paying for the effort. Further, the economic viability of the system, which is precarious at best, dissolves rapidly under the most likely scenario of some degree of cost overrun associated with construction.

These considerations are amplified by the recognition that underground infrastructure for freight movement is both fixed in location and dedicated to a single purpose. If market dynamics change in any appreciable manner, the usage of a freight pipeline may fall to decidedly uneconomic levels. Further, the specific designs associated with TTI's and most other underground systems means that the infrastructure is unsuitable for alternative uses.

The Freight Shuttle

By transferring many of the transport, propulsion, and control systems developed for underground use to a surface application, TTI is proposing a hybrid transportation system that combines the favorable elements of the freight pipeline, with the economic advantages of surface construction and operations. Importantly, the Trans Texas Corridor concept, by providing an analog to underground infrastructure in terms of security and grade and alignment separation has provided the opportunity for the confluence of several promising elements:

- The TTC is predicated on the private sector working with the public sector to undertake and implement transportation systems that provide freight and passenger mobility under new financing and operational paradigms.
- The Freight Shuttle provides an economical alternative to intermediate-distance, intercity trucking with the potential for rates of return that meet investment grade quality – even taking into consideration the premium required for unusual levels of risk.

- The Freight Shuttle embodies characteristics that provide for the avoidance of the social costs associated with both intercity and intracity trucking.
- The Freight Shuttle, operating in a separated and secure (fenced) alignment will provide for greatly improved levels of freight security. The system, by virtue of its cradling of containers and uninterrupted movement, will ensure that sealed containers – inspected prior to transfer to the Shuttle – are not tampered with in transit.
- The provision for UDVs to pick up and deliver freight in urban areas rather than heavy over the road diesel rigs to positively impact urban air quality.
- The favorable features of the system – including the focus on container transport and limited material handling – will achieve performance levels that ensure a level of use that is both profitable to the operators and beneficial to the public sector by removing trucks from the roadway.
- The Freight Shuttle takes an important step away from a transportation infrastructure design married to petroleum-based systems. The use of electrical power for propulsion allows the system to operate with electricity generated from a wide array of sources.

By adding a program for Urban Dray Vehicles to replace over the road diesel tractors for pick up and delivery of urban area freight, the Freight Shuttle will facilitate significant improvements in the entire complex of safety, environmental, technical, service, and financial challenges facing local, state, and federal transportation agencies. The Freight Shuttle concept provides these public transportation entities with a significant advance in the state of the art relative to the movement of freight.

RECOMMENDATIONS

Most observers of the current research, particularly the sponsors at TxDOT, will not be surprised at the conclusions reached by the study team – excavation adds inordinately to the cost of any construction effort. As desirable as grade and alignment separation are, in the final analysis the costs related to this feature must be commensurate with the benefits attained. Since the Trans Texas Corridor provides an alternative, lower-cost approach to achieving the same ends, the likelihood of proceeding with a completely underground system seems remote.

TTI recommends that the results of this research, which proposes an automated Freight Shuttle system dedicated to intermodal container movements within the Trans Texas Corridor, be extended through a subsequent research effort designed to:

1. Establish the financial viability of the Freight Shuttle through the development of a detailed feasibility assessment.
2. Develop and evaluate a preliminary technical design for the Freight Shuttle vehicle, control systems, and guideway.
3. Develop a scaled-model demonstration of the Freight Shuttle vehicle, control systems, and guideway.
4. Establish the parameters for a public-private consortium(s) to undertake the financing, construction and operation of the system in a demonstration program through a detailed planning evaluation.
5. Work with Congressional sponsors, the Office of the Governor, the Texas Transportation Commission, the US DOT, the private sector to define the interface of the Freight Shuttle with the current freight transportation system.
6. Work with state and local officials to establish the parameters for a viable and effective program of tax support and incentives for Urban Dray Vehicles as a measure to improve urban air quality.

Advances in technology coupled with the growing recognition that the public sector and the private sector can and should work together to solve transportation problems strongly suggests that the Freight Shuttle concept – applicable in a wide variety of settings – is worthy of further, serious consideration and study.

REFERENCES

1. Griffin, J.M., and Steele, H.B., *Energy Economics and Policy*, 2nd ed., Academic Press College Division, Orlando, Florida, 1986.
2. John A. Volpe National Transportation Systems Center, *Tube Transportation*, Report RSPA/VNTSC-SS-HW495-01, Cambridge, MA, U.S. Department of Transportation, Research and Special Programs Administration, 1994
3. Medhurst, G.A., *A New System of Inland Conveyance for Goods and Passengers*, London, 1827.
4. Visser, J., and Binsbergen, A., *Underground Goods Distribution in the City of Leiden: The Results of a Feasibility Study*, International Symposium on Underground Transportation by Capsule Pipelines and Other Tube/Tunnel Systems, Sep 1999.
5. Zhao, Y.J., and Lundgren, T.S., Sampson, J., *Electrical Capsule Pipeline System for Freight*, Journal of Transportation Engineering, May-June, 2000.
6. Allen, W.B., and Plaut, T., *Transport of Solid Commodities Via Freight Pipeline – Demand Analysis Methodology*, Volume IV, U.S. Department of Transportation, 1976.
7. Koshi, M., *An Automated Underground Tube Network for Urban Goods Transport*, Journal of International Association for Traffic and Safety Science, Vol. 16, No. 2, 1992.
8. Stein, D., Stein, R., Weller, W., and Schoesser, B., *Transportation of Goods Through Pipelines – A Comprehensive Study*, International Symposium on Underground Transportation by Capsule Pipelines and Other Tube/Tunnel Systems, Sept 1999.
9. Goff, Z.A., and Patil, S., Shih, C.S., *Feasibility of Freight Pipelines to Relieve Highway Congestion*, Report 1803-S, Texas Transportation Institute, 1998.
10. Zandi, I., and Gimm, K.K., *Transport of Solid Commodities Via Freight Pipeline – Impact Assessment*, Volume V, U.S. Department of Transportation, 1976.
11. Oberlender, G.D., *Project Management for Engineering and Construction*, 2nd ed., McGraw-Hill Companies, Inc., New York, 2000.
12. Federal Highway Administration [Internet]. Washington, DC: Addendum to the 1997 Federal Highway Cost Allocation Study Final Report; [updated 2000, June 20; cited 2002, March 21]. Available from: <http://www.fhwa.dot.gov/policy/hcas/addendum.htm>
13. *Expenses Per Mile for the Trucking Industry: 1990-2000*, Federal Highway Administration Office of Freight Management, 2001.
14. Louis Berger & Associates, *Effect of the North American Free Trade Agreement on the Texas Highway System*, Texas Department of Transportation, Austin, Texas, 1998.
15. HNTB Corporation, *I-35 Trade Corridor Study: Recommended Corridor Investment Strategies*, Texas Department of Transportation, Austin, Texas, 1999.
16. Texas TGV Consortium, *Franchise Application to Construct, Operate, Maintain, and Finance a High-Speed Rail Facility*, Vol. III, Texas High Speed Rail Authority, Austin, Texas, 1991.
17. *Diesel vs. CNG Debate Rages On*, Natural Gas Fuels, 12(3), pp 6-7.
18. *Emission Standards Reference Guide for Heavy-Duty and Nonroad Engines*, US EPA, EPA420-F-97-014.

SUPPLEMENTAL INFORMATION – AVAILABILITY OF TRANSPORTATION FUELS IN THE 21ST CENTURY

INTRODUCTION

Transportation planning is based on several criteria, including roadway capacity, environmental impact, route selection, safety and economics. All of these issues are considered in order to provide infrastructure that improves quality of life, promotes a vibrant economy, and enhances national security. As part of this process, transportation agencies have begun to examine how a wider array of infrastructure choices, such as rail or transit, can best be combined with roadway construction to address the transportation needs of the future. Now that the feasibility of “alternative infrastructure” choices is being debated, the most fundamental question pertaining to transportation planning must be asked:

Does the transportation planning process adequately consider the outlook for fuel availability when allocating resources to meet state and national needs?

Naturally, there is no expectation for transportation planners to be well versed in the science or politics of petroleum. However, oil provides virtually 100 percent of all transportation fuels, and that approximately 80 percent of current oil production occurs from fields discovered more than 30 years ago. Therefore, planners should require transportation research to consider long-term fuel availability so that the true value of each transportation mode can be properly assessed (1).

The value of petroleum to a country’s ability to amass power and strategic importance in the world cannot be overstated; perhaps the best example of this was Japan’s preemptive strike on Pearl Harbor in 1941, which was intended to eliminate our nation’s capacity to respond to their capture of the vast East Indies oil fields. Over half a century has gone by since that time and U.S. strategic interests remain centered around the importance of oil, as evidenced by the Persian Gulf War in 1990 and the Iraq War in 2003. Without tremendous advances in the development of economically viable alternatives, the nation’s future will largely depend upon two fundamental issues concerning petroleum:

- the amount of world oil reserves available for future production, and
- which regions of the world hold these remaining reserves.

To understand the critical nature of these issues, one must examine fundamental geosciences principles and the behavior of oil & gas producers, both in the U.S. and throughout the world. This chapter has been prepared to explain the reality of these issues, and to give additional perspective to the value of non highway transportation systems.

TRANSPORTATION FUELS

Oil and natural gas currently supply 62 percent of the nation’s energy and virtually 100 percent of all transportation fuels, as reported in 2001 by the National Energy Policy Development Group to President George W. Bush (2). Of these two fuels, oil comprises virtually the entire share of the transportation fuel market, as shown from the historic trends in [Figure S-1](#).

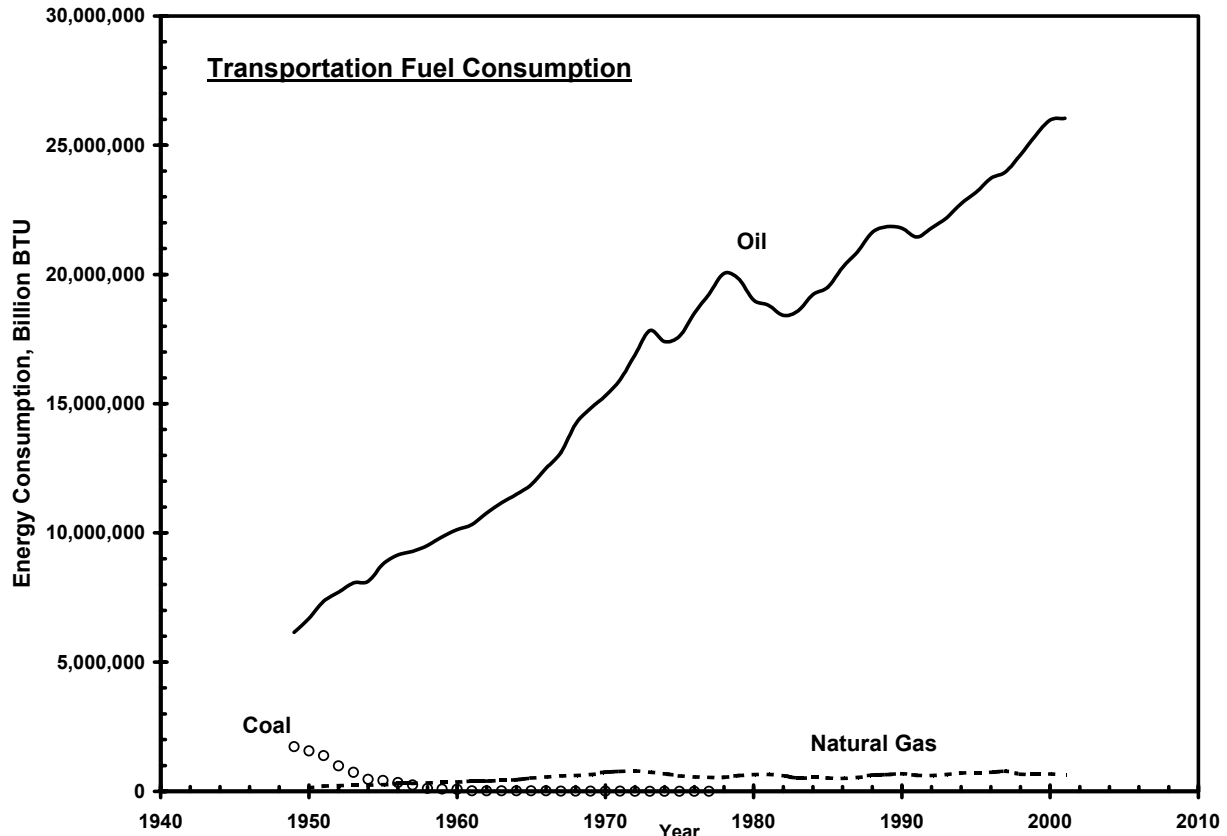


Figure S-1. Transportation Energy Consumption by Type of Resource (EIA Data).

Refined oil is consumed by the transportation sector in the form of gasoline and distillates (diesel). As expected, [Figure S-2](#) shows that greater quantities of oil have been used to produce gasoline than for truck diesel over the last 50 years. Even though, the consumption of oil

distillates has grown by 21,452 million barrels/day per year since 1970. According to the U.S. Department of Energy’s Energy Information Administration (EIA), 89 percent of the nation’s projected increase in demand for oil will come from a 2.5 percent annual growth in transportation energy to 2020 (3). Furthermore, alternative fuel use will continue to be restricted to buses and other public vehicles that operate using natural gas engines.

Based on the energy consumption trends shown in Figures S-1 and S-2, and on these EIA projections, sustainable growth of the transportation system must rely on some combination of the following:

- endless and increasing availability of economic oil supplies,
- unprecedented achievements in the development of alternative transportation fuels, and
- Design and construction of transportation infrastructure that curtails the growth in demand for oil.

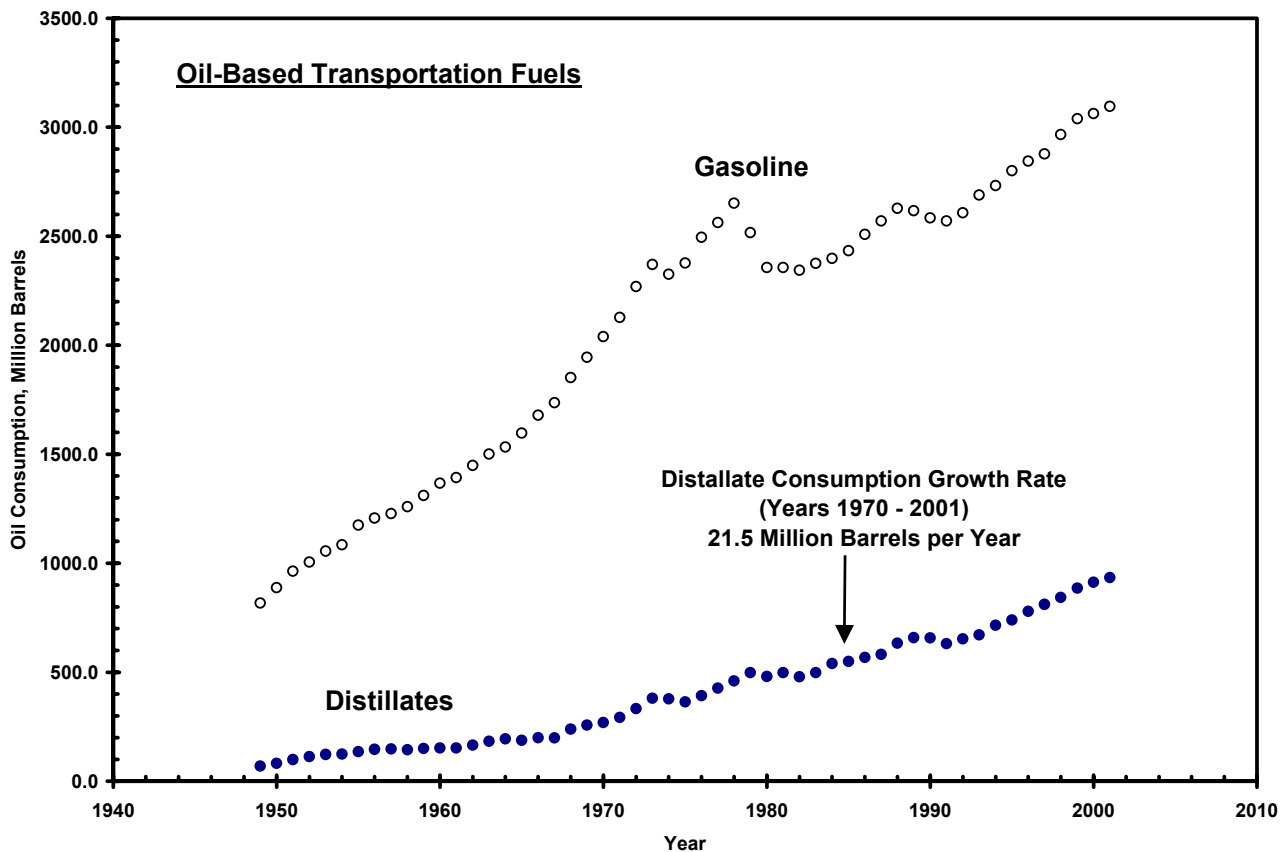


Figure S-2. Transportation Energy Consumption by Type of Fuel (EIA Data).

AVAILABILITY OF OIL FOR TRANSPORTATION USE

The planning and design of a transportation infrastructure has heretofore minimized transportation fuel availability as a selection criterion, primarily due to the fact that the issue has had little impact on society thus far. Furthermore, the U.S. mainly relies upon scientists or government agencies to deliver any impending news of oil shortages, despite the fact that these groups are not in the business of exploiting petroleum resources. A realistic oil supply outlook must be based on the exploration, production, and investment performances of petroleum companies, which, paradoxically, have little to do with economic planning or policy. Contrary to the mission of most scientists or government employees, these companies are in business to earn a profit on risk-bearing investments through the exploitation of oil & gas resources. These financial risks are only incurred when a prospect is foreseen to be profitable; consequently, the investor often sees much of what has been reported as “available resources” by scientists as actually being “uneconomic oil.”

The effect of economics on oil production is exemplified in the case of the Trans-Alaska Pipeline, which transports oil from the North Slope of Alaska to the southern port of Valdez. Oil was discovered at Prudhoe Bay on the North Slope in 1968, and by 1977 a 48-inch diameter, 800-mile long oil pipeline was completed across Alaska so that tankers could carry crude oil from the state’s southern coast to the west coast of the U.S. mainland. Maintenance and operation costs of this \$8 billion facility will require decommissioning of the pipeline once production from the North Slope falls below approximately 100 million barrels/year and the oil becomes unprofitable to transport. Consequently, at some point in the future (probably by 2020) oil will cease to be produced from many Alaskan fields even though they contain recoverable oil (4).

The sections that follow further explain the exploration and production performance of the petroleum industry and the inevitabilities that will confront the U.S. in the near future. The realities faced by investors is reflected in this analysis by examining the actual performance of those involved in supplying oil to the U.S. over the past century.

Discovery Versus Production

There are several ways to mathematically project future oil production using historical discovery and production data, estimates of total world resources, etc. Yet, the easiest way for the non-geoscientist to gain some perspective on oil availability in the 21st Century may be to consider this simple, but quite illuminating fact:

The volume of oil produced cannot exceed the volume of oil discovered

Therefore, world oil discoveries over the past century can be analyzed in conjunction with historic oil production to make some observations about oil production in the future. For example, [Figure S-3](#) shows a hypothetical case where the oil discovered over a series of years (recorded in barrels of oil) has been plotted versus the years in which the discoveries were made. As referenced on the plot, this bell-shaped curve is a typical trend for discoveries in the petroleum industry for the following reasons:

- A. Rudimentary technology and unfamiliarity with geology results in the discovery of limited numbers of oil reservoirs.
- B. Experience and improved technology (i.e., seismic detection methods, well logging, and rotary drilling) dramatically increases numbers of oil discoveries.
- C. Continued technical development and more widespread exploration leads to discovery of the largest, most economic reservoirs within the geographic area.
- D. Use of superior exploration techniques (i.e., 3-D seismic methods, simulation, horizontal drilling) contributes to the discovery of harder-to-find reservoirs.
- E. Exhaustive exploration and innovative infrastructure development (i.e., deepwater structures, arctic drilling, multilateral wells) extends discoveries, but in diminishing amounts.

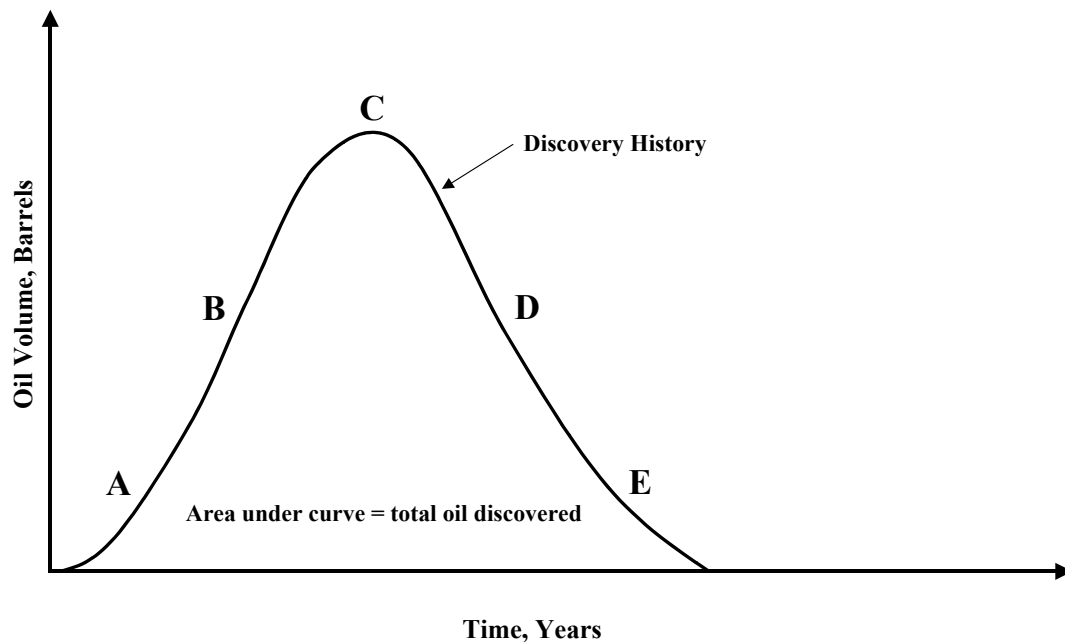


Figure S-3. Typical Plot of Oil Discovery History for a Given Geographic Area.

If the function describing the trend shown in [Figure S-3](#) were integrated over the range of years during which discoveries were made (in other words, the area under the curve is determined), the result would yield the total oil discovered throughout the geographic area. Since the oil produced from a region cannot exceed the volume of oil discovered, a plot of oil produced from this same geographic area must result in a trend line that, when integrated, is no larger in area than the area under the discovery curve. [Figure S-4](#) shows this same discovery curve with two possible production history scenarios. In Scenario 1, oil is produced at a rate equal to the rate at which it was discovered following some lag time that accounts for the construction of required production facilities and transportation infrastructure. Scenario 2 illustrates how a restricted rate of production lowers peak production and extends the life of the resource. What is most important about this figure is that the area under the curve of each production scenario is equal to the area under the discovery curve.

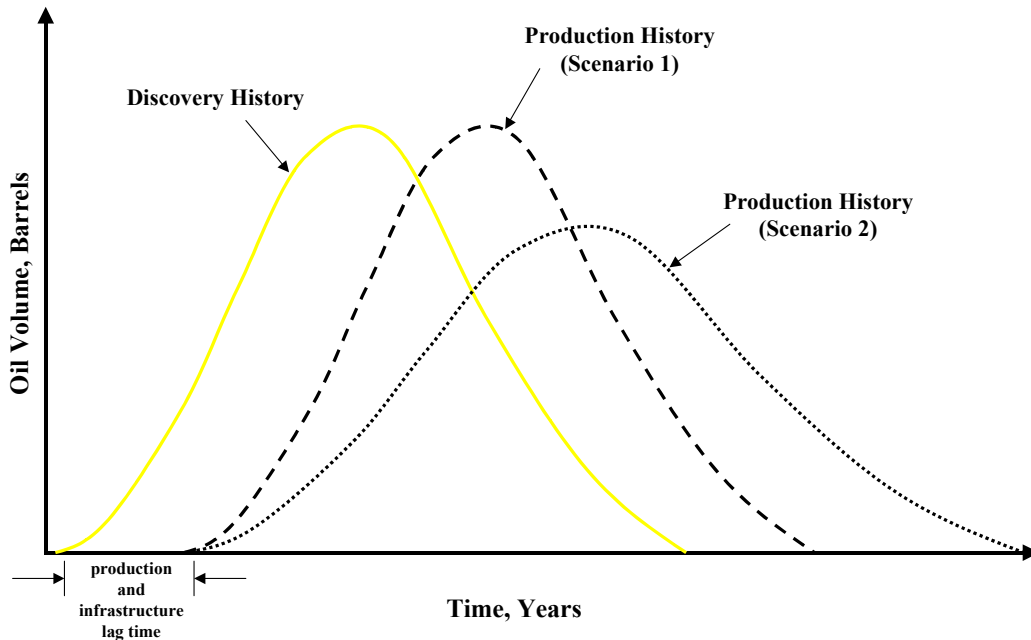


Figure S-4. Production Scenarios for an Assumed Discovery History.

World Discovery and Production Trends

The hypothetical discovery and production histories in the previous section were used to present the basis for analyzing actual petroleum industry trends over the past 100 years. Actual world discovery and production histories have been plotted in [Figure S-5](#) using the latest available data. The next two subsections discuss these trends, followed by an analysis of the information that they provide.

World Oil Discoveries

Masters, Attansi, and Root compiled a history of world oil discoveries for the years 1915-1995 in their work, “World Petroleum Assessment and Analysis,” reported in the *Proceedings of 14th World Petroleum Congress*; this has been used to develop the world oil discovery curve shown in [Figure S-5 \(5\)](#). The development of this information required a great deal of effort since “book” revisions to original reserve estimates (i.e., due to improved recovery technology) must be reassigned to the date of original discovery – accounting practice generally assigns such revisions as new discoveries in the current year, which inaccurately represents the results of exploration activity ([1,6](#)). Such ambiguity can be expected to occur when accounting information

is used to examine discovery trends; as noted by Aubrey K. McClendon, chairman and CEO of Chesapeake Energy Corporation, who said at the Independent Petroleum Association of America meeting in October 2002, “We haven’t replaced (U.S. oil and natural gas) production with new discoveries in 35 years. Any maintenance of production levels has been primarily through revisions and adjustments to original estimates of potential production of existing fields” (7).

The continuation of steep declines in oil discoveries over the past several decades is confirmed by reports of approximately 4-6 billion barrels/year being discovered in recent years, which is a good match to the discovery trend (a best-fit approximation) shown in Figure S-5. In other words, the oil industry is now discovering oil at about the same rate as it was in the early 1920s. In contrast, approximately 24 billion barrels of oil were produced in 2002, explaining why the generally accepted production-to-discovery ratio has been about 4:1 in recent years (8). The continuing and growing discrepancy in these discovery and production volumes leaves little hope for anything but a peak in world oil output at some time in the future.

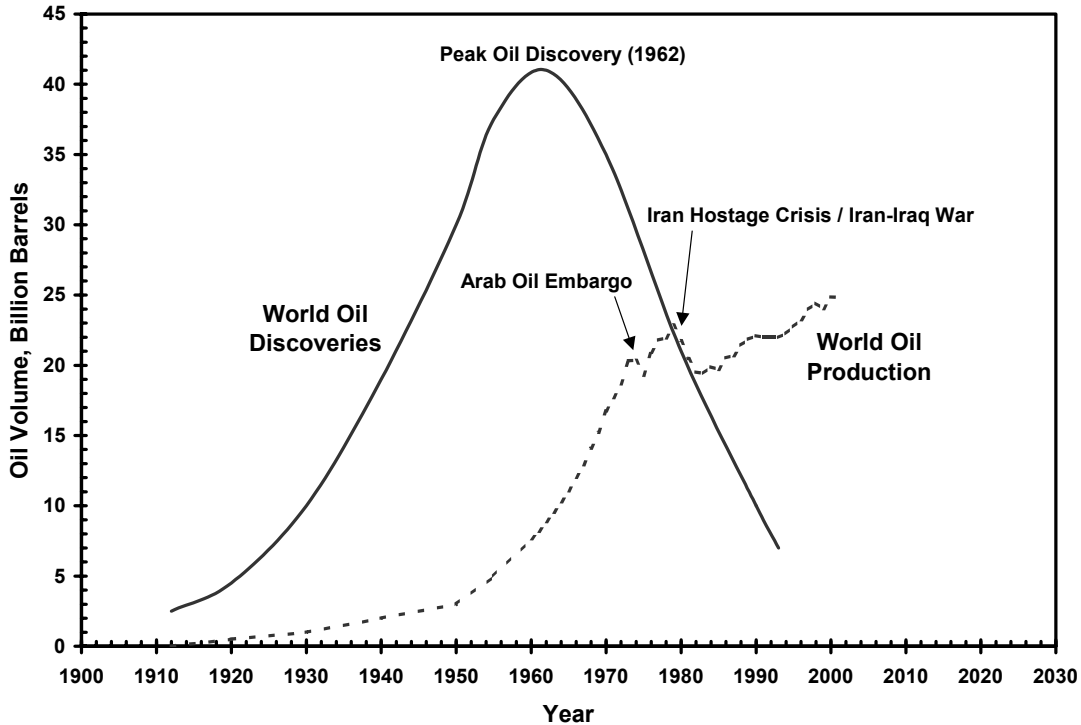


Figure S-5. World Oil Discovery and Production Trends.

World Oil Production

The production trend in [Figure S-5](#) has been developed from EIA data through 2001, and shows world production to have shifted from a steeper-curved depletion rate up to 1973, to a more restricted depletion rate over the past 30 years. In 1973, the Organization of Petroleum Exporting Countries (OPEC) retaliated against the U.S. for increasing military support to Israel during the Yom Kippur War by implementing an oil embargo. Although OPEC had been formed in 1960, it could not effectively use the curtailment of oil supplies as a retaliatory measure against the U.S. as long as spare capacity in the Free World was available (9). However, this situation changed once the U.S. reached peak production in 1970, a consequence of U.S. discoveries peaking in 1930. The second significant reduction in world oil supply occurred as a result of events centered on the Iran Hostage Crisis of 1979 and the Iran-Iraq War of 1980. The 1973 and 1979/1980 supply disruptions are reflected in [Figure S-5](#) as reductions in world oil production.

Significance of Peak Oil Production

A renowned geophysicist by the name of Dr. M. King Hubbert, who first worked for the U.S. Geological Survey and then with Shell Oil Company, first startled the world in 1949 by concluding that the fossil fuel era would be relatively short in duration. This was based on his observation that, for any large region, a plot of unrestrained extraction of a finite resource rises along a bell-shaped curve and peaks once approximately half of the resource is exhausted. His release of “Nuclear Energy and the Fossil Fuels” in 1956 was met with great skepticism because, by applying his theory, he predicted that increases in oil production from the lower 48 U.S. states would continue for about 13 years and then peak in 1969 (1,10). The plot of U.S. oil production history in [Figure S-6](#) shows how his prediction was off by only one year, and that U.S. production actually peaked in 1970. This figure also shows that the production of oil from Alaska (beginning 1977) helped stabilize oil production levels for several years, but was unable to prevent the ultimate decline in U.S. production.

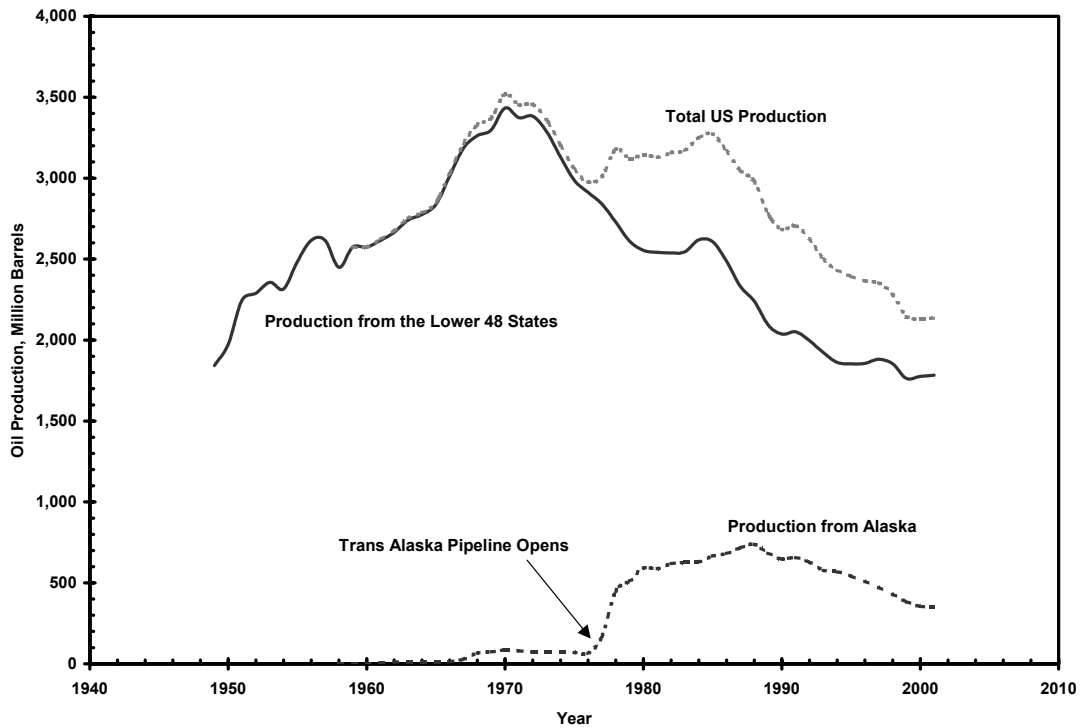


Figure S-6. U.S. Oil Production History.

HUBBERT’S MODEL

An excellent summary of Hubbert’s methodology is given by Wattenbarger, who explains his approach in 1956 as to “simply fit a symmetrical production rate curve to existing data such that the area under the curve (ultimate oil recovery) was equal to geologic estimates of ultimate U.S. oil recovery” (11). In 1962, his model was developed into a more mathematical expression that expresses production rate as a function of time, as shown in Eq. 1 (12). This equation can be used to produce plots of oil production (million barrels/day) versus time (years).

$$q = \left(\frac{1000}{365} \right) Q_{\infty} \frac{aN_0 e^{-a(t-t_0)}}{\left[1 + N_0 e^{-q(t-t_0)} \right]^2} \quad (\text{Eq. 1})$$

Where

- a = Hubbert model parameter
- q = oil production rate (million barrels per day)
- Q = cumulative oil production (billion barrels)

$$N_0 = (Q_\infty - Q_0)/Q_0$$

Q_∞ = ultimate oil recovery (billion barrels)
 $Q_0 = Q$ at reference time t_0
 t = time (years)
 t_0 = arbitrary reference time (years)

Instead of analyzing production statistics with an equation such as [Eq. 1](#), this research examines oil availability using a graphical approach that should be simpler to understand, but remains grounded in Hubbert's work. That is, the area under the production curve equals ultimate oil recovery.

Deviations from the Ideal Curve

Over time, geoscientists have come to notice that the time between peak discovery and peak production is typically 30 to 40 years when there are few restraints to production ([13,14,15](#)).

However, this time span may be lengthened when production is restrained due to events such as:

- economic recessions,
- limitations imposed by producers (such as OPEC),
- energy conservation, and
- availability of competing energy sources.

In a simplistic description, these factors can substantially determine whether long-term production history more closely resembles that of Scenario 1 or Scenario 2 in the hypothetical example of [Figure S-4](#). Similarly, while Hubbert's hypothesis that plots of cumulative discoveries and cumulative production are identical in shape holds true in ideal situations, the following subsection shows how events such as those listed above can distort the expected production trend.

PEAK IN WORLD OIL PRODUCTION

In [Figure S-7](#), the world oil discovery curve first shown in [Figure S-5](#) has been shifted 33 years to demonstrate how the early (unrestrained) production data mirrors the discovery data prior to the 1973 OPEC embargo. This trend conforms to Deffeyes' observation that cumulative world discoveries lead cumulative world production by approximately 34 years ([14](#)). Also, the

production and discovery trends diverge shortly after the U.S. reached peak production and was no longer able to fill the role of “swing” producer – that is, the role of adjusting marginal oil production to counteract the adverse effects of excesses or shortfalls in the world oil market. However, growing production from Alaska and the North Sea, in combination with emerging options in alternative energy supplies and energy conservation, eventually reversed production declines caused by the political events of 1973 and 1980; resulting in both a more cooperative relationship between OPEC and non-OPEC countries and a more moderate world production history thereafter (9).

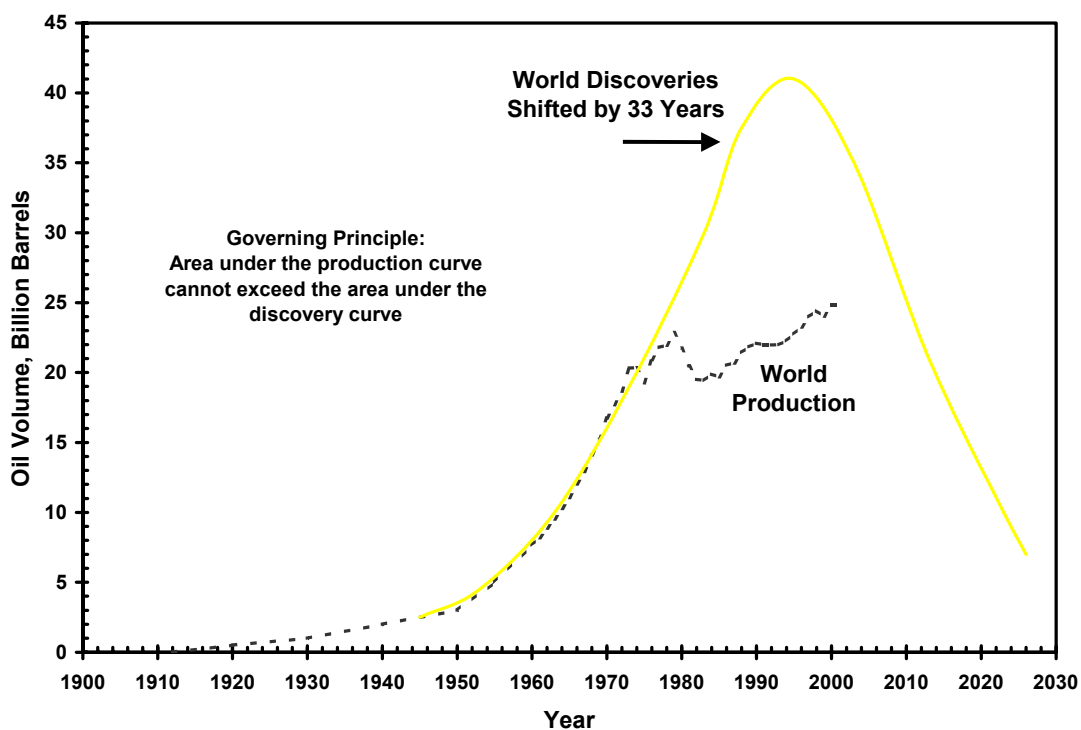


Figure S-7. World Oil Discovery Trend Shifted 33 Years to Match Production Trend.

The events of 1973 and 1980 curtailed the cumulative production of world oil supplies and most assuredly postponed the inevitable peak in oil production. Even though, this peak should occur once the area under the production curve equals approximately one-half of the total area under the discovery curve, at which time world production will not be capable of responding to a growth in demand for oil. Analyses by many geoscientists conclude that this event will occur prior to 2010, with less conservative estimates placing peak production prior to 2020 (1,8,10,14-17).

In addition to an overall peak in world oil production, the U.S. transportation sector should have concern for the disparity between peak production of non-OPEC countries and that of the OPEC countries. The International Energy Agency has concluded that production outside of the Middle East is now, or soon will be, at peak production, leaving the OPEC nations with a significant majority of future reserves (18). While the year in which peak production occurs can only be proven with time, the plot of EIA data in Figure S-8 shows oil production from non-OPEC nations to be nearing a plateau. This figure also illustrates how OPEC production is much less consistent than non-OPEC production, and portrays OPEC as an organization that historically has curtailed oil production for political or economic motives. Similar actions by OPEC in the future should have substantially greater economic effect once implemented in a more strategically favorable position, which will exist once non-OPEC production has peaked.

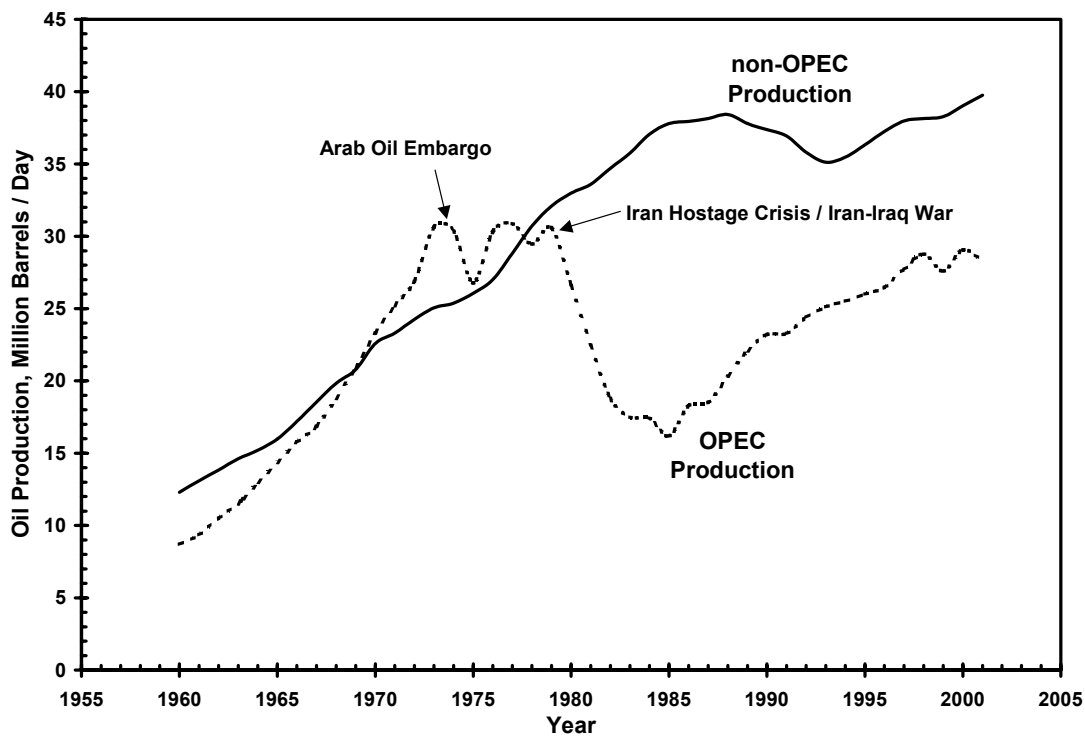


Figure S-8. Comparison of Oil Production from OPEC and non-OPEC Nations (EIA Data).

Evidence of Diminishing Oil Prospects

A rational investigation into oil availability must ask why world discoveries would diminish if remaining economic resources are so plentiful. Normally, an industry of limitless prospects

encourages new entries into the field to share in the awaiting prosperity, while an industry of diminishing prospects has the opposite affect. Consequently, the investigation should also ask why such severe contractions in the oil & gas industry have occurred during the last 20 years.

Shift from Exploration to Reserve Acquisition

Alaska was at one time thought to hold half of all undiscovered oil in the U.S., mainly in an area 14 miles off the state's northern coast within a geologic formation known as Mukluk. In 1983, the potential of such a prospect motivated several companies to join in developing an exploratory well, or "wildcat," that would ultimately cost over \$2 billion to drill due to the harsh physical environment. Unfortunately, the structure that geologists viewed as a low risk prospect was found at best to have once contained oil, resulting in a tremendously expensive dry hole (9).

The petroleum industry's tolerance for risk in oil exploration was drastically reduced following the failure at Mukluk, and many executives decided that "they ought to shift from exploring for oil to acquiring proven reserves, in the form of either individual properties or entire companies" (9). In fact, while the acquisition of large oil companies is commonplace today, the 1980s marked the beginning of the process in which large companies that failed to replace reserves were systematically sold. In 1984, the sale of Getty Oil, a worldwide independent company, and Gulf Oil, a major integrated company, highlighted the start of this era.

Getty Oil Company. J. Paul Getty established a financial basis for oil exploration by purchasing undervalued oil stocks following the 1929 stock market crash. In 1948, Getty won an oil concession in the Neutral Zone (1922-1969) of Saudi Arabia at an up-front cost of \$9.5 million and a guarantee of \$1 million per year. This entitled Getty to ownership rights of any discovered oil with an obligation of a 55¢/barrel royalty payment to Saudi Arabia. This venture earned substantial returns when oil was discovered in 1953, and made Getty America's first billionaire in 1957 (9). By the early 1980s, Getty Oil was failing to replace reserves, resulting in a stock price that undervalued the worth of the company's estimated 1.6 billion barrels in oil assets. Texaco virtually doubled its oil reserves when it purchased Getty Oil on January 5, 1984, for \$10.2 billion; however, a court ruled that the company interfered with Pennzoil's agreement to buy 3/7 of Getty Oil two days earlier and penalized Texaco \$3 billion.

Gulf Oil Company. Gulf Oil Company arose from the discovery of Spindletop at Beaumont, Texas on January 10, 1901. Not only did this event shift the focus of oil exploration away from the Pennsylvania fields and toward the Gulf Coast, but it also transformed the regional demand for transportation fuel from coal to oil. Gulf showed phenomenal growth during the first half of the 20th Century as a leading producer of West Texas and Gulf of Mexico oil, and as an international company with ventures in Venezuela, Kuwait, and Canada. The fact that, by 1983, Gulf was the sixth largest oil company in the U.S. did not protect the company from the realities of exploration failure, and only contributed to the significance of its demise. Contributing factors in the sale of Gulf were the nationalization of its Kuwait oil concession in 1975, and a 40 percent drop in domestic oil reserves between 1978 and 1982 despite costly exploration expenditures (9). Gulf was sold to Chevron in 1984 for \$13.2 billion in what was then the largest corporate merger in history.

Merger Strategy

Dr. Colin C. Campbell, an exploration geologist with more than 40 years of experience in the oil industry, discussed the importance of maintaining asset growth to an oil company's survivability during his presentation "The Imminent Peak of World Oil Production" given to a House of Commons All-Party Committee on July 7, 1999. [Figure S-9](#) is a reproduction of Campbell's plot of Shell's discovery record, which shows that it continues to find new sources of oil with the additional drilling of exploratory wells (6). However, this plot also shows that continued drilling has been met with diminishing additions to oil reserves.

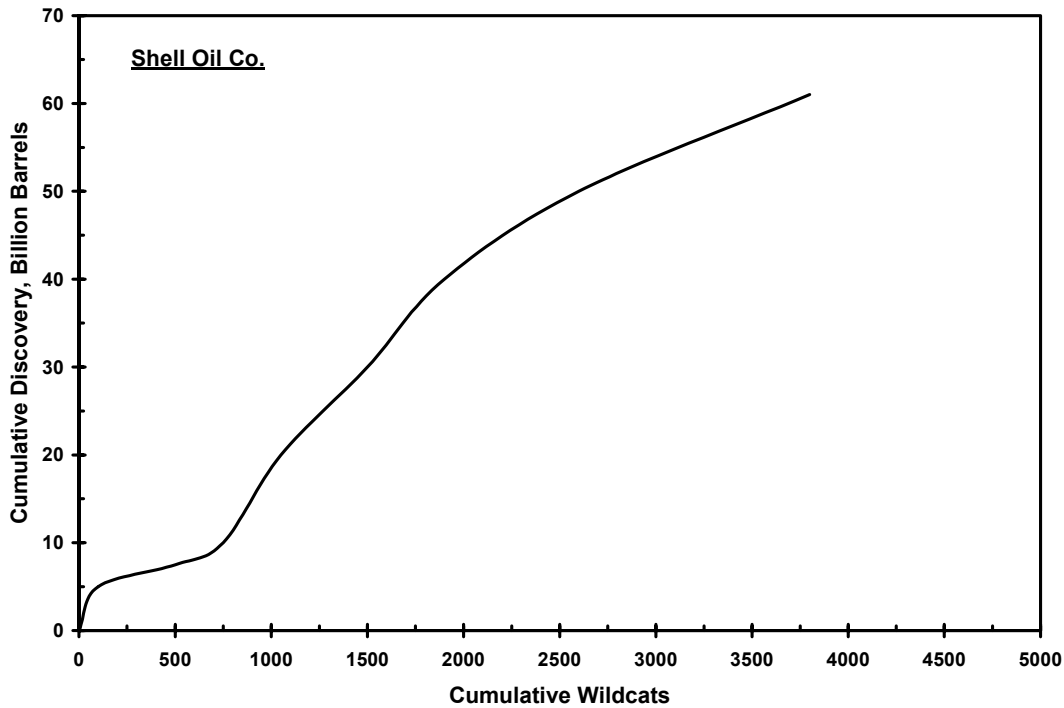


Figure S-9. Cumulative Oil Discovery Record for Shell Oil Company (after Campbell).

On the other hand, Campbell’s plot of Amoco’s discovery record, shown in [Figure S-10](#), portrays a company that had minimal success in replacing reserves during the second half of its drilling history and prior to being bought by British Petroleum (6). The first 450 exploratory wells drilled by Amoco resulted in the discovery of approximately 13.75 billion barrels of oil while the second 450 wells resulted in only 1.25 billion barrels, making the company a prime candidate for buyout by a company with sufficient cash and a desire to increase its own oil reserves.

As with the acquisition of Gulf by Chevron in 1984, the merger of Amoco into British Petroleum in 1998 exemplifies the mutual benefit of mergers that occur in the petroleum industry.

Essentially, companies with limited prospects can obtain a favorable purchase price for its shareholders based on the value of current assets. In return, the offering company acquires additional oil reserves and gains greater access to existing markets.

As [Table S-1](#) shows, the frequency with which mergers have occurred has accelerated since 1998. This table lists several of the world’s most prominent oil companies, their post-merger status, and the date in which the mergers occurred. Obviously, this trend in the consolidation of

such large international companies does not portray the oil & gas industry as one of growing prospects, and gives further support to the realities of the declining discovery curve first shown in [Figure S-5](#).

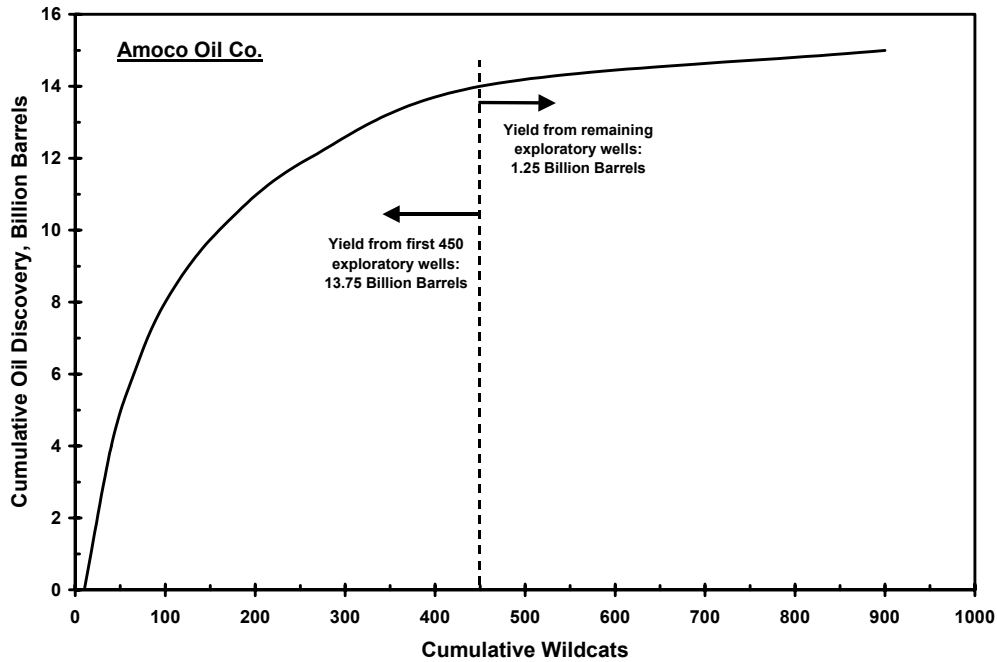


Figure S-10. Cumulative Oil Discovery Record for Amoco Oil Company (after Campbell).

Table S-1. Recent Mergers of Large Oil Companies.

Company Name	Merger	Merger Date
Conoco	Conoco-Phillips	2002
Phillips		
Chevron (purchased Gulf in 1984)	Chevron-Texaco	2001
Texaco		
Exxon	Exxon-Mobil	1999
Mobil		
Total (French)	Total-Fina-Elf	1999
Fina (Belgian)		
Elf Aquitaine (French)		
British Petroleum (British)	British Petroleum-Amoco-Arco	1998
Amoco		
Arco		
Shell (British)	None (Europe's largest oil co.)	-

Future Role of U.S. Companies

The diminishing U.S. domestic reserve base reflected in [Figure S-6](#) shows current production levels to have now decreased to 1952 production levels. This suggests that U.S. oil companies might redirect exploration and development (E&D) expenditures to countries with greater prospects in order to increase reserves. While international investments have grown, [Figure S-11](#) shows the ratio of domestic to international E&D expenditures in Year 2000 to still be greater than 6-to-1.

[Figure S-11](#) implies that the U.S. oil & gas industry continues to invest most heavily in domestic exploration and development even though the numbers of undiscovered oil prospects has been known for several decades to be quite limited, providing further rationale for consolidation within the industry. This investment strategy may be attributable to a:

- shift in expenditures from domestic oil exploration to domestic gas exploration,
- reallocation of expenditures from exploration to the development of existing fields,
- lack of foreign prospects that are not controlled by national oil companies, and
- desire to avoid investing in politically unstable countries.

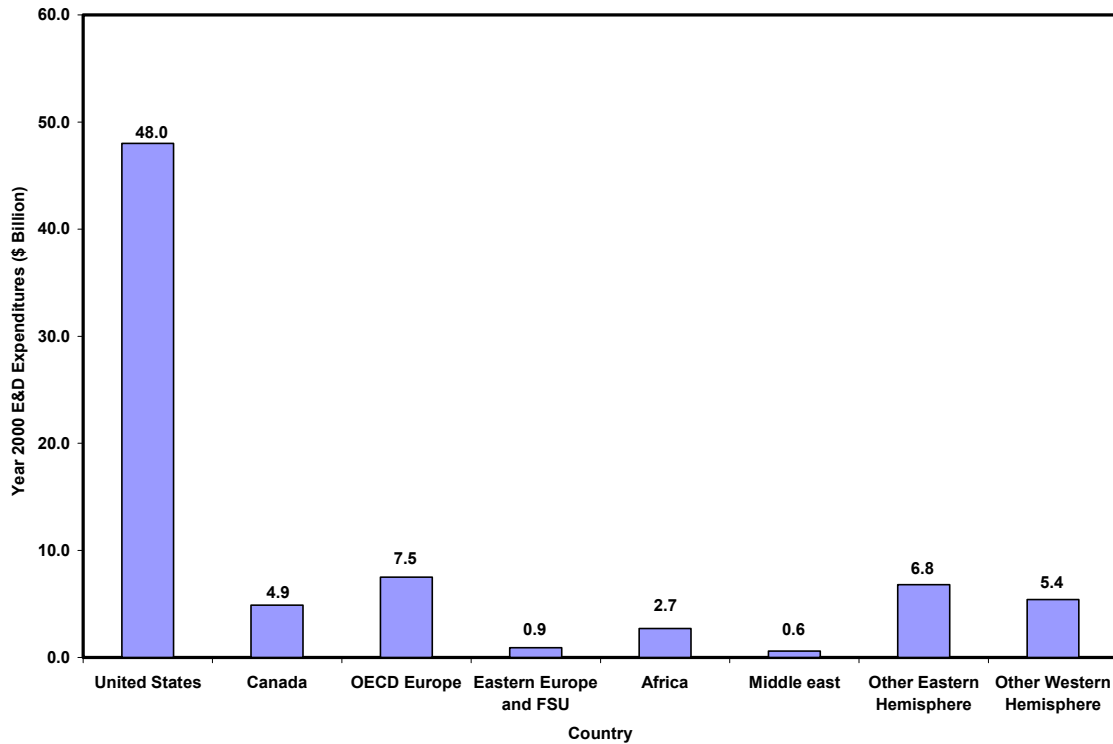


Figure S-11. Exploration and Development Expenditures by U.S. Companies in Year 2000 (EIA Data).

Without domestic-based petroleum companies to secure sources of transportation fuel, the U.S. will increase its dependence upon the production and distribution practices of foreign companies and states, with a particularly growing reliance upon OPEC nations. A significant milestone in this reliance will be reached by about 2010 when the Middle East’s market share is expected to exceed 50 percent of world oil production (18,19). Furthermore, the coincidence of a growing demand for fuel, both from industrialized countries and emerging countries such as China and India, with the inevitable peak in oil production could redefine the price structure of oil in a way that changes the transportation preferences of the public. A reexamination of the needs for sustainable growth in the transportation sector (as suggested in the section, “Transportation Fuels”) indicates that, without the prospect of endless and increasing supplies of oil, the transportation sector must focus on the:

- development of alternative transportation fuels, and
- design and construction of fuel efficient transportation infrastructure.

Of course, the need to begin developing plans for more fuel-efficient transportation infrastructure is the argument being made herein. Nevertheless, the following sections will examine the prospect of using alternative transportation fuels.

TRANSPORTATION PLANNING AND ENERGY AVAILABILITY

The purpose of the previous sections has been to show that the era of plentiful oil supplies for transportation use is indeed relatively short, and that the time of peak oil production is actually more significant than the time of eventual total production. Consequently, this research has determined that the availability of transportation fuel is a substantial issue in the evaluation of the freight pipeline considering that the project's 50-year design life is equal in time to more than one-half of the world's oil production history. Furthermore, these findings emphasize the need for energy studies to be incorporated into transportation planning in much the same way that environmental issues are now included.

Alternative Fuels

Geoscientists predict that world oil production will most likely peak within the first decade of the 21st Century, which is also the time at which the Middle East is predicted to capture 50 percent of the oil supply market. For example, Dr. Mamdouh G. Salameh, an international oil economist and consultant to the World Bank in Washington D.C., believes that the peak could occur as early as 2004-2005 (based on the fact that 935 billion of the world's estimated 2,000 billion barrels of oil reserves have already been produced); he also states that the development of unconventional oil, such as that from tar sands, shale oil, or extra heavy oil, would only delay this peak to 2010 (8). Regardless of the exact year or decade in which this event occurs, transportation planning should not be conducted on the belief that alternative fuels or unconventional oil will by themselves meet the future need for transportation fuel. This premise is supported in the following sections with an analysis of two of the most popularly discussed alternative fuels.

Hydrogen Fuel

With the expectation that hydrogen fuel cells will play a key role in the future of transportation, the White House proposed in January 2003 to fund a \$1.2 billion, 5-year hydrogen research project. According to White House officials, U.S. oil demand could be reduced by 11 million

barrels/day by 2040 if hydrogen power is developed to its full potential (20). However, the Energy Information Administration has projected that energy demand for U.S. transportation will grow at 2.5 percent per year throughout 1999-2020 (3). Figure S-12 plots this EIA scenario by increasing transportation fuel demand in Year 2000 (11 million barrels/day) at a rate of 2.5 percent/year through Year 2020, followed by an increase of only 1 percent/year to Year 2040 – resulting in a demand of 22 million barrel-of-oil equivalents in Year 2040. This scenario suggests that if the White House achieves the goal of replacing 11 million barrels of oil with hydrogen fuel by 2040, the transportation sector will still need the same amount of oil (11 million barrels/day) in 2040 as it does today, but by which time world oil production will be in significant decline and the Middle East will supply the majority of world oil.

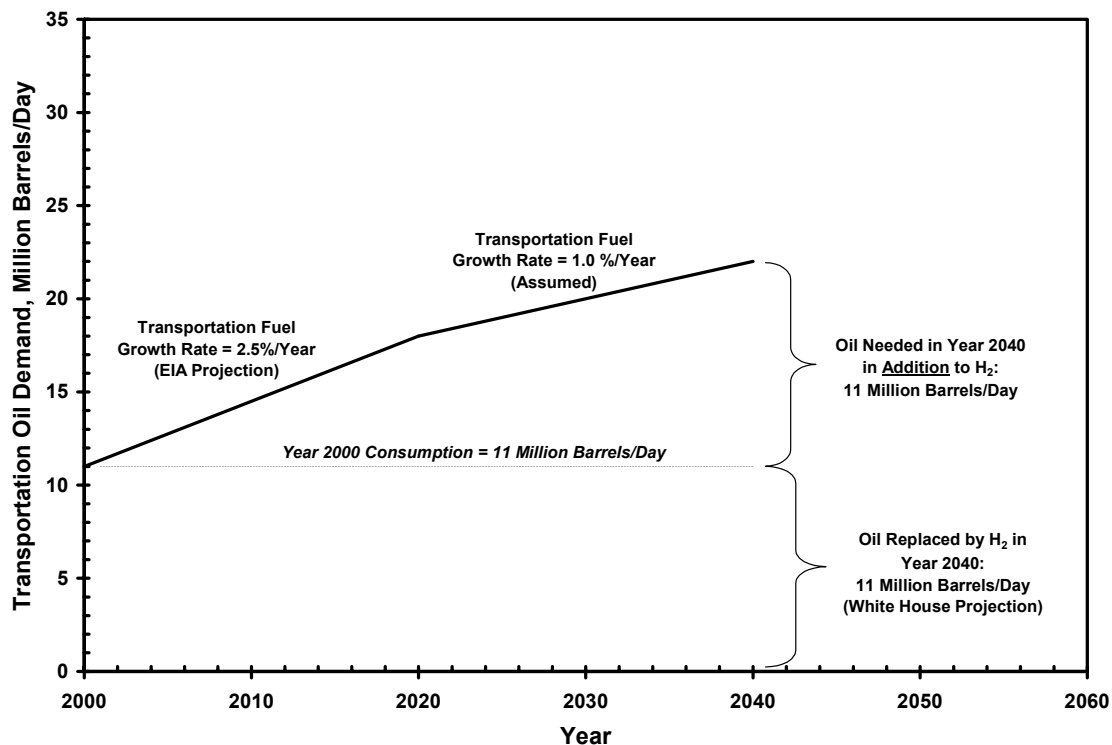


Figure S-12. Potential Role of Hydrogen in Reducing the Demand for Oil in the Transportation Sector.

In addition to fuel cell development, other challenges presented by the use of hydrogen include the development of reliable transportation and storage facilities. The potential for hydrogen embrittlement of pipelines at necessary operating pressures will exclude the use of the existing pipeline network, requiring hydrogen to be either produced at the distribution site or transported

through new, more expensive pipelines. Farrell and Keith speculate that the cost of building hydrogen refueling infrastructure might require focusing on vehicles that refuel at centralized facilities, such as transit buses, trucks, trains, and ships (21). They further explain the difficulty in designing hydrogen-fueled cars that have adequate storage space and acceleration, indicating that these larger vehicles would be more likely candidates for using hydrogen fuel. Also, the amount and source of energy required to convert water or hydrocarbons to hydrogen should not be overlooked.

Despite these problems, hydrogen holds promise as a long-term solution to the need for clean-burning fuels, and technological developments may allow hydrogen fuel to be widely used within several decades. Natural gas is considered to be a more immediate solution in the search for alternative fuels, but, as described in the following section, this resource has limitations of its own.

Natural Gas

Natural gas burns cleaner than either coal or oil and has become highly valued as an alternative fuel. In fact, the demand for this fuel has become great enough that Federal Reserve Chairman Alan Greenspan expressed his concerns on the future availability of natural gas to the Joint Economic Committee of the U.S. Congress on May 21, 2003. Electric power generation plants that use natural gas require 50 percent less capital for construction and produce 50 percent fewer greenhouse gases than coal or oil. Consequently, over 80 percent of new power-generating facilities are designed to use natural gas, which contributes to the strain that now exists on domestic gas supplies (22).

The National Energy Policy Development Group projects domestic natural gas production to peak by 2015 (2), which may be an overly optimistic scenario considering that Al-Fattah and Startzman conclude that U.S. natural gas production peaked in 1999 at 29 trillion cubic feet/year (23). Recent comments from industry and government suggest that production has indeed peaked, as reflected in current discussions on natural gas supply that now focus on:

- increasing liquefied natural gas (LNG) imports,
- promoting the exploitation of unconventional domestic gas resources (i.e., tight gas sands and coal bed methane),

- constructing a natural gas pipeline from Alaska to the lower 48 States,
- encouraging ultra-deep offshore projects in the Gulf of Mexico, and
- gaining access to restricted resource areas (i.e., off-limit federal lands and waters).

Alan Greenspan’s testimony made clear the fact that, as our leading source of gas imports, Canada has little capacity to expand shipments to the United States, and that barriers to the expansion of LNG import facilities will limit access to the world’s abundant supplies of natural gas. Furthermore, Guy Caruso, Administrator for the Energy Information Administration, provides reason for pursuing alternative sources by questioning whether “natural gas resources in the mature onshore lower 48 states have been exploited to a point at which more rapid depletion rates eliminate the possibility of increasing – or even maintaining – current production levels at reasonable cost” (22).

Perhaps the most exciting prospect for meeting the demand for this clean-burning fuel lies on land in permafrost regions and offshore at water depths exceeding 1,600 feet in a form known as methane hydrates (24). These hydrates consist of methane molecules trapped inside ice crystals that, while once considered a nuisance of transporting gas through pipelines in cold climates, in 1964 were found to occur naturally throughout the world. In the U.S., hydrates are found in Alaska, the East and West Coasts, and the Gulf of Mexico in quantities roughly 140 times that of conventional gas deposits. The pressing need for new domestic natural gas supplies has resulted in a venture between the Department of Energy, Anadarko Petroleum, and Noble Petroleum to determine the commercial viability of this resource (25). Drilling of the first test well was begun on March 31, 2003, in Alaska to test the potential for producing this “methane ice” with the hope of ushering in a new era in the petroleum industry.

RECOMMENDATIONS

This chapter has shown that, based on world discovery and production history, a point in time will be reached when world oil production peaks; possibly within the next several years. Unfortunately, energy forecasts also show that the demand for energy, particularly in the transportation sector, will grow substantially over the next several decades. This disparity between supply and demand will coincide with a growing percentage of the remaining supplies

coming from OPEC nations. Like any commodity for which the demand increases while the supply becomes more constrained, oil consumers will suffer one of two fates if faced with no viable alternatives:

1. In the case where prices are capped, oil supplies will become scarce and the capacity to transport people and goods will diminish, or
2. In the case where the free market prevails, oil prices will be bid upward and the cost of transporting people and goods will escalate.

In light of these circumstances, an obvious role for transportation planners should be to provide viable infrastructure alternatives that increase the demand elasticity of oil. It was shown in [Figure S-5](#) how the emergence of competing energy sources, alternative oil supplies, and conservation efforts contributed to more moderate oil production trends following the supply disruption of 1980. A similar effect may be achieved in the transportation sector by relying more heavily upon electrically powered systems that can operate on a variety of energy sources (natural gas, nuclear, coal, oil, etc.).

Clean coal and nuclear initiatives will likely be prominent components of any energy bill that is signed by President George W. Bush (26). More specifically, Senator Pete Domenici, Chairman of the Senate Committee on Energy and Natural Resources, believes that “we need to diversify this country’s energy portfolio. Our ongoing concerns regarding foreign oil and our pending crisis in natural gas makes that need absolutely clear. Nuclear energy is a key component of that diversity” (27). Regardless of the energy source, electrically powered transportation systems are powered from centralized facilities in the same manner as that which Farrell and Keith hypothesize will one day be used to distribute hydrogen fuel. In the first case, a raw energy source is used to generate electricity, and in the second case it would be used to produce hydrogen.

With regard to this research, linear induction rail technology has been identified as the most effective means of moving freight over moderate distances and, in addition to reducing marginal costs associated with trucking, provides an alternative to the reliance upon oil as an energy source. The implementation of this planning strategy can also be extended to high-speed rail and

transit systems for passenger transportation. In fact, the current fuel efficiency of high-speed rail travel rivals that of aviation for trips less than 600 miles, and an era of rising jet fuel costs would certainly shift the advantage to electrified rail systems (28).

SUPPLEMENTAL REFERENCES

1. Campbell, C.J., and Laherrere, J.H., *The End of Cheap Oil*, Scientific American, March 1998.
2. Report of the National Energy Policy Development Group, U.S. Government Printing Office, Washington, D.C., May 2001.
3. Energy Information Administration [Internet] International Energy Outlook 2002: Transportation Energy Use [cited 2003 Apr 28] Available from: <http://www.eia.doe.gov/oiaf/ieo/transportation.html>
4. Laherrere, J.H., *Learn Strengths, Weaknesses to Understand Hubbert Curve*, Oil & Gas Journal, April 17, 2000.
5. Masters, C.D., Attanasi, E.D., and Root, D., *World Petroleum Assessment and Analysis*, Proceedings, 14th World Petroleum Congress, John Wiley & Sons, Stavanger, Norway, 1994.
6. Campbell, C.J. [Internet] The Imminent Peak of World Oil Production, a presentation to a House of Commons All-Party Committee on July 7, 1999 [cited 2003 Apr 28] Available from: <http://www.hubbertpeak.com/campbell/commons.htm>
7. Fletcher, S., *IPAA: Lack of Good Prospects Undermines Drilling Activity, Heightens U.S. Gas Supply Concerns*, Oil & Gas Journal, Nov 4, 2002.
8. Salameh, M.G., *Filling the Global Energy Gap in the 21st Century*, Petroleum Review, Vol. 56, No. 667, August 2002.
9. Yergin, D., *The Prize*, Simon & Schuster, New York, 1991.
10. Ivanhoe, L.F., *Future World Oil Supplies: There is a Finite Limit*, World Oil, Oct 1995.
11. Wattenbarger, R.A., *Oil Production Trends in the CIS*, World Oil, June 1994.
12. Hubbert, M.K., *Energy Resources*, a report to the Committee on Natural Resources, National Academy of Science, National Research Council, Pub. 1000-D, 1962; reprinted 1973 by National Tech Information Service, U.S. Department of Commerce, No. PB-222401, 1973.
13. Laherrere, J., *Forecasting Future Production from Past Discovery*, OPEC Seminar – OPEC and the Global Energy Balance: Toward a Sustainable Energy Future, Vienna, Sept 2001.
14. Deffeyes, K.S., *World's Oil Production Peak Reckoned in Near Future*, Oil & Gas Journal, Nov 11, 2002.
15. Youngquist, W., and *Spending Our Great Inheritance – Then What?*, Geotimes, July 1998.
16. Andrea, I., Al Buraiki, O., *Future of Deepwater Middle East Hydrocarbon Supplies*, Oil & Gas Journal, June 17, 2002.
17. Al-Jarri, A.S., and Startzman, R.A., *Worldwide Petroleum-Liquid Supply and Demand*, Journal of Petroleum Technology, Dec 1997.
18. International Energy Agency, *World Energy Outlook, 2001 Insights: Assessing Today's Supplies to Fuel Tomorrow's Growth*, IEA Books, Paris, 2001.
19. Campbell, C.J., *Deepwater Oil – The End of the End Game*, Hubbert Center Newsletter # 99/4-1, Petroleum Engineering Department, Colorado School of Mines, Oct 1999.
20. Lorenzetti, M., *Hydrogen Power*, Oil & Gas Journal, Feb 17, 2003.

21. Farrell, A., and Keith, D., *Hydrogen as a Transportation Fuel*, Environment, Vol. 43, No. 3, April 2001.
22. U.S. Senate Committee on Energy and Natural Resources [Internet] Natural Gas Supply and Prices (Full Committee Hearing) [updated 2003 Feb 25; cited 2003 March 26] Available from: http://energy.senate.gov/hearings/testimony.cfm?id=591&wit_id=1605
23. Al-Fattah, S.M., and Startzman, R.A., *Forecasting World Natural Gas Supply*, Journal of Petroleum Technology, Vol. 52, No. 5, May 2000.
24. Fossil Energy, U.U. Department of Energy [Internet] Methane Hydrates [cited 2003 May 19] Available from http://www.fe.doe.gov/oil_gas/methanehydrates
25. Moritis, G., *Seeking Flammable Ice*, Oil & Gas Journal, May 26, 2003.
26. Puplava, J.J., Financial Sense Online, Newshour's Ask the Expert [Internet] Interview with Ronald Oligney, author of "The Color of Oil: The History, the Money and the Politics of the World's Biggest Business" [updated 2001 Sept 13; cited 2003 March 26] Available from: <http://www.financialsense.com/transcriptions/Oligney.htm>
27. U.S. Senate Committee on Energy and Natural Resources [Internet] Nuclear Energy Provision in S.14 Garners Broad Bipartisan Support (Press Release) [Released 2003 June 9; cited 2003 June 10] Available from http://energy.senate.gov/news/rep_release.cfm?id=204802
28. DeCicco, J., and Mark, J., *Meeting the Energy and Climate Challenge for Transportation in the United States*, Energy Policy, Vol. 26, No. 5, 1998.