

## MAGLEV CRUDE OIL PIPELINE

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## SUMMARY

This maglev crude oil pipeline consists of two conduits guiding an endless stream of long containers. One conduit carries loaded containers and the other empty returns. The containers are levitated by permanent magnets in repulsion and propelled by stationary linear induction motors. The containers are linked to each other in a manner that allows them, while in continuous motion, to be folded into side by side position at loading and unloading points. This folding causes a speed reduction in proportion to the ratio of container diameter to container length. While in side by side position, containers are opened at their ends to be filled or emptied. Container size and speed are elected to produce a desired carrying capacity.

## INTRODUCTION

## The Difficulty of Conventional Crude Oil Pumping

Long distance land transportation of crude oil, especially heavy crude, is very expensive with present technology. Oil from the north slope of Alaska is a classic example. It needs to be transported many thousands of miles to the market. However, in the first 800 miles, from Prudhoe Bay to Valdez by a conventional pumping method, the Alaska pipeline consumes, including interest and capital recovery, roughly one-third of the oil's value (ref. 1). The major reasons for this excessive cost are:

- a. The pipeline was designed with special concerns for the environment. For instance, remote control valves were installed at 5 mile intervals to limit spills to 64,000 barrels for each single line break.
- b. The line also had to withstand temperature extremes of minus 70 degrees Fahrenheit when empty of oil in midwinter, and plus 145 degrees Fahrenheit when filled with oil at the maximum pumping rate of 2 million barrels a day, without adversely affecting the surroundings.
- c. Pumping capacity of about 500 horsepower per mile at pressures of up to 1200 pounds per square-inch was needed to push the oil along at barely 7 miles per hour.
- d. To pump a large volume of 2 million barrels per day at this slow speed of 7 miles per hour required a 48 inch diameter pipeline.
- e. A 48 inch diameter pipeline under 1200 pounds per square-inch pressure needs 2 inch thick walls.

As a result of (a) to (e) above and more, environmental concerns, temperature extremes and large diameter pipelines with thick walls under high pressure, all added up to high cost major construction.

## How a Maglev Pipeline Would Improve Crude Oil Transportation

In assembly line fashion, the crude oil is put into containers at atmospheric pressure and sealed. The containers are then magnetically suspended over a track and propelled to their destination with linear induction motors. Freed of the drag caused by adhesion to the inside of a pipe and no matter if the oil is hot or cold, the oil can now be moved at much higher speed, for example, thirty times as fast as when conventionally pumped. Since capacity equals speed times cross sectional area, a thirty fold speed increase allows a thirty fold decrease in cross sectional area, which in turn means much less weight. Hence, the containers can be small and light, and they can easily be magnetically suspended with permanent magnets in repulsion. A conduit provides guidance and containment. The containers fold up at the ends of the line and slow to a crawl, at which time they are filled or emptied.

### BASIC COMPONENTS OF MAGLEV PIPELINE

#### Permanent Magnets in Repulsion as the Means of Suspension

The crude oil is put into containers which are suspended by permanent magnets in repulsion as shown in Figure 1. Not shown are lateral guidance controls, which can be either mechanical or magnetic. Figure 7 p.682 (refs. 2, 3 & 4) shows details of lateral guidance. A particular advantage of using permanent magnets in repulsion is that they require no power to levitate and the containers always remain levitated even when the system is turned off and has stopped. New magnetic compounds now virtually last forever in this type of application.

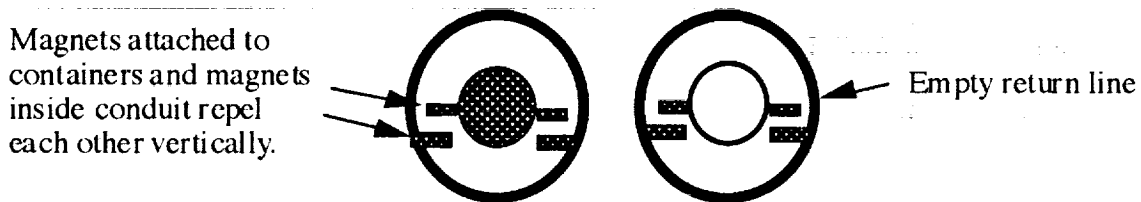
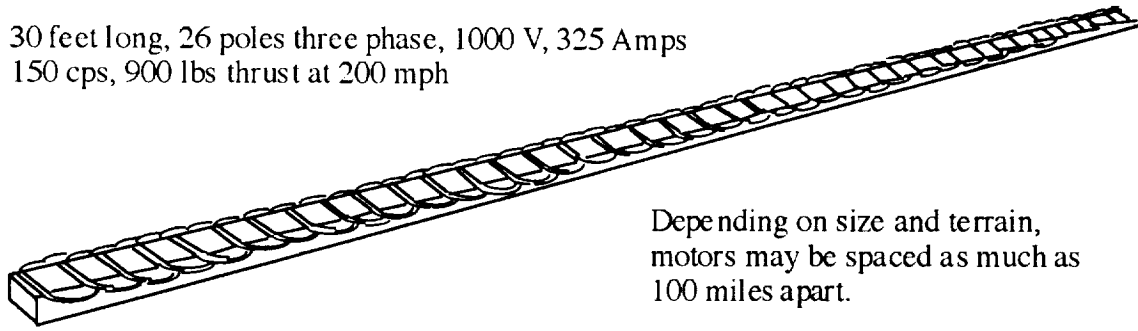


Figure 1. Typical cross section of maglev pipeline.

#### Electric Linear Induction Motors (LIM) for Propulsion

The primary portion of a typical electric linear induction motors (LIM) is shown in Figure 2. The secondary to this LIM consists of a metal sandwich attached to the bottoms of the containers (ref. 5). The speed of the shown LIM can be varied by varying the frequency of the supplied power. For instance, the speed can be reduced from 200 to 100 miles per hour (mph) by reducing the frequency from 150 to 75 cycles per second (cps). The LIM can also be reversed for braking. A power supply with appropriate controls would be required to meet the full range of possible operating needs.

30 feet long, 26 poles three phase, 1000 V, 325 Amps  
 150 cps, 900 lbs thrust at 200 mph



Depending on size and terrain,  
 motors may be spaced as much as  
 100 miles apart.

Figure 2. Typical high speed high performance linear induction motor (LIM).

### Dynamic Mechanical Loading and Unloading

The containers are flexibly attached to each other end to end and move in unison. A short distance before the end of the line is a cam that forces alternate container joints to diverge onto upper and lower tracks. This causes the containers to fold up against each other and slow down, the last stages of which are shown in Figure 3 (ref. 6). After they have completely folded, they pass through either a filling or a dumping station followed by a U-turn.

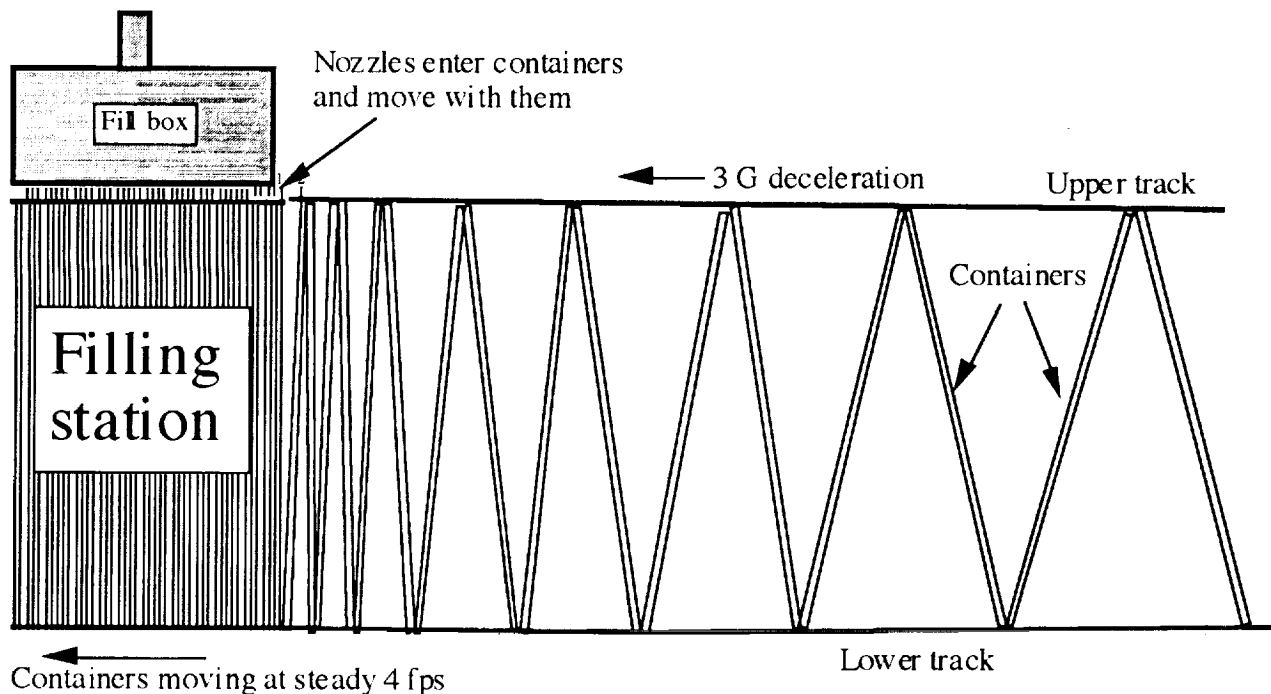


Figure 3. Typical folding and filling of containers.

*Comments on Figure 3.* Figure 3 is a cutout from a drawing that shows a 200 mph system. While this might be a look into the future in bulk materials transportation, initial speeds of between 50 and 100 mph would be advocated with provisions to step the speed up to a higher level later.

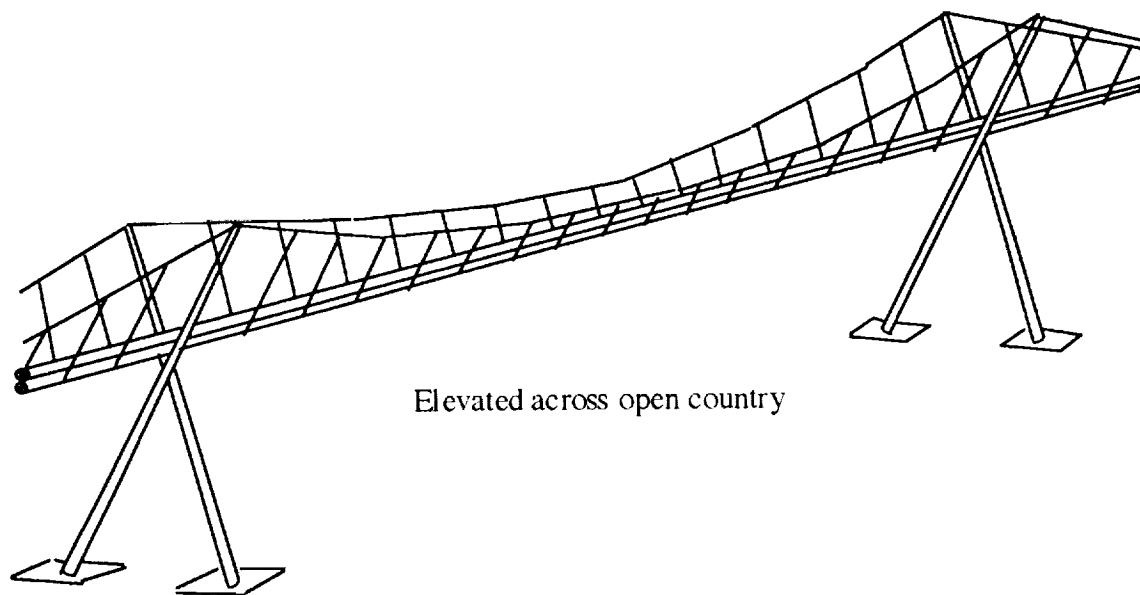


Figure 4. Typical design of maglev crude oil pipeline.

#### MAGLEV PIPELINE COST AND CAPACITY

*Construction Cost.* A detailed cost estimate shows that, if a medium size maglev crude oil pipeline were to be built in 1993 as an elevated system as shown in Figure 4, it would cost about \$500,000 per mile. Not included in this estimate are the costs of (1) right-of-ways, (2) power generators if needed, (3) service roads and (4) end facilities. The elevated design is preferred because of the continued need for very straight alignment similar to overhead wires or catenaries of high speed railroads.

Table 1. Assorted Carrying Capacities, Barrels per Day

Nominal container diameter (inches)	Speed 25 mph	Speed 50 mph	Speed 75 mph	Speed 100 mph
3	34,000	68,000	102,000	136,000
4	60,000	120,000	180,000	240,000
6	138,000	276,000	414,000	552,000
8	240,000	480,000	720,000	960,000
12	550,000	1,100,000	1,650,000	2,200,000

*Size, Speed and Capacity.* The carrying capacity of the pipeline is determined by multiplying the container cross-sectional area with the system velocity. The cross-sectional area is determined by the elected container diameter. However, the speed can be changed at any time later which in turn changes system capacity. Table 1 shows the pipeline capacities for various sizes and speeds when running continuously for 24 hours. Conversion factors are (a) one barrel = 42 gallons, (b) 7.48 gallons = 1 cubic foot, (c) oil weight is 55 pounds per cubic foot and (d) 550 foot-pounds/sec = one horsepower. These factors were used to

compute the data in Table 1 and also the energy use of the system, which is reflected in operating and maintenance expenses of later chapters.

### COMPARING MAGLEV COST WITH THE ALASKA (PUMPED) PIPELINE

About 25 years ago, oil was discovered in Prudhoe Bay, Alaska. As shipping lanes were blocked most of the year by ice, a 48-inch diameter, 800 miles long, 2,000,000 barrels per day pipeline was constructed to Valdez. Completed in 1976, it cost in excess of \$9 billion, or over \$11 million per mile. Taking inflation from 1976 to 1993 as roughly 100%, it follows that if the Alaska pipeline were to be built today it would cost about \$22 million per mile. This would compare with the above 1993 estimated maglev pipeline cost of \$500,000 plus costs of environmental stuff, right-of-ways, end facilities, service roadways, power lines and power generating plants. Without going into too much detail, let's be generous and say we could build the maglev pipeline with everything included for \$4 million per mile in 1993 dollars, or we could have built it for \$2 million per mile in 1976. Table 2 shows reported Alaska pipeline statistics (ref. 1), and Table 3 compares the Alaska pumped pipeline cost of \$11 million per mile with our maglev pipeline cost of \$2 million per mile (both 1976 dollars).

Table 2. Alaska Oil Pipeline Operating Results, 17 Years Recorded, 3 Years Estimated

	Year	Million Barrels per Day	Tariff Rate \$/Barl.	Oper. Expense \$/Barl.	Tax Loading Rate
		(a)	(b)	(c)	(d)
1	1976	0	6.00	0.4	0.33
2	1977	0.3	6.00	0.6	0.33
3	1978	1.1	6.00	0.8	0.33
4	1979	1.2	6.00	1	0.33
5	1980	1.5	6.00	1.2	0.33
6	1981	1.5	6.00	1.2	0.33
7	1982	1.6	6.00	1	0.33
8	1983	1.7	6.00	0.9	0.33
9	1984	1.7	6.00	0.8	0.33
10	1985	1.8	5.00	0.7	0.33
11	1986	1.8	4.75	0.65	0.33
12	1987	2	3.90	0.58	0.2
13	1988	2.1	3.40	0.57	0.2
14	1989	1.9	3.50	0.83	0.2
15	1990	1.8	4.00	1.1	0.2
16	1991	1.8	3.50	1	0.2
17	1992	1.8	3.70	1.2	0.2
18	1993	1.7	3.50	1.25	0.2
19	1994	1.7	3.60	1.32	0.2
20	1995	1.6	3.50	1.35	0.2

*Comments on Table 2.* This data was extracted from evidence presented in 1992 to the Federal Energy Regulatory Commission (ref. 1). Table 3 uses this data as follows: Annual revenues, columns (a) x (b) x 365, annual expenses, columns (a) x (c) x 365, annual income taxes, columns (a) x (b) x (d) x 365. An

'After Tax Margin' of 6.4% as return on investment or profit was arbitrarily elected by the owners of the pipeline, the annual total of which is calculated by multiplying 0.064 with the amounts of investment balance, columns (g) and (k) in Table 3.

Table 3. Investment Comparison of Pumped vs. Maglev Pipeline Using Recorded Alaska Pipeline Data (\$1,000,000)

Year	Common Data		Pumped Pipeline				Maglev Pipeline			
	Rev- enue	Tax Margin	O & M Expense	After Tax Margin	Earned Surplus	Invest- ment Balance	O & M Expense	After Tax Margin	Earned Surplus	Invest- ment balance
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
1	0	0	0	577	-577	9600	65	114	-179	1966
2	657	217	66	614	-240	9840	67	126	247	1719
3	2409	795	321	630	663	9177	70	110	1434	285
4	2628	867	438	587	735	8442	73	18	1669	-1384
5	3285	1084	657	540	1004	7438	76	-89	2214	-3598
6	3285	1084	657	476	1068	6370	79	-230	2352	-5950
7	3504	1156	584	408	1356	5014	82	-381	2646	-8596
8	3723	1229	558	321	1615	3399	85	-550	2959	-11555
9	3723	1229	496	218	1780	1619	89	-740	3145	-14701
10	3285	1084	460	104	1637	-19	92	-941	3049	-17750
11	3121	1030	427	-1	1665	-1684	96	-1136	3131	-20881
12	2847	569	423	-108	1962	-3646	100	-1336	3514	-24395
13	2606	521	437	-233	1881	-5527	104	-1561	3542	-27937
14	2427	485	576	-354	1720	-7247	108	-1788	3622	-31559
15	2628	526	723	-464	1844	-9091	112	-2020	4010	-35569
16	2300	460	657	-582	1764	-10855	117	-2276	3999	-39568
17	2431	486	788	-695	1851	-12706	122	-2532	4356	-43923
18	2172	434	776	-813	1775	-14481	126	-2811	4422	-48345
19	2234	447	819	-927	1895	-16376	131	-3094	4750	-53095
20	2044	409	788	-1048	1895	-18271	137	-3398	4897	-57992

*Comments on Table 3.* 1976 was the start up year without saleable production. Earned surplus column (f) = (b) - (c) - (d) - (e) and column (j) = (a) - (c) - (h) - (i). Investment balance is reduced annually by earned surplus, except at the beginning when it was increased due to negative earned surplus. Note how the pumped pipeline reached payoff in eight years and maglev in two years after the start of production.

Table 4. Computation \$10 Million per Day Financial Advantage of Maglev over Pumping, Based on Actual Alaska Crude Oil Pipeline Experience (\$1,000,000)

Year	Pumped		Maglev		Annual Maglev Savings (e)	Annual Million Barrels (f)	Daily Maglev Savings (g)	Present Value of (g) (e)
	(a)	(b)	(c)	(d)				
1	-577	577	-179	114	861	0	0.00	0.00
2	-240	614	247	126	975	110	2.67	5.83
3	663	630	1434	110	1290	402	3.54	7.35
4	735	587	1669	18	1503	438	4.12	8.15
5	1004	540	2214	-89	1839	548	5.04	9.50
6	1068	476	2352	-230	1991	548	5.45	9.79
7	1356	408	2646	-381	2079	584	5.70	9.74
8	1615	321	2959	-550	2215	621	6.07	9.89
9	1780	218	3145	-740	2322	621	6.36	9.87
10	1637	104	3049	-941	2456	657	6.73	9.94
11	1665	-1	3131	-1136	2601	657	7.12	10.03
12	1962	-108	3514	-1336	2781	730	7.62	10.21
13	1881	-233	3542	-1561	2989	767	8.19	10.45
14	1720	-354	3622	-1788	3336	694	9.14	11.11
15	1844	-464	4010	-2020	3722	657	10.20	11.81
16	1764	-582	3999	-2276	3929	657	10.77	11.87
17	1851	-695	4356	-2532	4342	657	11.90	12.49
18	1775	-813	4422	-2811	4645	621	12.73	12.73
19	1895	-927	4750	-3094	5022	621	13.76	13.10
20	1895	-1048	4897	-3398	5352	584	14.66	13.30
					20-year average:		7.59	9.86

*Comments on Table 4 and Figure 5.* The Alaska pipeline construction was financed on extremely favorable terms (6.4% interest) by oil companies who expected to later benefit greatly from its use. (See also "Comments on Table 2"). In the first five columns of Table 4 a more realistic investment value of 12.8% is imputed (by subtracting the 'After Tax Margin' of 6.4% a second time) and thereon computing the maglev over pumped pipeline savings:  $(e) = ((a) - (b)) - ((c) - (d))$ . Table 4 columns (a), (b), (c) and (d) are copies of columns (f), (e), (j) and (i) of Table 3. The last column (e) of Table 4 then shows that a maglev crude oil pipeline in Alaska could have saved an average of about \$10,000,000 per day over a 20 year period for a total of  $20 \times 365 \times \$10 \text{ million} = \$73 \text{ billion}$ . Column (e) is annually compounded present value of column (g) at 5% interest.

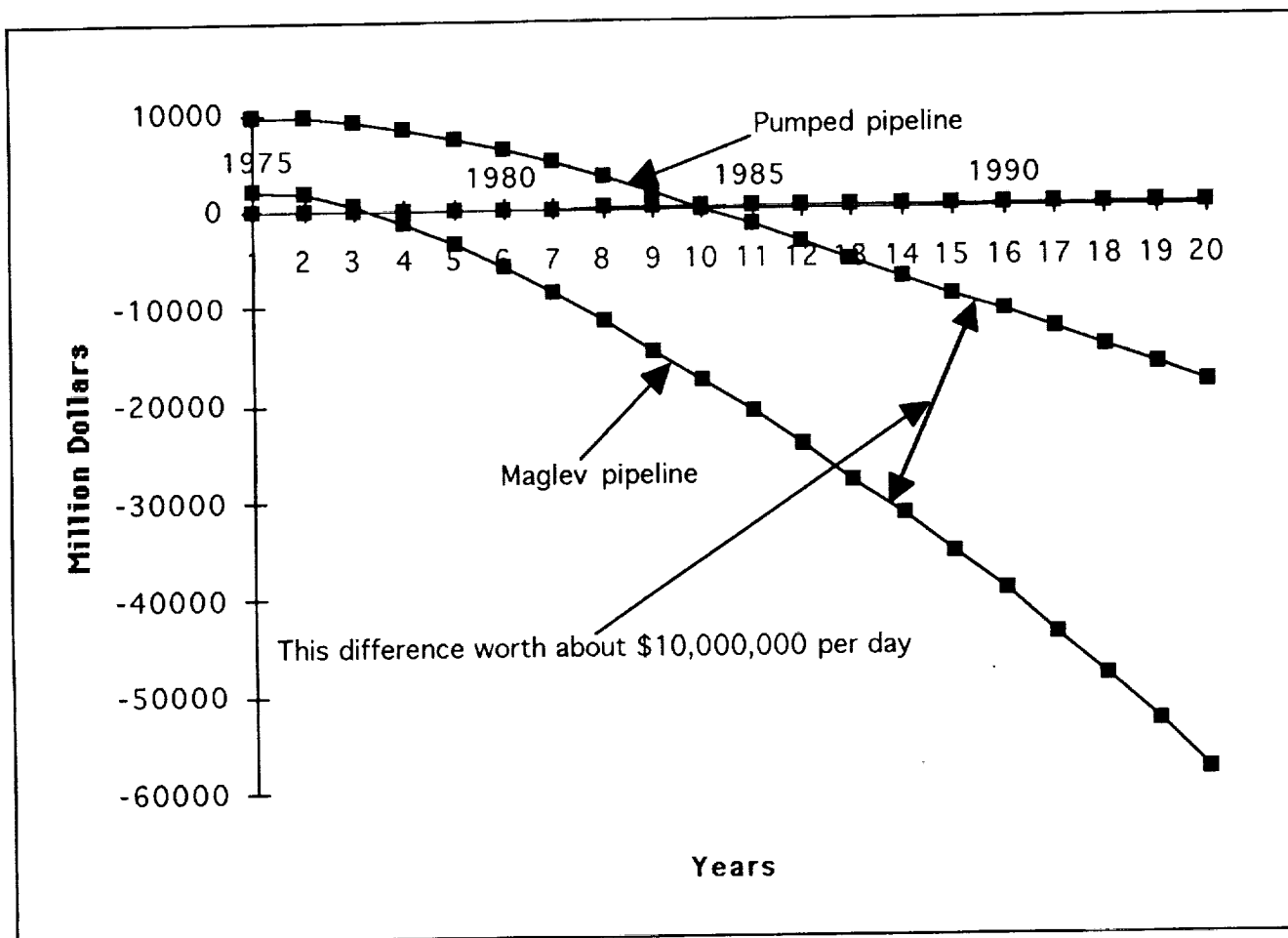


Figure 5. Amortization curve comparison of existing Alaska pumped pipeline with maglev pipeline based on reported 'After Tax Margin' of 6.4% as shown in columns (g) and (k) of Table 3. It shows that 20-year average savings worth \$10 million per day could have been achieved with a maglev crude oil pipeline instead of the existing pumped oil pipeline.

General consensus in the oil industry is that the Alaska oil pipeline was a financial disappointment. It was built with a view of oil prices rising and remaining around \$40 per barrel, which would have justified a \$6 per barrel pipeline transportation charge. Instead the oil prices dropped back down to less than \$20 per barrel. The above tables and Figure 5 bear this out. If the investors in the Alaska pipeline had demanded a more normal 'After Tax Margin' of around 13% instead of 6.4%, the pipeline company would have quickly gone bankrupt.

#### MAGLEV CRUDE OIL PIPELINE FUTURE - HOW ABOUT KASAKHSTAN?

There are several regions in the world where large oil fields are indicated which have limited economic access to markets. One of them lies in Tengiz, Kasakhstan, where a 1500 mile long maglev crude oil pipeline could economically carry the oil to a Black Sea shipping port. However, the maglev picture there is not quite as rosy as shown above for Alaska. In addition to this line being about twice as long as the Alaska pipeline, the required capacity is only 1,000,000 barrels per day instead of Alaska's 2,000,000 barrels per day. Furthermore, investors are not likely to be found who would advance capital at 6.4% as they did in Alaska.



Table 5 and Figure 6 show 15-year projected financial results of a 1500 mile long maglev crude oil pipeline in Kazakhstan, starting with 250,000 barrels per day in the first year and increasing in 5 years to 1,000,000 barrels per day, financed and taxed under conditions generally found in the U.S.A., i.e., 70% debt, 30% equity, interest on debt 13%, return on equity 20%, (combined cost of money 15.1%), cost escalation 5%, income taxes 40%, tax depreciation 10%, property taxes 1%. Table 5 shows the result assuming that original construction cost was \$4 million per mile and revenues at \$4.00 per barrel (plus annual escalation). Figure 6 shows three curves, \$4, \$3 and \$2 million per mile original construction cost levels with respective \$4.00, \$3.00 and \$2.00 per barrel revenue levels (also plus annual escalation).

Table 5. 15 Year Projected Financial Results of 1500 Mile, 1,000,000 Barrels per Day Maglev Crude Oil Pipeline in Kazakhstan at Original Cost Estimate of \$4 Million per Mile and Revenues at \$4.00 per Barrel (\$1,000,000)

Line	Year	Revenue	Opr. Exp	Prop. Taxes	Tax Deprec.	Interest on Debt	Income Tax	Return on Equity	Debt Repayments	Remain. Debt Balance
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
1	1996	423	131	90	845	769	0	507	-872	9327
2	1997	665	137	92	845	849	0	560	-748	10075
3	1998	932	144	94	845	917	0	604	-586	10661
4	1999	1223	151	96	845	970	0	640	-378	11039
5	2000	1798	159	98	845	1005	0	662	139	10900
6	2001	2157	167	100	845	992	21	654	485	10415
7	2002	2265	175	102	845	948	78	625	587	9828
8	2003	2378	184	104	845	894	140	590	702	9126
9	2004	2497	193	106	845	830	209	548	830	8295
10	2005	2622	203	108	845	755	284	498	973	7322
11	2006	2753	213	110	845	666	367	439	1133	6189
12	2007	2891	224	112	845	563	458	371	1310	4879
13	2008	3035	235	114	0	444	897	293	1170	3710
14	2009	3187	247	117	0	338	994	223	1358	2351
15	2010	3346	259	119	0	214	1102	141	1568	783

Table 6 shows how the initially estimated capital requirement of \$4 million/mile times 1500 miles = \$6 billion increases by inflation and capitalized interest during three years' of construction to \$8.454 billion. This amount plus first year loss of \$0.872 billion (Table 5, line (1), column (h)) equals the \$9.327 billion in Table 5, line (1), column (i).

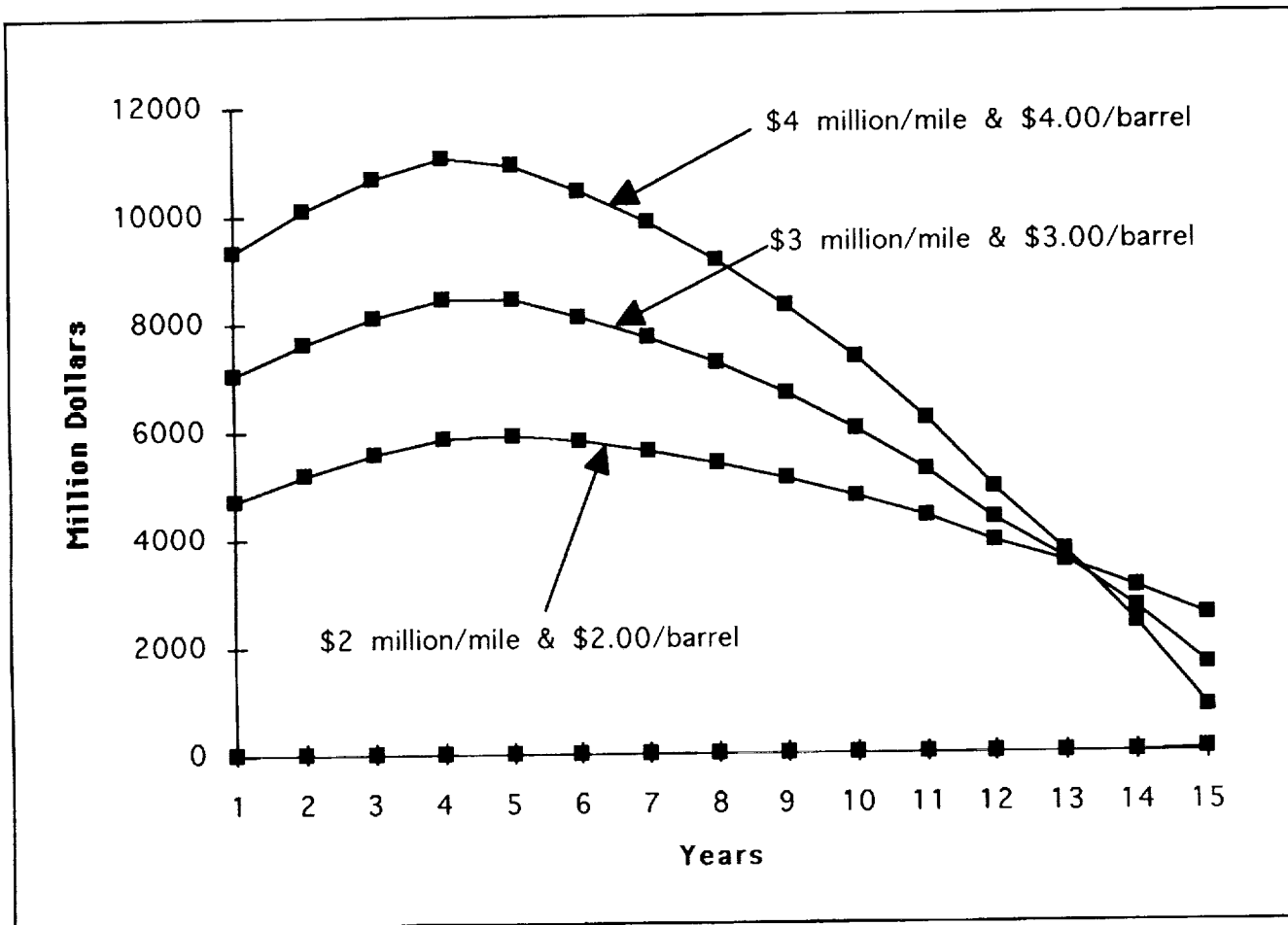


Figure 6. Amortization of capital investment for a 1500 mile maglev crude oil pipeline in Kazakhstan assuming initial capital investments of \$4 million/mile, \$3 million/mile and \$2 million/mile with respective revenues of \$4.00/barrel, \$3.00/barrel and \$2.00/barrel.

Table 6. Computation of Capital Requirement for \$4 Million per Mile, 1500 Mile Kazakhstan Maglev Crude Oil Pipeline, 3 Years Construction, Inflation 7% and Capitalized Interest (Cost of Money) 15.1% (\$1,000,000)

Line	Year	7% p/a Inflated Plant \$	Construction Completed		Capita- lized Interest \$	Total Invest- ment \$
			%	\$		
1	1993	6000	20	1200	181	1381
2	1994	6420	50	3210	693	5284
3	1995	6869	30	2061	1109	8454
4			100	6471	1984	8454

*Comments on Kazakhstan and Other Prospects.* Above comparison tables and examples are just a small sample of variations, which have been run by computer to gain insight on how they affect the end result. For example, in Table 5, in the first few years, the cost of money (interest on debt, column (e), plus

return on equity, column (g)) is more than 10 times as large as operating expense, column (b). Hence, keeping capital costs down is much more important than keeping operating expenses down. Figure 6 shows the amortization curves rising in the first few years due to the losses as calculated in Table 5, column (h), lines (1) to (4). If oil field production could be started at full capacity in the first year of pipeline operations, billions of dollars could be saved. However, in Alaska, it took five years before they had enough oil for the pipeline to run at full capacity. As to the cost of money, if one could finance a project with just one percent less in interest, for example cut interest on debt from 13% to 12% for the \$4 million/mile curve in Figure 6, it would mean construction cost savings of \$100 million and 15 year operations savings of \$1.5 billion.

## GREAT OPPORTUNITY FOR HIGH TECH AND MONEY MAKING

The above described basic components of the maglev crude oil pipeline, the permanent magnets, the linear induction motors and the container string with its folding function, are all pretty well straight forward and relatively simple and reliable technologies. There are opportunities for improvements in magnets, materials and container design, but the most challenging tasks lie in the field of maintenance (especially leakage prevention), lateral guidance, controls and failure prevention.

*Linear Induction Motors (LIMs) and Controls.* As stated in Figure 2 above, LIMs may be spaced as much as 100 miles apart at unmanned stations. However, the LIM shown in Figure 2 is only suitable for driving the system at high speed. For start up, intermediate speeds and reverse braking, several other specially designed LIMs are to be located next to the high speed LIMs. Additionally, for every type of LIM needed in operations throughout the speed range and reverse braking there will need to be one or more LIMs of equal size on standby. Motors may need to either be cooled heavily during start up or switched on and off in rotation. As an example, there might be five heavy thrust start up LIMs at each station that get the containers up to a speed of 5 mph. Each would take a turn and run for 20% of the time, and be off 80% of the time for cooling. There would also be a danger of overheating the containers. They must not stay too long over an active LIM.

To get a comparison of the magnitude, the largest movements of weight on land are unit trains for coal, ore or grain. They often have 100 cars, each carrying 100 tons for a total of 10,000 tons per train. A 100 mile long section of a maglev pipeline, having a capacity of 1,000,000 barrels per day, would weigh also about 10,000 tons (not counting the empty return line). So, the starting LIMs for each 100 mile section of maglev pipeline would have to exert a propulsion effort comparable to that of the (usually) eight locomotives of a unit train. However, for a 1500 mile Kazakhstan line it would require an effort equivalent to 120 locomotives. While this looks like an enormous physical task, the cost savings with maglev as calculated above would also be enormous.

*Power Supply to LIM Stations.* The Alaska pipeline has a mix of energy sources for pumping. Near Prudhoe Bay several pump stations receive natural gas from the oil field. Further along, oil from the line is dropped off, refined and then used for jet engine powered pumping. Also some power is obtained from private utilities. A maglev pipeline would probably also look at the best available but reliable source. If no other sources are available, one or more small power generating stations would be built and power lines strung along the same posts that carry the pipeline, see Figure 4.

*Surge Suppressors.* Common at hydroelectric power stations are surge towers for the purpose of preventing structural damage from sudden shut downs of the turbines following a power failure. The tremendous kinetic energy of the approaching water is dissipated by rising up in these surge towers and overflowing. The long stream of maglev pipeline containers has a similar problem and a similar solution. Along the line at intervals are longitudinal surge suppressor stations. These are locations where the containers are, for a short distance, forced by an upper and lower track to partially fold, similar to what is shown in Figure 3, above. However, unlike the rigidly fixed lower track in Figure 3, the lower track in a surge suppressor station is vertically movable so that it can absorb longitudinal surges that may run through

the containers. These stations also serve to compensate for longitudinal temperature expansions and contractions of the containers.

*Lateral Guidance of Containers.* Some 150 years ago, a transportation scientist by the name of Earnshaw, after experimenting with permanent magnets in repulsion, declared that 'it is impossible to suspend vehicles with permanent magnets in repulsion without secondary help', which is today known as Earnshaw's Theorem (ref. 4). While Einstein was able to refute Newton, nobody has yet been able to refute Earnshaw. Hence, we are stuck with the need for lateral guidance to ensure that the containers stay above their magnetic track and not fall off to the sides. Several methods of lateral guidance controls have been satisfactorily tested. They are items (1) to (3) below. However, items (4) and (5) below are being looked at as possible future alternatives.

(1) Self-adjusting, self-lubricating commercially available plastic sliders attached in pairs to each side of each container. The sliders follow polished stainless steel lined channels which are attached to the inside of the conduits, see left half of Figure 7. The sliders are periodically renewed. Unlike electro magnetic systems described below, this lateral guide method is fully operational throughout the speed range and needs no backup support system in case of power failure or at slow speed.

(2) Shown in the right half of Figure 7 are electro magnets attached in pairs to each side of each container, which are controlled by a gap sensor. A gap separates the electro magnets from dual channels with steel inserts. Power for the electro magnets may be generated off the permanent track magnets that suspend the containers (Figure 1). This system requires backup support in case of power failure and possibly also at low speed.

(3) Electro magnets with steel rails as in (2) above, except they are switched around. The electro magnets are stationary and the steel rails are attached to the moving containers. Power for the electro magnets can be either generated off the permanent magnet track or supplied by power lines that run along the pipeline. This system also requires backup support in case of power failure.

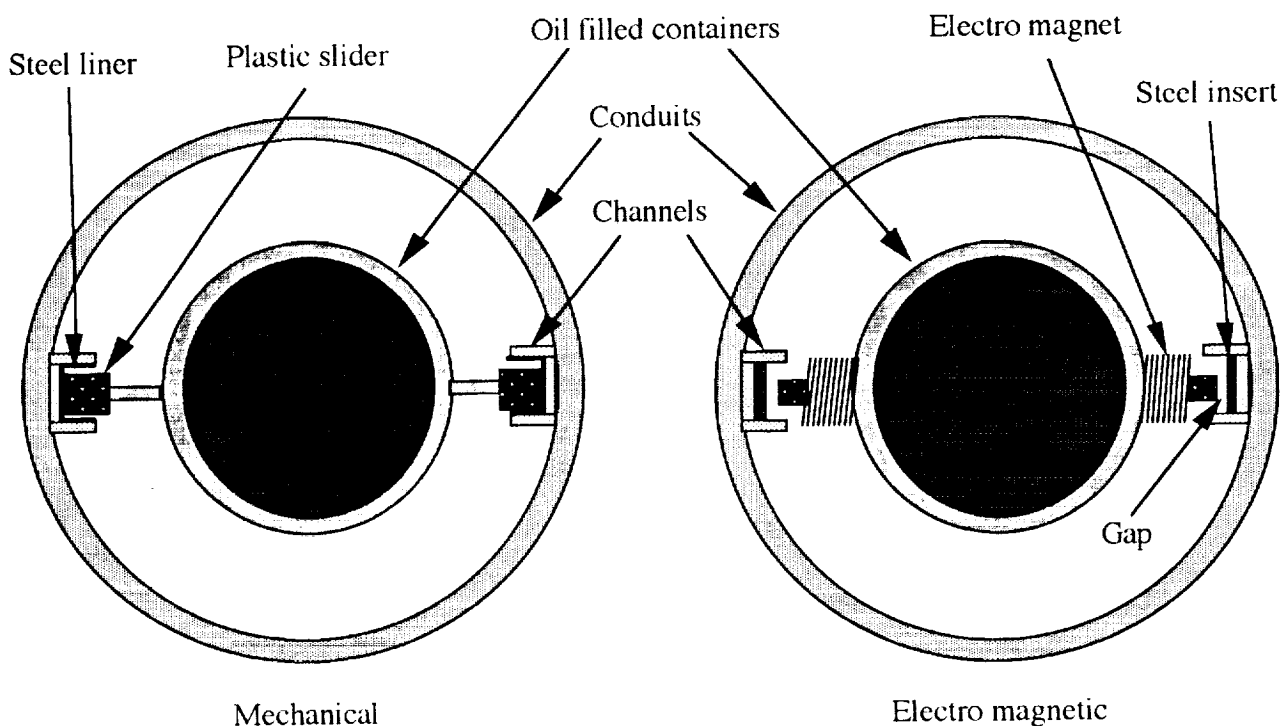


Figure 7. Typical choices of lateral guidance systems, mechanical or electro magnetic. For clarity, levitation magnets and LIMs are not shown.

(4) New magnetic suspension technology achievements as reported in NASA's 1991 first International Symposium on Magnetic Suspension Technology (ref. 7). These include practical applications of replacing friction bearings of rotary machinery with non-contact electro magnetic bearings. It seems feasible to have the container string of the maglev pipeline take the place of a rotating shaft of similar diameter and likewise have it controlled to remain contactless in the center while moving along at great speed. This system would also need backup support in case of power failure.

(5) A possible break-through in technology. Magnetic suspension by means of permanent magnets in repulsion is somewhat similar to riding a bicycle. At no speed and at low speed both have a strong tendency to fall over. However, at high speed it is nearly impossible to tip over with a bicycle. Remember, the kid shouting: 'Look Ma, no hands'? A bike becomes more and more self-steering as speed increases. By the same token, it should be possible to develop a kind of magnetic rudder that automatically steers the maglev containers through the center of the conduits when at high speed. Backup guidance support would be need at low speed, but power failures might not affect it.

*Quality Controls and Failure Protection.* If a light bulb goes out in a life buoy that marks a shipping channel, an automatic mechanism rotates another bulb in its place. If the second one goes, a third one comes up. New aircraft engines are tested numerous times. After each test, they are taken apart, checked and X-rayed until the probability of future failure has become extremely low. These are two examples of how to prevent disasters of major proportions. Both aircraft and shipping disasters, in addition to loss of life, can run into millions, even billions of dollars.

The above Kazakhstan pipeline proposal would carry 1,000,000 barrels of oil per day; that means about a million dollars' worth of oil every hour. Figure 6 shows how running at less than full capacity in the first five years has increased the indebtedness instead of decreasing it. It is obvious that any delay, breakdown or shut down would run into big financial losses. Hence, life buoy style, aircraft style and even better quality controls must be incorporated in design, operations and maintenance of a maglev crude oil pipeline, which might be the subject of a future paper.

## CONCLUSION

It is obvious that, as easily accessible sources of fossil fuel become depleted, a more economic land transportation mode needs to be developed. The 800 mile long Alaska (pumped) pipeline is an example of unsatisfactory and uneconomical present day pumping technology. Other remotely located oil fields lie untapped as they wait for advancements in transportation technology. Magnetic levitation is that new advancement in technology. A maglev crude oil pipeline could go very long distances and still be highly profitable in the hands of private enterprise. In the Alaska case, \$10 million per day (\$73 billion over 20 years) might have been saved, had the maglev technology been available and had it been used. Twice as long as the Alaska pipeline, a maglev crude oil pipeline from Tengiz in Kazakhstan to the Black Sea was calculated above to be also financially feasible.

The major components of the maglev crude oil pipeline are either mechanical or basic electrical in nature, which may need little further refinement. However, there are several areas of design and operations which need to be addressed and refined. To name a few, operational safety, quality control, failure prevention, start up procedure, shutdown procedure, lightning strikes, leakage, spills, earthquakes, ground shifting, temperature extremes, vandalism, guerilla attacks, etc. It is not going to be a simple project. However, the future looks bright for maglev pipelines. There is an immediate need to also transport coal, grain and ore more economically. Further into the future, it may some day be economically feasible to transport water by maglev pipeline from the north to arid lands in Arizona, New Mexico and Texas and turn them into lush green agricultural lands to supplement the world food supply.

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