U.S. Transportation Research Board (TRB) Meeting
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"Transporting Freight Containers by Pneumatic Capsule Pipeline (PCP): Port Security and Other Issues"

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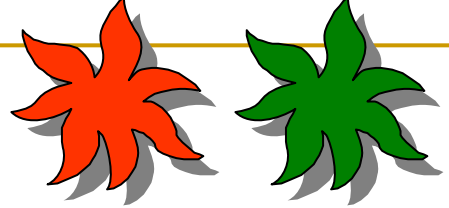


Dual Purpose of this Presentation:

1. Introduce the new technology of PCP to transportation planners and providers for consideration for possible use in future freight transport projects.
2. Discuss the feasibility and potential advantages of using large PCPs for transporting containers at seaports.

What is pneumatic capsule pipeline (PCP)?

PCP is the transport of materials or freight by capsules (i.e., containers or vehicles) propelled by air moving through a pipeline or conduit.

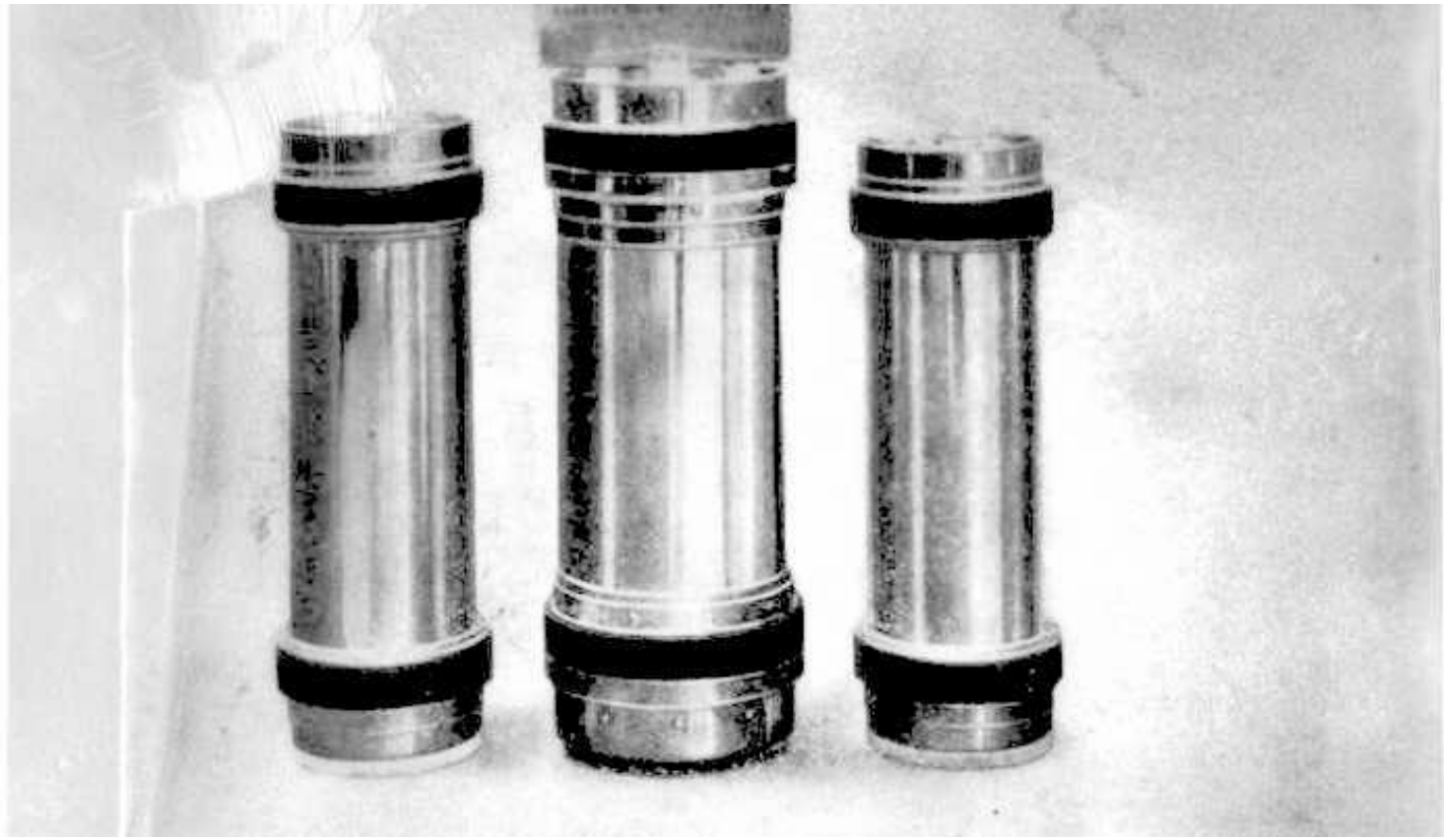
Two types of PCP:

1. Type I: Use non-wheeled capsules
2. Type II: Use capsules having wheels

Type 1 : No wheel

1. Because no wheels are used for capsules, the contact friction between the capsule and the pipe is high. Thus, Type 1 can only be used for lightweight cargo in small-diameter pipe – generally less than 1 ft.
2. It is a century-old technology improved and still being used today.
3. Examples of Applications: mail, drive-in bank, and large building complex such as hospitals, air terminal, and factories.

Use of non-wheeled PCP for transporting letters and parcels in USA (1900 – 1950 approximately)



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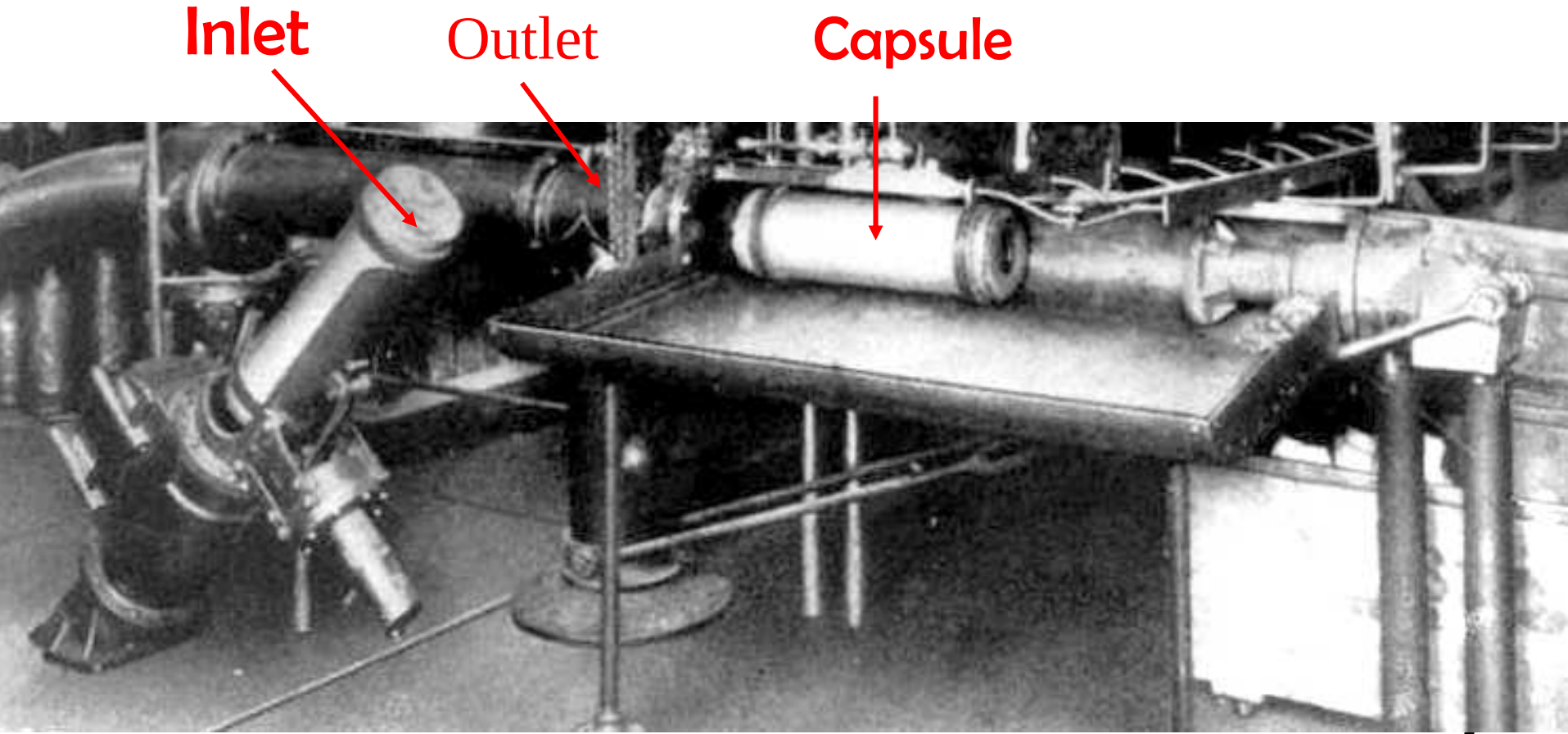

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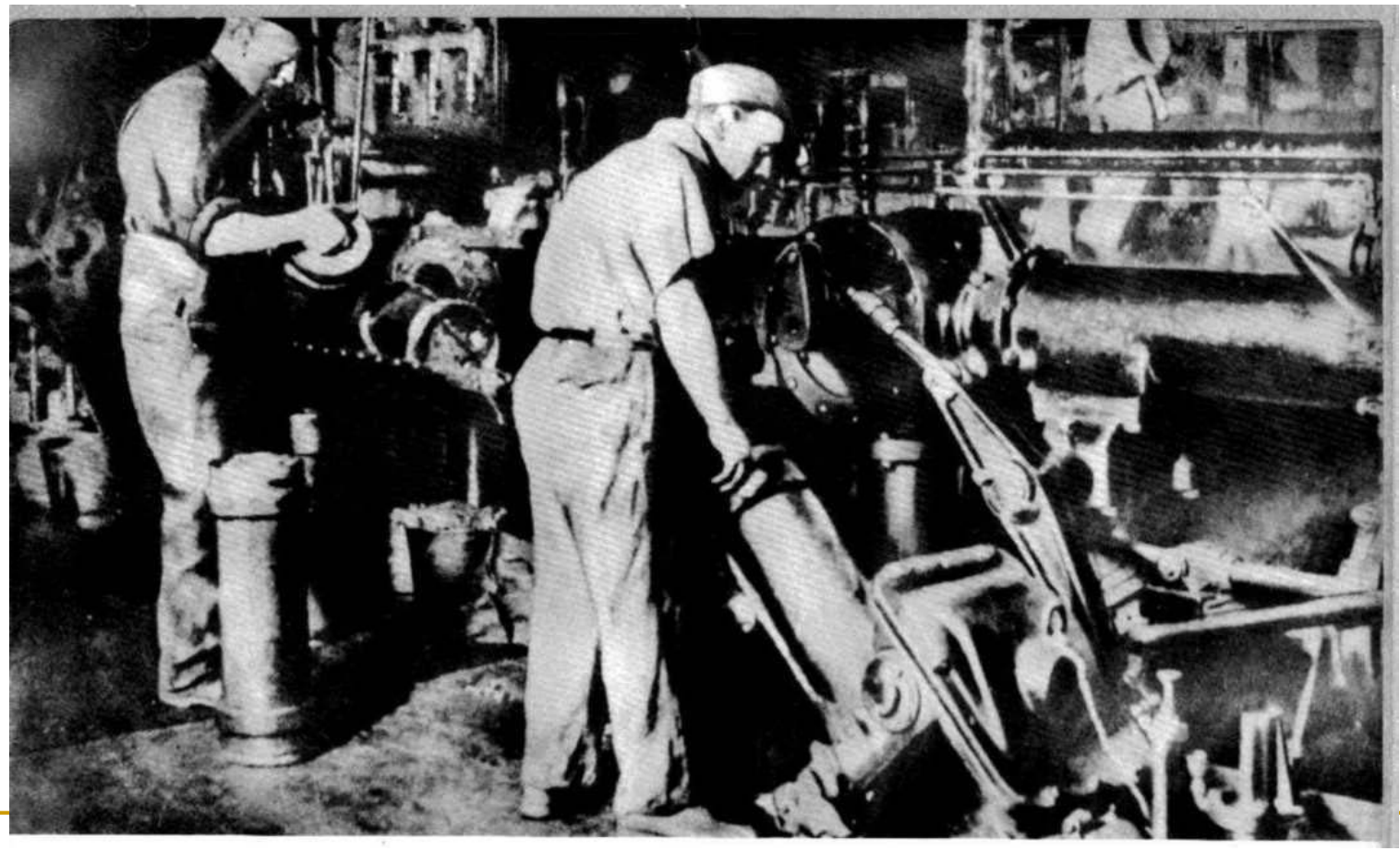


Current use of non-wheeled PCP in Hospitals

Current use of non-wheeled PCP in factories (BMW plant in Germany)

Type 2 : Use wheels

1. Due to use of wheels, friction between capsule and pipe is low. Therefore, heavy cargo can be carried by large capsules,
2 Type 2 can be used for any size of pipe or rectangular conduit – generally larger than 1 m (3.28 ft).

Why larger than 1 meter in size?

1. So that it can compete economically with truck
2. So that a person can enter the pipe or conduit whenever needed.

Type 2 : Wheeled PCP

Saliant Features:

1. Such a system was first developed in USA in 1970s, but it was never used commercially.
2. Canada and UK also developed such a system but was not used.
3. In 1970s, the Former Soviet Union developed and used such a system (1 m diameter pipe about 20 km length) to transport rock, but the system was abandoned years later due to unknown reasons.
3. Japan is the only country that has had successful commercial use, and still uses such a system to its advantage.

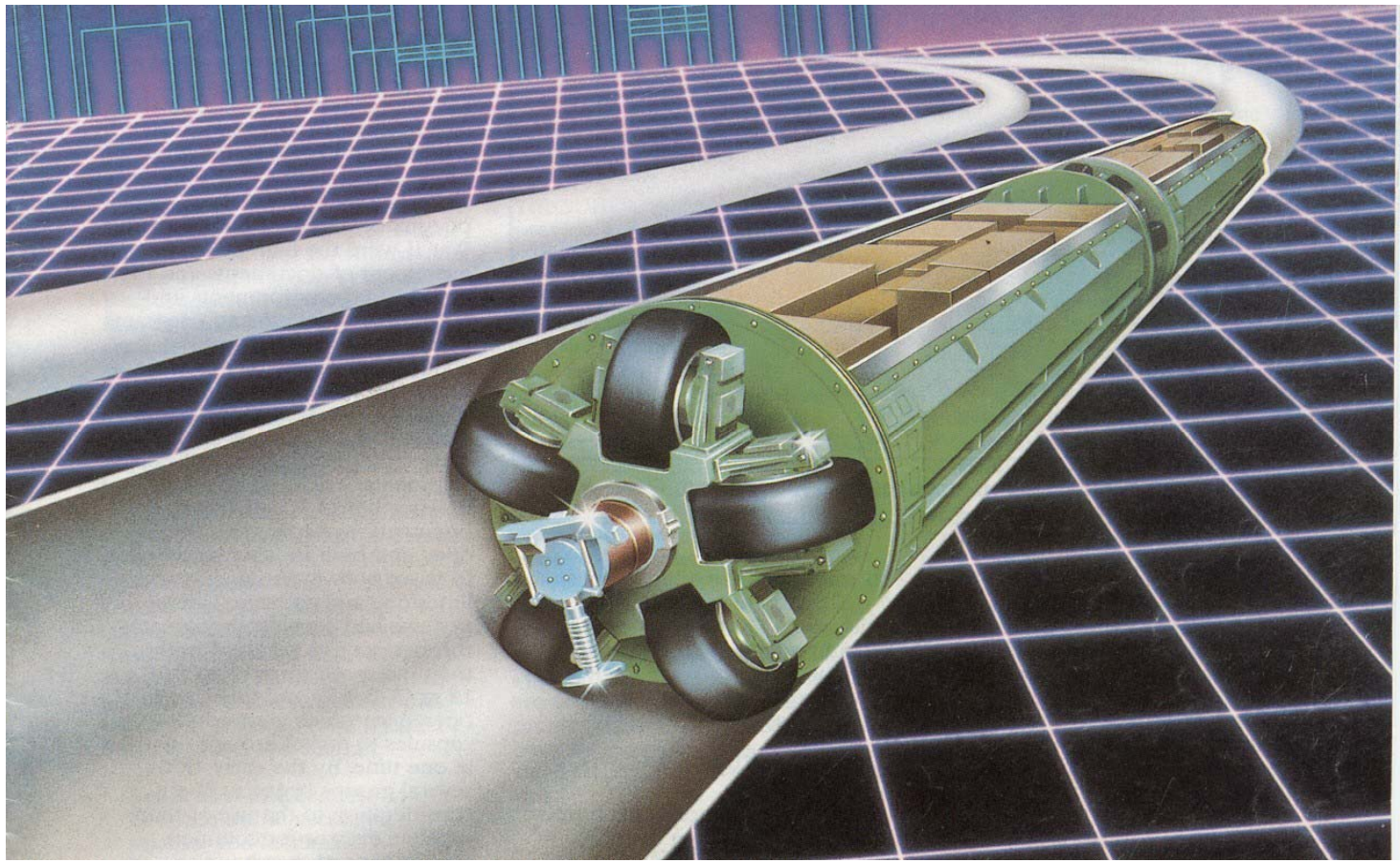
Successful Applications of PCP in Japan

1. Transport of Lime to Cement Plant
2. Use of PCP for constructing tunnels
3. Use of PCP for highway construction
4. Use of PCP for solid waste transport/disposal

Two Types of PCP used Successfully in Japan:

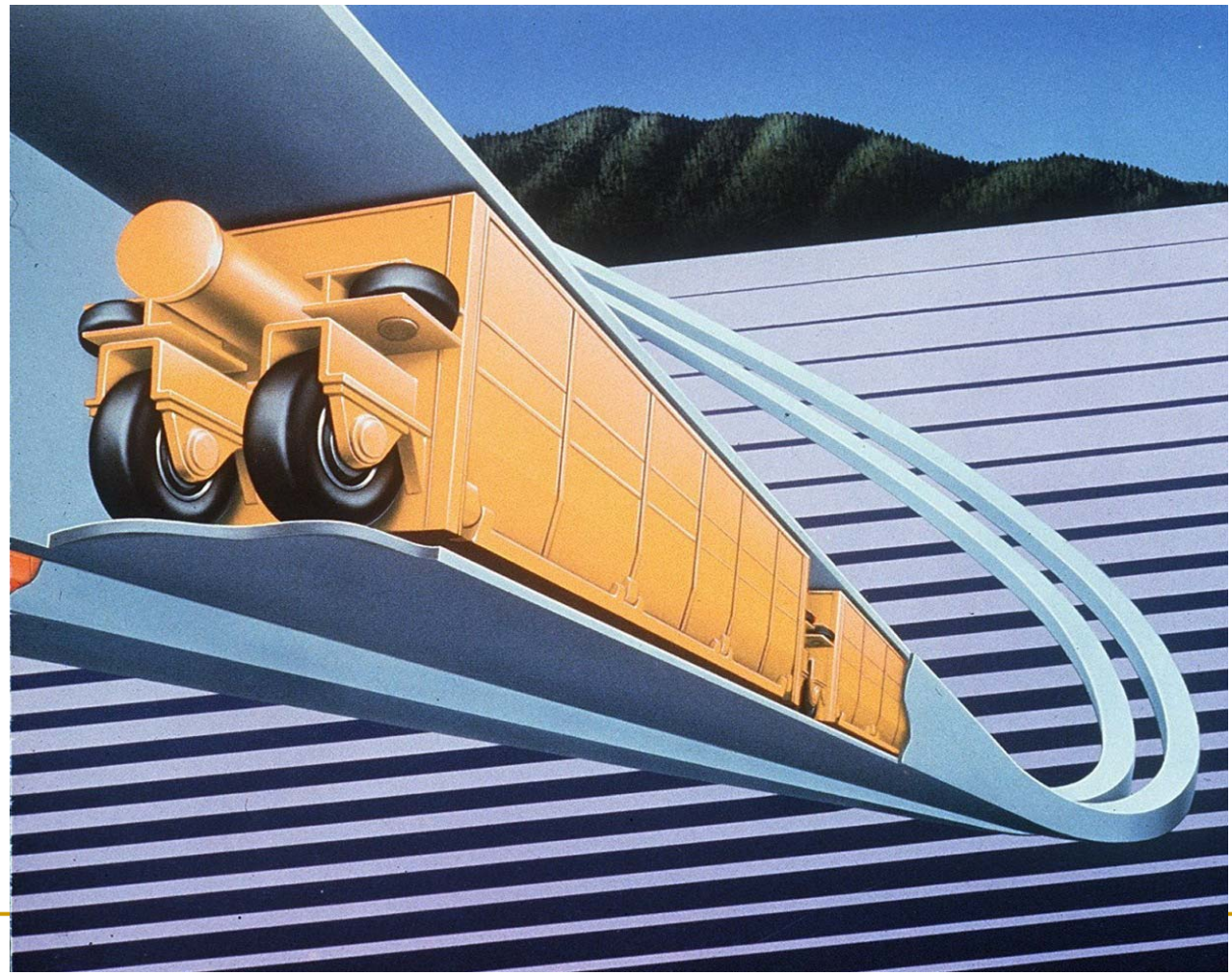
1. **Round (cylindrical) PCP**
2. **Rectangular PCP**

Round (Cylindrical) PCP:
Round Capsule in Round Pipe



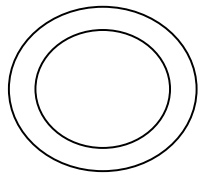
Rectangular PCP:

Rectangular Capsule in Rectangular Pipe



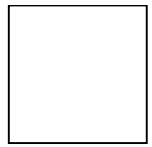
Comparing PCP of Different Cross-Sectional Shapes: Circle versus Rectangle (or Square)

Advantages of Circular Pipe:



1. Can withstand high internal pressure.
2. Lower construction cost when pipe is less than about 4 ft, which allows the use of commercially available steel pipes.

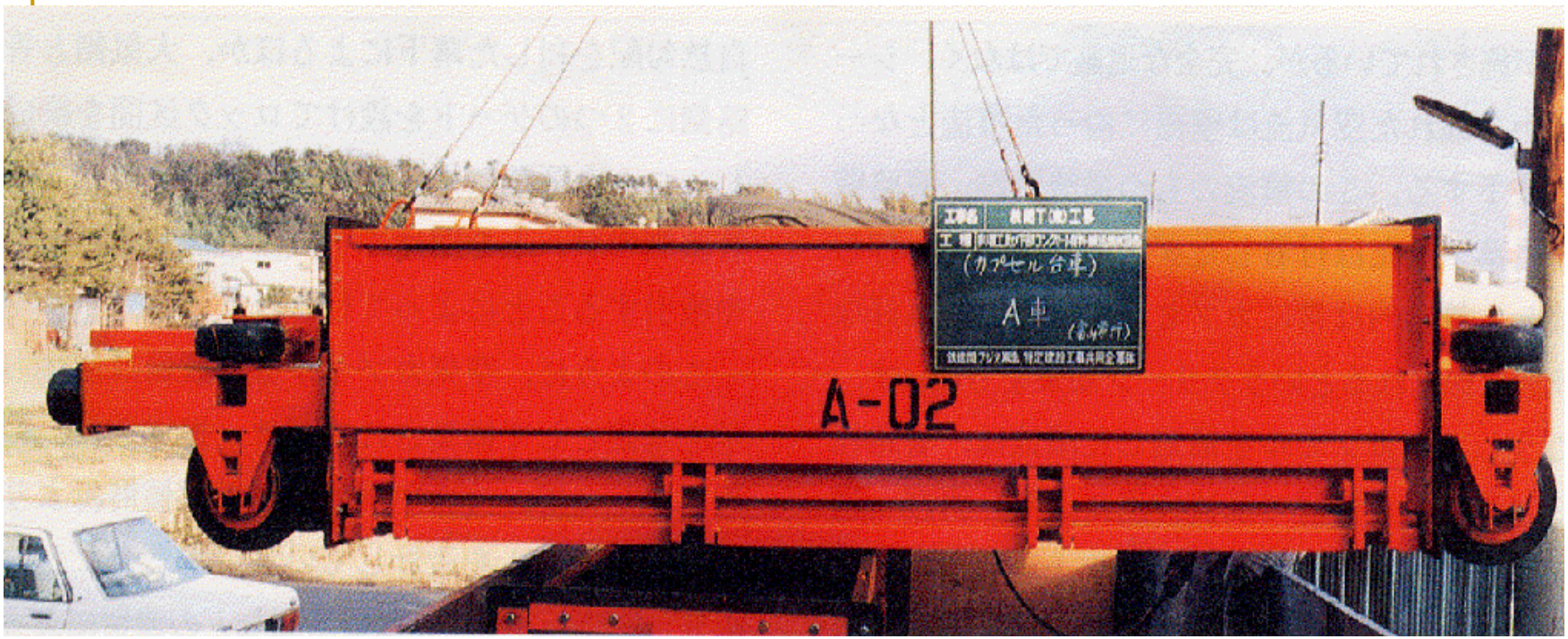
Comparing PCP of Different Cross-Sectional Shapes: Circle versus Rectangle (or Square)

- **Advantage of Rectangular or Squared Pipe:** 

1. **More compatible with cargoes in boxes, crates and pallets.**
2. **Capsules can use bottom wheels—Cost less and wear less; can use conventional automobile wheels.**
3. **Can go high speed without tire failure (30 m/s).**
4. **Large rectangular underground conduits can be constructed *in situ* with reinforced concrete, using the same technology that builds large concrete canals. This greatly reduces pipeline construction cost.**

The intake of PCP in Kuzuu, Japan for limestone transport

The rotary loader for loading limestone into capsules at pipeline intake of the PCP project in Kuzuu, Japan



Capsules of rectangular cross section used in the Akima tunnel project in Japan

Akima tunnel project in Japan during construction

1m x 1m cross-section pre-stressed concrete conduit leading to the Akima tunnel in Japan during construction

Outlet of the PCP used in constructing Akima tunnel in Japan. Excavated materials (spoils) are transported by the same pipeline to the dump site for landfill.

Question: Are there major differences between PCP and running a self-propelled vehicle such as an automobile or train through a pipe or conduit?

Answer: Yes! There is huge differences.

What are the differences?

Differences between PCP and self-propelled-vehicles-in-tube (SPVT) systems

1. **The capsules in PCP have no propulsion system; they are passive vehicles propelled by the air moving through the tube. In contrast, each SPVT vehicle or train of vehicles must contain a motor or engine in order to propel.**

Differences between PCP and self-propelled-vehicles-in-tube (SPVT) systems (continued):

2. For PCP, energy transfer is from air to capsules; for SPVT energy transfer is from vehicles to the surrounding air. Due to this difference, maximum energy transfer from air to capsule is desirable for PCP. This is accomplished by using capsules that have maximum drag coefficient, so that capsules can move at almost the same velocity as that of the air in the tube. This explains why streamlining capsules is counter-productive. Capsules are normally fitted with seal plates (end discs) to increase their drag coefficient.

Differences between PCP and self-propelled-vehicles-in-tube (SPVT) systems (continued):

3. In contrast, for SPVT the drag coefficient of the vehicles should be kept as small as possible, so that there is minimum energy transfer from the vehicles to the surrounding air. To accomplish that, the vehicles moving in tubes should be streamlined to have minimum drag. Also, the tube should have much larger diameter than the vehicle diameter to minimize drag.

Differences between PCP and self-propelled-vehicles-in-tube (SPVT) systems (continued):

4. Due to the foregoing differences, for capsules or vehicles of a given size, the tube diameter required for PCP is much smaller than that required by SPVT systems. This not only reduces construction cost but also makes construction easier.

Differences between PCP and self-propelled-vehicles-in-tube (SPVT) systems (continued):

5. The fact that capsules in PCP need no propulsion system such as motors or engine on each vehicle also reduces the system cost.

Differences between PCP and self-propelled-vehicles-in-tube (SPVT) systems (continued):

6. Generally, a PCP system is less costly than an SPVT system that has the same transportation capacity, unless the throughput of the system is small (i.e., when there is only a small number of vehicles moving through the tube). Under such condition, both PCP and SPVT cannot compete with trucks for freight transport.

Differences between PCP and self-propelled-vehicles-in-tube (SPVT) systems (continued):

7. The electric car based tube transport system developed in Delft, the Netherlands, and the electric train based "Cargo-Cap" system developed in Germany are both SPVT systems. They are not PCPs and hence don't have the low-cost advantage of PCP.

Large PCP Systems Considered for Underground Freight Transport in New York City

- Sponsored by the NYSERDA (New York State Energy Research and Development Authority), a study was completed in 2004 on determining the technical and economic feasibility of using large PCP systems for underground freight transport in New York City.
- The study examined 6 different potential applications.
- It found that all 6 cases are technically feasible using current technology, and that 5 of the 6 cases are also cost-effective.

Underground Freight Transport in New York City

Cost-effective applications of PCP:

1. Tunnel constructions
2. Solid waste disposal
3. Mail and parcel transport
4. Pallet-goods delivery system
5. Container transport

Key Reference:

Detailed analysis, including cost analysis, of each of the applications of PCP in New York City is given in the following report:

- **"Feasibility of Underground Pneumatic Freight Transport in New York City," Final Report submitted to the New York State Energy Research and Development Authority (NYSERDA), August 2004, 92 pages.**

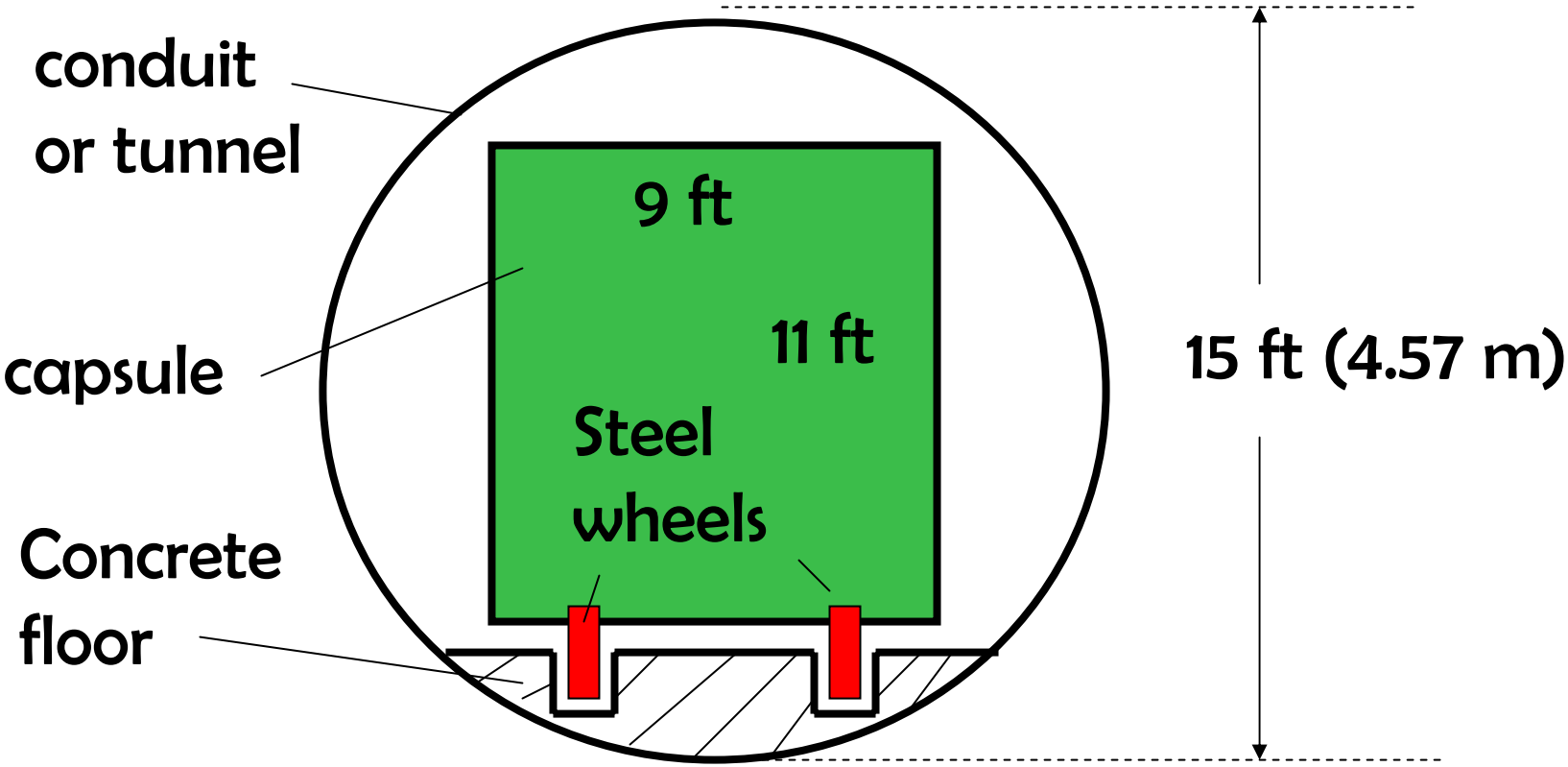
(Note: This report can be read and downloaded free of charge from the "Company Publications and Patents" section of www.freightpipelinecompany.com)

Application of PCP for transporting containers

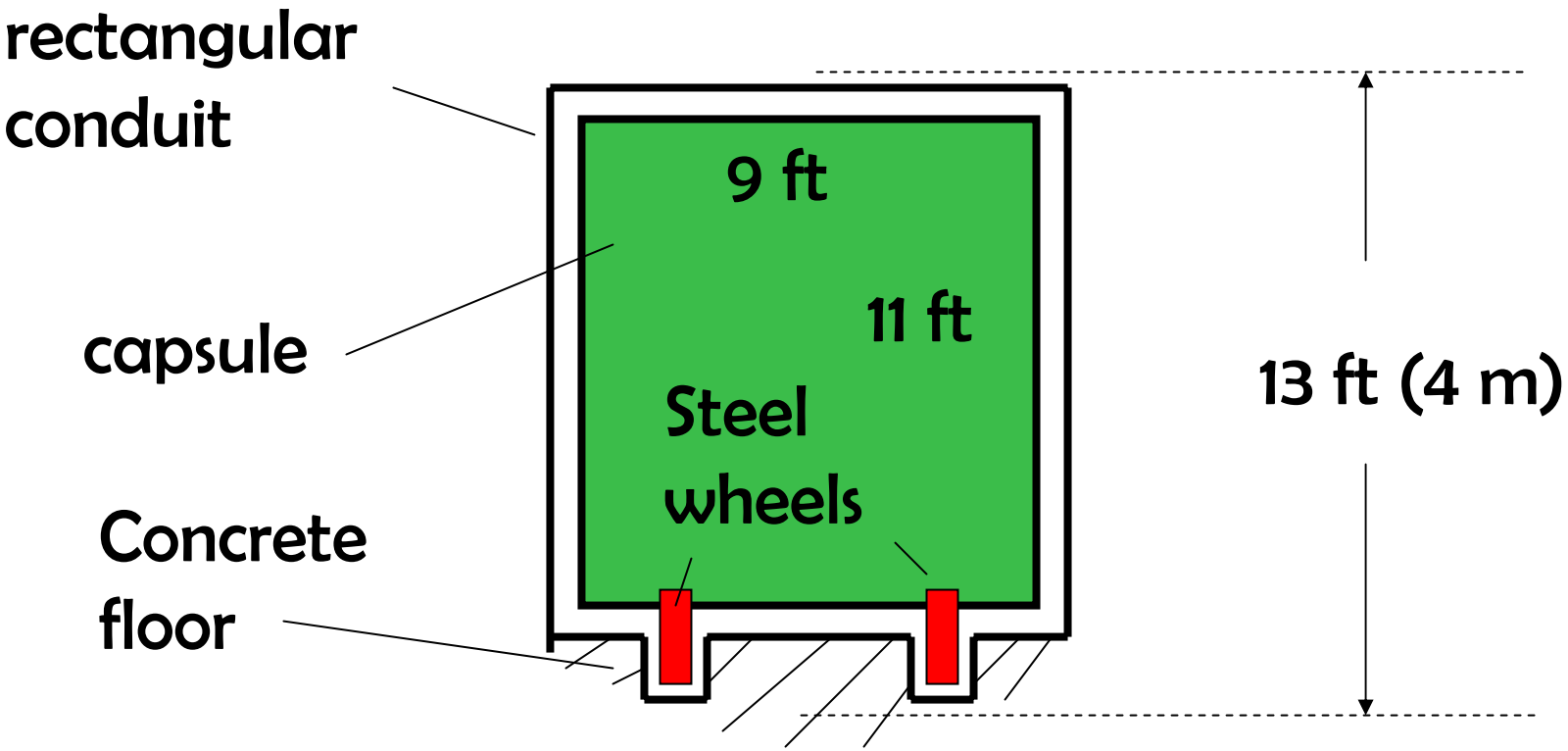
Standard Container:

1 Standard container = 2 TEU (**T**wenty-foot **E**quivalent **U**nit)

Round conduit/tunnel used for container-PCP (Dimensions):



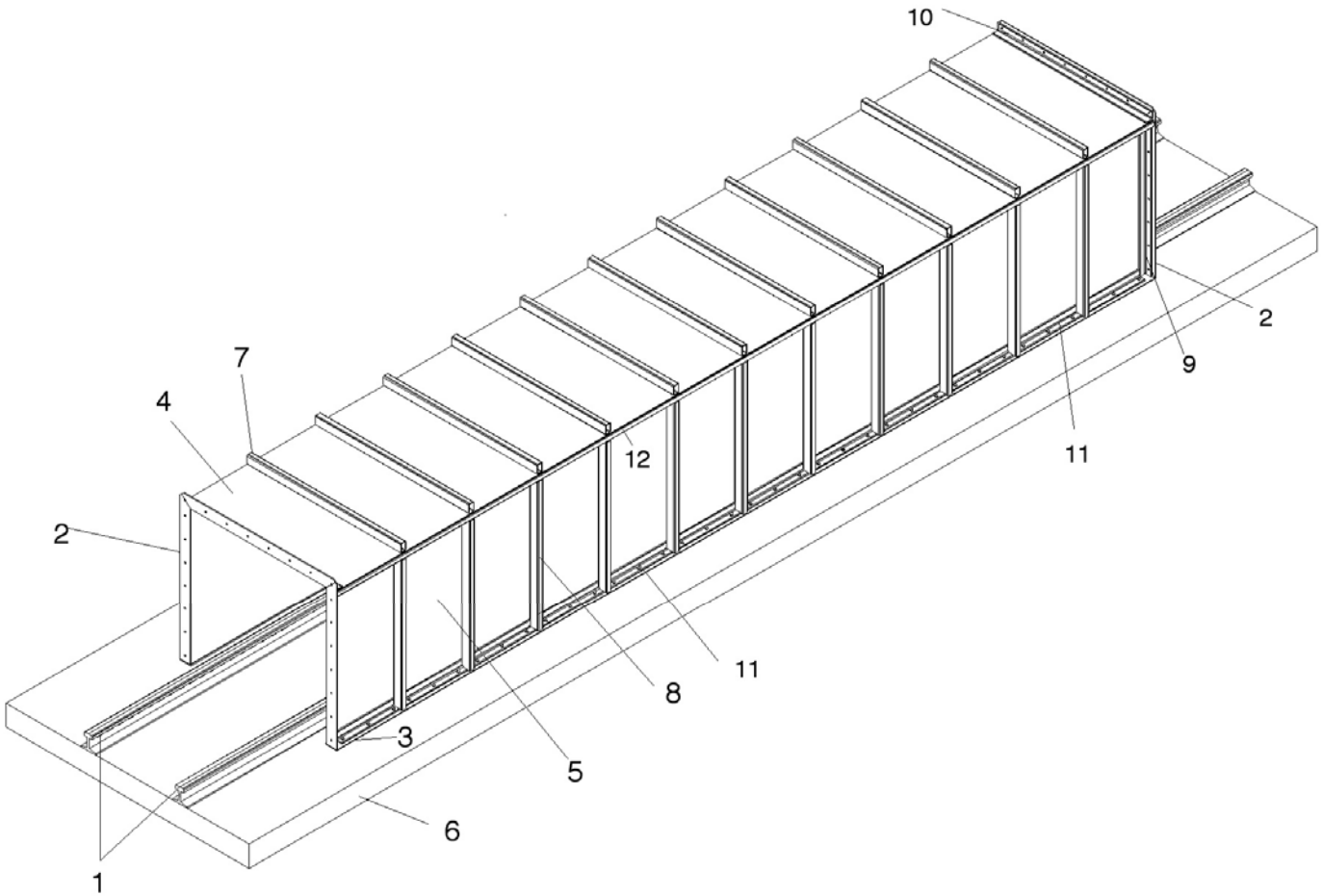
Rectangular conduit used for Container-PCP (Dimensions):



When to use rectangular- or round-conduit PCP ?

1. Use rectangular cross-section for PCP conduits that are above ground or buried near ground surface to facilitate construction and minimize cost.
2. Use round (circular) cross-section for PCP conduits deep underground or underwater where the earth pressure or water pressure is high.
3. Use round (circular) cross-section for PCP tunneled underground or under sea floors using modern TBM (Tunnel Boring Machine).

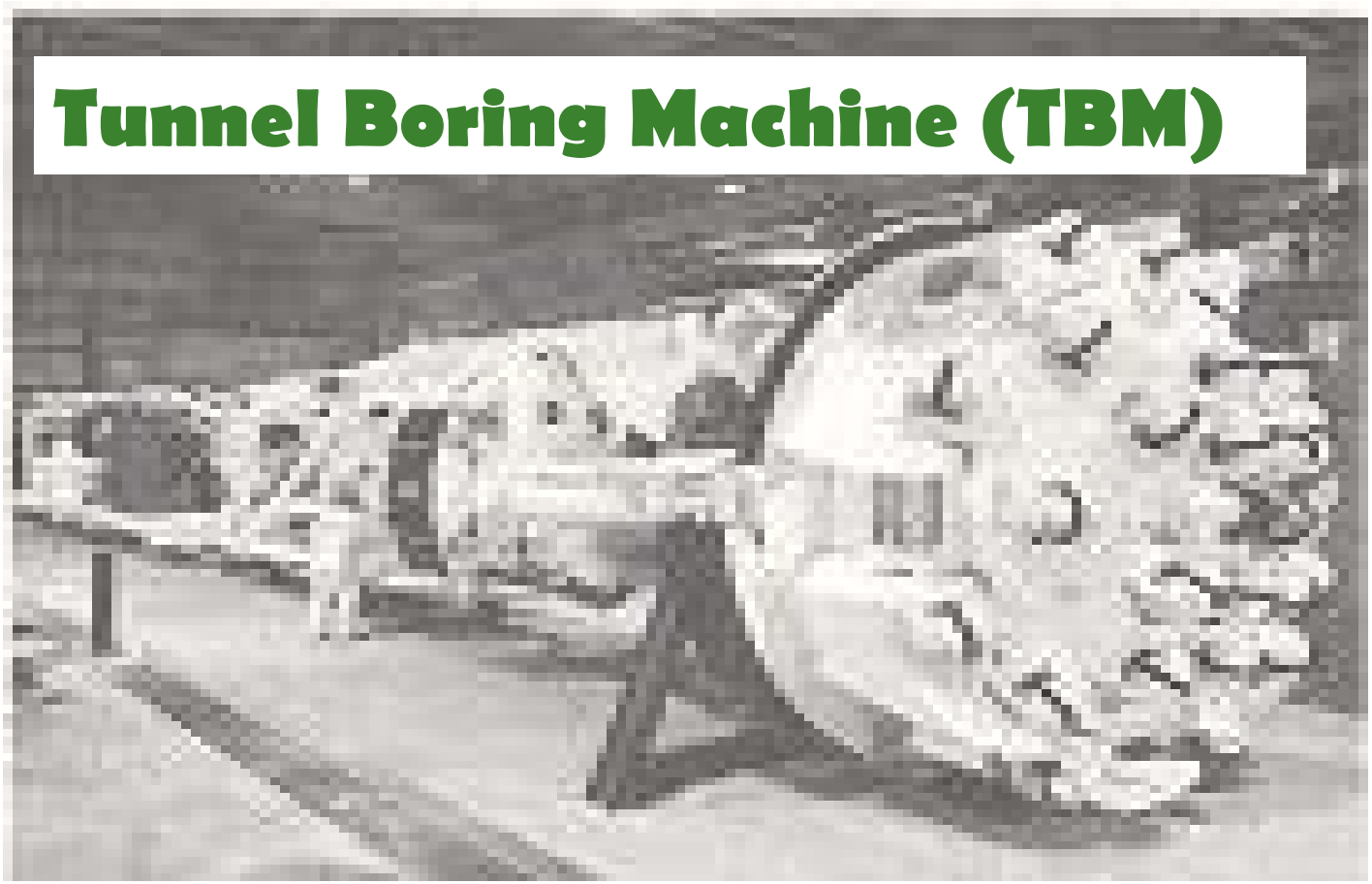
Use rectangular PCP for aboveground construction:



Use rectangular PCP for shallow underground construction:

Use round pipes for PCP buried deep underground :

Use round tunnel for PCP under urban areas, under sea floors, or under river beds :



Rail-based PCPs

Using capsules with steel wheels rolling inside steel rails has the following advatages:

1. **Energy conservation – wheel friction is 5 to 10 times less than for wheels with rubber tires.**
2. **Restrict lateral motion of capsules; no contact friction with side walls.**
3. **More wear-resistant than rubber tires, and hence reduces maintenance cost.**
4. **Easy to control at branching point and in terminals, where railroad switching and control equipment can be used.**
5. **Can go at higher speed without damage to wheels.**

Rail-based Capsule for PCP

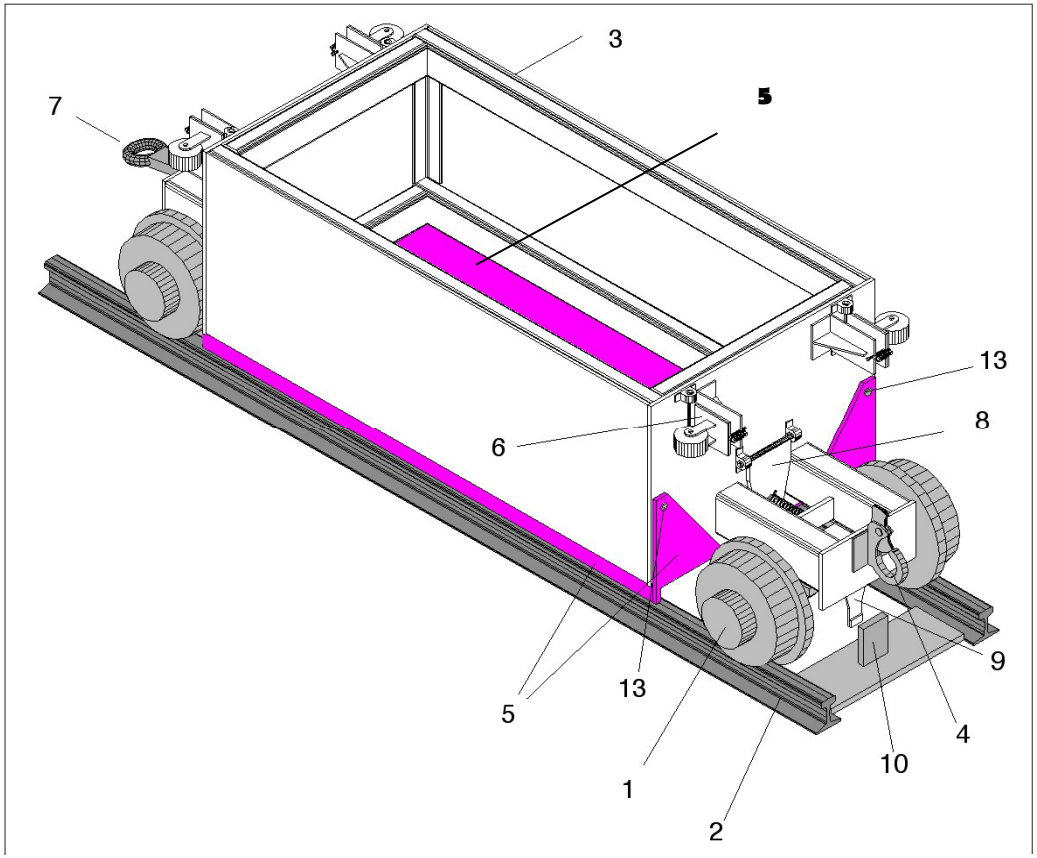
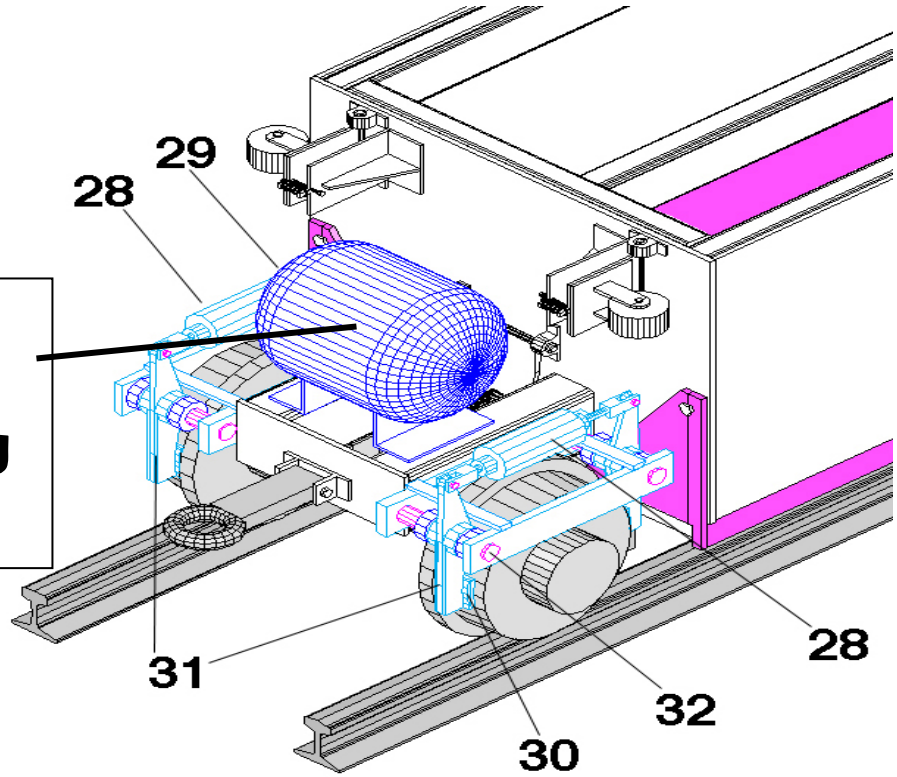


Figure 2.3.1 Capsule design (front 3-D siometric view)

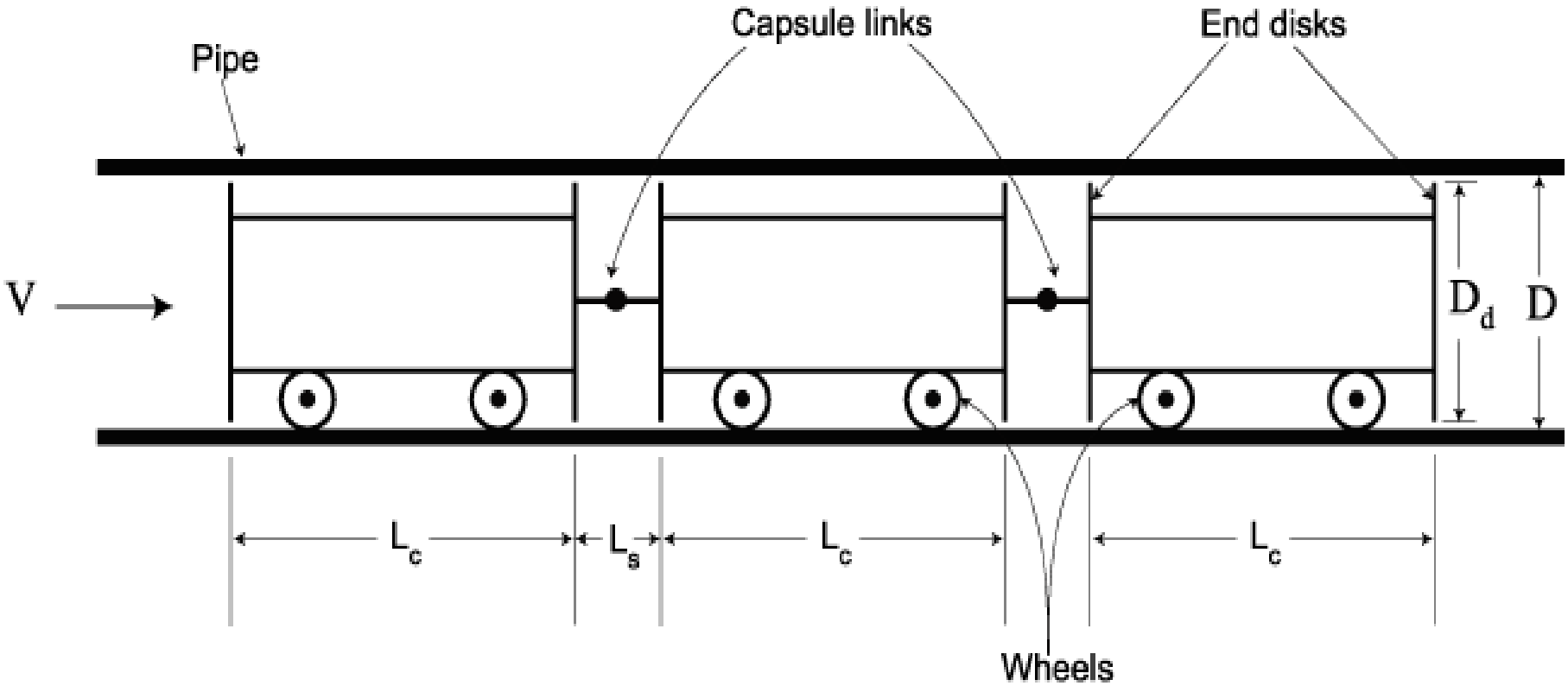
1. Wheel
2. Rail
3. Box
4. Latch (for capsule linkage)
5. Gate
6. Guide wheel assembly
7. Drawbar (to match latch)
8. Front latch assembly (for bottom gates)
9. Trigger
10. Front barrier plate
11. Rear latch assembly
13. Gate hinge

Rail-based Capsule for PCP (An end-view)

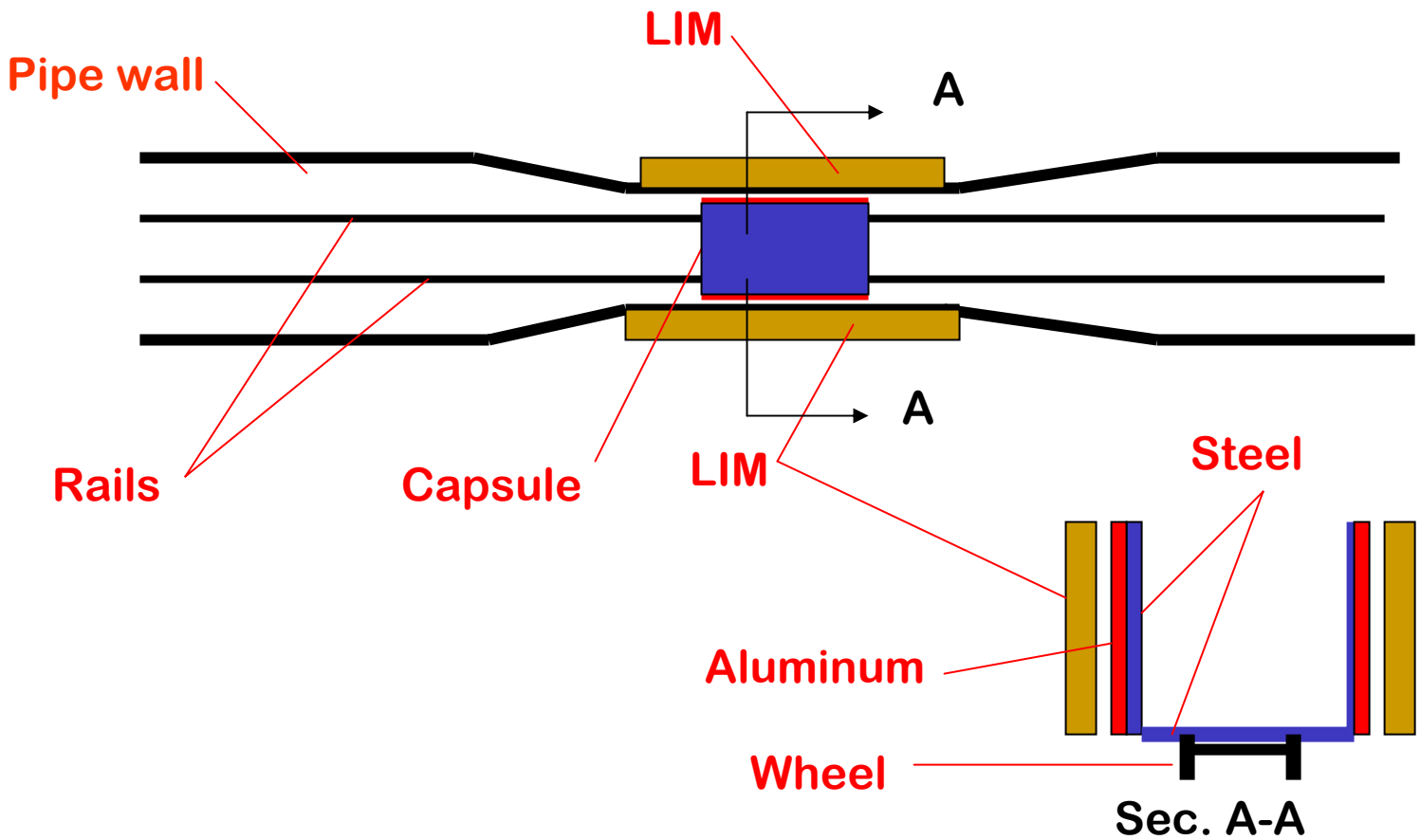
Compressed air tank for braking and control



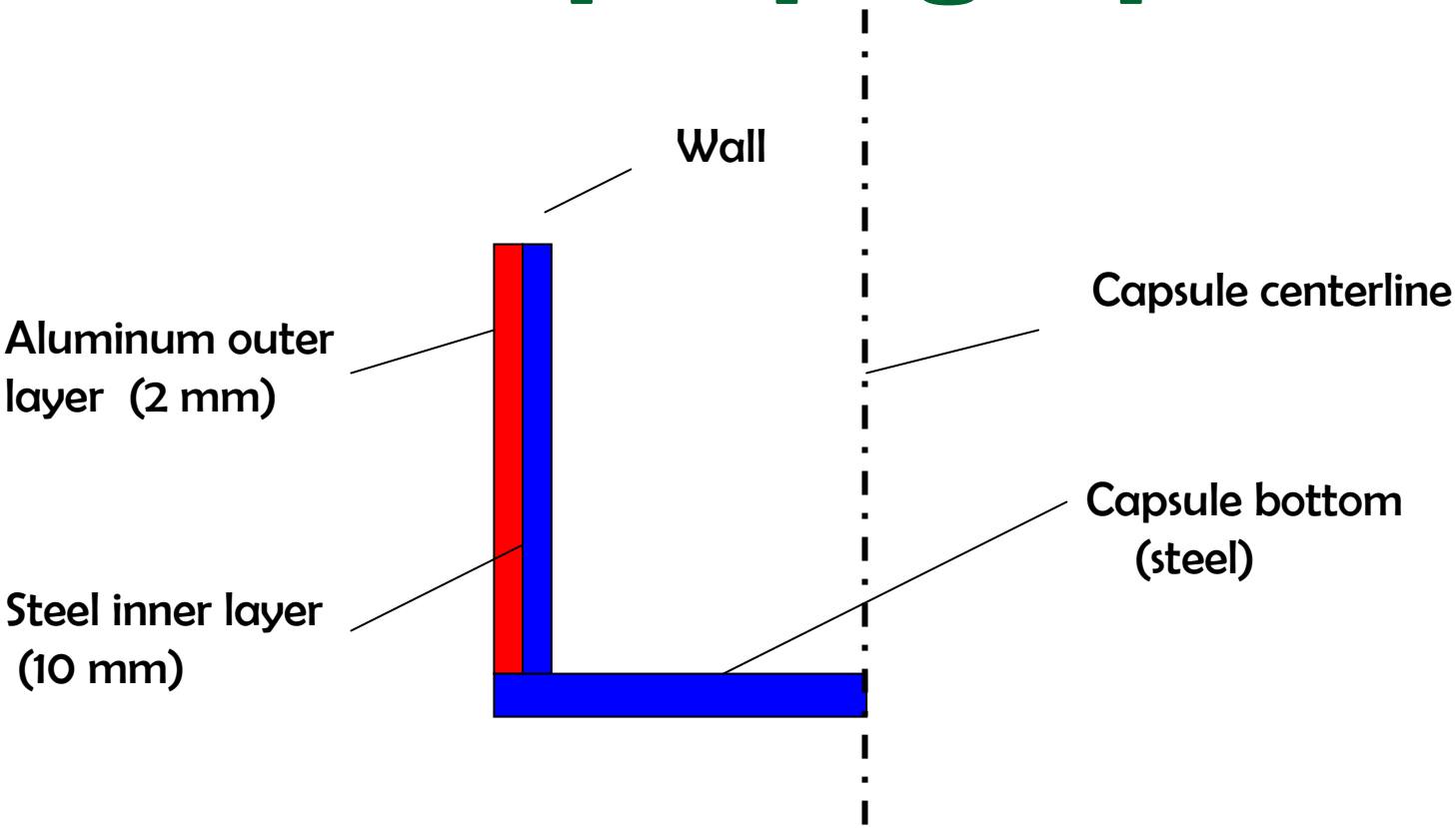
Capsule linkage and seal plates (end discs)



Linear Induction Motor (LIM) for Use as capsule pump



Capsule wall configuration when Linear Induction Motor (LIM) is used for pumping capsules

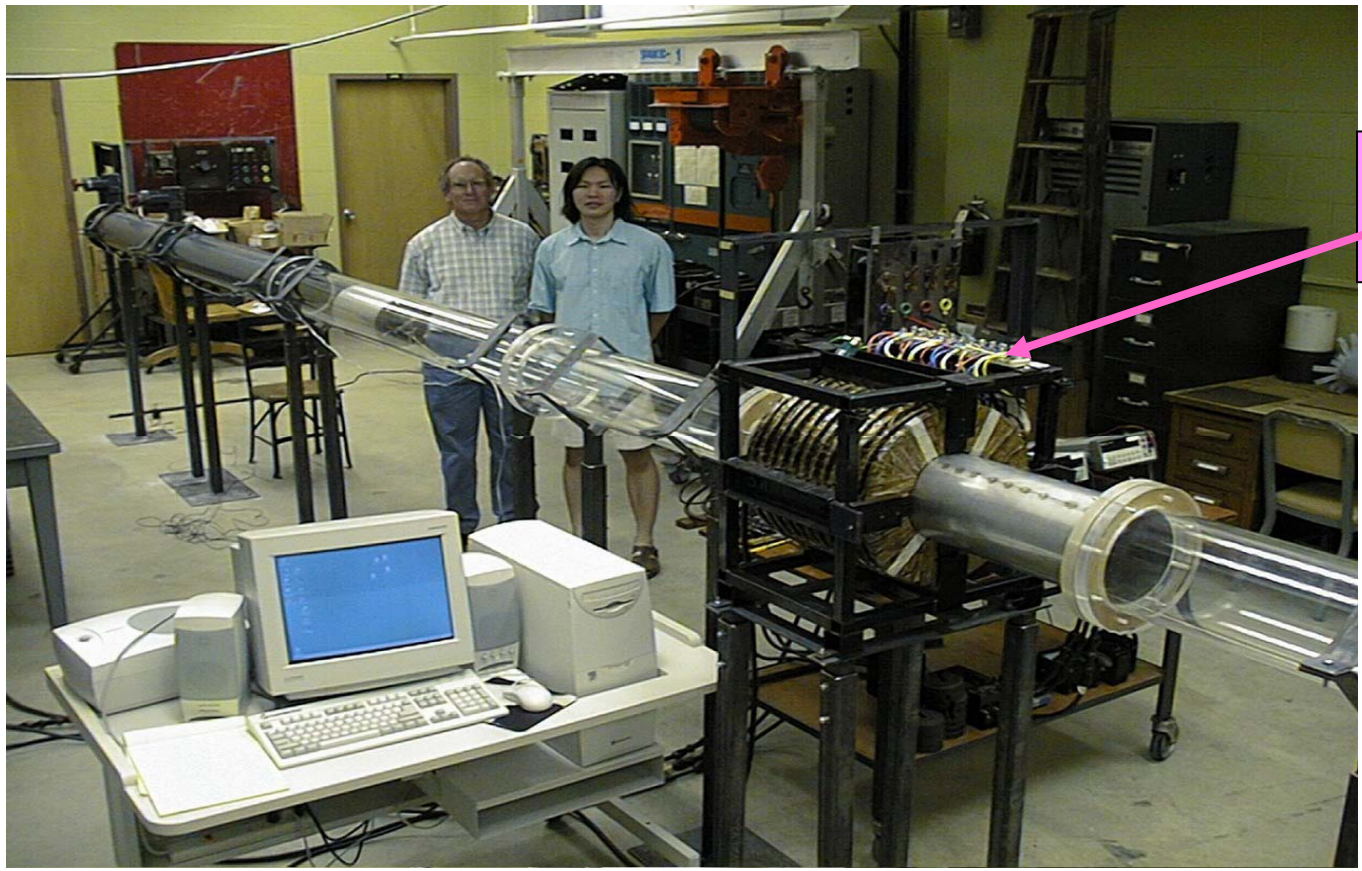


Linear Induction Motor (LIM) for Use as capsule pump

Advantages:

1. Non-intrusive pump that allows capsules to pass through.
2. Simple in design, construction and operation.
3. Low cost
4. Can have high efficiency (>90%) when properly designed.

Linear Induction Motor (LIM) tested at University of Missouri Power Electronic Lab



State-of-the-art in PCP-LIM

- PCP LIM has been studied and tested expensively at University of Missouri-Columbia (UMC).
- Design equations have been derived and analyzed in a DOE project conducted by Freight Pipeline Company in 2005. (See next slide.)
- Efficient PCP-LIMs can be designed using current state-of-the-art.

"An Electromagnetic Pneumo Capsule System for Conveying Minerals and Mine Wastes"

Final Report

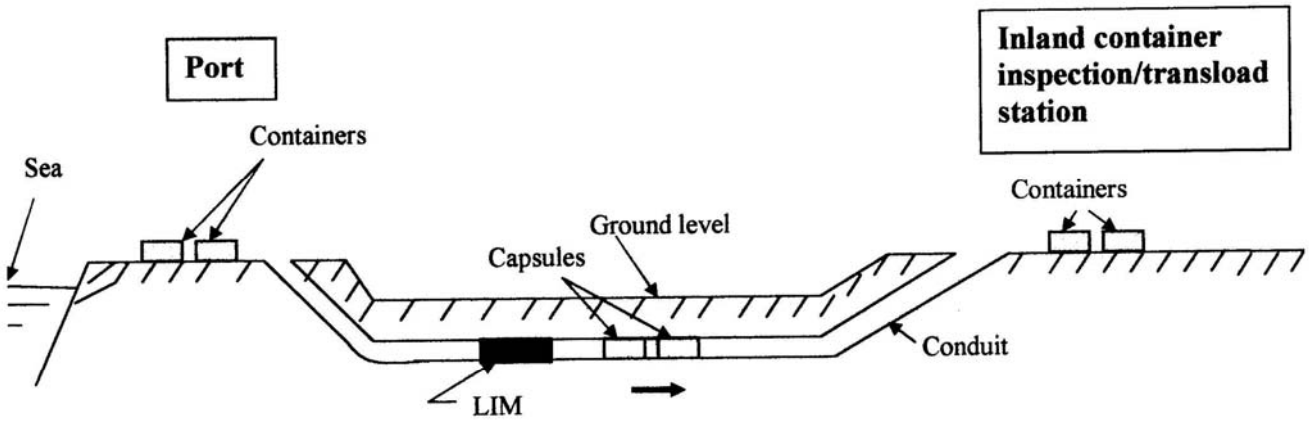
Henry Liu and Charles W. Lenau
Freight Pipeline Company
2601 Maguire Blvd.
Columbia, Missouri 65201

March 1, 2005

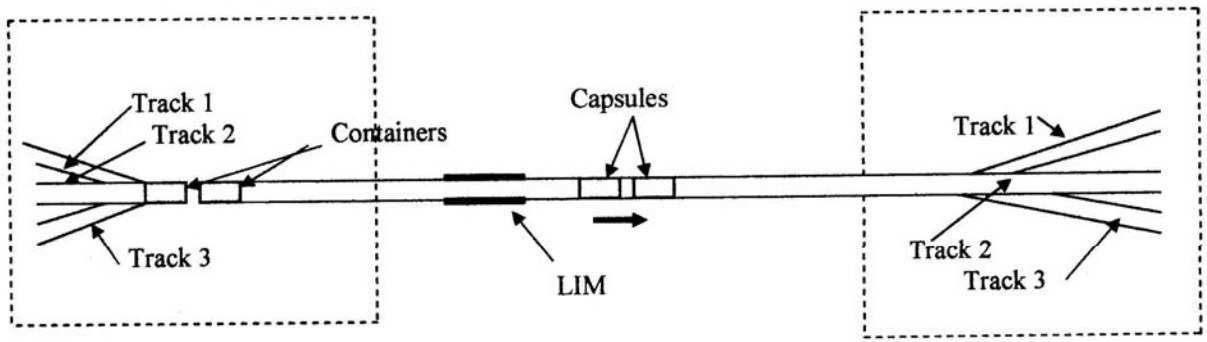
DOE Award No.: DE-FG26-03NT41928
Project Duration: 09/30/03 - 12/31/04
Project sponsored by the U. S. Department of Energy under program "Ground Breaking Innovative Technology Concepts for Mining"

(This report can be downloaded free from the "Company Publications & Patent" section of www.freightpipelinecompany.com)

General layout of a PCP system for dispatching containers from and to seaports



(a) System profile (side view)



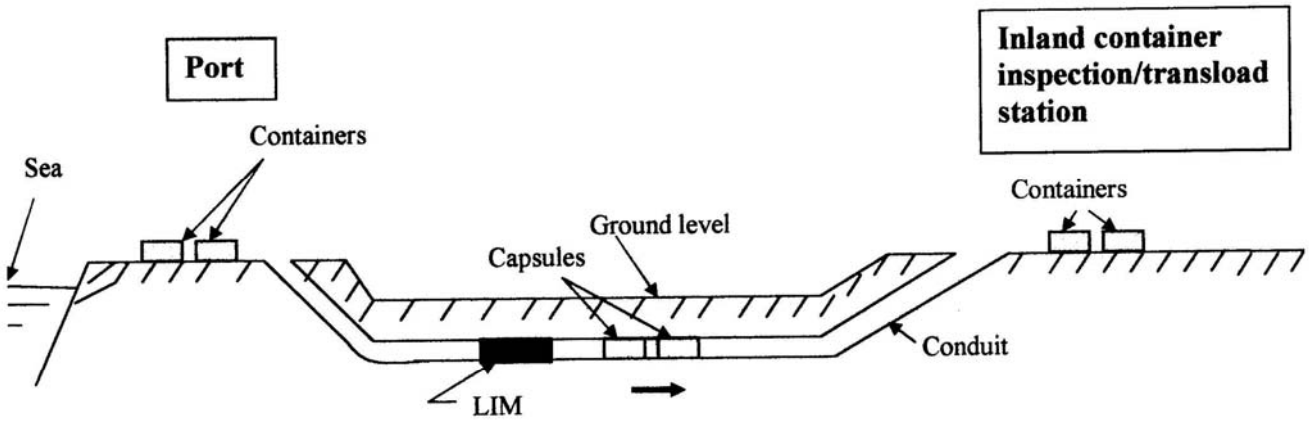
(b) System plan (top view)

Two types of inlet/outlet of PCP for dispatching containers at seaports

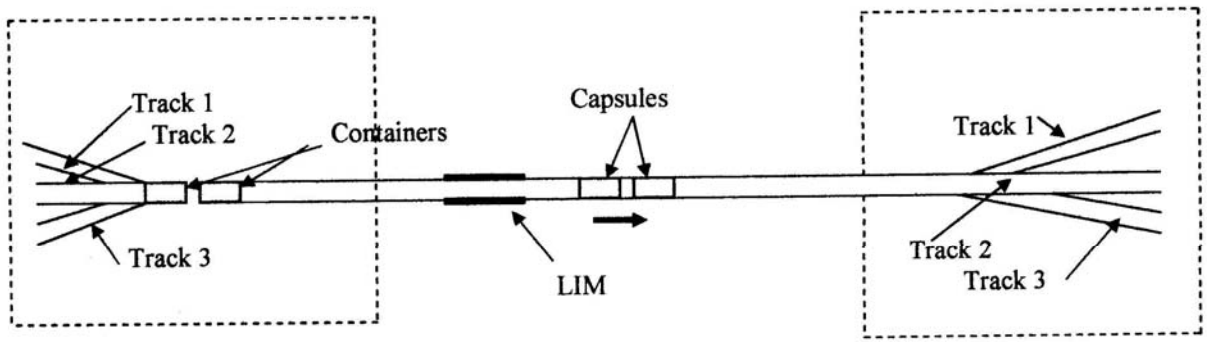
Type 1: Sloped inlet/outlet

Type 2: Vertical inlet/outlet

PCP for dispatching containers from and to seaports (sloped inlet/outlet)

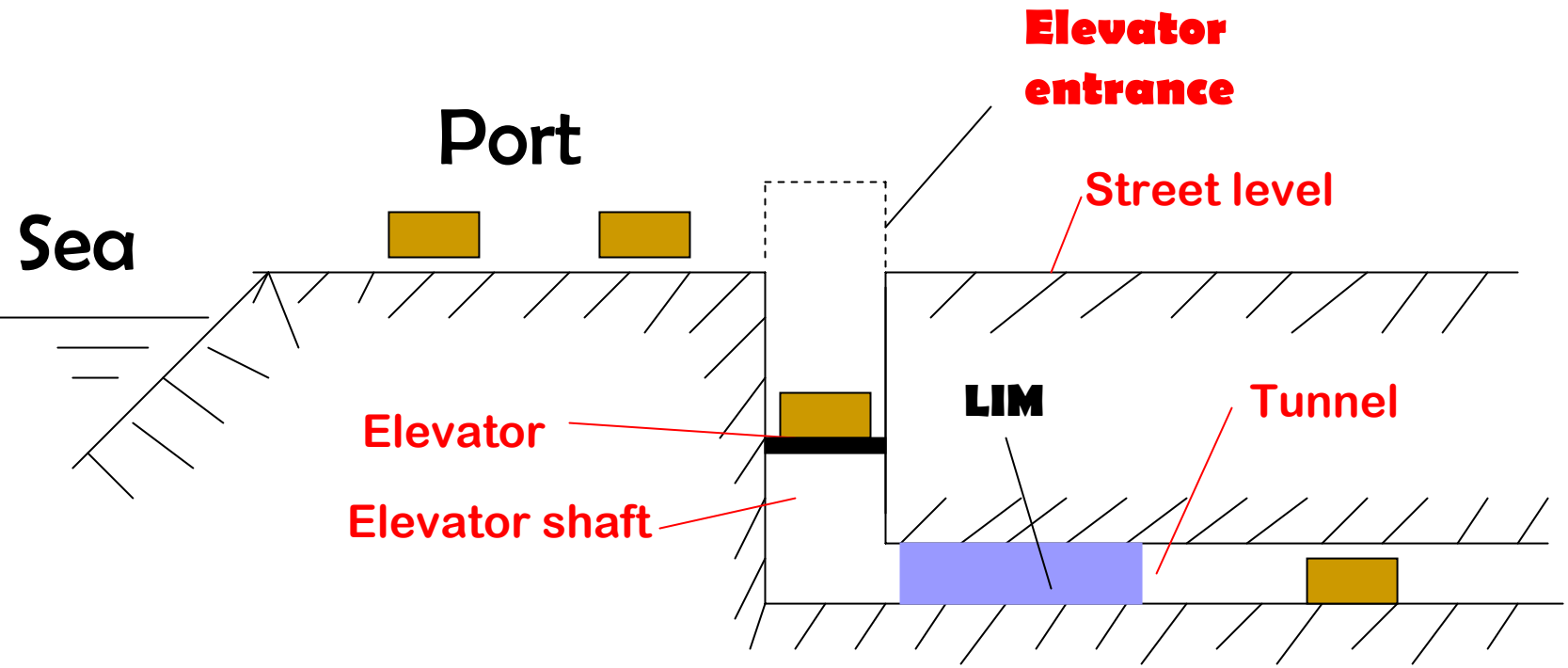


(a) System profile (side view)



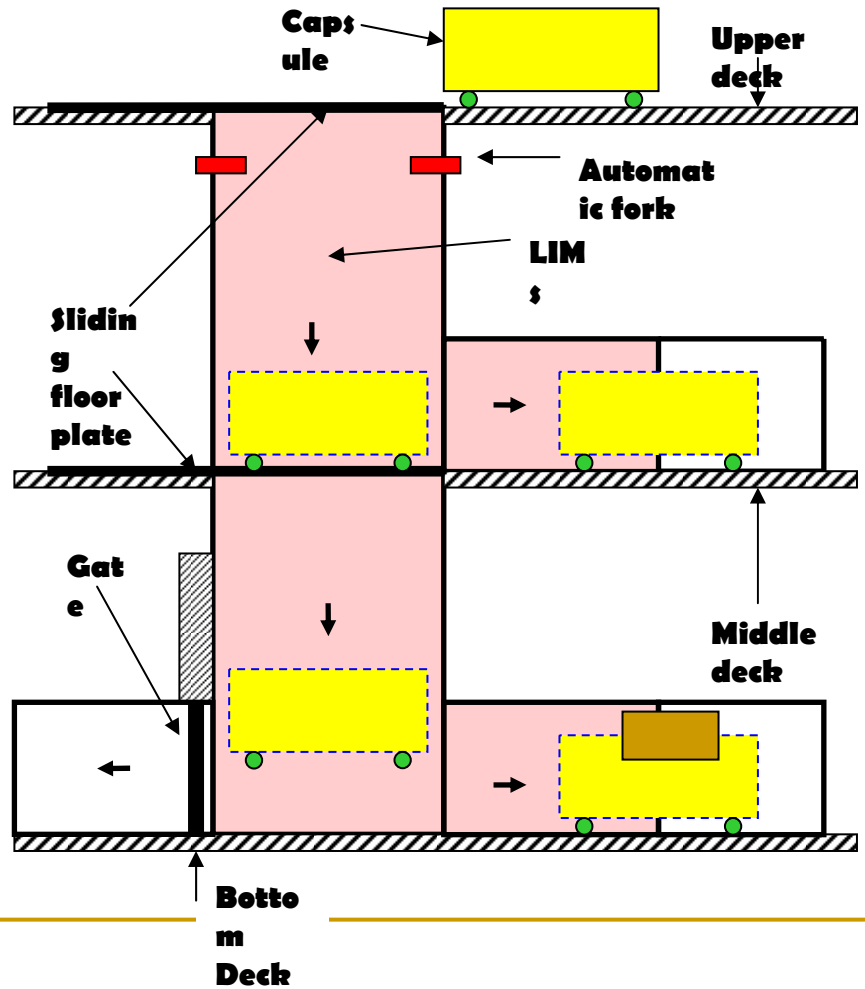
(b) System plan (top view)

Vertical entrance/exit of PCP at seaport



Horizontal-to-vertical transport

of PCP capsules using LIMs instead of elevators



Capsule sensing and identification technologies

- Two types of capsule sensing/identification systems were assessed – the barcode and RFID (Radio Frequency Identification) system. The latter was found to be more appropriate for the large PCP systems to be used in New York City.

Dispatching Containers at New York City

- This is a PCP system designed for dispatching containers away from seaports to an inland place for inspection, storage and intermodal transport by trucks or train.
- The study was sponsored by NYSERDA, and completed in 2004.
- Such a system has many advantages including security enhancement and transforming seaports from a truck depot and container yard to a nice waterfront commercial spot for recreation.

Container Dispatch PCP

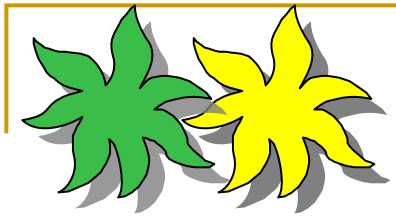
Engineering Analysis Results:

- The system for NYC harbor has four branches, each serving a container port in NYC or N.J.
- Twin conduits are used, so that containers can be moved simultaneously from and to the ports.
- The PCP consists of 21 miles (34 km) of circular tunnels constructed in bedrock, and 15 miles (24 km) of rectangular conduit near the surface in rural areas.
- Each capsule is designed to carry a 40-ft (12.2 m) container or two 20-foot equivalent units (TEUs).
- The system is driven by LIMs.

Container Dispatch PCP

Engineering Analysis Results (continued):

- The capsule velocity is 25 mph (40 km/h).
- The travel-through time is 34 minutes.
- Average injection time of capsules at each of the four ports is 23 seconds.
- The pressure drop along the PCP is approximately 23 psi (1.56 atm).
- The total power consumption of this system is about 141 mw.



Container Dispatch PCP

Economic Analysis Results:

- The total capital cost is 2.0 billion.
- The operation/maintenance cost is $312 million.
- Assumed economic life is 30 years.
- The unit cost is $17 for transporting a TEU over the distance of 24 miles (38.6 km).
- If the Port Authority of NY and NJ assesses a $30 fee per TEU, it can make an annual profit of $286 million when the system is operating at full capacity, and make an annual profit of $60 million at 50% capacity.

Advantages of using underground PCPs in cities:

1. Reduce the number of trucks that clog the City's streets.
2. Reduce air pollution, noise and accidents generated by trucks.
3. Economic development and creating jobs.
4. Increased safety and security.
5. More rapid delivery of goods than trucks can.
6. Greater reliability in delivering goods— unaffected by inclement weather, traffic jam and road/street repair.
7. Energy conservation – PCP uses much less energy than trucks do.
8. Reduce dependence on foreign oil.

Advantages in using PCP at ports for transporting containers:

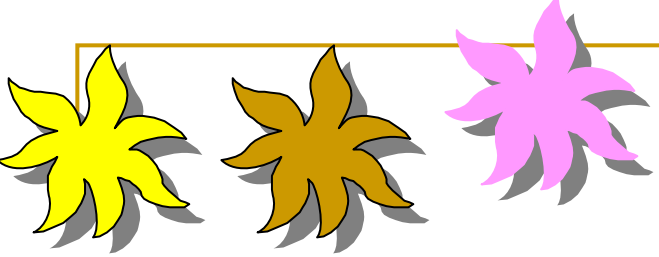
1. Enhancing port security.
2. Eliminating the use of trucks at ports, thereby turning ports from a large truck depot to a nice truck-free neighborhood.
3. Reducing air pollution, noise and accidents generated by trucks.

Conclusions:

- PCP is generally more cost-effective than SPVT systems due to the use of smaller diameter tubes and passive vehicles.

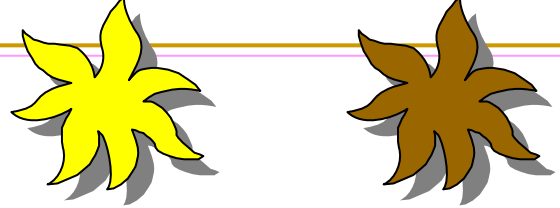
Conclusions:

- Great advancement in PCP technology has taken place in the last 30 years, enabling the use of large capsules (wheeled vehicles) to move freight through large-diameter pipes or conduits.
- Japan has successfully used such PCPs for transporting minerals, construction materials and solid wastes.



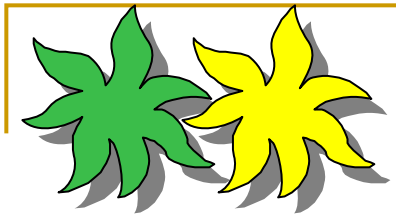
Conclusions (Continued):

- There are many potential applications of the modern PCP technology to Large Cities, such as for construction of tunnels, delivery of pallet goods, and dispatch of containers from and to harbors. In all such applications, freight is moved by capsules running through underground conduits or tunnels.



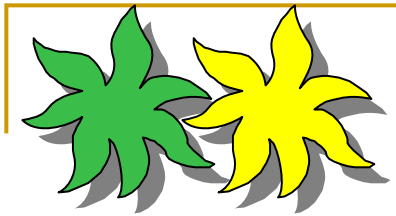
Conclusion (continued)

- The use of PCP for freight transport in large cities can play a significant role in reducing the need for using trucks for freight delivery. The cities will benefit in many ways, including reduction of traffic jams, accidents air pollution, and noise caused by trucks.



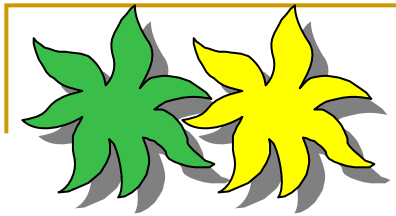
Conclusions (Continued):

- New technologies such as linear induction motor, digital computer, barcode and radio-frequency identification/sorting systems, and tunnel boring machine, have made it possible to construct and operate large, long and complex underground PCP systems.



Conclusions (Continued):

- PCP systems may use conduits of either rectangular or circular cross section, depending on individual circumstances.



Conclusions (Continued):

- A potential beneficial use of PCP is to transport containers from and to large seaports. Such use will greatly enhance port security, and benefit surrounding cities.
- R & D is needed to plan and design an optimal intermodal transport system for using PCP to move containers.

Last slide

Thank you!