

**Wrzecioniarz Piotr**

University Professor  
Instytut Inwentyki, CEO,  
Politechnika Wrocławska (em),  
Uniwersytet Przyrodniczy (em),  
Collegium Witelona  
piotr.wrzecioniarz@tvvpol.pl

**Mierzwa Karol**

Graduate of Wrocław University  
of Science and Technology  
karol.r.mierzwa@gmail.com

**Liškiewicz Dominik**

Graduate of Wrocław University  
of Science and Technology  
inz.domlis@gmail.com

**Pezowicz Piotr**

Dr  
Instytut Inwentyki  
info@tvvpol.pl

DOI: 10.35117/A\_ENG\_25\_07\_08\_09

**Concept of transportation system on the surface of the Moon and Mars**

**Abstract:** On the basis of previous own designs of Hyperloop system for Earth conditions, the concept of this type of transportation for the Moon and Mars was proposed. The basic technical parameters presented and discussed at the IAC conferences in Dubai are given, demonstrating the high technological readiness of the project.

**Keywords:** Hyperloop; Moon; Mars

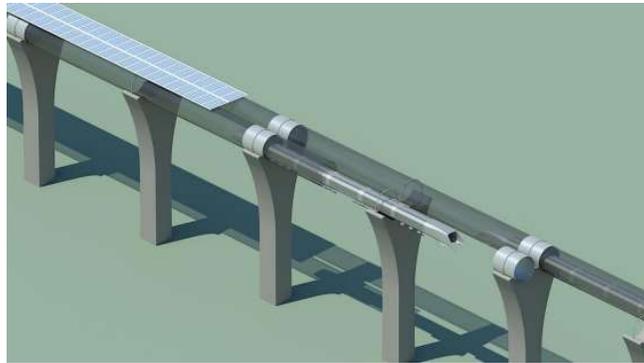
**Introduction**

The development of mass and mass transportation on Earth accelerated a little more than 100 years ago, as is well known. The steps being taken in the so-called "conquest of space" related to transportation on the surface of the Moon and possibly Mars will be implemented soon. It is obvious that the designers will use what we know from earthly solutions, but they will have to face different conditions and therefore the details will be different. Work on this issue was undertaken at the Wrocław University of Technology about 15 years ago. At that time, a number of problems were taken up similarly to what was happening in Elon Mask's group in the contractual so-called "Silicon Valley," where issues from the Hyperloop-type transportation system were considered in addition to electromobility and traffic autonomy. The study prepared for the NCBiR competition presented a concept for a Polish Hyperloop many times cheaper than Elon Mask's group's solution. Despite positive feedback, the project did not enter the implementation stage. For the record, the concept was presented at a national conference [3]. In the following years, a number of theoretical studies on the conditions for a transportation system outside the European continent were realized. The original concept was returned to by preparing a concept of a transportation system for Martian conditions [4]. After the world space agencies turned again to the Moon, another concept of this system was presented for this

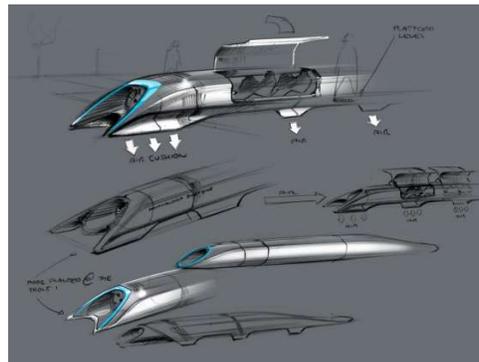
celestial body [5]. The discussion that ensued after the presentation at the Dubai conference demonstrated the usefulness of the concept in possible future production facilities on other planets, moons or even asteroids. This paper presents general conceptual work related to a transportation system beyond the Earth's surface focusing on programs for the Moon and Mars in line with anticipated activity in the coming years.

### Outline of the concept of low-pressure transport

Although the concept of transport in tubes with reduced pressure has been known for more than two hundred years, we can only describe the last 10 years as a significant advance in the development of the concept. In 2013, a group of SpaceX and Tesla engineers publishes the Hyperloop Alpha document, which outlines the assumptions of the new transport system. It assumes the use of tubes with reduced pressure up to 1hPa (run underground or on pylons - Figure 1) as infrastructure. The vehicles are to be carriages moving at a speed of 1200km/h using the phenomenon of magnetic levitation. The high speed is achieved by reducing aerodynamic drag, by depressurizing the infrastructure [1].



1. Hyperloop infrastructure covered with solar panels [1] (*Hyperloop Alpha*, page 26)

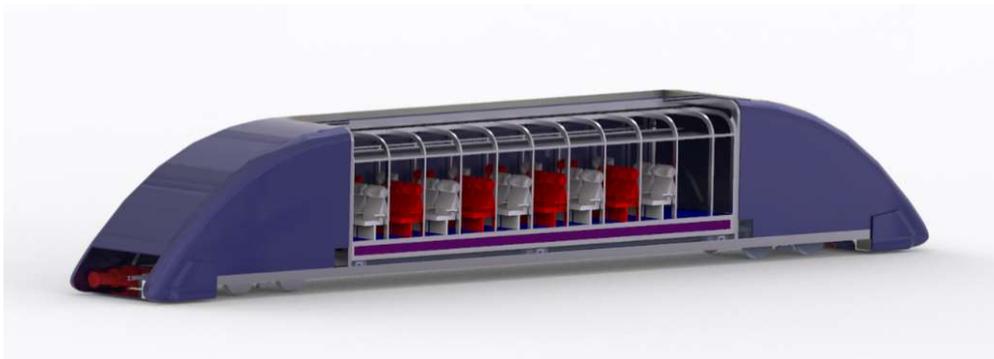


2. Hyperloop system vehicle concept [1] (*Hyperloop Alpha*, p.13)

Parallel to the Hyperloop concept, work is underway at the Wrocław University of Technology on a new proprietary concept for a transportation system adapted to the conditions in Poland. A team of about 20 engineers, led by Professor Piotr Wrzeconiarz, is writing a number of (15) scientific and thesis papers in 2013-2019, which develop the concept by analyzing aerodynamic drag, vehicle design, infrastructure design, safety systems, traffic control, costs, loading and unloading systems, potential routes, powering the system, and much more for Wrocław conditions, domestic conditions, and for other countries not only in Europe. Eventually, the outline of the general concept is presented in a paper entitled *Concept of the First Polish Vacuum Train - 4P*.

The 4P system consists of:

- rolling stock, which is a carriage that seats 28 passengers, with a Bo'Bo' axle layout (4 driven axles), equipped with a system of interchangeable passenger or freight modules, and a replaceable li-ion battery. The vehicle, using the current achievements of High Speed Rail, travels at a design speed of 600km/h,
- infrastructure, which, unlike the Hyperloop, involves the use of a wheel-rail connection, and which is a modular system of prefabricated railroad tunnels and a system for maintaining reduced pressure up to about 100 hPa (calculations have shown that this is the pressure limit below which the cost of providing and maintaining pressure increases dramatically),
- The station and loading system - 30m diameter turntables were used on the final sections of the route, preceded by a pressure lock, and interchangeable passenger-freight modules with traction batteries, (in accordance with the analyses of the conduct of passenger-freight streams in logistics programs) this allowed to reduce the time of the vehicle stay at the station to 30 seconds. After the sluicing is carried out, the passenger-cargo module is ejected together with the battery and the module is loaded with the charged battery prepared in advance,
- traffic control system, allowing fully autonomous travel to be programmed with top-down speeds on individual sections derived from an early known route profile. This also allows for more economical use of brakes and a three-stage brake system. The entire route is divided into sections and, as in rail traffic, these are blocked after the vehicle passes,
- safety systems that resulted from the team's analysis of 80 crisis and emergency scenarios and the design of solutions commonly found in aviation and railroads.



3. Visualization of the 4P system vehicle with the passenger and freight module [source. Own based on [9]]

The 4P transportation system is cheaper to build and maintain than the Hyperloop system. The cost of building a 1km route is about \$5million, while the cost of building a 1km Hyperloop route is assumed to be between \$9-12 million. The 4P system is ready for deployment, as evidenced by the high technological readiness (grade 9) of the various components, which are now widely used in railroads, electromobility and aviation. The 4P system is a better solution for European conditions, i.e., housing density and an average route distance of about 400km (there is no need for huge curve turning radii as in the case of Hyperloop's 1200km/h speed. [3])

In 2018, a team of experts from the National Center for Research and Development, led by Ziemowit Malech, PhD, at the request of the then Minister of Entrepreneurship and Technology Jadwiga Emilewicz, conducts an analysis of the technological readiness of a

transportation system using vehicles moving at high speed in a confined space with reduced pressure. The result of the work is a publicly available report that, verifying the national potential for KNC (Low Pressure Railway), distinguishes 7 teams working on the development of the concept (including the 4P team), presents a matrix of potential components of the transport system with possible configurations (based on the analysis of information collected from the teams), and presents the necessary steps and recommendations to develop KNC in Poland [2].

In 2019, the 4P team, drawing on its own extensive experience (working in the *space* sector) begins work on adapting the 4P transport system for the Moon and Mars. The final concept of the Mars transport system is presented in the paper *Vacuum transport system for Mars* at the International Astronautic Congress (IAC) conference in October 2020. And the concept for a transportation system on the Moon is presented in the paper *Vacuum transport system for Moon* at the International Astronautic Congress (IAC) conference in October 2021.

### Conditions on the Moon and Mars

In 2019, the US announced the Artemis program, which aims to establish a permanent human presence on the Moon. Crews will establish a base where solutions and technologies planned for use in a later mission to Mars will be tested. At the same time, the private company SpaceX is working on an interplanetary transportation system based on the Starship rocket. Thus, there is a need to develop a transportation system on the surface of the Moon and Mars, which would allow pinning down potential colonies and resource sites with a network of connections, ensuring the flow of people and goods. Depending on the conditions on the Moon or Mars, the 4P system, with appropriate modifications, addresses this need. [6,7,8]

Gravitational acceleration on the Moon is  $1.6\text{m/s}^2$ . The atmosphere is practically negligible (pressure  $3 \times 10^{-13}$  bar). The temperature ranges from  $-233^\circ\text{C}$  to  $123^\circ\text{C}$  with an average of  $-23^\circ\text{C}$ . The surface of the Moon is covered with regolith (85% of particles smaller than  $\varnothing 0.5\text{mm}$ ) - electrostatically charged. There is strong solar radiation, solar wind and myrcometeorites. Cosmic radiation comparable to that in space. [5]

On Mars, the gravitational acceleration is  $3.7\text{m/s}^2$ . The atmosphere is relatively thin - at the surface it is about 0.6% of Earth's atmosphere (7hPa). Temperatures range from  $-125^\circ\text{C}$  to  $+20^\circ\text{C}$ . There are harmful cosmic rays and UV radiation. Sandstorms and accompanying lightning are observed. The planet's magnetic field is very weak. Mars is geologically diverse. [4]

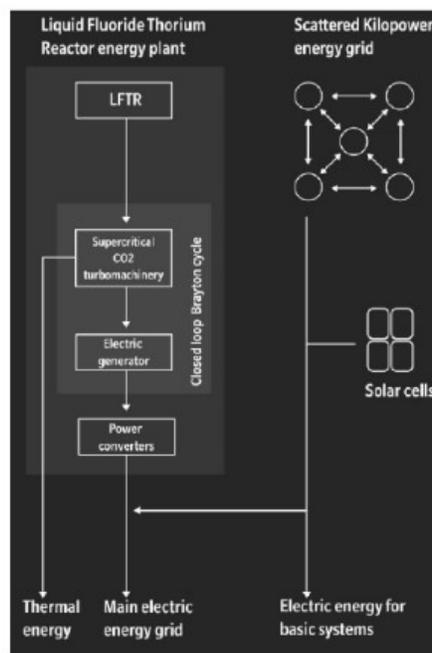
It is possible to distinguish 3 main problems related to the implementation of the 4P transportation system on the Moon and Mars. These are:

1. conditions that require infrastructure to protect against radiation, dust and to maintain the assumed pressure,
2. transportation and manufacturing of system parts, in the initial stages of system implementation, all necessary components and machinery for manufacturing system components should be transported already on site,
3. manufacturing of in situ system components (ISRU), it is mainly assumed to manufacture components such as infrastructure modules, stations, architecture, buses, etc., the rest of the minor components, i.e., electronics and high-precision components will have to be transported from Earth.

### 4P system for Mars

The resistance to motion, which above relatively high speeds (is directly proportional to the square of the speed) consists mainly of aerodynamic drag, is about 9 times lower on Mars relative to the resistance to motion on Earth. At a speed of 460km/h on Mars (230km/h on Earth), we can observe a sharp increase in the value of aerodynamic drag. This phenomenon

allows us to reach higher speeds or consume less energy than on Earth to power the entire system. The infrastructure is a tunnel (isolating the system from atmospheric conditions and stabilizing the conditions inside, i.e., constant temperature and pressure), which consists of a steel structure in a matrix of regolith, whose porosity is mitigated by sealing the modules with plastic. 3 concepts are assumed for the construction of the infrastructure, firstly, in the initial stage it is assumed to transport elements from Earth, secondly, a gradual transition to the use of local raw materials (with the development of the colony), thirdly, the transport of inflatable support structures manufactured on Earth and covering it with local materials. In order to manufacture the modules, it is assumed to use additive manufacturing machines using SLS (selective laser sintering) technology and sintering regolith for prefabricated functions. Based on the team's extensive experience in the design of Martian colonies (including the *Twardowsky* project), the LFTR reactor and the supporting Kilopower reactors used by NASA were chosen as the energy source [4].



4. The energy production system of the Twardowsky project [4]

#### 4P system for the moon

On the Moon, due to the lack of an atmosphere, aerodynamic drag is negligibly small, and the main component of drag is rolling resistance of 16kN at the assumed design speed of the vehicle of 600km/h. Using the assumptions of the 4P system, with an acceleration of 0.2m/s<sup>2</sup> the power of the engines equal to 600kW (according to the fact that each of the 4 axles of the vehicle is driven, we can, for example, use Emrax 268 engines, which have an excellent power-to-weight ratio - 117kW con., 210kW peak, 22kg) [<https://emrax.com/e-motors/emrax-268/>]. Knowing the potential route lengths, we can assume that we need a traction battery that will allow 2h of continuous operation (1200 kWh). The infrastructure must be a tunnel in order to protect it from dust, regolith and radiation, and in the case of human transport to ensure proper conditions (temperature, pressure). An underground tunnel was assumed, taking advantage of the phenomenon of the decrease in porosity with depth on the surface moon. This phenomenon also allows the use of ruts at relatively lower speeds and in the initial stages of system implementation. Stations have been used in the final stages of the route (e.g., connecting colonies or resource extraction sites), where the habitation part must be separated by a system

of sluices from the tunnel. The stations use a system known from the 4P system for replacing passenger-cargo modules and/or traction batteries. The energy source of the system can be solar energy and/or a reactor, stored in traction batteries and energy storage systems (composed of traction batteries whose original capacity has fallen below 80% of nominal) [5].



5. Visualization of the habitat on the Moon [5]

#### **In-Situ Resource Utilization (ISRU) [5].**

In-Situ Resource Utilization, defined as *the collection, processing, storage and use of materials found or produced on other astronomical objects that replace materials that would otherwise have been brought from Earth*, is one of the important elements necessary for the implementation of the 4P system on Mars and the Moon.

As potential sources of raw materials we can distinguish:

- rocks and regolith, from which we can extract metals and ceramics and make prefabricated products,
- atmosphere, from which we can extract the necessary gases,
- materials of organic origin, which are mainly resins and plastics necessary for sealing infrastructure.

The extracted raw materials can find potential use mainly in:

- tunnels and stations, built with plastic-covered regolith prefabricated elements,
- rail infrastructure, using wheel-rail cooperation, which at relatively high speeds requires the use of steel for rails (at low speeds, ruts can be used).

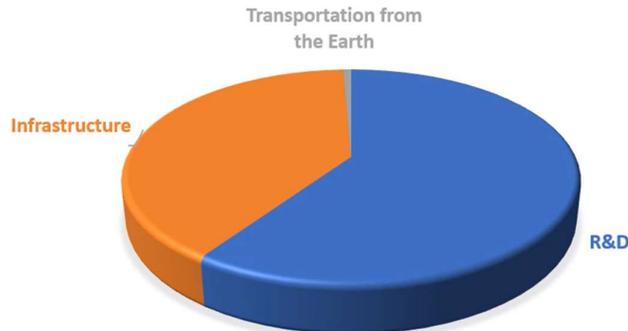
Other high-tech components (e.g., motors, pumps, electronics) should be transported from Earth.



6. Robot producing habitat protective layer using microwave sintering of regolith [5]

### Costs

The largest part of the cost, as much as \$300million, will be consumed by research and development (R&D). The basic system itself, which is an 11km route, a fleet of 20 vehicles and 2 terminal stations, costs \$200million. Transportation of the necessary materials from Earth (in the final phase of implementation of the system is ) \$3million. The cost of building 1km of route is estimated at \$10million [9].



### 7. Breakdown of costs that will be absorbed by the implementation of the system [9]

#### Final conclusions

The system shown is characterized by resilience (risk reduction) due to reduced contact with external factors such as weather, eruptions, sandstorms and temperature fluctuations.

There is low or negligible aerodynamic drag and reduced rolling resistance (lower g-value), so higher speed obtained at a lower energy cost.

The system is highly scalable; due to its modularity, it can be easily scaled according to the transportation needs and the degree of colony development.

The system is a relatively low-cost solution to the transportation system problem. It is more economical to build and operate than other conventional means of transportation (which is crucial in space conditions).

It is possible to transport people and/or goods in a fast way, by achieving high speed with low energy input, which is crucial for the exploitation of a new planet (possibility to establish colonies in longer distances, ease of communication with mines).

The project concept is ready and prepared for further work and prototype construction. All the technologies used in the project are well known and thus relatively inexpensive. The design can be suitable for both long and short distances. The system, with minor modifications, can be implemented on both the Moon and Mars. The group of engineers working on the project is already prepared for further development of the project. We are ready to undertake international cooperation.

#### Source materials

- [1] SpaceX, Hyperloop Alpha, 2013.
- [2] NCBIr Competition, Technology readiness analysis of a transportation system using vehicles moving at high speed in a confined space with reduced pressure, Piotr A. Wrzecioniarz with team, 2018.
- [3] Wrzecioniarz P.A., Mierzwa K., Pindel A., Concept of the First Polish Vacuum Train-4P, Scientific Papers of the Warsaw University of Technology. Transport, 2019.
- [4] Wrzecioniarz P. Mierzwa K., Liśkiewicz D., Pauli M., Pezowicz P., Vacuum transport system for Mars, 71st International Astronautical Congress (IAC) - The CyberSpace Edition, Vacuum transport system for Mars, 2020.

- [5] Wrzecioniarz P. Mierzwa K., Liśkiewicz D., Pauli M., Pezowicz P., Vacuum transport system for Moon, 72st International Astronautical Congress (IAC) - The CyberSpace Edition, Vacuum transport system for Moon, 2021.
- [6] <https://pl.wikipedia.org/wiki/Hyperloop>
- [7] [https://pl.wikipedia.org/wiki/Program\\_Artemis](https://pl.wikipedia.org/wiki/Program_Artemis)
- [8] [https://pl.wikipedia.org/wiki/Starship#Interplanetary\\_Transport\\_System](https://pl.wikipedia.org/wiki/Starship#Interplanetary_Transport_System)
- [9] 4P team presentation at IAC congress, Vacuum transport system for Moon, P. Wrzecioniarz with team, 2021.