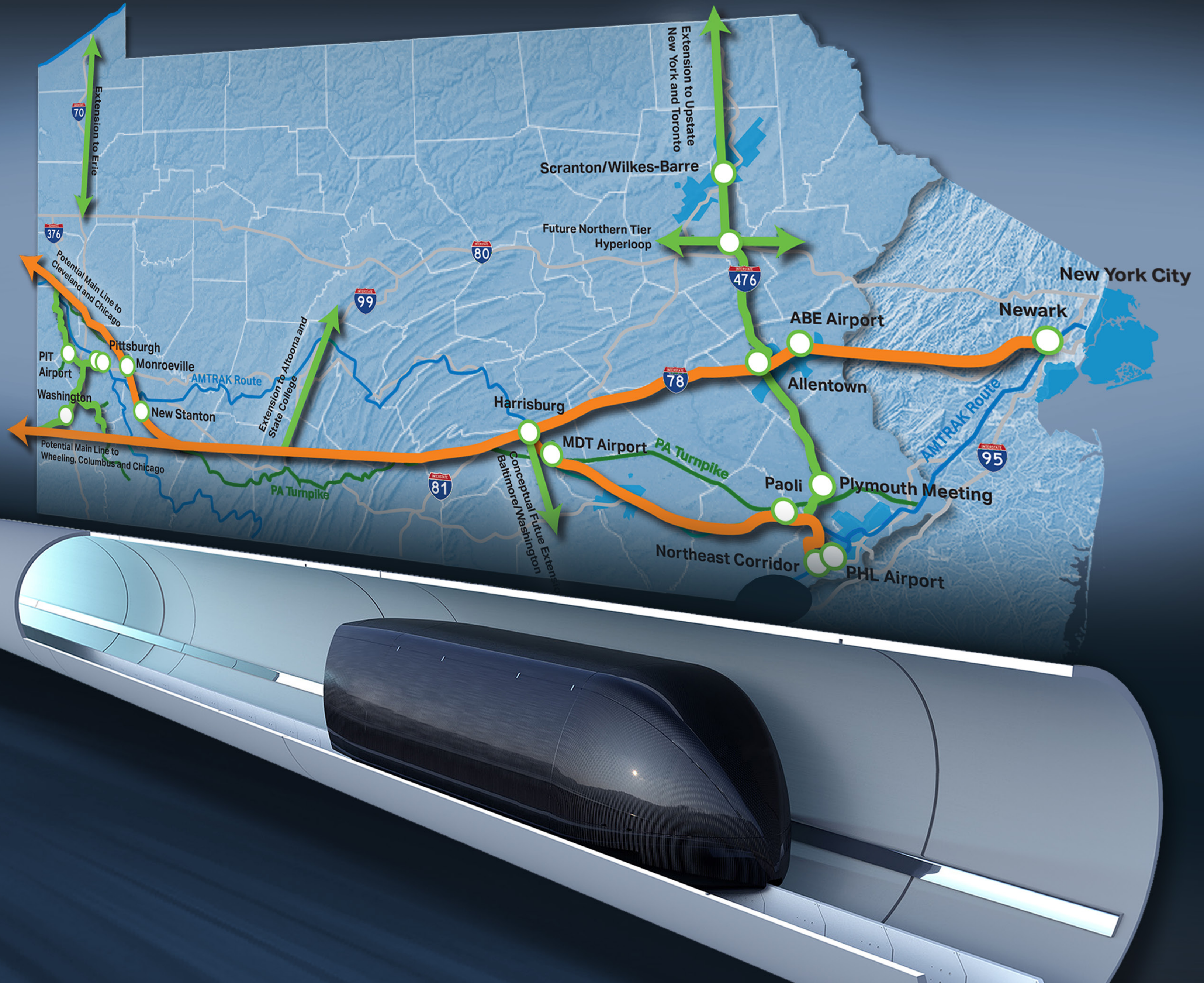

Pennsylvania Hyperloop

DRAFT REPORT

June 2020

PENNA TURN PIKE

Image: Virgin Hyperloop One

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ACRONYMS

BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
BUILD	Better Utilizing Investments to Leverage Development
CAHSRA	California High-Speed Rail Authority
CAPEX	Capital Expenditure
Commission	Pennsylvania Turnpike Commission
Commonwealth	Commonwealth of Pennsylvania
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPC	Engineering, Procurement, and Construction
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
FAST	Fixing America's Surface Transportation
FHA	Federal Highway Administration
FRA	Federal Railroad Administration
GDP	Gross Domestic Product
GRP	Gross Regional Product
GSP	Gross State Product
HCC	Hyperloop Certification Center
HSR	High-Speed Rail
HR-1057	Pennsylvania House Resolution 1057
HTT	Hyperloop Transportation Technologies
LOS	Level-of-Service
Maglev	Magnetic Levitation
MUTCD	Manual on Uniform Traffic Control Devices
MORPC	Mid-Ohio Regional Planning Commission
MPO	Municipal Planning Organization
MPH	Miles Per Hour
MSA	Metropolitan Statistical Areas
NEG	New Economic Geography
NEPA	National Environmental Policy Act
NETT	Non-Traditional and Emerging Transportation Technology
NOACA	Northeast Ohio Areawide Coordinating Agency
O/D	Origin/Destination
O&M	Operating & Maintenance
PAB	Private Activity Bonds
PennDOT	Pennsylvania Department of Transportation
RRIF	Railroad Rehabilitation & Improvement Financing
RPO	Rural Planning Organization
SAFETEA-LU	Safe Accountable, Flexible and Efficient Transportation Equity Act: a Legacy for Users
SEPTA	Southeast Pennsylvania Transportation Authority
SPC	Special Purpose Company
TEA-21	Transportation Equity Act for the 21st Century
TIFIA	Transportation Infrastructure Finance and Innovation Act
TRL	Technology Readiness Levels
TRP	Trips Between Zone Pair
TSHV	Time-Sensitive, High-Value
US	United States
VHO	Virgin Hyperloop One
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled
WEB	Wider Economic Benefits
YOE	Year of Expenditure

EXECUTIVE SUMMARY

Background

Hyperloop technology uses magnetic conveyance and electric propulsion to move vehicles (pods or capsules) through guideway tubes in a near-vacuum or low-pressure environment to transport passengers and freight at speeds up to 500+ mph.

In October 2018, the Pennsylvania House of Representatives adopted Resolution 1057 (HR 1057), which was sponsored by State Representative Aaron Kaufer and introduced by Representatives Donald "Bud" Cook, Tina Pickett, Harry Readshaw, David Millard, Ed Neilson, Jack Rader, and Mary Jo Daley. This legislation called for a study to determine the potential benefits of a hyperloop system to the State of Pennsylvania. This bi-agency analysis, initiated by the Pennsylvania Turnpike Commission (the Commission) and supported by the Pennsylvania Department of Transportation (PennDOT), is the initial effort to study hyperloop within the state. Acknowledging that other studies throughout the United States and internationally have developed feasibility and environmental impact assessments, the intent of this study on hyperloop, regardless of the provider, is to provide Pennsylvania legislators and public agencies with a high-level strategic analysis and information about the state of the industry.

THE PENNSYLVANIA HYPERLOOP STUDY INCLUDED

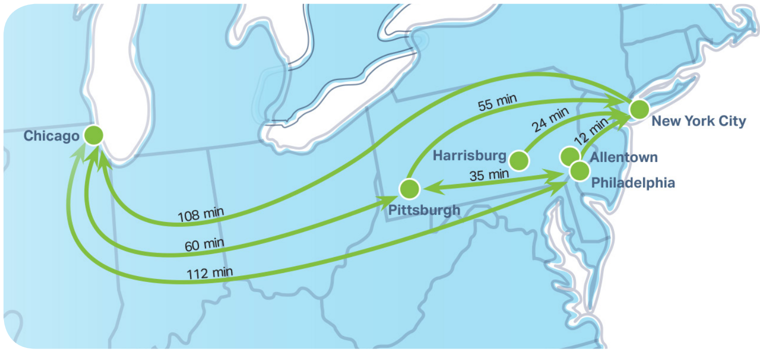
- Technology readiness, existing policy and legislation, and requirements for technology standardization and safety.
- Two high-level scenarios, considering the intent of HR 1057, which will be the basis for costs, potential revenue, benefits and impacts of hyperloop in Pennsylvania.
- High-level economic impacts if hyperloop is constructed inside or adjacent to Pennsylvania.
- A review of a possible business case required to advance hyperloop in Pennsylvania.
- Suggested next steps.

Technology Summary

The hyperloop technology, at its current level of advancement, has demonstrated recorded speeds near 288 mph, within scaled models, with the theoretical potential to exceed 500 mph in a full-scale deployment. As per discussions with the technology providers, a full-scale demonstration of a commercialized system that meets the anticipated speeds could be five or more years into the future. Safety and certification would follow, based on the creation of applicable compliance standards. This technology advancement, along with the creation of national safety and testing standards, and the adoption of hyperloop in adjacent states, will be required prior to the state progressing further study of hyperloop.

The theoretical travel times shown could be realized, assuming 500+ mph for mainline routes, with slower speeds approaching urban areas.

Potential hyperloop travel times (Time in vehicle/pod)



- 12 minutes – Allentown to New York City Metropolitan Area
- 24 minutes – Harrisburg to New York City Metropolitan Area
- 35 minutes – Pittsburgh to Philadelphia
- 55 minutes – Pittsburgh to New York City Metropolitan Area
- 60 minutes – Pittsburgh to Chicago
- <2 hours – Philadelphia to Chicago
- <2 hours – Chicago to New York City Metropolitan Area

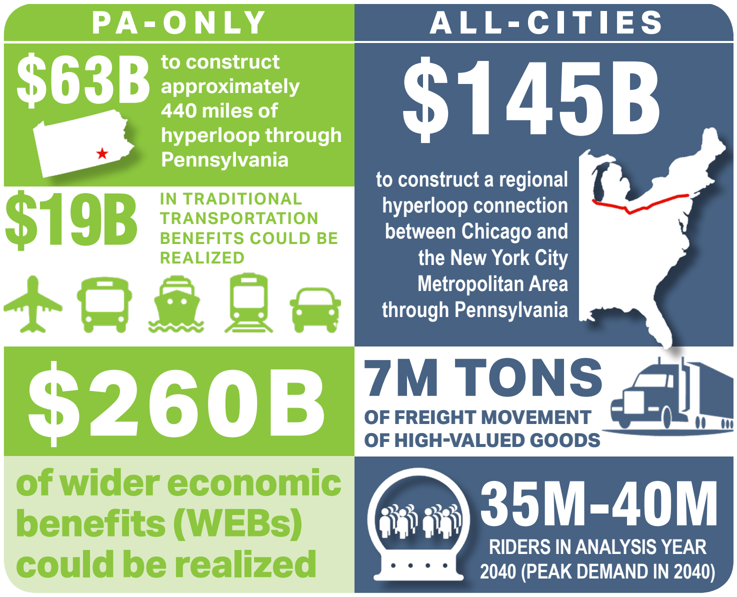
High-Level Scenario

The HR 1057 legislation recommended the review of a potential hyperloop system connecting Pittsburgh, Harrisburg and Philadelphia, along with the evaluation of connectivity to the northeast between Harrisburg and Wilkes-Barre/Scranton.

This report provides an initial analysis of two scenarios. The first, the Pennsylvania-Only scenario, connects Pittsburgh, Harrisburg, Philadelphia, and then Harrisburg to Allentown. A connection to Wilkes-Barre/ Scranton would be considered as an extension from Allentown in a subsequent phase to enhance the viability of the first phase of this evaluation. The second is an All-Cities scenario, which connects Chicago to the New York Metropolitan Area through the Pennsylvania cities in the first scenario.

Economic Impact

The two scenarios were analyzed over a 30-year period, and it was determined that the All-Cities scenario would provide more significant economic impact to Pennsylvania based on anticipated freight and ridership movement. A benefit-cost analysis determined that the Pennsylvania-Only scenario does not provide enough freight and passenger movement, and associated revenue to be a sustainable alternative. Economic considerations include securing capital funding for such an investment, and that there is industry compliance with defined certification and safety standards.



As the hyperloop technology advances, Pennsylvania will have potential competition from adjacent states to connect megaregions. As a historical example, the New York Central Railroad connected Buffalo to Chicago though either Cleveland or Detroit (via Canada). The Pennsylvania Railroad connected Philadelphia to Chicago through Harrisburg, Pittsburgh and Columbus. Similar options could be considered as alternative routes outside Pennsylvania, and pose a potential threat for a hyperloop network bypassing the state.

POTENTIAL ECONOMIC IMPACTS TO PENNSYLVANIA – HYPERLOOP BY-PASSES COMMONWEALTH

- $197 billion potential opportunity loss over a 30-year period if hyperloop bypasses Pennsylvania. Additional impacts of disrupted industries, such as logistics companies, manufacturing, transportation, service, and oil and gas in Pennsylvania would need to be further studied.
  - $260 billion (WEBs) – $63 billion Capital Cost
- $1.7 billion of potential toll revenue loss (due to mode shift to hyperloop) over a 30-year analysis period. This represents approximately 5% of toll revenue over this time period, without considering toll increases.

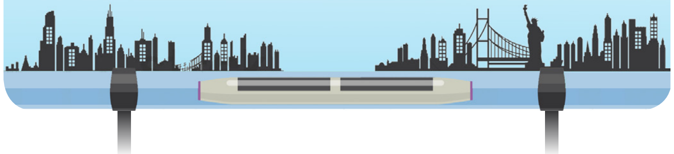
Business Case

This study's analysis concludes that, in the current technology state, there is no feasible method that could currently be defined to finance capital expenditures to construct, operate and maintain such a large-scale infrastructure project. Without private sector investments that exceed the risk appetite of the current market, and/or public sector grants that far exceed existing state and federal programs, there is not a current model that defines an appropriate business case to financially advance the study of hyperloop within the state.

A pro forma was developed for hyperloop illustrating the following:

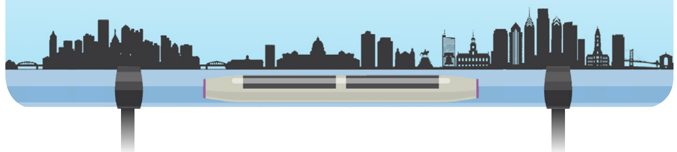
AN ALL-CITIES SCENARIO

A potential to generate a pre-tax net cash flow between $107 billion and $292 billion over a 50-year analysis period, which could recover capital costs over a 30-40-year period.



A PENNSYLVANIA-ONLY SCENARIO

A potential to generate a pre-tax net cash flow between $20 billion and $10 billion over a 50-year analysis period, which could recover capital costs over a 50-65-year period.



Next Steps

As the hyperloop technology advances to become a more safe and reliable transportation option, and there is advancement in neighboring states, the following strategies are offered:

Proactively Monitor

- Stay informed on the progression of technology: Schedule annual conference calls with the technology providers to keep abreast of hyperloop industry advancements, infrastructure and operations and maintenance (O&M) costs.
- Monitor the construction of and operational results from national and international testing and certification centers: Engage neighboring states, on an annual basis, to discuss the advancement of hyperloop including implementation of a certification and/or test center, and other defined national focus topics.
- Examine the progression of the Great Lakes and Midwest Connect hyperloop studies to keep abreast of project advancement.

Develop Partnerships

- Should neighboring states advance hyperloop scenarios, participate in a coalition of states, from New York to Illinois, with the charge to review the study of an All-Cities hyperloop scenario. On a semi-annual basis, discuss hyperloop during existing coalition meetings or forums to strategize on the All-Cities scenario to minimize risk and maximize benefits, discuss hyperloop advancements, review national/international deployments, and create a multi-state roadmap, if appropriate.
- Coordinate efforts between state, Commission, and legislative members to participate on the USDOT Non-Traditional and Emerging Transportation Technology (NETT) Council to stay informed of federal advances in hyperloop and other technologies. Report to state agencies and the Pennsylvania legislature annually on NETT Council activities.
- Meet annually with tunneling and infrastructure partners to understand new construction means and methods.
- Schedule an annual meeting with local partners (i.e., Chambers of Commerce, airports, logistics companies, manufacturing) or through existing planning partners and/or PennDOT meetings to share hyperloop information.

Business Plan Updates

- Review the pro-forma business case as major changes in technology readiness occur.
- Review new funding mechanisms for hyperloop to determine project interest from both the private and public sectors.

I. BACKGROUND

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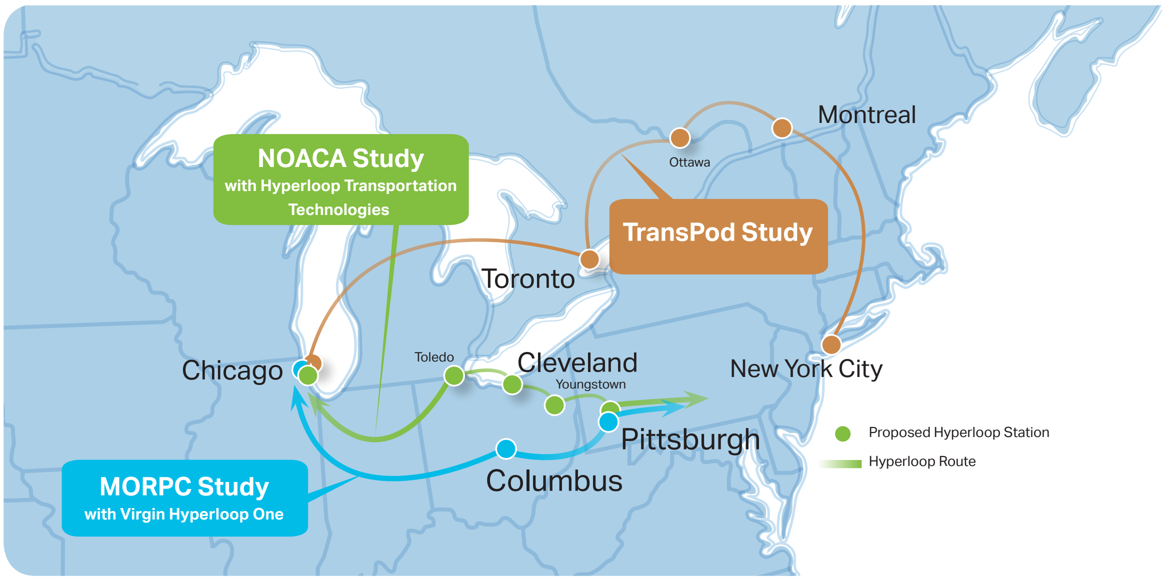
Figure 1 illustrates the potential hyperloop connectivity in Pennsylvania, based on HR 1057, and potential connections to ports and the I-95 corridor.

Figure 1 - Potential Hyperloop Connectivity in Pennsylvania

Regional Hyperloop Studies

One of the driving factors behind this study is the adjacent hyperloop efforts conducted by two Ohio planning agencies. Both agencies are supported with financial and technical assistance provided by competing hyperloop companies, Hyperloop Transportation Technologies (HTT), and Virgin Hyperloop One (VHO). Both studies propose to connect Chicago to Pittsburgh through different routes across Ohio and Indiana. A third competitive route, being investigated by Canadian company TransPod, is a potential connection between Chicago and New York, through Canada (via Toronto, Ottawa and Montreal). To date, the proprietary hyperloop technologies developed by each company are not compatible to share the same conveyance tube. Figure 2 depicts the routes being studied.

Figure 2 - Regional Hyperloop Studies



NOACA (GREAT LAKES HYPERLOOP) STUDY[1]

NORTHEAST OHIO AREAWIDE COORDINATING AGENCY
NOACA: Planning For Greater Cleveland

The Northeast Ohio Areawide Coordinating Agency (NOACA) is a metropolitan planning organization (MPO) serving Cuyahoga, Geauga, Lake, Lorain and Medina counties. Teaming with Hyperloop Transportation Technologies (HTT), the Great Lakes Study recognizes that Cleveland to Chicago represents a natural convergence of major interstate travel routes.

Hyperloop Transportation Technologies (HTT)

Purpose of the NOACA Hyperloop Study

To determine a business case for developing a hyperloop corridor connecting Chicago and Pittsburgh via Cleveland. The Great Lakes final feasibility report was issued in December 2019.

Findings of the NOACA Hyperloop Study

- Preliminary findings indicate that hyperloop could be technically and economically feasible, should funding be secured and the technology continues to advance towards theoretical speeds. The study has not been independently verified and validated.
- Potential 60-minute vehicle travel time between Chicago and Pittsburgh.
- $24 billion – $30 billion capital costs to construct.
- Could create 40,000 jobs.
- Could generate $2.02 billion new local taxes and $1.27 billion in property taxes over a 25-year period.

[1] Great Lakes Hyperloop Feasibility Study, December 2019

MORPC (HYPERLOOP MIDWEST CONNECT) STUDY

The Mid-Ohio Regional Planning Commission (MORPC) is the MPO and rural planning organization (RPO) for the greater Columbus and the surrounding nine-county area. The study was performed in coordination with Virgin Hyperloop One (VHO) and project consultants and reflects MORPC's selection as a Hyperloop One (later Virgin Hyperloop One) Global Challenge winner.

Virgin Hyperloop One (VHO)

Purpose of the MORPC Hyperloop Study

To determine a business case for developing a hyperloop corridor connecting Chicago and Pittsburgh via Columbus. The Midwest Connect report is due to be released in Spring 2020.

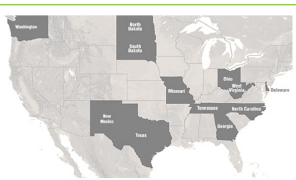
Findings of the MORPC Hyperloop Study

- Preliminary findings may indicate that hyperloop could be technically and economically feasible, should funding be secured and the technology continues to advance towards theoretical speeds. The study is anticipated to be released in the spring or summer of 2020.
- Potential 60-minute travel time for passengers and shipments between Chicago and Pittsburgh.
- 50% increase in passenger travel between the corridor metro areas.

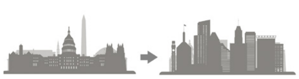
These two studies acknowledge that connecting Chicago to Pittsburgh provides a more bearable construction alternative, versus crossing the Allegheny Mountains. Pennsylvania understands that should neither of these projects advance, the state would not consider further studies on hyperloop. It is assumed that either the NOACA or MORPC scenarios would advance and that there would not be two parallel route options between Pittsburgh and Chicago.

OTHER REGIONAL ACTIVITY

New York State, under State Senate S03185 / State Assembly A01903 bills, established a hyperloop and high-speed rail (HSR) commission to study transportation modes that could travel up to 220 mph. Funding for this commission has yet to be allocated.



In the fall of 2019, VHO solicited proposals for a Hyperloop Certification Center (HCC) project development and partnership program. The goal of the project is to construct a testing and certification center to help advance VHOs technology. Nineteen states responded and are in competition for the center.



In 2019, the Boring Company submitted its draft environmental assessment (EA) to create the initial HSR segment between Washington and Baltimore.

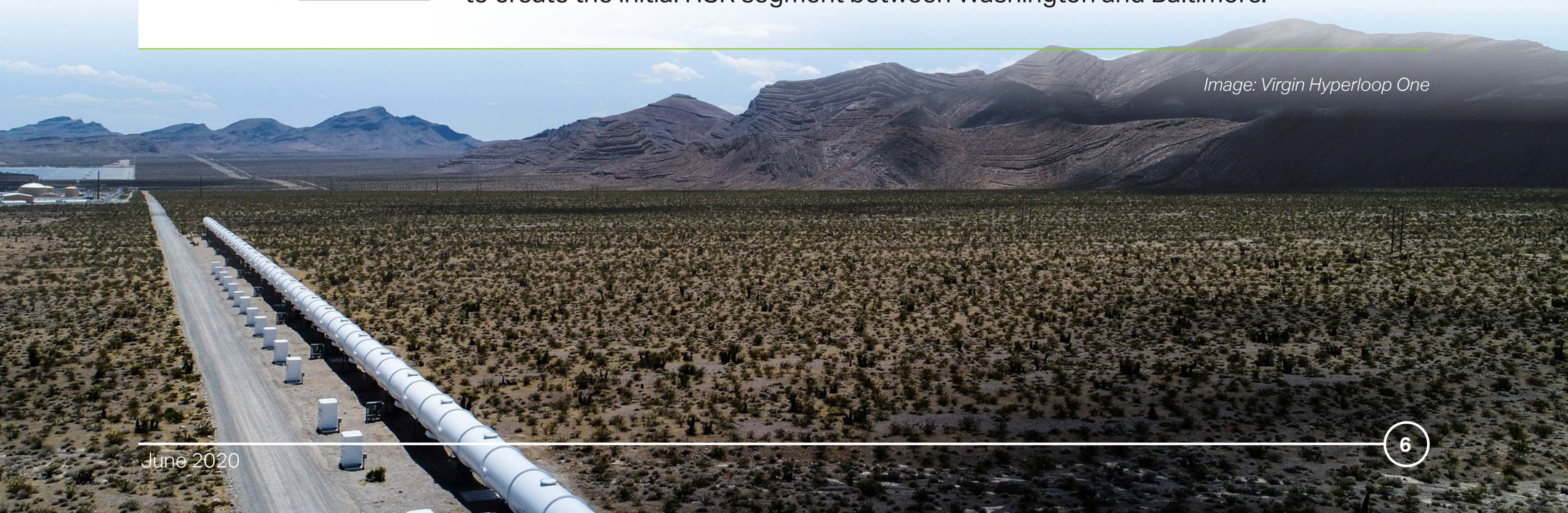


Image: Virgin Hyperloop One

History of Transformational Technologies in Transportation

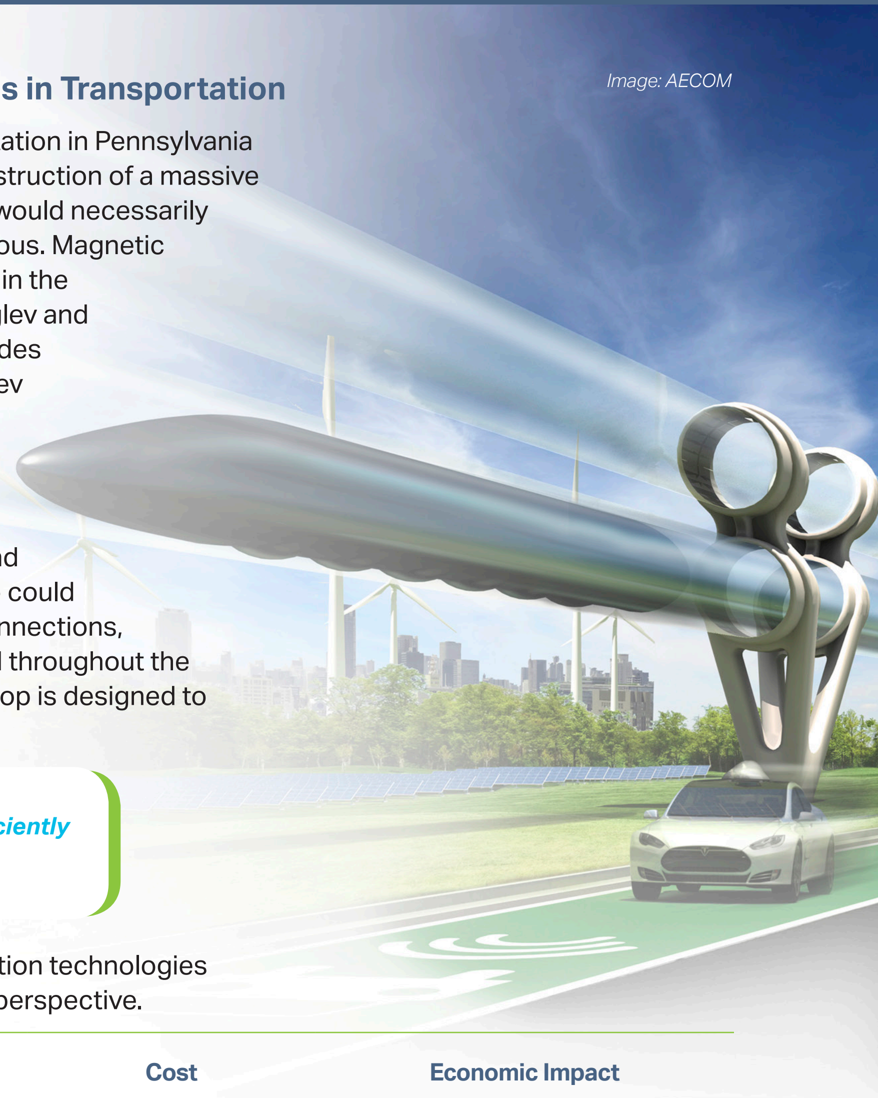


Image: AECOM

Hyperloop has the potential to transform transportation in Pennsylvania and throughout the United States. Design and construction of a massive new system covering major metropolitan markets would necessarily be expensive, but the potential benefits are enormous. Magnetic levitation (maglev) trains were also considered within the state, and other areas throughout the country. Maglev and hyperloop, even though both are higher-speed modes of transportation, differ in many ways. Where maglev trains are designed to reach upwards of 200+ mph and have more station stops, hyperloop is theoretically designed to travel at least twice as fast, while having lower maintenance costs (through less friction), travel in a quieter manner, and would be more environmentally friendly. Hyperloop could also be designed for on-demand point-to-point connections, where pods could maintain a higher cruising speed throughout the trip. Unlike most HSR or maglev proposals, hyperloop is designed to transport both passengers and freight.

Throughout United States history, the ability to transport goods and services faster and more efficiently has led to the growth of regional economies and commerce, and an increase in job opportunities.

The following comparisons of historical transportation technologies puts the benefit to develop a hyperloop system in perspective.

Infrastructure Advancement	Infrastructure Supplemented	Owner	Cost	Economic Impact
Canal System (e.g., Erie Canal)	Animals pulling wagons	State of New York	362.9 miles @ $7 million (1825) $183 million (2020)[2]	By 1853, the Erie Canal carried 62 percent of all U.S. trade.[3]
Railroads	Canals	Central Pacific Railroad (Chartered by Congress)	$162 million (1869)[4] or $4.3 billion (2020)	$74.2 billion to Gross Domestic Product (GDP) (2017)[5]
Interstate Highways	Railroads	Operated and maintained by the state. Funded at both federal and state levels	42,795 miles @ more than $550 billion (2020) 90% financed by public funds.	Increased mobility, contributed to development of suburbs. Contributes 10%-14% of the nation's GDP and saves more than 5,000 lives per year.[6]
Aviation	Long-distance surface transportation	Multiple private companies	$90 million for a 737-800[7]	Movement of 925 million passengers and 16 billion ton-miles (2019) $2.7 trillion to GDP (2016)[8]

All of the successful transportation transformations were triggered by a convergence of technical readiness, strong business cases, and national and/or regional leadership. This is a large reason why maglev failed, where canals, railroads and the interstate system succeeded. Based on historical precedence, it is this combination that could drive to make hyperloop a nationwide success.

[2] http://www.canals.ny.gov/history/history.html
[3] https://www.history.com/topics/landmarks/erie-canal
[4] https://ap.gilderlehrman.org/essays/financing-transcontinental-railroad
[5] https://www.railwayage.com/news/rail-supply-industry-contributed-74-2b-to-gdp/
[6] https://tripnet.org/wp-content/uploads/2018/08/Interstate_Highway_System_TRIP_Report_Appendix_June_2016.pdf
[7] https://www.statista.com/statistics/273941/prices-of-boeing-aircraft-by-type/
[8] https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

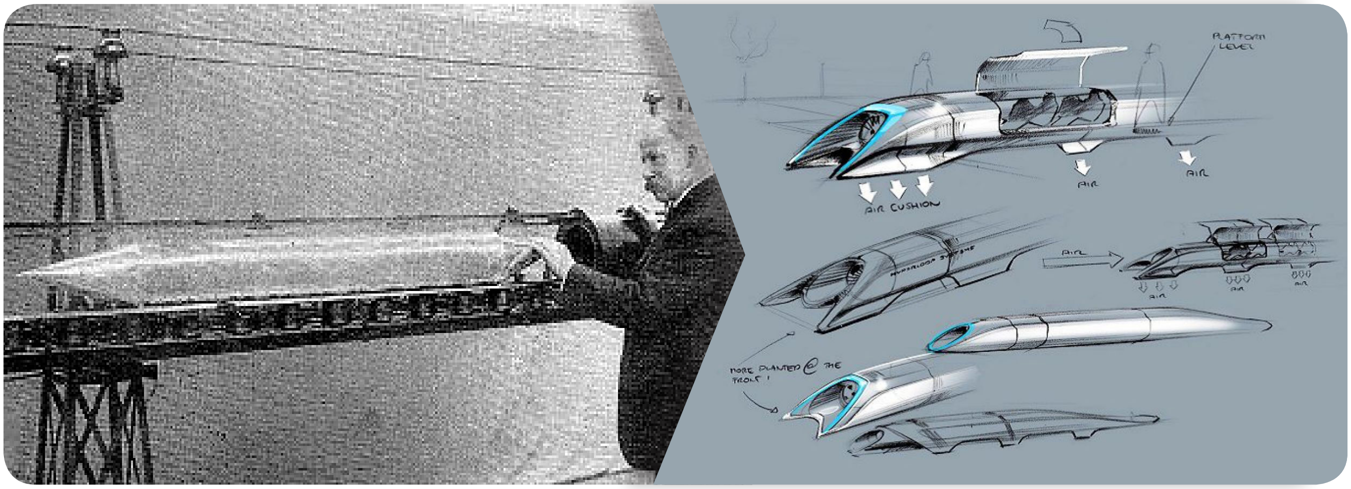
II. HYPERLOOP STATE OF THE INDUSTRY

Hyperloop Technology Background

The concept of vacuum-based transportation was first developed by Robert Hutchings Goddard, an American engineer, professor and physicist. He is credited with creating the vactrain (or vac-train) concept, shown in Figure 3, as a freshman at Worchester Polytechnical Institute in 1904. In simple terms, by removing all air out of a sealed tunnel a transport capsule can be accelerated through with less energy.

Hyperloop technology was inspired by Robert Goddard's vactrain theory from 1904 and popularized in 2013 by Elon Musk and SpaceX in his "Hyperloop Alpha" white paper.

Figure 3 – Goddard's Vactrain (1904) and Elon Musk's Hyperloop Concept (2013)



Hyperloop technology uses magnetic conveyance and electric propulsion to move vehicles (pods or capsules) through guideway tubes in a near-vacuum or low-pressure environment to transport passengers and freight at speeds up to 500+ mph. The concept was first proposed in the modern era by Elon Musk in 2013 and has since been advanced by various technology providers.

500+ **mph** Theoretical Speed

288 **mph** Highest Tested Speed (2019)

2013 **Hyperloop** Concept Released

Hyperloop Technology Providers

This section briefly describes the major hyperloop technology companies at the time of this study. The list presented in Table 1 is not exhaustive, as hyperloop technologies are rapidly evolving. This overview represents a general status at the time of publication based on information from literature research and discussions with technologists. It should be noted that at the time of this report, there is no technology interoperability between the major technology providers. There are advances in Europe to create a unified technology, but those standards have not yet been developed.

Table 1 – Hyperloop Technology Providers

Hardt Global Mobility – Founded October 2016 in Zuid-Holland, The Netherlands; www.hardt.global

Technology: Uses both 'permanent magnets' - magnets with a permanent magnetic field - and electromagnets. The permanent magnets have sufficient magnetic attraction and are positioned and stabilized by the electromagnets. As a result, the suspension system uses virtually no energy.

Potential First Full Scale Installation: Delft, Zuid-Holland, The Netherlands (2022)

Studies: The Netherlands

Hyperloop Transportation Technologies (HTT) – Founded November 2013 in Playa Vista, CA; www.hyperlooptt.com

Technology: HTT uses a passive magnetic levitation system called Inductrack. Magnets arranged in what is known as a Halbach array enable passive levitation over an unpowered but conductive track that moves capsules through the low-pressure environment.

Potential First Full Scale Installation: Pre-feasibility study, Bangkok to Chiang Mai, Thailand

Local Study: Chicago to Pittsburgh, via Cleveland, in partnership with Northeast Ohio Areawide Coordinating Agency (NOACA), to give the US Department of Transportation a first look at a full system and present certification guidelines

TransPod – Founded October 2015 in Toronto, Canada; www.transpod.com/en

Capsule Vision: 28-40 passengers per capsule, 160,000+ passengers and 4,000 cargo shipments a day.

Technology: Transpod vehicles are driven by electrically-driven magnetic propulsion.

Potential First Full Scale Installation: Chicago-Toronto-Montreal

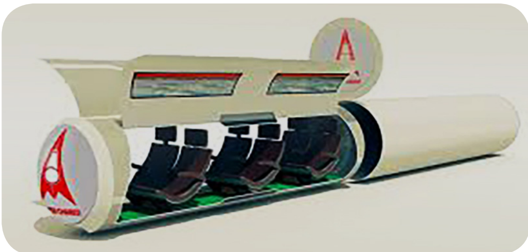
Studies: Toronto-Windsor corridor connects Canadian and European Hyperloop leaders in an industry-first partnership to establish international standards and regulatory framework

Virgin Hyperloop One – Founded June 2014 in Los Angeles, CA; www.hyperloop-one.com

Technology: Virgin Hyperloop One vehicles are propelled using a linear electric motor. The stators are mounted to the tube, the rotor is mounted to the pod, and the pod straddles the stators as it accelerates down the tube.

Potential First Full Scale Installation: Pune, India (2022)

Local Studies: Chicago to Pittsburgh, via Columbus, in partnership with Mid-Ohio Regional Planning Commission (MORPC), as well as with the St. Louis to Kansas City study. VHO has approximately five other studies in the U.S.

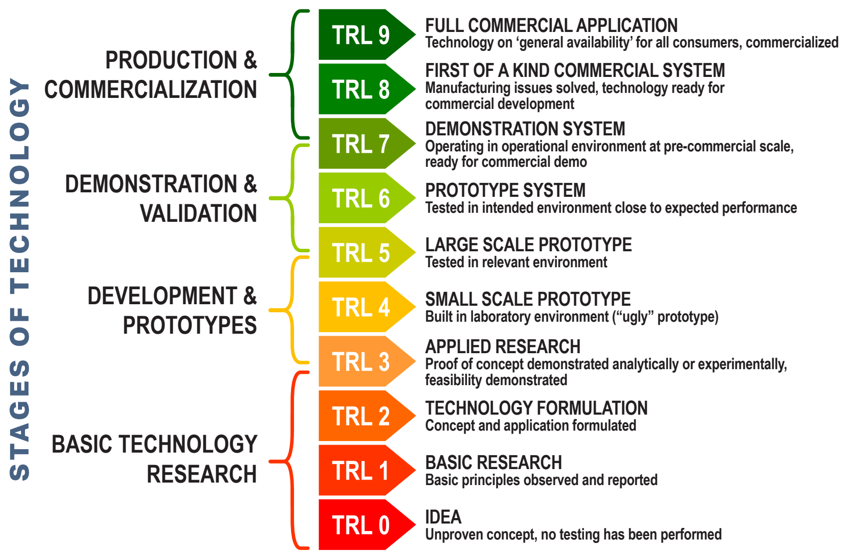


Hyper Chariot – Founded 2016 in West Hollywood, CA; www.hyperchariot.com

Hyperloop Zeleros – Founded November 2016 in Valencia, Spain; www.zeleros.com

Technology Readiness

The development of any technology project will depend greatly on the speed of the technology's readiness level and sophistication. Technology readiness levels (TRLs)[9] are formal metrics that support assessments of a particular technology and provide the ability to consistently compare levels of maturity between different types of technologies. The National Aeronautics and Space Administration (NASA) originally developed the concept of TRLs, shown in Figure 4, which were later adopted by other federal agencies (e.g. U.S. Department of Energy).



Source: Adapted from GAO Technology Readiness Assessment Guide

Figure 4 - Technology Readiness Levels (NASA)

For hyperloop, at the time of this report, the project team views the technology at a Level 5, as the maximum speed recorded by any technology company is only 288 mph, with the theoretical ability to achieve speeds in excess of 500 mph in a large scale prototype. It should be noted that between TRL 6 and 7 is a point where technological maturity has been demonstrated successfully in a large scale environment. When the technology approaches TRL 7, Pennsylvania should consider further evaluation.

National Initiatives / NETT Council

In March 2019, U.S. Secretary of Transportation Elaine Chao announced the formation of the Non-Traditional and Emerging Transportation Technology (NETT) Council, which aims to explore the regulation and permitting of hyperloop and other technologies. The intent is to consider new forms of mass transportation in the United States, including hyperloop. While this technology will continue to be explored at the federal level, at this time there are limited initiatives (studies and discussions) by federal government agencies concentrating on hyperloop.

Safety, Verification and Regulations

FRA Tier IV safety regulation level could be an option for a system like hyperloop, which would fall outside current FRA safety regulations. Hyperloop is expected to travel faster than systems currently under regulatory review by the FRA, but has the potential to fall under the purview of the FRA.

Safety regulation processes determine whether a proposed high-speed transportation system is safe to operate, and hence whether it can achieve the appropriate safety certifications to move forward into development. Safety certification will mostly likely be required for new high-speed transportation systems to operate in the United States, as per the FRA. The safety certification process would likely differ by technology depending upon the project's geographic context and agency jurisdiction. It is important to note that human safety certification may also be required to transport passengers at high speeds. An FRA Tier IV safety regulation level could be an option for a system like hyperloop, which would fall outside current FRA safety regulations. Hyperloop is expected to travel at speeds above 220 mph within insular systems but has the potential to fall under the purview of the FRA. The overarching process for safety certification is likely to be organized into three primary processes: engineering standards, development of a structured safety case and independent verification by external bodies. Engineering standards would most likely follow existing civil design standards used in traditional infrastructure projects, but new standards may be necessary specific to the unique operations of the new technology.

[9] https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

The existing standards, along with those adapted from other federal and state agencies and new standards, could then be compiled into standards that can be used for certification. The development of certification and design standards would be parallel efforts to technology advancements. These combined efforts would aid in the path to commercialization, as design, operations, and safety parameters would have to be established and proven prior to commercial use.

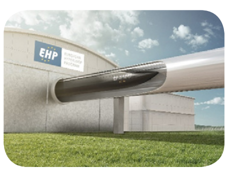
The Commission and PennDOT would most likely not lead the safety certification for hyperloop, but would presumably collaborate with the respective technologists to understand the certification process and provide support as needed. In addition, safety certification or at a minimum safety checks will be required in different forms throughout the project lifecycle, including during revenue operations. State and federal agencies may have jurisdiction over these processes. As per discussions with the technology providers, a full-scale demonstration of a commercialized system that meets the anticipated speeds could be five or more years into the future. Safety and certification would follow, based on the creation of applicable compliance standards.

Independent Verification

As part of the certification process, a level of assurance needs to be adopted through independent safety assessors or other international external bodies that may certify for safety. These external bodies may have different functions and levels of purview. In addition, federal or state agencies that have jurisdiction over the project's site location may also provide a safety review and/or assessment. The primary agency that oversees safety certification for high speed passenger rail systems in the United States is the FRA.

It is advantageous for the technologists to bring in safety assessment bodies and federal and state agencies early in the process. This will help provide education concerning the new technology, and could help streamline later phases of review and certification. In addition, test tracks can help demonstrate the safety of a new technology. A test track for hyperloop that, demonstrates a system a system internationally, may assist with proving the application within the United States.

European Committee for Standardization (CEN)



The European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) has been organized to define, establish, and standardize the methodology and framework to regulate hyperloop travel systems and ensure interoperability and safety standards throughout Europe. While this standardization would aid in bringing Europe closer to interoperability, the preliminary reaction within the United States is that findings and conclusions created by this consortium will not be fully applicable for the development and deployment of hyperloop in the United States. At the time of this report, there is not a similar consortium in the United States.

Governance

Governance represents a long-term management structure for design, construction, maintenance and operations. It will apply to both the hyperloop system level and the station/freight access point level. Governance scenarios could include:

The Commission or PennDOT Owns Land/Developer Owns and Operates System: Under this scenario, the Commission or PennDOT would become a partner with the system developer (which may or may not include the technologist having an active role during operations) to handle long term governance of the system.

Another Public Entity Owns Land/Developer Owns and Operates System: For example, if a new technology could run parallel to an existing public utility or railroad, agreements would be necessary with that utility or railroad. If a system were to operate within an existing agency's right-of-way, the developer would likely enter into agreements with the existing agency to operate a new system in the right-of-way.

III. DEFINING PENNSYLVANIA HYPERLOOP SCENARIOS

Drivers for Building Pennsylvania-Concept Scenarios

The Pennsylvania-Concept scenario is based on four key drivers illustrated in Figure 5:

A Pennsylvania Scenario
The conceptual scenarios, a Pennsylvania-Only scenario and an All-Cities scenario that connects Pennsylvania to the New York City Metropolitan Area and Chicago), represent a preliminary identification of potential hyperloop paths of travel.

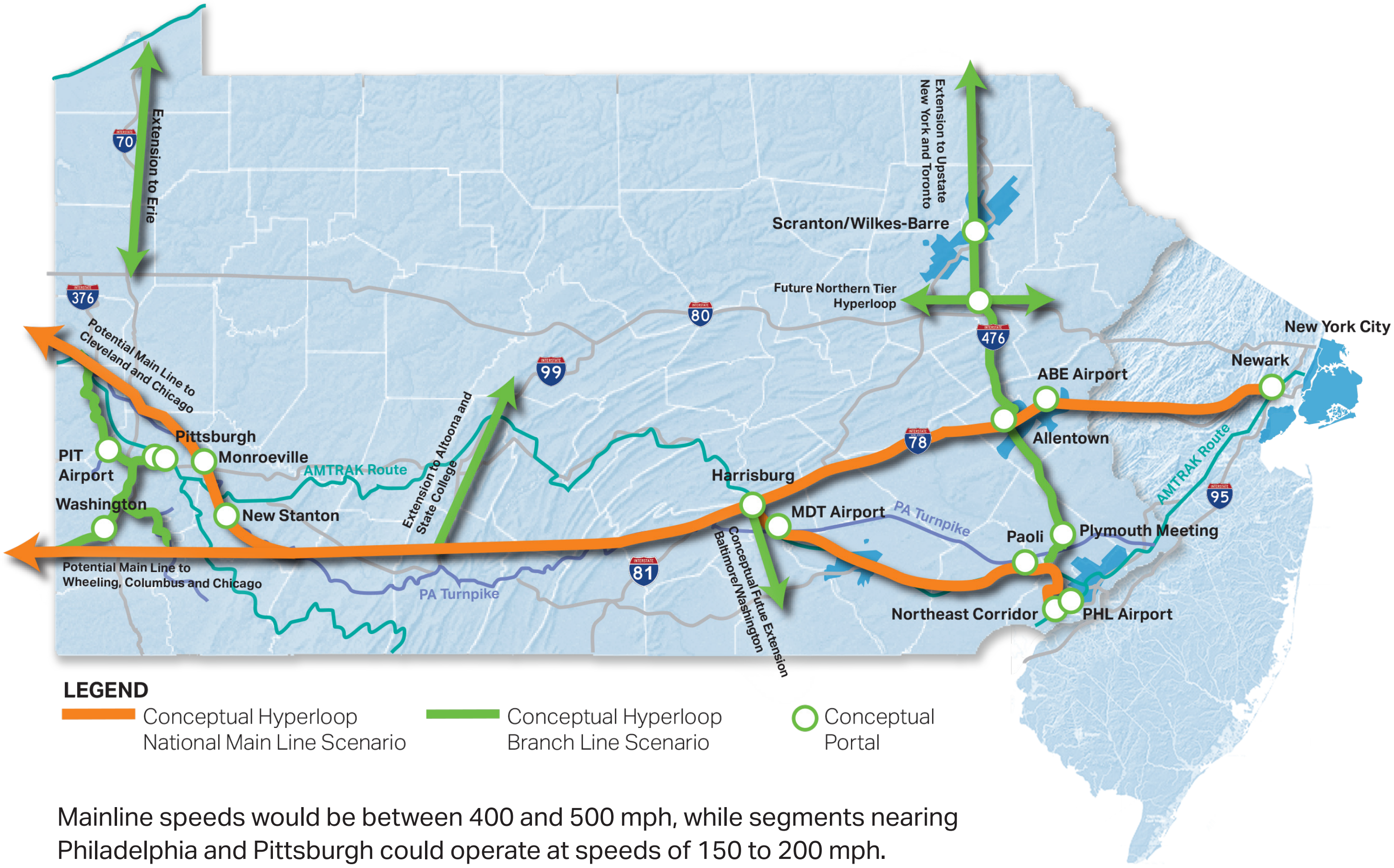
Figure 5 - Key Drivers in the PA Hyperloop Scenario

The criteria below were used to evaluate and consolidate initial scenarios into a recommended network.

1. Geographic Alignment
2. Comparative Cost
3. Engineering Complexity
4. Right-of-Way Acquisition
5. Environmental Constraints

The Pennsylvania Hyperloop network recommended for analysis in this study is depicted in Figure 6.

Figure 6 - Pennsylvania Hyperloop Scenario



Mainline speeds would be between 400 and 500 mph, while segments nearing Philadelphia and Pittsburgh could operate at speeds of 150 to 200 mph.

Alternative Scenarios

A "Northern-Tier" scenario, paralleling I-80, was not selected for further analysis as hyperloop would be more cost effective when serving major metropolitan markets. Due to its northern alignment, the I-80 scenario would require branch lines extending southward from the I-80 corridor to Allentown, Philadelphia, Harrisburg and Pittsburgh. This would not make for efficient and effective transport of passengers and materials within the state. The eastern portion of the I-80 corridor may offer potential for hyperloop service linking northeastern Pennsylvania toward New England and Canada.

Further information on the scenario definition can be found in Appendix A of this report.

IV. DEMAND, BENEFITS AND COSTS

Passenger Demand

The study included an analysis of passenger demand for hyperloop within Pennsylvania and connecting to other states. The full analysis is located in Appendices B and C to this report. When evaluating the Pennsylvania-Only model, passenger demand was below the threshold to consider investment in hyperloop. When New York and Chicago are connected by hyperloop via Pennsylvania, overall travel in the corridor grows noticeably, while air and auto travel decline. Hyperloop emerges as the dominant mode for intercity passenger trips, with passenger rail transitioning from a long-distance mode to a regional feeder/distributor to and from hyperloop. The economic impacts to rural areas, due to hyperloop portals being concentrated in metro areas, would have to be further investigated. It is anticipated that hyperloop would replace all passenger rail connections between Philadelphia and Pittsburgh, dropping revenue of these lines to almost zero. Estimated travel by mode is displayed in Table 2. The estimated hyperloop ridership reflects a gradual ramp-up to 2040 service demand levels, as shown below.

Table 2 – Estimated All-Cities Travel by Mode (2040)

Hyperloop Scenario	Auto	Air	Hyperloop	Total	Induced Additional Demand
Pennsylvania Main Line Network (not including Scranton / Wilkes-Barre Branch)	13,825,000	11,000	5,530,000	**19,366,000**	15%
Between Scranton/Wilkes-Barre and Philadelphia	2,504,000	(No scheduled flights)	852,000	**3,356,000**	14%
New York City–All Pennsylvania	42,461,000	16,000	12,798,000	**55,275,000**	12%
Chicago–All Pennsylvania	7,954,000	94,000	13,327,000	**21,375,000**	46%
Chicago–New York City (not including Pennsylvania origins and destinations via Pittsburgh–Harrisburg–Allentown)	1,201,000	1,276,000	7,430,000	**9,907,000**	46%

Due to the speed at which hyperloop would travel, it would create new surface transportation markets for longer distance trips. Induced travel between Pennsylvania and Chicago, and between New York City and Chicago, is forecast at nearly 50%. It is anticipated that more than 5.5 million passenger trips would be made with hyperloop, within Pennsylvania, in 2040.

5.5M
Annual Passengers
(2040)

75%
Air Trips/Year
Shift to Hyperloop
(2040)

The analysis suggested 75% of air travel between Chicago and New York—75% of 4.4 million trips per year—would shift to hyperloop.

Pennsylvania Hyperloop Travel Times

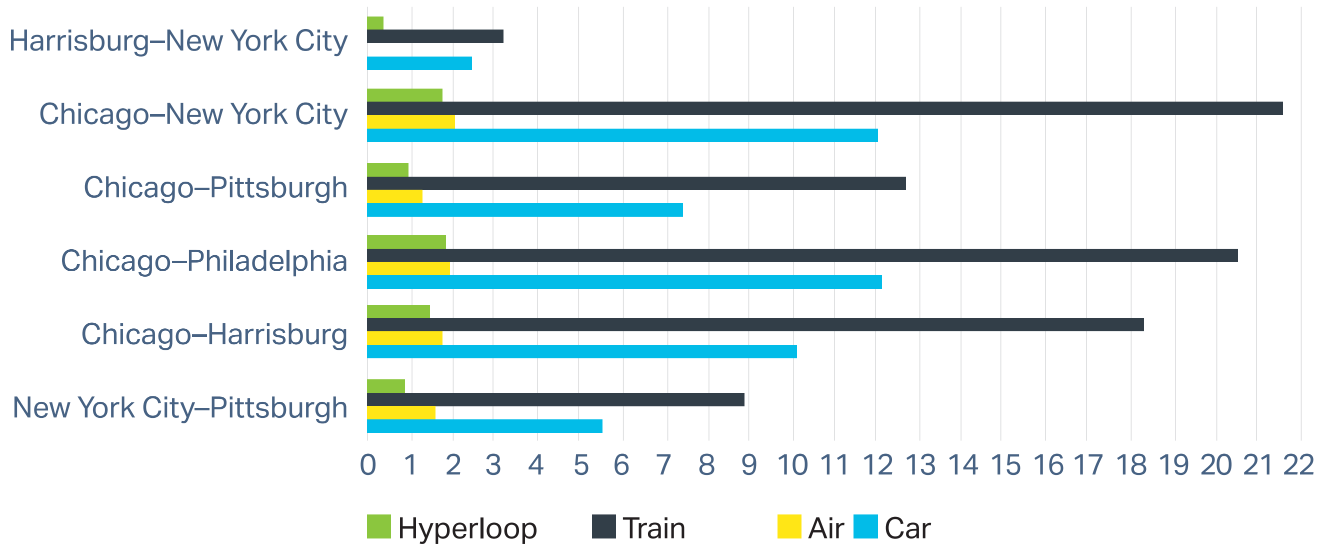
The All-Cities hyperloop Chicago-New York Metropolitan Area main line would be designed for theoretical travel speeds (roughly 500 mph, with the potential for faster travel along some segments). The Harrisburg-Philadelphia branch would travel more slowly at its endpoints, but could accelerate through Lancaster and Chester Counties. The entire network would be designed for express point-to-point service. Table 3 shows assumed All-Cities scenario travel times for both passengers and palleted freight between select city pairs.

Table 3 – Potential Pennsylvania Hyperloop Travel Times

City Pair	Travel Time
Chicago to Metro New York City (Newark, NJ)	2 hours
Chicago to Philadelphia International Airport	< 2 hours
Pittsburgh to Harrisburg	35 minutes
Pittsburgh to Philadelphia International Airport	1 hour
Harrisburg to Philadelphia International Airport	< 25 minutes
Harrisburg to Metro New York City (Newark, NJ)	25 minutes
Allentown to Metro New York City (Newark, NJ)	< 15 minutes
Allentown to Philadelphia International Airport	15 minutes
Scranton / Wilkes-Barre to Philadelphia International Airport	< 30 minutes
Scranton / Wilkes-Barre to Harrisburg	25 minutes
Scranton / Wilkes-Barre to Metro New York City (Newark, NJ)	25 minutes

Figure 7 displays a comparison of intercity travel times by air, train, car and hyperloop. The travel times reflect time within the vehicle or airliner and does not include time to get to a station or airport, or passage through security. Note that hyperloop is anticipated to be faster than even air travel between these cities, as taxiing, flight patterns and congestion are minimized or eliminated. For trips between downtown areas, this would eliminate the time for travel to and from an airport—which often requires more time than the onboard trip between cities. It is anticipated that trips between Harrisburg and the New York Metropolitan Area would be made via hyperloop and not through commercial air travel.

Figure 7 – Potential Corridor Travel Time by Mode (in hours)



Freight Movement

Truck Freight

An analysis of freight demand for hyperloop was conducted. The full analysis is located in Appendix C to this report.

200k
Truck Drivers
Needed could be fulfilled by Hyperloop

The introduction of hyperloop as a fifth mode of transportation has, in theory, the potential to dramatically alter the existing paradigm of freight movement. The Pennsylvania hyperloop would be able to operate on a 24-7 basis without the level of human safety limitations posed by the current trucking industry. Hyperloop could, in theory, be far more environmentally sustainable than existing modes of freight transportation, particularly short-haul flights that expend much of their energy during takeoff and while reaching cruising speed.

A complementary transportation system that allows for the ultra-fast movement of time-sensitive freight would allow companies to increase the size of the market they are able to service. In some cases, an improvement in freight movement times by a few hours could allow those companies or industries to access new global markets that they currently do not service.

Hyperloop firms are focused largely on passenger movements and preliminary vehicle designs which incorporate freight capabilities and would allow for palletized cargo only.

The introduction of mode choice for the movement of freight dovetails well into regional, state and national objectives of alleviating recurring road congestion; reducing wear and tear on the Interstate and regional highway systems; and reducing emissions from diesel trucks, locomotive engines and short-haul flights. Furthermore, the speed at which goods, particularly high-value goods, could be moved would further support the ubiquitous growth of e-commerce, and could be a compliment to Pennsylvania's extensive freight rail system.

The ability to move time-sensitive, high-value (TSHV) cargo more quickly, particularly when coupled with long-haul air freight, could improve the corridor's export capabilities. In addition, it could alleviate congestion throughout its intrastate network by shifting some road freight to hyperloop. In this way, hyperloop could aid in filling the need for more than 200,000 truck drivers throughout the country, or could prove effective in locations where there is an infrastructure gap or road construction that delays existing truck services. As shown in Table 4, the analysis assumes that by 2049, if the speed and cost of using hyperloop reaches the projected levels, a majority of TSHV freight in the immediate hyperloop corridor will shift from truck to hyperloop. TSHV accounts for 19% of roadway freight in Pennsylvania.

Table 4 – Temporal Rate of Time-Sensitive, High-Value (TSHV) Freight Diversion from Road to Hyperloop – All-Cities Scenario

Calendar Year	2030	2035	2040	2045	2049
Year of Operation	1	5	10	15	20 and beyond
Percentage of TSHV Road Freight Diverted to Hyperloop	5%	21%	40%	50%	60%

Air Freight

A Pennsylvania hyperloop scenario has the ability to reduce the need for a significant component of existing regional air freight services. It could potentially drive economic development through increasing the corridor's overall shipping capacity over time. Mode-shifting even a portion of freight from road to hyperloop vehicles would result in less congestion on the interstate systems (including the Commission's network of toll roads) and the generation of a variety of traditional economic benefits.

Air freight is fast, but expensive, and the total weight moved by air – less than 2% of the total ton-miles moved in the US – accounts for nearly 40% of the total freight value. Air freight is enabled by both lack of fixed guideways and by the hub and spoke airport system. International air freight makes up a significant proportion of the freight that is deplaned and enplaned at the major airports in the evaluated scenario.

Should hyperloop be introduced, airlines and truck freight shippers can be expected to adopt the new mode in their portfolios. This could have a negative impact on regional airports, depending on their need for express delivery and proximity to a hyperloop portal/station, as the cost of hyperloop could be competitive with that of other modes. Subsidies that fund more regional modes of transportation could be reduced, or eliminated, if hyperloop development is seen as a priority.

Economic Development

The project team undertook a very high-level, exploratory analysis of the potential wider economic impacts resulting from small increases in productivity brought about by the conceptual hyperloop system connecting Chicago to Philadelphia and New York via Pennsylvania markets and neighboring states. The project team utilized the 20-year historical gross regional product (GRP) growth for the major cities, at a Metropolitan Standard Area (MSA) level, along the proposed alignment, as shown in Table 5.

Table 5 – Gross Regional Product, Major Cities Along Pennsylvania Hyperloop – All-Cities Scenario (Chicago-Philadelphia-New York Hyperloop via Ohio and Pennsylvania) (MSA Level)[10]

Cities	2018 GRP (MSA Level) Billion $
Chicago, IL	411.7
Sample Indiana Market	21.8
Sample Ohio Market	97.8
Pittsburgh, PA	96.7
Harrisburg, PA	23.6
Allentown, PA	24.0
Philadelphia, PA	120.5
New York, NY	712.0
Total	**1508.1**

An increase in gross economic productivity of 0.05% (one twentieth of 1%) per annum was assumed for each year of the scenario's first 30 years of operation. The historical GDP growth for each MSA, as per growth experienced between 2001-2018, was assumed to be constant for all years of the assessment period. The annual productivity increase was then applied to the constant growth rate.

At the end of the assessment period, the aggregate GRP under the build (hyperloop) scenario is estimated to be approximately $115 billion higher per year than in the baseline (no hyperloop) scenario. Over 30-years of operation, the annual increase in productivity as a result of the operation of a Midwest to East Coast hyperloop scenario (All-Cities) results in an estimated aggregate augmentation of GRP achieved by these MSAs of approximately $1.5 trillion. In the Pennsylvania-Only scenario, linking just those cities in Pennsylvania, the aggregate augmentation of GRP is estimated to be approximately $260 billion over the same time period.

Image: Hyperloop Transportation Technologies

[10] Federal Reserve Economic Data. Accessed from https://fred.stlouisfed.org/release/tables? rid=397&eid=1057581&od=2001-01-01

Capital Costs

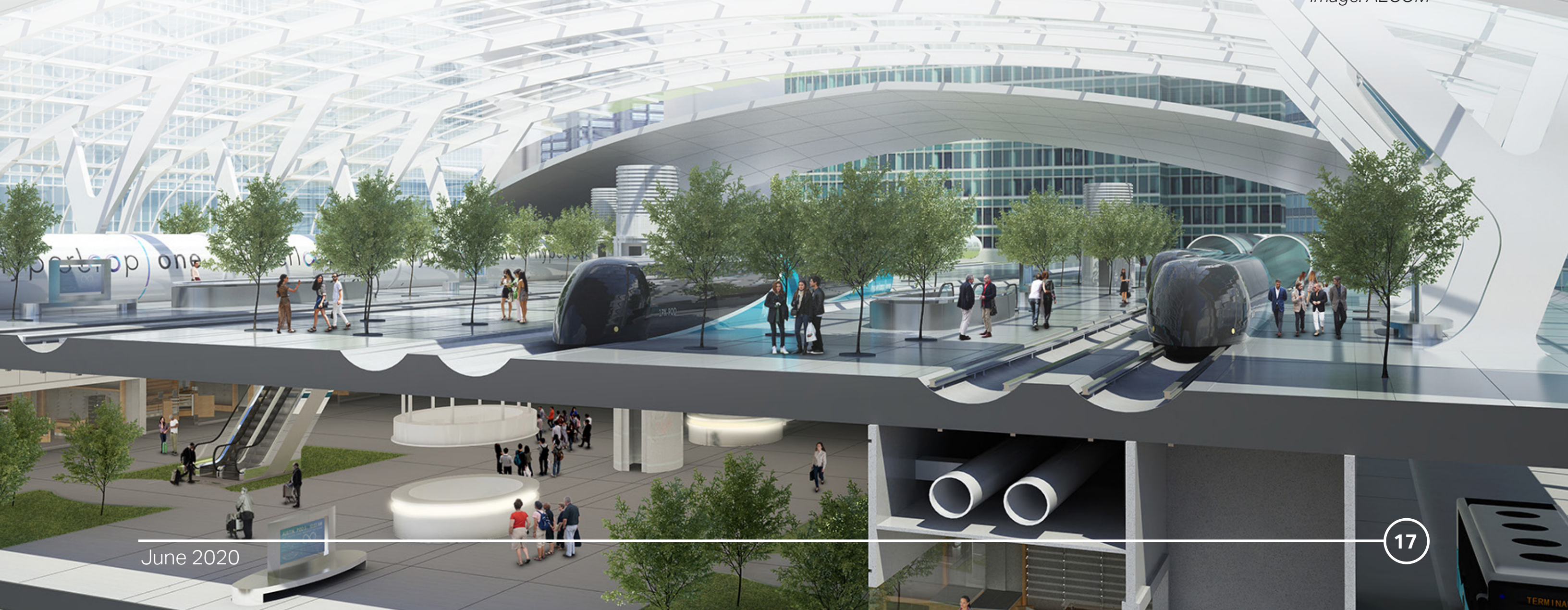
Cost estimates developed for the Pennsylvania-Only hyperloop scenario apply quantities of specific infrastructure elements as unit costs. Allocated contingency between 20 and 30% was then applied to each type of infrastructure. An unallocated contingency of 13% was applied to the total of the cost estimate, including those costs to which allocated contingencies were not applied (such as professional services). The estimate shown in Table 6 reflects only those costs for the hyperloop network within Pennsylvania.

Table 6 - Estimated Capital Cost for Pennsylvania Hyperloop (infrastructure within PA only)

Description	%Total Costs	Base Cost	Allocated Contingency	Total Cost
			Million $	
Guideway & Track Elements	46.5	24,508	4,487	28,996
Stations, Depots & Ancillary Structures	7.4	3,564	1,069	4,633
Support Facilities	3.2	1,540	462	2,002
Direct Cost Subtotal	57	29,612	6,018	35,630
Sitework & Special Conditions	10.5	5,019	1,506	6,525
Systems	1.5	950	0	950
Construction Subtotal	69	35,581	7,524	43,105
ROW, Land & Existing Improvements	0.6	302	91	392
Vehicles	1.1	712	0	712
Subtotal	87	46,558	7,615	54,172
Unallocated Contingency	13.0			8,126
Subtotal	100			62,298
Finance Charges	0.0			0
2020$ Total Project Cost	100			62,298
Escalation	15.9			9,923
YOE$ Total Project Cost	116			72,221

The cost for a complete All-Cities (Chicago to New York Metropolitan Area) hyperloop network would require a much greater investment than is shown in Table 6. Based on studies conducted in neighboring states, an additional $30 billion to $100 billion investment, outside of Pennsylvania, could be required to link Pennsylvania's hyperloop network with Chicago and New York City.

Image: AECOM



V. Benefit-Cost Analysis

Overview

A BCA was conducted for the proposed hyperloop network connecting Pennsylvania to Chicago and the New York Metropolitan Area. The analysis assumes a connection to Chicago via either northern or southern Ohio and Indiana (the "All-Cities" scenario). A separate BCA was developed for a potential alignment within Pennsylvania connecting the cities of Pittsburgh, Harrisburg, Allentown, and Philadelphia (the "Pennsylvania-Only" scenario). The Scranton / Wilkes-Barre hyperloop branch was not included in this evaluation as the costs for that segment outweighs benefits in this scenario. Should the Scranton / Wilkes-Barre hyperloop branch extend to major markets north of Pennsylvania, such as Toronto, that branch could be more cost effective, but further analysis would have to be conducted. The full BCA analysis is located in Appendix D to this report, but the results are as follows:

HYPERLOOP BENEFIT-COST ANALYSIS OVERALL FINDINGS (OVER 30-YEAR ANALYSIS)

- **$155 billion of user benefits generated in the All-Cities scenario**
- **$19 billion of user benefits generated in the Pennsylvania-Only scenario**

- **1.2:1 Benefit-Cost Ratio in the All-Cities scenario**
- **0.3:1 Benefit-Cost Ratio in the Pennsylvania-Only scenario**

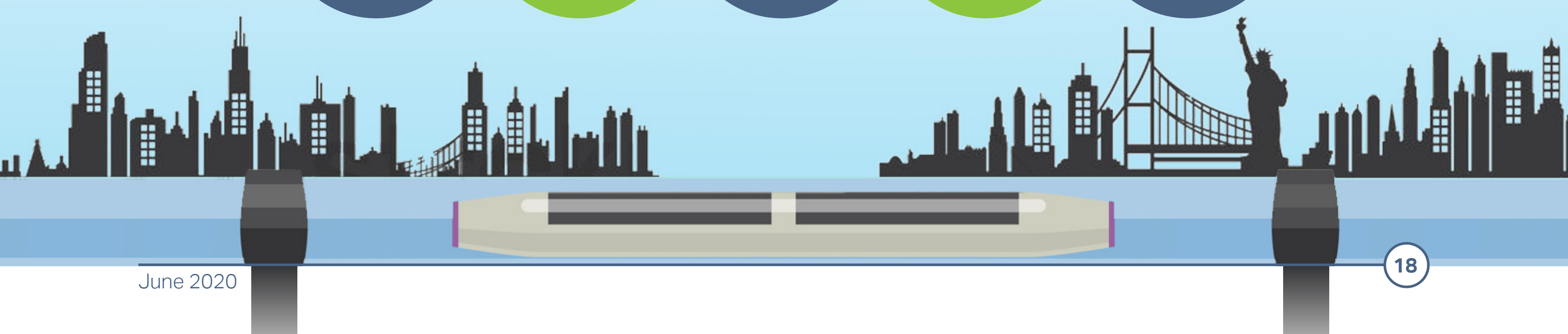
Using discounted capital costs, the actual cost of financing business activity through either debt or equity capital, would be between approximately $55 billion and $133 billion. This is detailed further in Appendix D.

The project team used the standard USDOT methodology for determining project progression, through a BCA analysis. The analysis concludes that an All-Cities hyperloop, operating between Chicago and the New York Metropolitan Area, through Pennsylvania, is estimated to generate more benefits than costs. The Pennsylvania-Only scenario , however, shows a much lower benefits-to-cost ratio reflective of lower levels of ridership and freight movement.

Key Findings from the All-Cities (Chicago to New York City Metropolitan Area) Scenario

Over its first 30-years of operations, the Pennsylvania hyperloop is estimated to generate:

- **500k** Vehicle Crash Reduction
- **2.5k** Fewer Fatalities
- **210B** Fewer Vehicle Miles Traveled
- **2.7B** Fewer Vehicle Hours Traveled
- **460M** Fewer Hours Traveled on Airplanes
- **125M** Fewer Hours Traveled on Trains
- **4B** Fewer Truck Miles Traveled
- **62M** Fewer Truck Hours Traveled
- **125M** Metric Tons Reduction CO2



An overview of the results of the BCA for the All-Cities scenario is shown in Table 7.

Table 7 – Pennsylvania Hyperloop Benefit-Cost Analysis: All-Cities Scenario – (2030-2059)- Discounted to 2019 dollars at 2.5%

Costs / Benefits	(Million $) 2019
Construction Costs	133,500
Economic Competitiveness	
Travel Time Savings (Auto)	30,400
Travel Time Savings (Commercial Trucks)	1,900
Travel Time Savings (Air)	10,170
Travel Time Savings (Train)	2,700
Travel Time Savings (Induced)	29,300
Operating Costs Savings (Auto)	21,000
Operating Costs Savings (Induced)	20,100
Operating Costs Savings (Commercial Trucks)	1,900
Safety	
Mode shift Safety Savings (Auto/Comm to HL, Including Induced Passenger)	32,400
Environmental Protection	
Mode shift Emissions Savings (Auto to HL)	4,573
Mode shift Emissions Savings (Air to HL)	838
Mode shift Emissions Savings (Train to HL)	201
Mode shift (Comm Truck to HL)	42
Total Benefits	155,600
Benefits Costs Ratio	1.2
Net Benefits	155,645

Source: AECOM

Key Findings from the Pennsylvania-Only Scenario

Under the Pennsylvania-Only scenario, over its first 30-years of operations, the Pennsylvania Hyperloop is estimated to generate:

60k Vehicle Crash Reduction

320 Fewer Fatalities

26B Fewer Vehicle Miles Traveled

320M Fewer Vehicle Hours Traveled

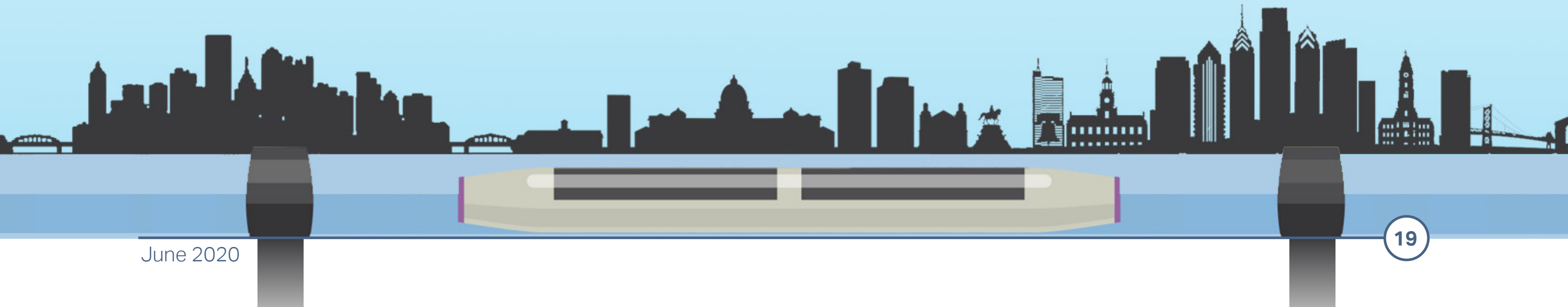
7M Fewer Hours Traveled on Airplanes

27M Fewer Hours Traveled on Trains

4B Fewer Truck Miles Traveled

5M Fewer Truck Hours Traveled

38M Metric Tons Reduction CO2



An overview of the results of the BCA for the Pennsylvania-Only scenario is shown in Table 8.

Table 8 – Pennsylvania Hyperloop Benefit-Cost Analysis: Pennsylvania-Only Scenario – (2030-2059) Discounted to 2019 dollars at 2.5%

Costs / Benefits	(Million $) 2019
Construction Costs	58,544.7
Economic Competitiveness	
Travel Time Savings (Auto)	5,683.7
Travel Time Savings (Commercial Trucks)	145.0
Travel Time Savings (Air)	145.7
Travel Time Savings (Train)	562.4
Travel Time Savings (Induced)	2,507.2
Operating Costs Savings (Auto)	3,265.1
Operating Costs Savings (Induced)	1,817.5
Operating Costs Savings (Commercial Trucks)	113.2
Safety	
Mode shift Safety Savings (Auto/Comm to HL, Including Induced Passenger)	3,977.8
Environmental Protection	
Mode shift Emissions Savings (Auto to HL)	652
Mode shift Emissions Savings (Air to HL)	7
Mode shift Emissions Savings (Train to HL)	41
Mode shift (Comm Truck to HL)	4
Total Benefits	18,922
Benefits Costs Ratio	0.32
Net Benefits	(39,623)

Source: AECOM

Not Implementing Hyperloop in Pennsylvania

This study concluded that the wider economic benefits from a hyperloop network linking Pennsylvania to New York City and Chicago exceed $1.5 trillion during the network's first 30 years of operation. This hyperloop network's passenger travel and freight delivery within Pennsylvania is valued at $260 billion in gross state product (GSP) over the same period. Thus, the opportunity cost to Pennsylvania should hyperloop bypass the state (such as an alignment around the mountains through upstate New York) is the anticipated benefit value minus the cost to implement hyperloop ($260 billion minus $65 billion), or roughly $195 billion over 30 years.

In addition, $1.7 billion of potential toll revenue loss (due to mode shift from road freight to hyperloop) over a 30-year analysis period was calculated. This represents approximately 5% of toll revenue over this time period, without considering toll increases.

Scorecard Evaluation

To help assess and illustrate the current hyperloop industry readiness, and potential impacts to Pennsylvania, a scorecard was created. (Figure 8). The evaluation was based on a 440-mile hyperloop concept network and analyzed the years 2030 through 2059. This assessment ranks the 14 most important criteria for Pennsylvania, as developed by the stakeholders participating in the study. These criteria were assessed using the following rating system:

- **Strong Potential** for implementation;
- **Good Potential** for implementation, but still various areas of question or technology infancy;
- **High Risk** for implementation, with great impediments that threaten success.

Figure 8 – Hyperloop Rating Criteria

CRITERIA	RATING*	DOMINANT REASON
		INDUSTRY READINESS AND COST
Overall State of Hyperloop Industry	!	Technology Readiness Level (TRL) for hyperloop has not successfully passed the large-scale demonstration and validation stage.
Safety / Security	X	Safety and security of hyperloop vehicles are still in the theoretical stage and have not demonstrated readiness for moving goods and passengers.
Policy / Regulation / Legislation	X	There have been limited federal policies, regulations and legislation on hyperloop. The Federal Railroad Administration (FRA) has limited guidance for Tier IV trains that travel over 220 mph.
Capital Costs	X	Capital costs for the Pennsylvania-Only hyperloop scenario are between $63 billion and $75 billion for 440 miles of system. The most significant physical impediment for Pennsylvania is its terrain.
Business Case	X	While there are economic benefits to building large transportation projects, including hyperloop within Pennsylvania, funding from either the private or public sector would be required. Assuming that initial capital funding is secured, the payback period could be between 40 and 100 years. At this time, there are no current or future allocated public or private funds for this project.
Economic Benefit	!	Increase to Pennsylvania's gross regional product (GRP) could be $260 billion over the first 30 years of operations with $19 billion in transportation benefits over the same period of time. Transportation benefits include travel times safety, savings, and mode shift emissions savings.
Productivity Loss	!	$197 billion potential opportunity loss over a 30-year period if hyperloop bypasses Pennsylvania. Toll minimum revenue loss of $1.7 billion over 30-year period (5% of toll revenue) due to diversion to hyperloop (assumes no toll increase).
		MOBILITY BENEFITS
Speed / Travel Time	!	The theoretical travel times between Pennsylvania cities and megaregions are: • 12 minutes – Allentown to New York City Metropolitan Area • 24 minutes – Harrisburg to New York City Metropolitan Area • 35 minutes – Pittsburgh to Philadelphia • 55 minutes – Pittsburgh to New York City Metropolitan Area • 60 minutes – Pittsburgh to Chicago • <2 hours – Philadelphia to Chicago • 2 hours – Chicago to New York City Metropolitan Area
Passenger Demand	!	Based on mode shift and comparable cost to traditional transportation methods, intra-Pennsylvania ridership could be between 4 million and 6 million annually. Interstate travel to Chicago and the New York City Metropolitan Area could be 30 million and 35 million riders annually.
Freight Demand	!	Intra-Pennsylvania freight movement could be approximately 700k tons annually. Interstate freight movement to Chicago and the New York City Metropolitan Area could be approximately 7 million tons annually.
Intermodal Connectivity	!	Scenarios for this report were created by taking into consideration intermodal connectivity to exiting airports, large logistics facilities and access to metro areas.
Major Markets Serviced	!	The Pennsylvania hyperloop could service the largest cities in the state including Philadelphia, Pittsburgh, Harrisburg, and Allentown. There is also the potential for a branch line to the Scranton/Wilkes Barre area.
Costs Savings from Existing Modes	!	Total passenger mode shift savings for Pennsylvania under the Pennsylvania-Only scenario would be approximately $19 billion over the 30-year analysis period via reduced travel times associated with driving, flying or riding the train. Under the All-Cities scenario, passenger mode shift savings would be approximately $155 billion over the same time period.
		ENVIRONMENTAL / SOCIAL IMPACTS
Economic Development	!	Under the All-Cities scenario connecting Pennsylvania to Chicago and the New York City Metro Area, a potential wider economic development benefit of $260 billion over 30 years, or an average of $8.5 billion annually, could be derived for Pennsylvania in increased Gross State Product (GSP) due to hyperloop-driven productivity increases.
Environmental Benefits	!	Approximately $700 million in emissions savings for the state under the Pennsylvania-Only scenario. Approximately $5.6 billion in emissions savings for Pennsylvania and neighboring states in the All-Cities scenario.

CRITERIA	RATING*	DOMINANT REASON
Right-of-Way Impacts	✗	The concept alignment assumes a hyperloop configuration near the Commission and PennDOT right-of-way. Main line segments require a potential horizontal curve 16x larger than those used for a roadway design at 70 mph, and limited existing Turnpike and PennDOT rights-of-way can be used.

Since the Technology Readiness Level (TRL) for hyperloop is not greater than Level 5, this study concludes that criteria could not be rated higher than Good Potential, assuming future advancement. TRL will be further described in Section II.

VI. Business Case

Preliminary Business Case Results

The preliminary hyperloop business case analysis studied two possible scenarios for the system. The first represents the estimated build cost for the entire Chicago to New York Metropolitan Area system (All-Cities scenario). The second is Pennsylvania-Only (PA-Only scenario). The full analysis is located in Appendix E of this report.

Based on preliminary estimates, the All-Cities scenario capital cost is $145 billion in Year of Expenditure (YOE) dollars. For the purposes of analysis, construction is assumed to start in 2022 with completion in 2029. The estimated capital cost for the Pennsylvania-Only scenario is $63 billion in YOE dollars with the same timeframe for construction.

Tables 9 and 10 present an analysis of two cost scenarios for both the All-Cities and PA-Only scenarios based upon high and low levels of operating, maintenance and capital replacement costs relative to revenues. These costs are estimated to be 70% of revenues for the high operating scenario and 52% for the low operating scenario, based upon averages of long-term net cash flow from operations from California High-Speed Rail Authority's (CAHSRA) forecasts. Revenues and costs have been escalated at an assumed inflation rate of 2.5% to forecast the cash flow profiles in year of expenditure dollars.

Table 9 - All-Cities Scenario Business Case

Capital Costs & Debt	Full System (O&M @ 70% of Revenue)	Full System (O&M @ 52% of Revenue)
Total Capital Required (2030 YOE, Million $)	$145,000	$145,000
Operations 2030 (Base Year $)		
Annual Escalation	2.50%	2.50%
Year 1 Passenger Revenue/year (Million $)	$3,682	$3,682
Year 1 Freight Revenue/year(Million $)	$854	$854
Total Revenue	$4,535	$4,535
Year 1 O&M and Lifecycle (Million $)	($3,175)	($2,177)
Year 1 Net Cash Flow (Million $)	$1,361	$2,358
Cash Flow Analysis (2030-2080)	Million $	
Total Passenger Revenue	$450,050	$450,050
Total Freight Revenue	$390,843	$390,843
Total Revenue	$840,893	$840,893
Total O&M and Lifecycle	($588,625)	($403,629)
Public Capital Payback	($145,000)	($145,000)
Cumulative Pre-Tax Net Cash flow	$107,268	$292,264
Estimated Years to Recover Capital	40 Years	30 Years

Table 10 – Pennsylvania-Only Business Case

Capital Costs & Debt	PA-Only System (O&M @ 70% of Revenue)	PA-Only System (O&M @ 52% of Revenue)
Total Capital Required (2030 YOE, Million $)	$63,000	$63,000
Operations 2030 (Base Year $)		
Annual Escalation	2.50%	2.50%
Year 1 Passenger Revenue/year (Million $)	$863	$863
Year 1 Freight Revenue/year (Million $)	$146	$146
Total Revenue	$1,009	$1,009
Year 1 O&M and Lifecycle (Million $)	($706)	($484)
Year 1 Net Cash Flow (Million $)	$303	$525
Cash Flow Analysis (2030-2080)	**Million $**	
Total Passenger Revenue	$97,677	$97,677
Total Freight Revenue	$43,587	$43,587
Total Revenue	$141,264	$141,264
Total O&M and Lifecycle	($98,885)	($67,807)
Public Capital Payback	($63,000)	($63,000)
Cumulative Pre-Tax Net Cash flow	($20,621)	$10,457
Estimated Years to Recover Capital	65 Years	50 Years

A hyperloop project that spans the length of Pennsylvania either as a standalone system or connecting to the wider New York to Chicago system is likely to be a significant undertaking for the state both from a financial resourcing and human resourcing perspective.

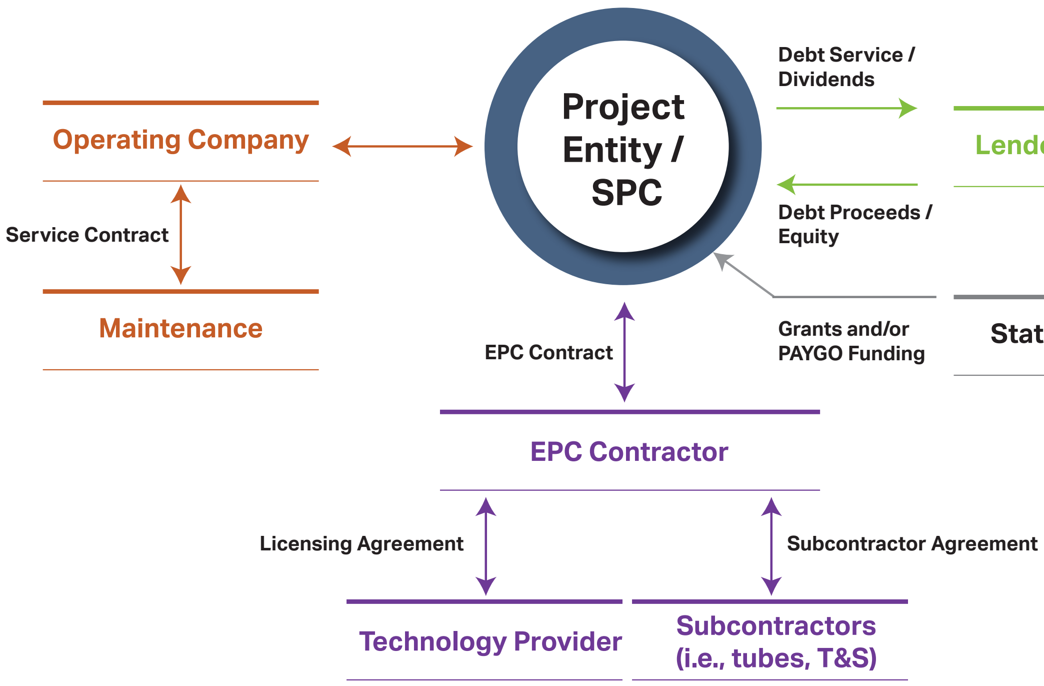
Projects of this nature are rarely self-sustaining and must find a public sponsor to succeed. From a funding/financing and procurement point of view, a hyperloop project would not differ significantly from the delivery of any other large piece of transportation infrastructure and would be guided by the same principles and requirements to demonstrate financial viability or source public funding and subsidy.

Image: TransPod Inc.

Business Model Options

To execute the full commercial deployment of hyperloop, the industry would likely require management and execution expertise from an array of financiers, contractors, operating companies and technology providers/vendors along with the support of a robust regulatory framework. Together, these entities could form the business model that brings hyperloop operation to reality. The primary and most immediate goal is proof of concept. Figure 9 provides an example of potential participants in the eventual business model configuration. The special purpose company (SPC) would be a contractual entity created by a lender/financier, an operating company, an engineering, procurement and construction (EPC) provider, and specialty technology and service (T&S) companies, which would work together to provide a turnkey design-build-finance-operate-maintain (DBFMO) solution. Consortium members included would be similar to those shown in the exhibit.

Figure 9 – Potential Hyperloop Business Model



Project Funding Options

Funding for a hyperloop network could be accessed from a wide variety of sources, as shown in Figure 10. The project would likely need a diverse funding and financing program to accommodate the significant level of capital expenditure required to bring the project to operations.

Figure 10 – Potential Funding Options

The public sector (at the local, state and federal levels) and the private sector (through private equity and debt facilities) could contribute to the full funding package. Much of the access to funding, particularly from private sources, would be dictated by the robustness of the final business case that is presented.

To a large extent, access to any of the public funding options presented above is highly dependent on the regulatory framework that would most likely be instituted at the federal level for hyperloop. This is noted as a key milestone for which the industry is actively seeking clarity.

Public sector funds can generally be divided into two categories for the purposes of understanding project funding: grants and loans (debt).

Grants – Grants are awards of funding that do not require any payback from the project. In this sense they provide the best form of funding available because they come at a zero cost of capital to the project. It is common for grants to be a component of most large-scale infrastructure projects.

The FY 2020 Appropriations Act specifies that Better Utilizing Investments to Leverage Development (BUILD) Transportation grants must be between $5 million and $25 million. The difference between the estimated hyperloop project costs and available federal funding through this grant program, demonstrates the challenge of funding hyperloop in Pennsylvania with federal grants. Since these national infrastructure grants have been created, $8 billion has been awarded for capital investments in surface transportation infrastructure over eleven rounds of competitive grant opportunity.

Public Sector Debt – Public sector debt can come in numerous forms. Fundamentally, its repayment is either conditional on a pledge from the revenues derived from the project or it is pledged by the full faith and credit of the government.

- The Transportation Infrastructure Finance and Innovation Act (TIFIA) program provides credit assistance for qualified projects of regional and national significance.
- The Railroad Rehabilitation and Improvement Financing (RRIF) program was established by the Transportation Equity Act for the 21st Century (TEA-21) and amended by the Safe Accountable, Flexible and Efficient Transportation Equity Act: a Legacy for Users (SAFETEA-LU). Under this program the FRA Administrator is authorized to provide direct loans and loan guarantees up to $35.0 billion to finance development of railroad infrastructure.
- Private Activity Bonds (PABs) are debt instruments authorized by the Secretary of Transportation and issued by a conduit issuer on behalf of a private entity for highway and freight transfer projects, allowing a private project sponsor to benefit from the lower financing costs of tax-exempt municipal bonds. The law limits the total amount of such bonds to $15 billion and directs the Secretary of Transportation to allocate this amount among qualified facilities.

Private Sector Debt – Private debt and equity is available in a range of forms for infrastructure projects. However, the conditions for private sector participation are specific and generally driven by risks such as:

- Acquisition of right of way
- Environmental permitting process
- Technology development
- Cost uncertainty
- Schedule uncertainty
- Return horizon
- Ridership and revenue forecast

Key Business Case Elements

The key considerations for evaluating a business case for most infrastructure projects involve the assessment of the following:

The project team has reviewed the high-level costs against current estimates of CAHSRA's most recent capital cost projections. This program was chosen as a comparator because:

- The right of way and environmental permitting costs would likely be similar
- The civil works elements including tunnels, bridges, viaducts and elevated sections which form a significant component of the overall program cost are reasonably similar to those required for hyperloop
- The stations and exteriors may share similar attributes

According to CAHSRA's Draft 2020 Business Plan, the base case YOE cost estimate for Phase 1 of its build-out is $80 billion, with a projected range between $63 billion and $98 billion, or $150 million per mile with a projected range of $120 million to $190 million per mile. As discussed previously, the project team's full system YOE estimate is approximately $145 billion or $150 million per mile and the PA-Only YOE estimate is approximately $63 billion or $145 million per mile.

These hyperloop project estimates are relatively close to the range of the CAHSRA estimate, which implies that the project team's estimate is within a reasonable order of magnitude. It is noted that the project preliminary estimate is a Class 5 estimate that is based on 0% to 2% project definition whereas the CAHSRA estimate is supported by more substantial engineering work that has been completed to date. It should be noted that this comparison only presents an indicative result to provide some frame of reference.

Another significant element of any business case assessment is the socio-economic benefits that the project is forecast to bring. Preliminary project estimates indicate that a hyperloop system can generate substantial economic benefits over a period of 30 years. Below is a high-level break-down:

- Productivity increases could lead to $260 billion in wider economic benefits for the State of Pennsylvania
- Passenger and freight service in Pennsylvania could lead to approximately $20 billion in user and environmental benefits.

VII. Next Steps

This study concludes that hyperloop has not yet advanced to the point of commercial viability, nor is there significant capital and a compatible business plan for Pennsylvania to advance studying the technology's implementation within the state. The state maintains a position where it would provide support, where applicable, to support the industry leaders. The implementation of hyperloop would require partnerships with both the private and public sectors for both funding and right-of-way alignments that can accelerate and streamline implementation.

Full scale deployment is still unproven to reach to the top speeds promoted. Safety and legislative regulations have not been created.

Regional opportunities, threats and dependencies exist. Interest from the Midwest, New York State, West Virginia, Maryland, Delaware and Canada are potential threats for Pennsylvania being bypassed by hyperloop. This could equal an opportunity loss approaching an estimated $195 billion over 30-year period.

The financial viability of hyperloop has yet to be proven. Pennsylvania needs to further investigate the financial implications of hyperloop as the current benefit-cost ratio, capital costs required, and business case of the project do not support advancement at the present time. Once full-scaled testing and commercialization have matured, then Pennsylvania should re-evaluate the business case.

Where Do We Go from Here?

This report provided an initial overview of hyperloop and the current technology readiness, including existing policies and legislation, technological development and safety standardization. An illustration of a high-level scenario, meeting the intent of HR-1057, was created to be used as the basis for costs, potential revenue, benefits and impacts of hyperloop in Pennsylvania. Estimations of the potential economic opportunity cost to Pennsylvania should hyperloop be routed around Pennsylvania were provided. An initial business case for hyperloop in Pennsylvania and partnerships was outlined.

The following strategies are offered to position Pennsylvania for success should hyperloop technology advance in neighboring states as a reliable and safe transportation option:

Proactively Monitor

- Stay informed on the progression of technology: Schedule annual conference calls with the technology providers to keep abreast of hyperloop industry advancements, infrastructure and operations and maintenance (O&M) costs.
- Monitor the construction of and operational results from national and international testing and certification centers: Engage neighboring states, on an annual basis to discuss the advancement of hyperloop including implementation of a certification and/or test center, and other defined national focus topics.
- Examine the progression of the Great Lakes and Midwest Connect hyperloop studies to keep abreast of project advancement.

Develop Partnerships

- Should neighboring states advance hyperloop scenarios, participate in a coalition of states, from New York to Illinois, with the charge to review the study of an All-Cities hyperloop scenario. On a semi-annual basis, discuss hyperloop during existing coalition meetings or forums to strategize on the All-Cities scenario to minimize risk and maximize benefits, discuss hyperloop advancements, review national/international deployments, and create a multi-state roadmap, if appropriate.
- Coordinate efforts between state, Commission, and legislative members to participate on the USDOT Non-Traditional and Emerging Transportation Technology (NETT) Council to stay informed of federal advances in hyperloop and other technologies. Report to state agencies and the Pennsylvania legislature annually on NETT Council activities.
- Meet annually with tunneling and infrastructure partners to understand new construction means and methods.
- Schedule an annual meeting with local partners (i.e., Chambers of Commerce, airports, logistics companies, manufacturing) or through existing planning partners and/or PennDOT meetings to share hyperloop information.

Business Plan Updates

- Review the pro-forma business case as major changes in technology readiness occur.
- Review new funding mechanisms for hyperloop to determine project interest from both the private and public sectors.

Image: Virgin Hyperloop One

For more Information

The Pennsylvania hyperloop study is evaluating this paradigm shift in transportation.

To learn more about the project, please contact:

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Image: Virgin Hyperloop One