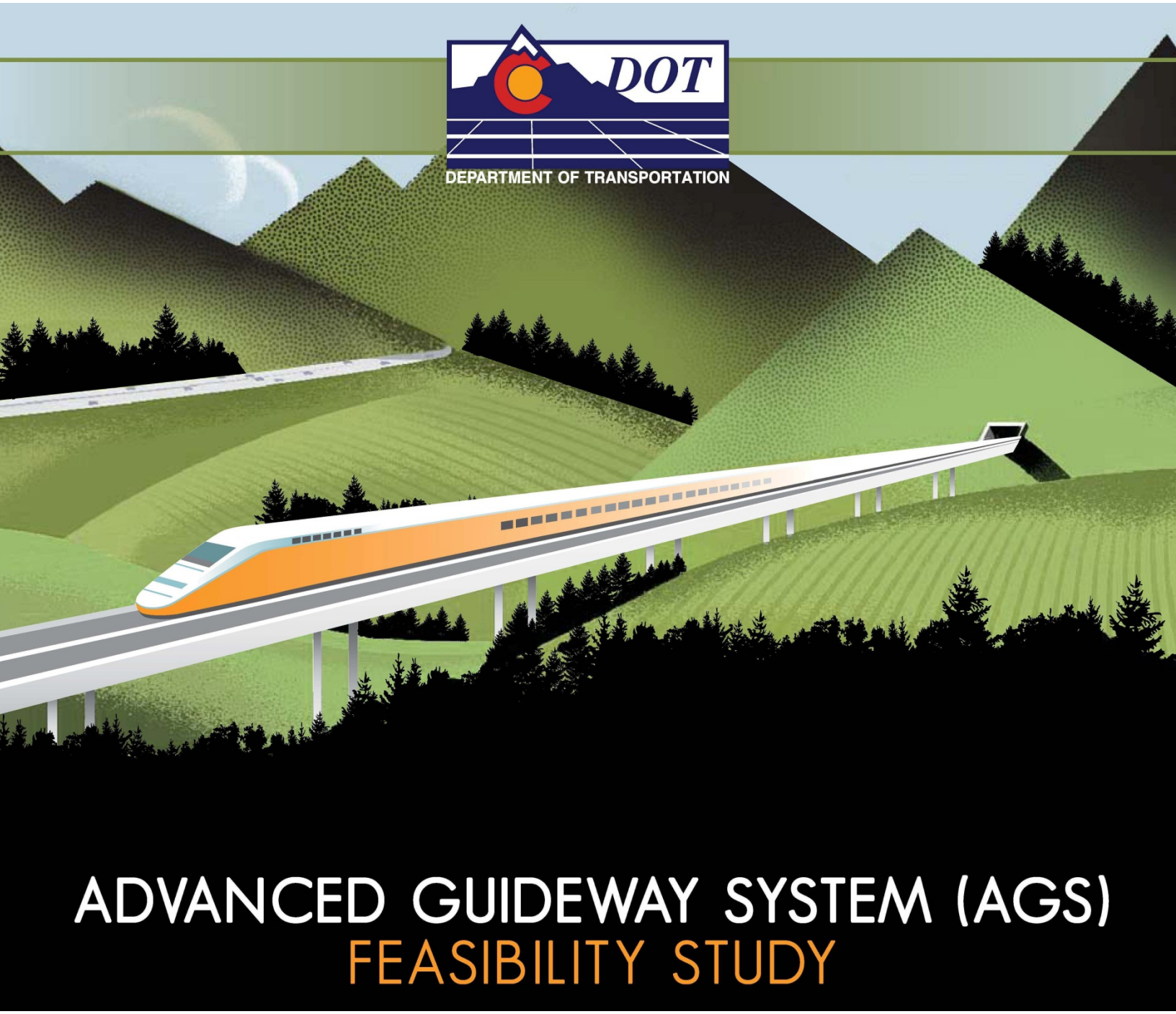


ADVANCED GUIDEWAY SYSTEM (AGS)
FEASIBILITY STUDY

CHAPTER 2
TECHNOLOGY EVALUATION

Chapter 2 Technology Evaluation

2.1 Overview

The first step in assessing the feasibility of an AGS was to determine if there are existing high-speed transit systems (technologies)—or systems in a sufficient stage of development—to overcome the unique challenges posed by the I-70 Mountain Corridor and that meet the desired system performance and operational criteria developed for the AGS.

This chapter documents the technology evaluation process used by the AGS Study Team to identify and evaluate high speed transit system technologies that were considered further in the development of alignments discussed in Chapter 3.

The Technology Evaluation process included:

- *Development of System Performance and Operational Criteria*
- *Solicitation of Statements of Technical Information from technology providers*
- *Evaluation of the Statements of Technical Information*
- *Hosting of a Technology Forum and Technology Presentations*

2.2 System Performance and Operational Criteria

To specify to potential technology providers what types of technology might be appropriate for the I-70 Mountain Corridor, the AGS Study Team developed a set of System Performance and Operational Criteria. The criteria describe the desired attributes of the AGS, as envisioned in the Final PEIS and ROD. The AGS Study Team worked with the AGS Technical Committee, AGS PLT, and technology providers to refine and expand the Final PEIS and ROD performance criteria.

System Performance and Operational Criteria for the AGS were developed by refining and supplementing the Collaborative Effort's Consensus Recommendation, which included AGS Technology Performance Criteria.

During the development of the Final PEIS, the I-70 Coalition Technical Committee, as part of the Collaborative Effort team's Consensus Recommendation, included in Attachment B: AGS Technology Performance Criteria, a list of performance criteria that could be useful in evaluating viable AGS technologies. The envisioned AGS technologies included both those that currently exist and those that were in the research and development phase. The criteria were not meant to be detailed, specific, and definitive, but were intended to serve as a basic evaluation tool for AGS studies. These performance criteria were used as the basis for development of the System Performance and Operational Criteria for this *AGS Feasibility Study* (Study).

The AGS Study Team reviewed the Collaborative Effort team's AGS Technology Performance Criteria with the AGS Technical Committee at two three-hour meetings held June 11 and

June 14, 2012. The purpose of the meetings was to refine, define, and develop the System Performance and Operational Criteria for evaluation of technologies.

The AGS PLT met on June 13, 2012, to discuss the proposed criteria developed by the AGS Technical Committee and endorsed the following refinements to the criteria:

Alignment – The AGS PLT recognized that the station locations were the driving factors for alignment. They concluded that the station locations were the most important criterion, not where the AGS is located in relation to I-70. This is particularly true for crossing the Continental Divide and for serving dispersed origins & destinations in Summit County.

Triggers in the ROD – The AGS PLT indicated that the 2025 trigger included in the ROD was meant to be a guide, not a drop-dead date. They explained that the Collaborative Effort did not intend for the Maximum Program of Improvements for the highway to be triggered if the AGS were deemed feasible before 2025, but not fully constructed and operational. They agreed that the AGS Study Team should challenge the industry to fund and/or complete the AGS by 2025. If an industry team could not meet that goal, the AGS Study Team should propose when and how the AGS could be completed.

Termini – The AGS PLT agreed that incremental development of the AGS would be acceptable and that the industry should determine the location of the first phase within the general parameters of the Final PEIS, which stated termini in the Denver metropolitan area and somewhere west of the Continental Divide. They also felt that the market should determine when the remainder of the system would be constructed.

Station Locations – The AGS PLT agreed that the AGS must serve the four corridor counties (Jefferson, Clear Creek, Summit, and Eagle Counties) and that the industry should propose the best solutions to serve them.

Land Use Considerations – The AGS PLT agreed that transit-oriented development (TOD) and development rights should be allowed or encouraged around stations, depending on the unique needs/situation of each community. They also indicated that rezoning most likely would need to occur. The local communities were also encouraged to begin crafting land use policies and/or plans for potential station locations if they had not already done so.

Right-of-Way – The AGS PLT agreed that it should be assumed that CDOT and the local governments would commit to obtaining all necessary right-of-way, noting that right-of-way is an important asset of the local communities.

Interface with Existing and Future Transit Systems – The AGS PLT acknowledged that it would be a responsibility of the local agencies to provide transit systems that would connect to and from the AGS station to local destinations. They also agreed that the local communities would be responsible for identifying solutions for connecting AGS passengers to other destinations, such as trail heads and campgrounds which are not typically served by conventional transit.

AGS Governance Authority – The AGS PLT agreed that the AGS would need to have some level of public oversight and asked the AGS Study Team to look into the governance options and provide details for further discussion. It was noted that the I-70 Coalition would soon be a Transportation Management Organization, and that should be considered during the evaluations.

Potential System Owner/Operator – The AGS PLT indicated that they would not support a wholly-owned private system. Rather, they would prefer a level of public ownership, like that of a transit authority.

Travel Time – The AGS PLT suggested that travel time be based on time and not speed. A suggestion was 45 minutes from Golden to Frisco and 60 minutes from Golden to Vail.

Technology Transfer – The AGS PLT indicated that allowing a technology provider to lease a proprietary technology that would eventually become publicly owned/controlled was a desirable criteria. This would increase the likelihood that a new or currently proprietary technology for the I-70 Mountain Corridor could become part of a national system. There was strong recognition that use of a proprietary technology could be a severely limiting factor in garnering private sector interest to fund and/or finance the system.

This input was taken back to the AGS Technical Committee on June 14, 2012, and the Draft AGS System Performance and Operational Criteria were prepared by the AGS Team and forwarded to the AGS PLT for review. On August 8, 2012, the AGS PLT provided final comments on the Draft AGS System Performance and Operational Criteria. The comments were addressed, and on August 31, 2012, the AGS PLT endorsed the Final AGS System Performance and Operational Criteria, which are included in Appendix A.

2.3 Request for Statements of Technical Information

To identify potential AGS technologies, CDOT used a Request for Statements of Technical Information (RFSOTI) to technology providers. The AGS Study Team began preparation of the RFSOTI in August 2012 for review. The Draft RFSOTI was forwarded to CDOT, the AGS PLT, and the AGS Technical Committee on August 22, 2012. After addressing comments, the Final RFSOTI was completed and posted on CDOT's website on September 7, 2012.

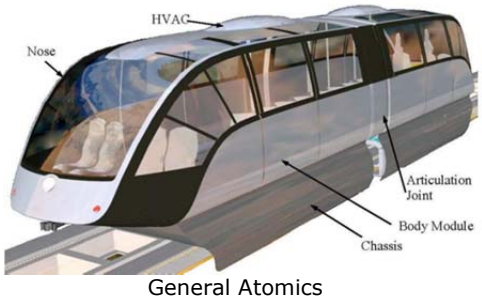
The RFSOTI requested information and data concerning the following criteria:

- Travel Time
- Vehicles
- Noise
- Footprint and Context Sensitive Solutions
- Grade (for various significant locations)
- Safety
- Weather and Wind
- Scalability and Growth
- Passenger Comfort
- Baggage Capacity
- Distribution
- Energy Efficiency
- Sustainability
- Cost
- Termini
- Right-of-Way
- Interface with Existing and Future Transit Systems
- Potential System Owner and Operator
- Technology at System Stations

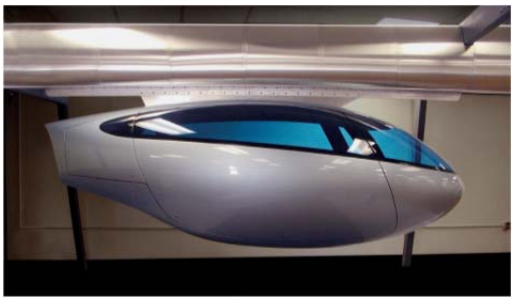
- Freight
- Tunnels
- Reliability
- Headway
- Power Generation, Transmission, and Additional Technology Information
- Propulsion System
- Operation Control System
- Performance
- Environmental Considerations
- Technology Readiness

The RFSOTI included a requirement for the technology providers to participate in a webinar conducted by CDOT and the AGS Study Team. The first webinar was held on September 19, 2012, and repeated so that all technology providers had a chance to fulfill this obligation.

American Maglev



General Atomics


SkyTran


Talgo


TransRapid

CDOT issued three addenda to address questions. The Final RFSOTI, which includes the addenda issued through September 25, 2012, is included in Appendix B.

The SOTI were due to CDOT on October 10, 2012. CDOT received 18 SOTIs from the following technology providers:

- American Maglev
- ET3
- Flight Rail
- General Atomics
- Kestrel
- MagneMotion
- Mediatrik/Techtronics
- MegaRail
- Monobeam
- Owen Transportation Group
- Personal Rapid Transit Consulting
- Public Personal Rapid Transit Consortium
- Roane Inventions (TriTrack)
- SkyTran
- Swift Tram
- Talgo
- Tubular Rail
- TransRapid

After review of the submittals, CDOT sent Requests for Clarifications to technology providers to obtain more detail or information on October 24, 2012. The clarifications were received on October 29, 2012.

2.4 Evaluation of SOTIs

The AGS Study Team developed the evaluation guidelines for the SOTIs in conjunction with the AGS Technical Committee. They are included in Appendix C. It should be noted that the RFSOTI stated that the results of this evaluation process would not preclude technology providers from future involvement in an AGS on the I-70 Mountain Corridor.

The evaluation was a two-step process conducted by a Consultant Review Team. The role of the Consultant Review Team was to make recommendations to CDOT about which technologies would meet each of the system performance criteria, the operational criteria, and the Technology Readiness Level requirements; and which technology providers would be invited to participate in a Technology Forum.

2.4.1 Qualification Criteria

The first step was an evaluation according to the technology providers' responses to six of the qualification criteria. These criteria were used because they reflected the core requirements of the ROD and the criteria established by CDOT with endorsement from the AGS PLT.

Statements of Technical Information were first evaluated for six key Qualification Criteria that needed to be met for the technology to be qualified for further review by the AGS Study Team

Qualification Criteria 1 – Travel Time (RFSOTI Section 3.1) – How the technology would meet the minimum speed requirements and provide a minimum capacity of 4,900 passengers per hour in the peak direction by 2035.

Qualification Criteria 2 – Grade (RFSOTI Section 3.5) – How the technology could cost-effectively traverse the grades within the I-70 Mountain Corridor.

Qualification Criteria 3 – Safety (RFSOTI Section 3.6) – How technology providers would meet applicable passenger safety standards and test data or system expectations concerning safety. These included how the technology addressed vehicle/system safety

requirements to provide grade-separated and wildlife crossings; an access-controlled guideway; emergency egress from the vehicles and guideway, including guideway on structure and guideway in tunnels; and system security.

Qualification Criteria 4 – Weather / Wind (RFSOTI Section 3.7) – How the technology could operate in severe weather events and extreme alpine windstorms while still maintaining safety and reliability.

Qualification Criteria 5 – Light Freight (RFSOTI Section 3.11) – How the technology would be able to accommodate light freight.

Qualification Criteria 6 – Technology Readiness (RFSOTI Section 3.25) - How the technology would meet the Technology Readiness Level (TRL) requirement of TRL 9 by 2017. This was a primary requirement of the candidate technologies. The Consultant Review Team assessed the technology provider's verified plan to attain TRL 9 by 2017 and evaluated it based on the current TRL and the demonstrated ability to reach TRL 9 by 2017.

The Consultant Review Team gave a grade of either "Pass" or "Fail" for each of the criteria. If the technology did not receive a "Pass" for all six of the criteria, the SOTI was deemed incomplete/non-responsive, and it was not included in the next level of evaluation.

The Consultant Review Team provided CDOT a list of the 11 technology providers who qualified to pass to the next level of review, along with the reasons why some of the technology providers were not qualified. The results of the Qualification Criteria evaluation are shown in Table 2-1.

Table 2-1: Qualification Criteria Scoring

	Qualification Criteria						
Technology Provider	**1 Time**	**2 Grade**	**3 Safety**	**4 Weather**	**5 Freight**	**6 TRL**	**Qualified**
American Maglev	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ET3	Yes	Yes	**No**	Yes	Yes	**No**	**No**
Flight Rail	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General Atomics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kestrel	**No**	**No**	**No**	**No**	**No**	**No**	**No**
MagneMotion	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mediatrik/Techtronics	**No**	**No**	**No**	**No**	**No**	**No**	**No**
MegaRail	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monobeam	Yes	**No**	**No**	**No**	**No**	**No**	**No**
Owen Transportation Group	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Personal Rapid Transit Consulting	**No**	Yes	Yes	Yes	Yes	Yes	**No**
Public Personal Rapid Transit Consortium	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Roane Inventions (TriTrack)	Yes	Yes	Yes	Yes	Yes	**No**	**No**
SkyTran	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Technology Provider	Qualification Criteria						
	1 Time	2 Grade	3 Safety	4 Weather	5 Freight	6 TRL	Qualified
Swift Tram	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Talgo	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TransRapid	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tubular Rail	**No**	**No**	**No**	Yes	Yes	**No**	**No**

2.4.2 Additional Evaluation Criteria

During the second step of the process, the Consultant Review Team reviewed and evaluated the 11 technology providers against all other criteria. Their evaluations concentrated on developing an understanding of the strengths and weaknesses of each of the technologies. During this step, a Secondary Evaluation Team divided the SOTIs into Technology Groups. Those groups were:

Technology Group 1 – Technologies that could be operated wholly within the I-70 right-of-way (except to deviate to stations). The following technology providers were included in Technology Group 1: PPRTC, SkyTran, SwiftTram.

Flight Rail

Technology Group 2 – Technologies that could not operate within the I-70 right-of-way because of grade or curvature issues. The following technology providers were included in Technology Group 2: Talgo, TransRapid. High-speed rail, represented by the Talgo submission, requires flatter grades (maximum grade of approximately 2 percent) and, therefore, cannot operate alongside I-70, which has many grades greater than 2 percent. Both high-speed rail (Talgo) and high-speed maglev (TransRapid) technologies require broader, more sweeping curves to travel at speeds of 150 to 200+ mph than the narrower highway curves in the I-70 alignment, which are limited by passenger comfort tolerances.

Swift Tram

Owen Transit Group

Technology Group 3 – A hybrid of the first two groups, these technologies could operate within the I-70 right-of-way for a significant portion of the route, but would have to deviate from the right-of-way in places because of grade or curvature. The

MegaRail

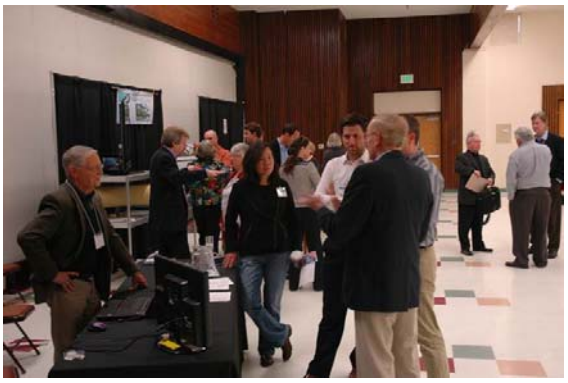
following technology providers were included in Technology Group 3: American Maglev Transit, Owen Transit Group, MegaRail, General Atomics, Flight Rail, and MagneMotion.

The Secondary Screening Team submitted a Recommendation Memo dated November 8, 2012, to CDOT DTR, the AGS PLT, and the Technical Committee describing the technology providers in each Technology Group that were recommended for further evaluation. Those recommended providers would attend a public Technology Forum and have the opportunity to present.

On November 14, 2012, the AGS Study Team presented the results of the SOTI review to the AGS PLT. The AGS PLT endorsed the evaluation and the recommendation that the 11 technology providers participate in the Technology Forum, and which 5 would present.

2.5 Technology Forum and Presentation

To allow the AGS Study Team, CDOT staff, and the public to learn more about the various technologies, a Technology Forum was held on December 13, 2012, at the Jefferson County Fairgrounds. Each of the 11 technology providers was provided space in which to exhibit their technologies and interact with the attendees. Table 2-2 shows the participants at the Technology Forum. Four of the invited technology providers did not attend the forum.



Technology Forum

Table 2-2: Technology Forum Attendees

Technology Provider	Public Forum Booth	Presented at Forum
American Maglev	Yes	Yes
FlightRail	Yes	No
General Atomics	Yes	Yes
MagneMotion	No	No
MegaRail	Yes	Yes
Owen Transit Group	No	No
PPRTC	Yes	Yes
SkyTran	Yes	No
Swift Tram	Yes	No
Talgo	No	Yes
Transrapid	No	No

The public part of the Technology Forum was well-attended by 300 members of the public. In addition, both print media and television reporters were present.

Five representative technology providers were invited to make confidential presentations to a Technical Review Panel of CDOT staff, State Transportation Commissioners, elected officials, the AGS PLT and Technical Committee, and the AGS Study Team. These presentations, which occurred on December 13 and 14, 2012, at the Jefferson County Fairgrounds, consisted of a 45-minute presentation by the technology provider followed by 60 minutes of in-depth discussion and questions.

Each of the five technology providers addressed the following during their 45-minute presentation:

Technology Forum Presentation

- Provide an overview of the technology and the SOTI.
- Describe the plan for stations and maintenance facilities, including size and possible locations.
- Describe how safety certifications will be obtained and explain the performance characteristics of the system, especially with respect to severe weather conditions and terrain (grade) challenges.
- Describe how the system will meet the operational capacities specified in the RFSOTI and how headways will be managed considering offloading of baggage and gear associated with mountain activities (bikes, skis, snowboards, etc.). Also, describe how the system could be expanded to include branch lines and additional stations.
- Describe estimates of cost for infrastructure (cost per mile) and rolling stock. Also, describe how cost efficiencies might be realized and where major system components will be built.
- Describe how the system will interface with other travel modes and how it will accommodate light and heavy freight.

Following the 45-minute presentation, the Technical Review Panel engaged the technology providers in a 60-minute interactive discussion of various elements of the technology and questions they had about the technology provider's SOTI.

2.6 Technology Evaluation Findings

After the Technology Forum, the AGS Study Team and project stakeholders determined that there were several items that would prevent a definitive recommendation for potential technology providers. These are described in the following sections.

2.6.1 Cost Estimates

The cost terms, basis, assumptions, and potential accuracy of the raw data developed by technology providers meant that the costs could not be relied upon for comparison purposes.

The AGS Study Team contacted a select number of technology providers to follow up on those items that could impact cost estimates, primarily further definition of the infrastructure components required by each system. This also gave the AGS Study Team a better understanding of the technology proposed, system elements, and technology maturity.

In many cases, the technology providers had good information about their own proprietary system components (vehicles, communications systems, propulsion systems, etc.), but did not necessarily have good cost information about the track/guideway, foundations, columns, and other items needed to build their systems in the I-70 Mountain Corridor.

Technology providers included cost data in their SOTIs, but the AGS Study Team largely developed their own cost estimates.

For reasons of due diligence, fairness, objectivity, and methodological consistency, the the AGS Study Team developed independent cost estimates using as detailed information as was available. In addition, the AGS Study Team was interested in computing a total cost, inclusive not only of construction costs, but also including right-of-way, environmental clearances & mitigation, permitting, utility relocations, and professional / management services required to deliver the project.

2.6.2 Peak Hour Capacity

A requirement of the PEIS/ROD was that the AGS accommodate the number of passengers, equivalent to the number that could be accommodated in one lane of traffic in the peak hour, peak direction. Based on the current average vehicle occupancy of I-70 and the capacity of a freeway lane in the mountains, this equated to about 4,900 passengers per hour in one direction. It became apparent that meeting the capacity requirement presented in the PEIS/ROD for 4,900 passengers per hour in the peak direction would not be as simple as expected for all technologies. Table 2-3 presents the number of consists required for each technology to provide the stated 4,900 passengers per hour in the peak direction. The higher the number of consists needed per hour, the more important technology readiness becomes to adequately demonstrate safety of operation in terms of vehicle separation, vehicle deceleration/braking, and switching.

Table 2-3: Consist Requirements

Technology Provider	Consist Capacity*	Consists Needed
American Maglev	186	26
FlightRail	800	6
General Atomics	200	25
MagneMotion	150	33
MegaRail	128	38
Owen Transit Group	48	102
PPRTC	6	817
SkyTran	2	2,450
Swift Tram	32	153
Talgo	300	16
Transrapid	960	5

* As provided in the SOTIs.

2.6.3 Off-line Stations

Some configurations of train / train-like technologies and most of the personal or pod-based technologies would require off-line stations. Analysis of the required off and on ramps for the off-line stations showed that the infrastructure required to provide off-line stations would be significant. Depending on the speed of the vehicle, from 1,800 to 5,400 feet of parallel guideway would be needed. The footprint of the guideways for stations located within developed areas would require significant property acquisition and have greater impacts than on-line stations. Figure 2-1 illustrates the length of the parallel guideways required at the off-line stations, depending on the speed of the acceleration and

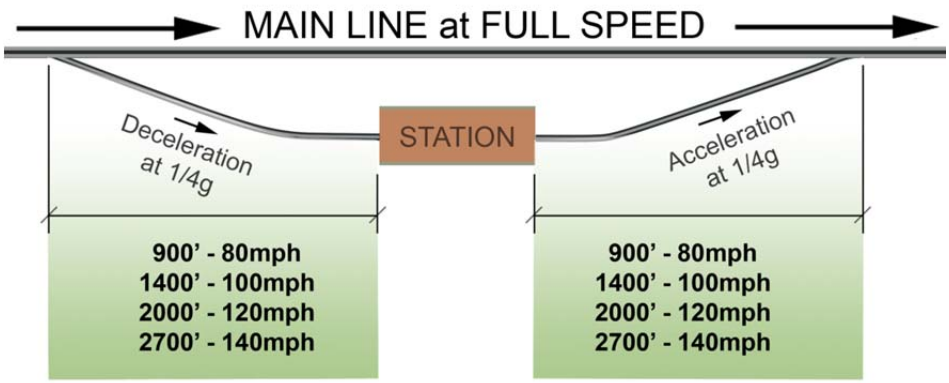


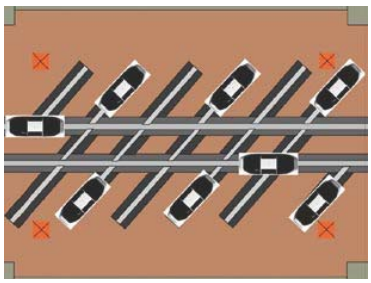
Figure 2-1: Required Parallel Guideway Lengths for Off-Line Stations

deceleration speeds at the stations.

The significance of the off-line stations for the corridor project leadership team rested less with the additional length of guideway added (2-12 more miles / 1-8% more guideway if same six stations as train/train-like technologies) and more with the perceived visual impacts of adding transit "interchanges" to highway interchanges already on the ground.

Additionally, the distributed point-to-point nature of many of the pod / personal transit system concepts offered initial appeal for smaller stations in more locations. In high activity areas, this concept created some questions:

- The more personalized the level of travel becomes, the more the expectancy rises that a pod might stay with a particular user, holding the user's belongings. This possibly creates the need for pod storage similar to auto parking.
- In locations like resort villages and regionally-serving collector park-and-rides, hundreds of pods per hour might be needed to serve thousands of persons per hour. With a single linear train-like station, station size would not be



Example of Pod Station

expected to be reduced as compared to other technologies. Curbside taxi and loading/unloading areas in large cities and airports are auto-based examples illustrating this concern. Station size might be larger if multiple "platforms" or loading areas were provided in parallel.

2.6.4 Commercial Availability

While all of the technologies presented a reasonable explanation about reaching TRL 9 by 2017, several of the technologies were either theoretical or in early research and development stages. Only high-speed rail (Talgo, among many vendors and installations worldwide) and TransRapid are commercially available at this time. TransRapid only has a single deployment in Shanghai, China. TransRapid, American Maglev, and General Atomics have full-size test facilities. FlightRail has a scaled-down test facility.

2.7 Technologies Advanced in the *AGS Feasibility Study*

Because of their current status of commercial availability, it was decided that a more detailed analysis for this Study would focus on three technologies:

- 120 mph Maglev – American Maglev or General Atomics
- High Speed Maglev – Transrapid
- High Speed Rail – Talgo

These technologies would also require the most significant infrastructure (guideway, structures, and tunnels), so they would generate the most conservative cost estimates. Any of the emerging technologies' costs could be re-evaluated to determine possible "savings" relative to rail and maglev costs, when their commercial/technology readiness improves the availability and reliability of information.

Technologies that are either commercially available or far into research and development were selected for more detailed analysis, but no technologies have been precluded from future implementation of the AGS.

As was stated in the RFSOTI, technologies not advanced in this Study are not precluded from being used in the ultimate implementation of the AGS. Any of these technologies could be implemented on one or more of the proposed alignments that are presented in the next chapter.