K Novel Technologies

A key requirement of this study is that all proposed technologies should be proven and capable of receiving required regulatory approvals within the implementation time scales of the project. The study has assessed proven technology options and their potential speed, focusing on existing technologies that have been proven in actual revenue service. Proposed “Novel” or new technologies that are still under development cannot be considered practical for this study unless they can show that they can be implemented within a 5-10 year time horizon. This includes meeting FRA/FTA safety regulatory requirements as well as demonstrating the practical capability to commercially operate in the Colorado environment. Accordingly, and consistent with the scope of the I-70 Draft PEIS, it has focused on rail and Maglev-based technologies.

Various groups have advocated new or “novel” technologies for potential application to the Colorado corridors. However, the RMRA funding grant from the Colorado Department of Transportation specifically excluded detailed consideration of “novel” technologies from this study, restricting application of funds only to proven technologies:

1. The CDOT Transportation Commission Resolution Restricting Front Range Commuter Rail Study passed 6 to 1 in November 2006.
2. DMU, EMU, Diesel Locomotive Hauled or Magnetic Levitation are the only technologies allowed by the Transportation Commission because of work done previously in I-70 Draft PEIS.

Per this direction from the RMRA and CDOT, “novel” technologies cannot be evaluated at the same level as “proven” technologies. Nonetheless, a survey was conducted that includes novel technologies so we can understand their development potential for possible long-run implementation. This includes identifying how and when they might become part of Colorado’s rail plan process.

K.1 Definition of a “Novel” Technology

The I-70 Draft PEIS evaluated rail and maglev (AGS) technologies, so for consistency those same two technologies were used for development of the RMRA Business Plan. The operative definition here for a “Novel” technology is anything that lies outside the range of technologies that were evaluated by the I-70 Draft PEIS. The Executive Summary (page ES-11) of the I-70 PEIS defines AGS as follows:

“The Advanced Guideway System (AGS) alternative would be a fully elevated system that would use new or emerging technologies providing higher speeds than the other transit technologies under study. The AGS is based on an urban magnetic levitation (maglev) system researched by the Federal Transit Administration (FTA). The system uses High-Speed Surface Transportation (HSST) vehicles developed in Japan over the past 25 years,
with a history of proven performance and certification by the Japanese government, but would need to be heavily modified to meet the constraints of the Corridor. Another system considered under AGS, a monorail system, was proposed by the former Colorado Intermountain Fixed Guideway Authority and has not been tested to verify its performance. Nevertheless, either system serves as an example of the types of systems to be evaluated if the AGS alternative were to be identified as the preferred alternative.”

K.2 Definition of a “Generic” Technology

The I-70 PEIS, like the current RMRA Business Plan, adopted a “Generic Technology Grouping” approach. That is, by characterizing its alternative as “AGS” the category was intended to cover a whole range of technology classifications, not just the Japanese HSST. In addition the I-70 PEIS did not base its evaluation on the existing HSST, but rather the I-70 PEIS was based on a performance specification that had been developed by the 2004 Colorado Maglev Study. While definitions of technology groups may be influenced by the capabilities of existing or proposed trains, in point of fact such evaluations are based on a broad set of assumptions regarding the general capabilities of each technology group. In this way the analysis can develop general conclusions regarding whole technology categories that are independent of any single manufacturer’s train.

The current Business Plan has adopted the same general framework as the I-70 PEIS by also relying on a “Generic Technology” approach. The basic structure of the Business Plan is the same as the I-70 PEIS since it develops both Rail and Maglev based alternatives. However, the Generic Technologies evaluated by the RMRA business plan are actually more refined than those assumed by the I-70 PEIS. For example:

- Instead of having only a single AGS technology group, the maglev options have been subdivided into two groups: “low speed” 125-mph systems, primarily represented by the HSST concept, and “high-speed” 300-mph systems represented by Transrapid.

- Similarly the single “Rail” technology group used by the I-70 PEIS has been subdivided into four distinct rail technology types: 79 mph, 110 mph, 150 mph and 220 mph. The first two are diesel options that were evaluated only in the I-25 corridor. The last two are electric rail options with the primary distinction being that the 150-mph technology is locomotive-hauled, whereas the 220-mph technology is self-propelled, or Electric Multiple Unit (EMU.)

Thus, it can be seen that the Generic Technology groups utilized in the RMRA Business Plan analysis are consistent with, but more refined, than the groups that were utilized by the I-70 PEIS.

K.2.1 Incorporation of Maglev Technologies into “Generic” Groupings

Regarding Maglev, specific vendors’ products (proposed or under development) offer performance capabilities that fall within the two Maglev generic technology groups already defined:

- The “low speed” 125-mph category is a generic group that covers concepts evolved from Urban Maglev or People Mover systems. Of these, the proposed American Maglev appears to be most similar to the HSST concept that formed the primary basis for the definition of this group. Both American Maglev and HSST would be LIM-powered vehicles that place the
motor on board the vehicle rather than in the guideway. However, General Atomics has proposed a low-speed urban maglev for Pittsburgh that would use a LSM motor in the guideway (like Transrapid’s) rather than an LIM motor on the vehicle. These systems differ in some details of levitation and control, but the 125-mph class evaluated in this study also reasonably reflects the likely performance capabilities of the American Maglev and General Atomics systems as well.

- **The “high-speed” 300-mph category** is a generic grouping that covers High-Speed maglev concepts. This category is primarily based on the Transrapid since that system is proven in revenue service in Shanghai. However, the performance of the proposed “Guideway 21” concept that was developed for the Colorado Intermountain Fixed Guideway Authority would also place that concept in to 300-mph category. It consists of a high-speed monorail that uses maglev technology for propulsion. Originally the maglev motor was proposed on top of the guideway, where it could provide partial or even complete levitation as vehicle speed increased. In later designs the maglev motors were moved to the side of the guideway, so the lifting effects would cancel each other out and the vehicle would not be levitated. The proposed “Guideway 21” is the only maglev design known to include an active tilting capability. This extreme tilting capability would in theory allow the vehicle to go through sharp curves on the mountain corridor faster than conventional trains or maglev vehicle could. The “Guideway 21” monorail is clearly intended as a competitor to the high-speed Transrapid, since it is a concept that was developed from the start for high-speed intercity application – it is not an adaptation of a lower-speed technology. However, “Guideway 21” has not benefited from the large Research and Development budget that has been invested in Transrapid. Accordingly “Guideway 21’s” performance would be most closely reflected using the 300-mph forecast.

In spite of minor differences in the operating characteristics of individual vendors’ trains, a “lead technology” has been designated for each group. This designation is based on the characteristics of technology that has actually achieved implementation in revenue service.

- For the 125-mph group it is the HSST technology that is operating in Nagoya, Japan;
- For the 300-mph group it is the Transrapid technology that is operating in Shanghai, China.

American Maglev and General Atomics vehicles exist on a test track but have not yet attained revenue service. Some components of “Guideway 21” such as the mag-lift motor have been tested individually. But as a system concept, “Guideway 21” has not yet been proven on a test track. Therefore, it is reasonable that those technologies that are operational in revenue service were given greater weighting in the definition of the characteristics of each generic technology group.

The two categories of maglev technology defined for this study incorporate all the critical technology aspects, particularly related to top speed, normal banking capability and propulsion system capability (LIM versus LSM drive.) These can be used to derive insights with respect to the potential applicability of specific variants of maglev technology. In particular, Chapter 7 gives a comparison of the energy efficiency of rail (220 mph) versus LIM-maglev (125 mph) and LSM-
maglev (300 mph) technology classes. It can be seen in Exhibit 7-3 of the main report, that the energy costs for LSM propulsion and rail systems are roughly the same, but that the electrical inefficiency of the LIM drive wastes up to 30% of the energy fed into it as heat.

This results in much higher energy costs for the LIM drive as opposed to LSM drive or steel wheel technology. This effect is amplified on steep mountain grades because of the added energy required to go up the hills. With such inefficiency the regenerative braking going back down the hill also fails to recover much of the energy that could otherwise be fed back into the power transmission system, wasting much of the energy needed to go both up and down hills in the form of heat.

“Guideway 21” claims only 70-75% electrical efficiency\(^{10}\) in the same range as standard LIM drive, whereas the electrical efficiency of LSM drive is 90-95%, almost as good as a standard electric traction motor. (However, another source\(^{11}\) claims that “Guideway 21” would have better energy efficiency than Transrapid.) This poor electrical efficiency results in a blatant waste of energy. Trains that go fast or tackle heavy grades need increasing amounts of energy. LIM propulsion works adequately for low speeds but as speeds or grades go up, the wasted energy rises to the point where it becomes a substantial share of operating cost. Accordingly, LIM-based maglev can hardly be characterized as a “Green” technology for the I-70 corridor. However, the two Maglev systems that use LSM drives, Transrapid and General Atomics, would not have this problem since they have about the same energy efficiency as rail.

“Guideway 21” proposes up to 25° of tilt. The use of high degree of tilt would likely restrict passengers to their seats and require use of seat belts. It would not be possible to walk about the train to use rest room facilities, offer food cart or bistro service, or provide other kinds of comforts and amenities that passengers expect and have become accustomed.

To correct any misperception that it is possible to go around sharp curves at a high rate of speed, Exhibit K-1 shows a portion of the proposed “Guideway 21” alignment that was used to estimate a 5-minute running time from Genesee to Idaho Springs. Even “Guideway 21” is incapable of going around the sharp curve at the bottom of Floyd Hill at full speed. A 6,500’ tunnel was assumed to ease the curve.


\(^{11}\) Hopkins, Silva, Marder, Turman and Kelley, Maglift Monorail, Presented to High Speed Ground Transportation Association, Seattle, June 6-9, 1999.
Exhibit K-1: 6,500’ Tunnel in the proposed “Guideway 21” Alignment at the Bottom of Floyd Hill

Current RMRA study alignments did not include the 6,500’ tunnel at the bottom of Floyd Hill that was suggested by the “Guideway 21” evaluation. Had that tunnel been included, it would have improved the performance of conventional rail and maglev technologies as well. A tunnel in this location could be a viable route enhancement option that should be looked at again as part of the NEPA process.

For evaluation of novel technologies like “Guideway 21” it is essential to ensure that any technology comparison is based on comparable routes and alignments. Otherwise what is fundamentally an alignment characteristic may be mistakenly attributed to the vehicle technology.

Exhibit K-2 shows Maglev technologies that were aggregated into the existing Generic Technology groupings. As described above, the performance of these particular technologies has been characterized under either the “low speed” or “high-speed” maglev categories evaluated by the current study.
Exhibit K-2: Specific Technologies Incorporated into the Generic Maglev Categories

<table>
<thead>
<tr>
<th>Technology Group</th>
<th>Technology Name</th>
<th>Photo</th>
<th>Likely Development Time Frame</th>
</tr>
</thead>
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<tr>
<td>Low-Speed 125 mph</td>
<td>HSST</td>
<td><img src="image" alt="HSST Photo" /></td>
<td>5-10 Years</td>
</tr>
<tr>
<td></td>
<td>American Maglev</td>
<td><img src="image" alt="American Maglev Photo" /></td>
<td>5-10 Years</td>
</tr>
<tr>
<td>High-Speed 300 mph</td>
<td>Transrapid</td>
<td><img src="image" alt="Transrapid Photo" /></td>
<td>0 Years</td>
</tr>
<tr>
<td></td>
<td>Guideway-21</td>
<td><img src="image" alt="Guideway-21 Photo" /></td>
<td>15-20 Years</td>
</tr>
</tbody>
</table>

In terms of meeting the development time frames required for this study, both the HSST and American Maglev concepts are operational today at low speeds. HSST is operational in revenue service, whereas American Maglev is on a test track. To develop a higher speed, these systems need extensive redesign and testing. Most certainly it would require development of longer test track facilities than now exist, probably in a closed-loop formation like Transrapid’s track in Emsland, Germany, to verify system operation and performance. For both of the 125-mph maglev technologies, minimum required time frames to develop a test track facility and to modify, verify and fine-tune the 125-mph technology, and to obtain required regulatory approvals and certifications, has been estimated at 5-10 years.
For 300-mph Maglev technology, Transrapid technology has completed testing and is in revenue service today in Shanghai, China. Its development time has been assessed at zero years, since the technology is available today for immediate implementation and has already received necessary FRA approvals.

Guideway-21 development, in contrast, lags behind any of the other available maglev technologies, since it has not yet even been deployed on a test track. In addition to this, Guideway-21’s goal for supporting 300-mph operations is very aggressive compared to more conservative 125 mph for the lower-speed systems; this will undoubtedly take more time to develop. The mechanical complexity of the concept with its active tilting mechanism, suggests a minimum 15-20 year development period before such technology could be available for commercial implementation.

K.3 Other Novel Technologies

Exhibit K-3 shows technologies based on other approaches to vehicle guidance or propulsion. Some of these are based on adaptations of urban people mover systems, while others reflect truly new and innovative means for providing intercity passenger transportation.

K.3.1 Historical Development Lead Time Experience for New Systems

Our assessment of system development lead times is informed by historical experience for developing and implementing improvements to rail and maglev systems. In particular:

- The first Japanese Shinkansen or “bullet” train operated at 136 mph in 1964, a speed that today we would find unremarkable; the “300-series” trains introduced in 1992 were still only capable of 168 mph. 186-mph trains were not introduced in Japan until 1995, fully 30-years after the first line opened.

- Similarly, the French TGV from Paris to Lyon initially achieved only 168 mph in 1978, and its break-in period was far from trouble-free, requiring over 15,000 modifications to the original design.12 186-mph operations were not achieved until the opening of TGV-Atlantique in 1988, ten years later. This top speed of 186 mph remained the High-Speed Rail standard for nearly 20 years until TGV-East opened in 2007. This new line is designed for a top speed of 220 mph, ushering in a new generation of High-Speed travel, but generally operates at 200-mph.

- Tilt systems took a similarly long time to develop. The first successful European tilting train design was the Talgo in Spain, developed in the 1950s. This train was tried in the United States in 1957-1958 but because of the New Haven Railroad’s financial difficulties at the time, the technology was set aside. Meanwhile tilt systems continued to develop with the

12 “On 28 July 1978, two pre-production TGV trainsets left the Alsthom factory in Belfort. These would later become TGV Sud-Est trainsets 01 and 02, but for testing purposes they had been nicknamed “Patrick” and “Sophie”, after their radio callsigns. In the following months of testing, over 15,000 modifications were made to these trainsets, which were far from trouble-free. High-speed vibration was a particularly difficult problem to root out: the new trains were not at all comfortable at cruising speed! The solution was slow in coming, and slightly delayed the schedule. Eventually it was found that inserting rubber blocks under the primary suspension springs took care of the problem. Other difficulties with highspeed stability of the trucks were overcome by 1980, when the first segment of the new line from Paris to Lyon was originally supposed to open. The first production trainset, number 03, was delivered on 25 April 1980.” From: http://www.trainweb.org/tgvpages/history.html
introduction of active tilt by British Rail on its Advanced Passenger Train (APT) in 1981. The APT however was never reliable enough to go into service and the project was scrapped, although the Pendolino group purchased some of the APT technology, including the tilt mechanisms. Pendolino and Asea then successfully implemented tilt technology\textsuperscript{13} on their ETR 450 and X-2000 trainsets in 1989. Since then, these trains have demonstrated over 20 years of reliable service, but the tilt technology itself took over 30 years to develop and mature.

- The development of maglev technology also has a long history. Planning of the Transrapid system started in 1969 at which time the first maglev prototype vehicle, the TR-01, was constructed. After this the technology developed through a series of prototypes until the Emsland test facility was completed in 1987. The TR-07 became operational the next year in 1988, the TR-08 in 1999\textsuperscript{13}, and the TR-09 in 2008. The first revenue application of Transrapid technology became operational in Shanghai in 2002. From 1969 until 2002 it took 33 years to reach the first revenue application of maglev technology, and by now over 40 years of research and development have been invested in this technology.

It can be seen that the development lead times for introduction of new rail technology are typically significant, in the order of 20-30 years for all of the key innovations that we take for granted today. Given the early development stage of many of the proposed “Novel” technology concepts, it would be a reasonable expectation that commercialization would require at least 15-20 years of development and testing effort – and will succeed only if backed by a sizeable research budget, sufficient to support a sustained, uninterrupted and consistent effort over those years.

Aside from this there are technical concerns regarding the potential viability of many of the system concepts that will be outlined below.

**K.3.2 Novel Technologies Reviewed**

As shown in Exhibit K-3, five different non-Maglev technologies have been reviewed for potential application to the RMRA system. All five technologies are in their very early development stages, leading to an assessment of 15-20 years minimum development lead time, before any of them could realistically be ready for commercial deployment. As shown in Exhibit K-3:

- **Megarail** has proposed a rubber-tire based, elevated system based on a concept for very low initial cost of ultra-light, automated production guideways.

\textsuperscript{13} See: \url{http://www.uctc.net/papers/113.pdf}
\textsuperscript{14} See: \url{http://www.thyssenkrupp-transrapid.de/download/HMB2_e.pdf}
## Exhibit K-3: Novel Technologies Based on other Means of Guidance or Propulsion

<table>
<thead>
<tr>
<th>Technology Name</th>
<th>Photo</th>
<th>Likely Development Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Megarail: <a href="http://www.megarail.com">www.megarail.com</a></td>
<td><img src="https://via.placeholder.com/150" alt="Megarail" /></td>
<td>15-20 Years</td>
</tr>
<tr>
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<td>15-20 Years</td>
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</tr>
<tr>
<td>Air Train Global: <a href="http://www.airtrainglobal.com/">http://www.airtrainglobal.com/</a></td>
<td><img src="https://via.placeholder.com/150" alt="Air Train Global" /></td>
<td>15-20 Years</td>
</tr>
</tbody>
</table>
• **Lashley Bi-Rail Systems** proposes a wide bodied, light elevated system that would run at high-speed and would pick up and drop passengers along the way without stopping. A shuttle would move through a given city picking up passengers at several conveniently located points then wait on a side-track until the train passes. Then the shuttle will overtake the moving train and dock with it.

• **Advanced Transit Solutions** has proposed a monorail system that would be powered by wind turbines. Very few other details about the proposed technology are available.

• **Suntram** has proposed a high-speed aerial tramway using a vehicle stabilized by aerodynamic controls.

• **Air Train Global** has proposed a vehicle using a combination of Motor-In-Hub traction wheels and Ducted-Thrust-Fan technology to move along an elevated guideway.

A wide range of alternative vehicle technologies has been proposed. Some technologies, such as those proposed by Megarail, are clearly evolved from urban people-mover applications. The others were proposed as new high-speed transportation modes. The technologies would use a variety of different means for propulsion and guidance.

Technical concerns regarding some of the technologies are as follows:

• Rubber tires as proposed by Megarail use more energy than steel wheel vehicles do, and the wheels have poorer traction, limited weight-bearing capacity and tend to overheat at high-speeds resulting in a need for frequent tire replacement.

• Vehicle stability and the ability to operate at high-speed over a suspended cable are potential concerns regarding the Suntram technology.

• Existing trains could do the docking maneuver proposed by Lashley. Rail systems already uncouple helper locomotives at speed, but the proposed coupling operation is potentially dangerous and it is not clear how it can be safely managed. The joining section would also have to accelerate to a speed *faster* than that of the main section in order to catch up with it, which limits the speed of the main section. It is not clear that limiting train speed in this way really provides an advantageous concept.

• The LIM vehicles proposed by the 2004 *Colorado Maglev* study would have their propulsion units on-board. It is not clear how all this LIM electrical equipment could be brought on board the vehicle, and still produce a vehicle that is as lightweight, roomy and comfortable as Transrapid’s existing LSM vehicle, which has the propulsion equipment built into the guideway. This analysis has assumed that the LIM vehicle must be heavier than the equivalent LSM vehicle for the same level of passenger comfort and capacity. It is not clear then, except for the cost of the embedded coils, how the heavier LIM vehicle can claim a lower-cost guideway structure than Transrapid’s.

• In addition, high energy costs continue to be a concern for LIM propulsion in high-speed/high gradient applications. LIM has much poorer electrical efficiency than LSM propulsion. Moreover, LSM propulsion is available today in proven maglev systems that are ready for immediate commercial implementation. So it is not clear why one would want to
invest in developing a technology that is likely to cost more to operate than an off-the-shelf solution.

K.4 Novel Technologies and the myth of the “Low Cost Guideway”

A common theme seemingly underlying development all the “Novel” technology proposals (which was also shared by the 2004 Colorado Maglev Study) is the concept of the “low cost guideway.” The presumption appears to be that by deployment of smaller or lighter vehicles, a substantial sum could be saved through construction of lighter guideways. However, whenever it has been tested, this theory has not been supported by detailed Engineering analysis. For example:

- The proposed 2004 Colorado Maglev system proposed guideway costs of only $10.7-13.8 million per mile (Table C-1 on page 48) coming to a total system cost of $5.8 Billion for a 157-mile system ($37 Mill/mile) from DIA to Eagle Airport. American Maglev has proposed similar costs.

- However, the I-70 PEIS, adopted a much higher cost of $6.15 Billion for the AGS alternative from C-470 to Eagle Airport (only 115 miles at $53.5 Million per mile, up 45% from the Colorado Maglev estimate.) This compares to $4.92 Billion in the I-70 PEIS for the rail option.

Both the I-70 PEIS and the current RMRA Business Plan agree that rail is less expensive than Maglev, while offering a very similar performance capability.

Recent accidents on the Transrapid maglev test track and very recently Washington Metro have shown, that even maglev and supposedly fail-safe, highly automated rail systems are not totally immune to the risk of accidents. The German ICE train suffered an accident in Eschede, Germany15 when a fatigue crack in a wheel failed, causing the train to derail and slam into a bridge. The cars telescoped into one another exacerbating the death toll. The U.S. FRA and others have cited this train accident as justifying a tightening of vehicle crashworthiness standards.16 Accordingly, long distance travel requires a substantial vehicle, in order to maintain not only passenger safety at high speeds but also comfort. A key requirement is the ability for passengers to get up and move freely around the vehicle, for access to bathroom facilities, food service, social/recreational purposes or simply the ability to exercise and stretch ones’ legs.

The kinds of comforts and amenities that characterize the level of service associated with intercity rail travel simply cannot be provided on a small tram-like vehicle adapted from an urban people mover. Comfortable vehicles are necessary to attract riders from the automobile in a competitive mode environment. These vehicles will be substantial enough to exert heavy forces on a guideway structure.

Dynamic loadings exerted by higher speed vehicles necessitate rigid guideway structures that can maintain tight geometry tolerances under load. Lighter structures might technically carry the load

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15 See: http://en.wikipedia.org/wiki/Eschede_train_disaster
but deform too much to maintain the required geometry. A flimsy guideway structure would impose significant speed restrictions on both speed and ride quality. In addition over time a lightweight structure would tend to fatigue leading soon to safety concerns, and its need for premature replacement.

The likelihood of intercity service requirement being compatible with a lightweight and flimsy guideway structure seems rather remote. Unfortunately there is no “free lunch.” For the time being it appears that these vehicle and guideway parameters are inextricably linked.

For the current RMRA study as well as the earlier I-70 PEIS, guideway costs have been estimated based on known costs for the kinds of rail and maglev systems that have been proven in revenue service. These guideways are estimated to cost between $75-100 million per mile rather than the $20-40 million cited by some suppliers. The evaluation is based on technologies that are known to meet the comfort, safety, speed and other service parameters of the intercity passenger market. The vehicle technologies that are needed are available today and could be deployed in an operational Colorado system by 2025.