A 40 Trillion Dollar Opportunity

In the 1800's the railroads created more millionaires than had ever before existed. The opportunity described here is greater. The math will follow, but first, just what is the opportunity? The answer is tunneling. Tunneling can remake the surface of our cities and our residential neighborhoods, with revolutionary implications for our quality of life. And those who lead this revolution, besides doing immense service to the planet, could become richer by far than the railroad barons of old.

The ascendency of tunneling depends on one thing – reducing the cost. How that can be done will be suggested below, but first let us look at the wonderful possibilities that would be opened by radically reducing the cost of tunneling.

1. Car Tunnels. The first most immediate result from cheaper tunneling would be underground roads for electric cars. We are talking here about tunneled roads exclusively for non-polluting cars operating under computer control. This is, in no way, 20th century "rapid transit". No big trains. No monumental stations, for waiting. No getting on, then continuously stopping and starting. That is no way to get anywhere. It's all very yesterday.

What we want is to get in our computer controlled electric car and go, steadily go. Cheap tunnels will make that possible. We are talking here about streams of small cars traveling fast and close in tunnels under computer control. At first you drive to the underground tunnels, then you relax during computer controlled tunnel transit, and, at the other end, you drive away from the tunnel to your destination. Later, of course, the whole trip may be automatic. The underground road system would be supplementary to existing surface roads which would still carry all larger vehicles. With tunnels beneath, the surface roads would just be less crowded.

The technology is ready. Already, Google has demonstrated feasibility with its "driverless car". The membership of the Intelligent Transportation Society of America can create the network control system. Existing or entrepreneurial car companies can build the computer controlled cars. Scores of small car designs are out there and most could be adapted for tunnel travel. The tunnels would provide for fast, close packed streams of cars traveling in safety beneath the congestion above. It all depends on cheaper tunneling.

We love our cars. Despite vast expenditure on public transit in America and growing traffic congestion, the percentage of people who commute by car has not diminished. Citizens of other countries, as their fortunes rise, are just now falling too for the convenience and autonomy of cruising in their own cars laden with their own stuff with their own tunes playing.

Don't expect this to happen first in the U.S. It might, but the vested interest of conventional transit will resist and the drag of environmental studies, permissions, and lawsuits will delay. Rather, the initial market is the world's burgeoning new super-cities. There, leaders must weigh the massive disruption, enormous cost, and limited reach of conventional 20th century transit. If we help, they may opt to jump ahead to a faster, more extensive, 21st century network of small tunnels streaming computer controlled electric cars.

2. Roadless Communities. In time, commuting underground in computer controlled cars will become pervasive. Then, roadless communities will become an option. To visualize roadless communities roll your imagination back to before there were cars, or wagons, or even wheels. People lived in gatherings of homes along streams, in clearings in the woods, and in villages perched on hillsides. Those who have traveled to rustic areas can recall the quiet charm of such places.

Anthropologists tell us our ancestors descended from the trees and started walking upright and using tools a million or so years ago. For a long time we lived in small bands and huddled in caves. Sometime around 10,000 years ago we started living in villages. Towns and cities grew up only relatively recently. Genetically, in our natures, in ways we do not consciously appreciate, we are still villagers. We like our surroundings on a human scale. Witness the popularity of malls and downtown closed-to-traffic walking streets.

In modern life the basic sound background is the internal combustion engine, tire noise, the siren, and the 4 wheel boom box. We sometimes only realize how grating it is in its absence. In contrast, in "primitive" villages one is often impressed by the peace and quiet. Birds, crickets, frogs and other natural sounds form the background.

In traditional villages the children run around. Nobody seems particularly worried. Reflect upon the relaxed nonchalance of those parents versus our own modern parental paranoia. We have built our residential environment inside a web of hurtling metal boxes. Their roads take up lots of space. They are noisy, smelly, and, most seriously, potentially fatal to children and pets.

Now imagine all the roads put below, in tunnels. The surface would be much more quiet and amenable. And that would change our quality of life. In this scenario, everyone would have cars just as they do now but they would come and go below. The surface would be residential with homes connected by paths for walking and bikes. Children would be safer and could get themselves to school.

So, what we mean by "roadless communities" is **apparently** roadless communities. The roads are there, below, in tunnels. The cars operating in these tunnels would have to be non-polluting, be they electric, fuel cell, or what–have-you. Because non-polluting cars would be prerequisite to living in roadless communities the two developments would be mutually reinforcing.

It is hard to overestimate the degree to which our communities have been shaped by the automobile. Commensurately, it may be hard to appreciate how putting cars underground might enhance our enjoyment and appreciation of our community.

Most importantly would be the effects on children and their parents. Kids could run around, bike themselves to school and lessons and generally grow up more independently and naturally. Parents would be relieved of their chauffeuring duties and that portion of their paranoia related to motor vehicle tragedy. Families living in roadless communities would be more in harmony with nature.

.It is interesting to think about the effects tunneled roads would have on residential architecture and community planning. If roads were underground, physically, our communities could be free of the limitations imposed by topography. Each home could be located on esthetic considerations. We would not be carving up the neighborhood with roads and driveways but living in nature. It would also make sense to say goodbye to the grid. Property lines could be set to surficial landmarks, whatever makes immediate sense locally. Underground roads would be accompanied by underground parking. There need be no trenching of the surface since all utilities would be brought through the tunnels.

Homes might be often served by elevators and that could invite a vertical architecture taking advantage of the view. A modern home with all amenities could easily be supported on a single 12 foot diameter elevator shaft coming up from underground parking. Or, two pillars could support a single level home wrapping around the mountainside. Imagine the possibilities.

Life not lived around hurtling metal boxes would be better. Our neighborhoods would be quieter and our kids would be safer. At the interface between the roadless community and the rest of the world, on Saturday mornings, there could be a community carwash, polishing, and caressing. Oh, we love our cars. But we don't need them hurtling about in our residential midst.

3. Cheaper Tunneling The single development that would make car tunnels and roadless communities practical is cheaper tunneling. And cheaper tunneling is very possible. Think about tunneling in its raw basics. Demolition and disruption of existing improvements is nil. We don't need real estate. In essence, all that is needed is a ring of concrete to support the ground and a place to put the excavated earth. Improvements in three main areas could greatly reduce the cost of tunneling: better technology, better tunnel contracting practices, and empowering enabling legislation.

A. Technology. Compared to the Model T, today's cars are complicated. But they are more reliable. Excavators, rock drills, and tunnel boring machines are complicated. Jet airplanes are even more complicated, and yet, more reliable. Complexity has not and does not necessarily bring unreliability. We must not be overly impressed by the old tunneler's aphorism, KISS – "Keep It Simple, Stupid". It's worth keeping in mind, but it's not a General Rule. In fact, there may not be any general rules other than: "Pragmatism Rules".

However, there may be general principles that can inform our approach. The first general principle is that it's going to take energy to remove the in situ ground and take it outside. On the website cheapertunnels.com we come up with this equation:

Tunnel Advance Rate = Power Intensity x Effectiveness x Continuity x Intelligence

It is important to note that this equation is merely a reflection of the definitions that went into it. No empirical information is expressed. It is opinion. It says that for maximum progress the power in a tunneling machine should be effectively applied to the rock as continuously as possible. Probably that seems pretty intuitive.

It is the last term, "Intelligence" (volume of rock excavated per amount of energy applied) that provides an interesting departure point. In 1955 the U.S. Army Snow, Ice, and Permafrost Research Station undertook research to build military installations under the ice in Greenland as part of the DEW Line. They measured the specific energy for ice excavation by many methods including hand labor, many kinds of mining machines, and even melting.

The lowest specific energy, by far, was a man with a pickaxe. What they saw was that a man with a pickaxe would attack the ice and once having started a crack would locate subsequent blows to enlarge the crack. Each blow was predicated on the results of the previous blow. He was using his intelligence to maximize the amount of excavated ice. Anyone having done hand digging has done the same, seizing every opportunity to pry out large chunks.

A relevant aside at this point is to note that rock is generally already cracked. Often there are three intersecting planes of cracking producing an in situ rock body of tightly assembled chunks. We might usefully view rock excavation in such cases as "rock disassembly".

Rock is much weaker in tension than in compression. An interesting development is the CERAC Breaker. Developed in 1978 at Institute CERAC in Switzerland, this breaker is designed to capitalize on the weakness of rock in tension. The device is inserted into a short drilled hole. It mechanically expands, gripping the inside periphery of the hole and, pushing off of the bottom of the hole, pushes the gripped rock outward, breaking it in tension.

In the 1980's the CERAC breaker was extensively studied by the U.S. Bureau of Mines as an enabling technology for what they termed the "Drill/Break System" of mining. The Bureau investigator found the system very promising, but it has never been implemented commercially. Mechanizing the process has, perhaps, been perceived as too difficult.

The Rapidex system, developed and tested in the 1970's was a semi-continuous drill and blast system designed to advance into the rock utilizing small blasts in a spiral pattern resembling a lighthouse stairway. The government funded development through many testing stages, but the mechanical difficulties encountered in finding, loading, and initiating previously drilled holes were too much for the technology of the time.

Many other systems have been proposed for excavating rock more "intelligently". Some involve drilling small holes and microblasting on a semi-continuous basis. Others involve injecting a highly pressurized combustible gas and igniting it, or pumping in water and creating hydraulic shocks. A recent system based on injecting high pressure foam has potential.

All these systems require drilling holes into the rock face and introducing some means to push the rock outward towards the free face. Although most hold promise, none of the many novel methods proposed have been developed to the point of commercial success. Consistently, the difficulty seems to be in the mechanization.

All these concepts were developed and prototyped before the recent proliferation of computer controlled industrial manipulators. Now, with position sensors and control programs worked out and generally available, an array of mining duty manipulators could be developed and used to test and refine any of these systems.

Or, turn it around; a general purpose array of mining manipulators not wed to any specific method could test any and all promising methods. The idea is that the manipulators could grab drills and other tools of many kinds and through programming changes turn them into an Adaptable Tunnel Excavation System.

Robots are generally recommended for harsh, dangerous environments. A rapidly advancing tunnel heading is a crowded, loud, and dangerous place. Good for robots - not so good for humans. But, to take maximum advantage of intelligence the manipulator array would need to be under human supervisory control. The operator would not be, as today, working the valves. Rather based on the results he or she is seeing, they would be adapting the supervisory program.

Normal excavation with a given complement of tools would see the details of the attack vary as the lay of the rock changes. Major discontinuities such as faults or water inflows would call for a rapid switchover to different tools in a new configuration with a different control program.

Beyond adapting continuously to differing rock conditions on any one project, an Adaptable Tunnel Excavation System would be easy to adapt between projects. The manipulators, control systems and the many tools would be modular. They would only need to be reconfigured to mine different size tunnels in different ground conditions. The basic backbone of equipment and expertise would carry over.

B. Contracting Practices. After technological advance, the largest contribution to reducing the cost of tunneling could come from changing contracting conditions. A few suggestions:

Keep everything light. The cars traveling in these tunnels would be small, light vehicles. Each tunnel, maybe 13 ft in diameter, would be two narrow lanes, one for a stream of cars at speed, the other for merging and exiting.

Simplify. All that is needed is a stable hole, smooth, paved, not too leaky.

Tunnel where it's easy. So much of tunneling today is in the worst possible conditions: soft ground with major liabilities above, waterlogged ground, downtown in crowded conditions with limited working hours. No way! Instead, put the tunnels through the surrounding hills above the water table. We are talking about a new road system supplementary to the existing, but separate. It can't happen unless the tunneling is cheap, so put it where it's easy.

Encourage innovation. The most regressive requirement common in tunneling contracts is something like "The contractor must have successfully completed several similar projects using the method to be employed on this project within the past so many years." Could there be a better way to stifle creativity and innovation? Better, a parallel, quite dissimilar requirement such as:

"The goal of this agency is to build underground road systems. To do so requires massive amounts of tunneling. To make this feasible, the cost of tunneling must be reduced. This will require innovation. Therefore, no bid will be eligible for award if it proposes to use any completely tried and true method. All bids, to be eligible for award, must have at least one experimental element that promises to reduce the cost of tunneling. Completely novel approaches will be given priority."

Allow time. A system of underground road tunnels would take years to build. Similarly it would take years to develop and perfect the automatic car control systems. So, instead of putting it out for bid one phase after another, each with barely enough time, put it all out for bid at once with each piece then having plenty of time.

Quit Whenever You Want. No bonds required. This would be a total departure, which might work as follows: The tunneling contractor bids to build a reach of tunnel at so much a foot. The owner never pays more under any circumstance. But, the contractor can quit for any reason at any time. If the existing contractor quits, all the contractor's peers, and even the same contractor, rebid the job a few weeks later under the same deal, Quit Whenever You want. With reduced competitive barriers and need for contingency the costs would be less. We must experiment.

C. Enabling legislation. With the best intentions, we have, as a nation, worked ourselves into a semi-paralysis where the problems fester while solutions are tied in legal and procedural knots. So, as a final bit of whimsy, let's consider what truly enabling legislation might do:

1. Appropriate funds and direct them to the selected construction organization. Or, as was the case with the railroads, if construction is anticipated by private funding, grant the necessary licenses and powers.

2. Modify contracting laws, as required, to allow Quit Whenever You Want and other experiments in construction administration designed to most economically build the finished system.

3. Streamline resolution of eminent domain and all hindering lawsuits: The desired result is that the courts be directed to expedite any and all litigation related to the underground road system.

4. Relief from environmental laws: Our courts have become the playground of legally savvy obstructionists. Underground roads can not happen without some relief from environmental restriction and litigation. Can traditional American "can-do" stand against the current tide of can't, mustn't and won't?

4. A 40 Trillion dollar Opportunity

In rural areas tunnels to individual homes and farmsteads will probably never be economic. But in urbanized areas the advantages of roadless communities will be apparent. Cheap tunnels will give people the opportunity to live in quieter, less hazardous, and more congenial suburban settings. Electric cars in tunnels will logistically connect our homes. On the surface, bike paths and walking trails will personally connect the people. No chauffeuring, children will ride their bikes to school. The greatest hazard will probably be teenagers on bicycles.

Here's the math:
A. The medium U.N. projected world population is around 10 billion in 2050. Over half of that population is projected to be urbanized. If we assume an average household size of five persons, that's 1 billion urban households.
B. Worldwide, incomes are going up, led by the emerging and developing economies.
Let's say average home prices today in the U.S., Europe, and the developed world are around $200,000. The long future is, of course, impossible to know, but extrapolating trends gives us a reasonable expectation that in the long future, say by 2100, the whole world will have attained the same average valuations as the developed world of today.
C. Around major cities a house in a "good" neighborhood will often be worth around twice what the same house in an average neighborhood would be worth. To be conservative, let's assume that changing a

typical asphalt-bound neighborhood into a roadless community would increase home values by 20%. This seems very conservative. The question we ask is: Would we be only willing to pay 20% more for our home in order to live in a modern village atmosphere as distinct from stuck in an asphalt grid?
D. One billion urban households times 20% of $200,000 per household is, checking our zeros, $40,000,000,000,000. And that's not counting the production of underground connecting roads or foreseeable additional markets such as mining or power.

The organization that starts now and pours every dollar into developing superior tunneling technology will be in a commanding position. Once superior tunneling technology is in hand, a business model, perhaps based on franchising, could organize the worldwide performing of the work.

Building networks of underground tunnels for electric cars is the 40 trillion dollar opportunity. Owning and operating such networks, perhaps as toll roads, is even larger. Developing the operating system for the underground road network that becomes the de facto standard is another. Microsoft succeeded by pioneering the operating system for our personal computers. What success might accrue to the creators of the operating system for our physical travels? It's an opportunity.