

# Underground Space: Good for Sustainable Development, and Vice Versa

International Tunnelling Association (ITA) Open Session  
World Tunnel Congress, Singapore  
May, 2004

by  
Harvey W. Parker  
Vice President, International Tunnelling Association (ITA)  
President, Harvey Parker & Associates, Inc.

## INTRODUCTION

Underground Works and Underground Space, which are referred to in this paper as “the Underground” are ideal means for improving the environment and supporting the principles of Sustainable Development.

As the examples in this paper will show, this is not a new revelation. Quite the contrary, since man first began to use caves for shelter, use of the underground has protected man and simultaneously enhanced the environment. Throughout time, society has looked to the underground anytime there was 1) a need for a safe haven, or 2) whenever something needed to be protected against harm or for future use or 3) for disposal of undesirable waste or hazardous materials.

Long before the environmental movement developed and the concept of sustainable development was conceived, use of the underground resulted in strong contributions toward the principles which, we now know, support sustainable development. At the present time (2004), use of the underground is contributing strongly to the goals of sustainable development. So, what is this thing called sustainable development? This paper addresses the importance of sustainable development to society and to the broad underground industry. This paper addresses the needs for rural areas as well as for developed and developing urban cities. It will be shown that the Underground is synergistic with respect to the environment and sustainable development. The combined effect and benefits of the individual aspects of use of the Underground combine to produce an effect greater than the total of the individual effects.

The environmental advantages of the underground are so strong that the author believes that a substantial portion of future demand for tunnels, and underground space in general, will be for environmental and sustainable development reasons. Accordingly, the underground is good for the environment and the environment is good for the underground industry.

## THE ENVIRONMENTAL MOVEMENT

Probably the beginning of the greatest push for sensitivity to the environment began with the publication of Rachel Carson's book, *Silent Spring* (Carson, 1962). Others, like Jaques Cousteau also made the public keenly aware of the environment. In fact, it was during this time that the word “environment” was added to our vocabulary with a range of very specific meanings. The movement has continued to get stronger with time and the environmental movement has documented these developments in timelines available on the web. To look back at the legacy of the environmental movement and its sustainability relative, look at the following URL's: <<http://www.iisd.org/timeline/>> and <<http://www.a420.com/design/SD-timeline.htm>>. There are many more websites addressing the same issues. Environmental issues and the environmental movement are here to stay. Moreover, the words “sustainable” and “development” are not just buzz words that will be soon forgotten. Our industry must recognize this and act accordingly. In fact, if our industry becomes pro-active, an enormous amount of work will result because of the advantages of tunnels and underground space to the environment and sustainable development.

## **ESTABLISHMENT AND DEFINITION OF SUSTAINABLE DEVELOPMENT**

Sustainable Development is defined by the United Nations and most other organizations as:

*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

The term "sustainable development" was first proposed by the World Commission on Environment and Development (WCED) in 1987. WCED was formed by the United Nations in 1984 and for three years studied the conflicts between growing global environmental problems and the needs of less-developed nations. Their report, "Our Common Future," proposed the term Sustainable Development (Brundtland, 1987). It is often called the Brundtland report after the chairperson of the commission, then Prime Minister of Norway, Mrs. Gro Harlem Brundtland. The Brundtland report states that we should strive to achieve:

"a form of sustainable development which meets the needs of the present without compromising the ability of future generations to meet their own needs.

And further states that:

"At a minimum, sustainable development must not endanger the natural systems that support life on earth: the atmosphere, the waters, the soils and living beings."

Most of us now talk nonchalantly about Sustainable Development and it has become a household word. However, we should recognize that the two words seem to be in opposition, at least considering how our society was living in the last part of the 20<sup>th</sup> century. Looking at it strictly from a linguistic point of view, on first glance, one would think that anything Sustainable could not include Development and any Development could not include the concept of Sustainability for the environment.

Although the Brundtland report essentially addressed poverty in the developing nations, the term Sustainable Development has evolved to include policies, attitudes, and actions by all nations and societies both developed and developing. This is a remarkable achievement in itself and is a testimony to the soundness of the concept since two vastly different cultures are addressing the same issue, admittedly from different points of view.

### **Importance of Sustainable Development to Engineers**

One of the more important engineering organizations in the field of sustainable development is the World Federation of Engineering Organizations (WFEO). Their Standing Committee on Technology, called ComTech, is very active in promoting the implementation of the concept of sustainable development by the worldwide engineering community. Much of this next section, including some of the figures are adapted from their materials which they offer free of charge without copyright protection to the engineering community so that these materials can be used widely. The WFEO website is <<http://www.unesco.org/wfeo/>> and the website of their ComTech Committee is <<http://www.wfeo-comtech.org/>>.

ComTech puts sustainable development into perspective with the following text:

"To an engineer, a sustainable system is one that is either in equilibrium, or one that changes slowly at a tolerable rate. This concept of sustainability is best illustrated by natural ecosystems, which consist of nearly closed loops that change slowly. For example, in the food cycle of plants and animals, plants grow in the presence of sunlight, moisture and nutrients and are then consumed by insects and herbivores which, in turn, are eaten by successively larger animals. The resulting natural waste products replenish the nutrients, which allows plants to grow and the cycle to begin again."



Fig 1 Natural Ecosystems and Food Cycle (From ComTech, WFEO)

The ComTech CD continues:

“If humans are to achieve sustainable development, we will have to adopt patterns that reflect these natural processes. The roles of engineers in sustainable development can be illustrated by a closed-loop human ecosystem that mimics natural systems. This model of a closed-loop ecosystem was first proposed in 1990. Other authors have since suggested modifications to this model”

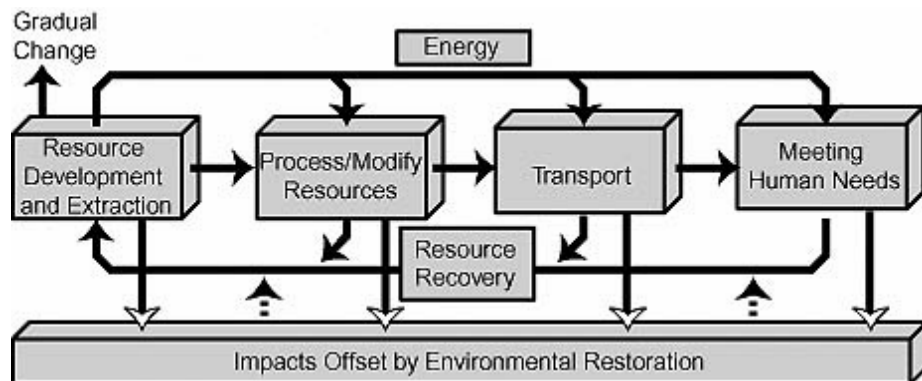


Fig 2 Roles of Engineers in Sustainable Development (From ComTech, WFEO)

ComTech suggests that engineers can play an important role in sustainable development by planning and building projects that preserve natural resources, are cost-efficient and support human and natural environments as shown in Fig 2.

Our tunnelling and underground space industry can contribute strongly to many of these areas. Development and extraction are the domain of our brothers in the Mining Industry which has already embraced Sustainable Development at the highest and strongest levels.

Obviously, our industry can make a big difference in the other segments shown in Fig 2, particularly in Energy, Transport, Meeting Human Needs, Resource Recovery and Impacts Offset by Environmental Restoration. As an example, tunnel projects are now finding ways to re-use tunnel muck which could be described as Resource Recovery.

ComTech describes ways that engineers can exercise an important role in sustainable development. These include:

- “Some environmental pollution is inevitable in the future, resulting from resource extraction, industrial processing and transportation, and from wastes generated by humans wherever we live. In the future, the impacts of residual wastes should be offset by a variety of environmental restoration projects.”

- “Engineering groups started educational programs for engineering students and practicing engineers on applying sustainable development concepts in their work.”
- “Many universities are beginning to introduce the principles of sustainable development into their curricula.”
- “Encouraging engineers to become environmental generalists will help advance sustainable development by broadening perspectives in engineering.”

## **BENEFITS OF THE UNDERGROUND WITH PARTICULAR REFERENCE TO SUSTAINABLE DEVELOPMENT**

In an editorial to TUST, the author listed the following benefits that the Underground provides for the environment and sustainable development (Parker, 1996) (See Table 1)

Table 1  
Benefits of the Underground for Sustainable Development

- Tunnels play a vital role by conveying clean water to urban areas and by conveying waste water out. Most major urban areas depend on tunnels for these services, which function with a minimum of maintenance
- The usable space off a parcel of land can, in some cases, be almost doubled by adding floor space or bulk storage below the ground surface. Life-cycle cost analysis may reveal the underground alternatives to be much more cost-effective
- It has been demonstrated by several recent events that tunnels behave very well in earthquakes. If urban planners want an important lifeline to survive earthquakes, they should go out of their way to use tunnels.
- The underground is the only safe location for storage of nuclear waste and other hazardous or undesirable materials.
- In transit systems, tunnels provide safe, environmentally sound, very fast, and unobtrusive transportation for people in all walks of life in both developed and developing countries.
- Underground space is being used increasingly for industrial, office and even residential facilities.
- Underground space for bulk storage of food, liquids, and gas has gained increasing acceptance in various areas of the world.
- Congestion in urban areas has been dramatically reduced by the use of the underground.

As environmental and sustainable development needs have become more important and more generally understood, the author now adds the following to the list.

Table 2  
Additional Benefits of the Underground for Sustainable Development

- Underground space inherently conserves energy. Because they are removed from climatic influences, underground facilities provide significant energy savings and conservation of energy
- Underground space is inherently energy efficient. Severe fluctuations of temperature are non-existent allowing more efficient control of temperature and energy.
- Underground space requires little maintenance
- Underground space generally has a very long life; some have been in continuous use contributing to sustainable development for centuries
- Long life & little maintenance not only reduce life-cycle costs but also reduce demand for renewable & non renewable resources
- Use of the underground permits preservation of open space for habitat, environmental, and scenic values
- The Underground provides strong protection from natural hazards

## OUT OF SIGHT – OUT OF MIND

The author is the official NGO representative to the United Nations in New York. In this capacity, he visits the United Nations frequently to highlight the benefits of the underground. The good news is that tunnels and the underground in general are very environmentally friendly. The bad news is that few people associate tunnels with the environment.

The advantages of the underground are taken for granted by almost everyone. The underground plays a dominant role in our standard of living and in the preservation of the environment. At least within the developed countries, every time one turns on a faucet or flushes a toilet, an “environmental tunnel” is put into use.

Yet the average person almost never makes this connection; even members of our industry take clean water in and wastewater out for granted. This is probably because our tunnels have been doing such a good job for such a long time with so little maintenance that they are invisible to sight and to mind.

## EFFECTS OF WORLD POPULATION ON THE UNDERGROUND INDUSTRY

A major factor in world demographics is that, in the future, most of the world's population will live in urban cities. There are numerous and inconsistent predictions on how fast the world's population will grow in the coming years, decades and beyond. Our industry need not be worried about these details because all the predictions are staggering and our industry needs to focus on being prepared for the upcoming demands for infrastructure all over the world.

It is a fact that the world population is increasing at a staggering pace. In October, 1999, the world population passed the 6 Billion mark. It is also a fact that people are moving to the cities at a rapid pace. In 1950, only about 1/3 of the world's population lived in the city. By October, 1999, about ½ of the 6 Billion people lived in urban areas.

The United Nations and other world bodies are giving special attention to those cities where more than 10 Million people live, the so-called Megacities. In 2001, there were only 19 Megacities. By 2015 it is estimated that there will be about 60 megacities and most of these cities will be in the Developing World.

As of 2001, the world population had become concentrated as shown in Table 3.

Table 3  
Distribution of World Population in 2001

Size of City	Number of Cities
Greater than 10 Million (The MegaCity)	19
5 Million to 10 Million	22
1 Million to 5 Million	370
0.5 Million to 1 Million	433

The trend will continue. By 2030, it is estimated that 4.9 Billion people will live in cities which is 60% of the estimated 8.1 Billion world population.

This means that substantial infrastructure must be constructed not just for these cities to be sustainable, but just for them to survive. Fortunately for the underground industry, if the environment and sustainable development are considered, the underground is the construction method of choice. It will require those of us in the industry to be pro-active to inform the city officials and planners, at very

early stages of a city's growth, of the importance of the underground to sustainable development and to quality of life.

Without appropriate substantial infrastructure, there is no possibility of improving the environment or even considering sustainable development.

## **WHO IS INVOLVED IN SUSTAINABLE DEVELOPMENT?**

Everyone! A quick glance at the internet and a Google Search will quickly convince you that almost everyone has embraced Sustainable Development. The broad support of Sustainable Development will also convince you that Sustainable Development will be part of our way of life for a long time to come. Some of those industries that have endorsed sustainable development and have incorporated it into their day to day operations include:

Owners (Private & Public)	Government	
Mining Industry	Consulting Engineers	Professional Organizations
Planners	Lawyers	Material & Equipment Suppliers
Large Design-Build Contractors	Construction Contractors	Specialty Contractors

There is even an ISO 14000 family of standards primarily concerned with "Environmental Management." Finally, since 1999, Dow Jones has tracked the performance of companies committed to sustainable development. The Dow Jones Sustainability World Indexes (DJSI World) consist of more than 300 companies that represent the top 10% of the leading sustainability companies in 60 industry groups in the 34 countries covered by the biggest 2500 companies in the Dow Jones Global Indexes.

## **ITA AND SUSTAINABLE DEVELOPMENT**

The changes to the Statutes of ITA that were adopted last year (2003) now reflect our association's role in sustainability. The Objectives of the International Tunnelling Association (ITA) now include the following: "to encourage the use of the subsurface for the benefit of the public, environment and sustainable development."

ITA and its Journal, Tunnelling and Underground Space Technology (TUST) have been active in the Environmental and Sustainable Development fields for a long period of time. Over the decades, there have been numerous articles in TUST addressing environmental issues and sustainable development. They are far too numerous to list but selected ones include: Celik (1996), Parker (1996), Ray (1998), Roberts (1996), and Sellig (1996).

ITA has actively promoted the advantages of the Underground to sustainable development and the environment to the United Nations for over a decade. ITA is recognized by the United Nations as a very active Non-Governmental Organization (NGO) in Consultive Status II.

## **ITA PROPOSALS TO THE UNITED NATIONS: UNDERGROUND SPACE, EARTH-SHELTERED WORKS & UNDERGROUND STORAGE**

Underground construction is not new and, in fact, enjoys an ancient legacy. Loretta Hall, the author of the book, "Underground Buildings: More than Meets the Eye", states in her introduction: "Unusual as they are, underground buildings are surprisingly common. They can be found all over the world. Significant developments exist in Japan, China, Australia, Russia, and throughout Europe..." (Hall, 2004). In a northern province of China, farmers have been living under their fields in underground housing opening onto sunken courtyards they have created for hundreds, if not thousands of years.

Underground space is used more and more for housing, offices, warehousing, factories, storage and military facilities. These facilities promote the environment and sustainable development by conserving

energy, leaving clean environment and open scenery above ground, and by giving the landowner multiple use of the land.

Earth-Sheltered Facilities represent almost the ultimate in environmentally-friendly sustainable development. They provide substantial energy conservation and are built by local labor out of local materials. During his career, the Author has proposed underground facilities for several developments in extreme climates; however, few owners are willing to take the risk, no matter how small the risk might be.

Last year (2003), the Author, together with David Bennett, FAIA, made a proposal to the United Nations on behalf of ITA in response to the UN program to reduce Rural Poverty. ITA proposed that the United Nations consider the inclusion of shelter design, and particularly the development of underground and earth sheltered construction be included as a part of the ECOSOC goals to create sustainable rural communities around the world. This year, (2004), Mr. Bennett and the author prepared another proposal to the United Nations on behalf of ITA and the American Underground Construction Association.

Each of these proposals made it clear that the sophistication of earth-sheltered structures, and underground space in general, can range from simple habitats to highly sophisticated high-tech complexes or communities depending on the needs and resources of the users. Housing and other community buildings can be built largely with local materials by local labor usually by cut-and-cover-techniques or earth-mounding. Underground facilities can be maintained with relatively little energy, providing pleasant and comfortable interior spaces.

Earth sheltering provides intrinsic energy conservation. Because of the insulating effects of the earth, the structures maintain a uniform temperature year round. In desert climates, where the temperature changes can vary 35 degrees C. or more from daytime to nighttime, this factor is particularly effective.



Fig 3 Typical Pleasant Well-lighted Interior of Earth-Sheltered Houses (From Hall, 2004)

Both of the interiors in Fig 3 are of earth sheltered houses created by mounding earth (and other materials) over the structures. Both use the thermal characteristics of massed earth combined with an orientation to collect and store solar heat.

### **Integration of Earth-Sheltered Concepts with Advanced Technologies for Sustainability**

On the other hand, contemporary industrial technology can bring to underground construction a warm environment filled with daylight, air, and energy for lighting and climate control. Its benefits are magnified by the intrinsic economies the earth provides. The following is a discussion based on David Bennett's (Bennett, 2003) ideas on how sophisticated earth sheltered facilities and communities can expand in complexity and size to meet even challenging demands.

It is time to integrate advanced technologies with the earth sheltered facilities to get synergistic results. Because of the relatively low energy demand, typical underground and especially earth sheltered buildings can take advantage of established sustainable energy production technology, such as direct solar systems for heating and hot water, and advanced technology like photovoltaics and microhydroelectric production.

The interiors of earth sheltered facilities need daylight. Some of this need can be effectively met simply by good architectural design, like the proper orientation of openings and well conceived sky lighting, as illustrated above. However, situations always arise where the introduction of high technology may be an effective tool. One such idea, to project light into underground space is called Solar Optics which employs stamped plastic Fresnel (flat) optical lenses which track the sun optically and directs sunlight deep into the interior. In addition to daylighting by good architectural design and by passive optical systems, electrical production is an essential part of creating a sustainable environment for self-contained living. An example of another product of recent technology which has the potential to create a sustainable environment is photovoltaics, a means of converting light directly into electrical energy. Photovoltaic technology is long past the experimental stage and is well on its way to general application for energy generation in the developed world.

### **Rain Water Collection and Storage for Rural Areas in Developing Countries**

One of the most serious problems facing rural communities worldwide is access to clean, unpolluted water. For many centuries communities and families in rural areas have collected rainwater and stored it in underground cisterns. This system has been only marginally adequate even in the best of times because the means of collection has been limited and the individual cisterns could not be linked together to create a reservoir.

A good solution is to provide a collector which empties directly into an underground cistern where the water can be stored. It is possible to build a framework for a dish structure which can be assembled locally of small components arranged in a form which, when all the pieces are assembled, creates a structure adequate in size and strength to the purpose.

It is in the underground cistern system to store the collected rainwater that underground infrastructure development can play an important part in creating sustainability. By microtunnelling to interconnect residential scale cisterns as they are added a modular reservoir can be created.

Individual rain collectors can be extended into a complete residential scale system of water collecting dish, photovoltaic array and cistern. Individual systems can be constructed individually and connected together later by microtunnelling. This can be extended to the scale of villages and small communities.

### **Storage of Food and Other Goods for Developing Countries**

Underground cellars and bins have been used for centuries to safely store food and other goods. This may be one of the best and least expensive ways to improve the quality of life in rural areas and in the Least Developed Countries. The inherent qualities of underground space protect the product and provide improved security against loss from intruders. Many food products such as grain, potatoes, corn, other vegetables and fruit, water and even ice, can be safely stored underground. Underground spaces can provide a good and safe environment for storage of a variety of products and equipment. Although fuel is usually stored underground worldwide, a wide variety of other products and equipment can be stored underground and would be more appropriate to the needs of the Least Developed Countries.

Underground storage can be created to suit the needs of the user. For centuries, small openings in the ground have been used by individual families to store vegetables such as potatoes. This individual storage can be continued but larger underground spaces could also be made to cold-store foods for several families, a village, or larger community.

### **Integrated Underground Development for Future Communities**

David Bennett, FAIA, argues that the result of the marriage of ancient technologies, which are inherently resource and energy conservative, and advanced modern technologies, which are configured for efficiency, has the potential to ultimately create communities combining ground level, earth sheltered, and underground development which are self-sustaining and productive.

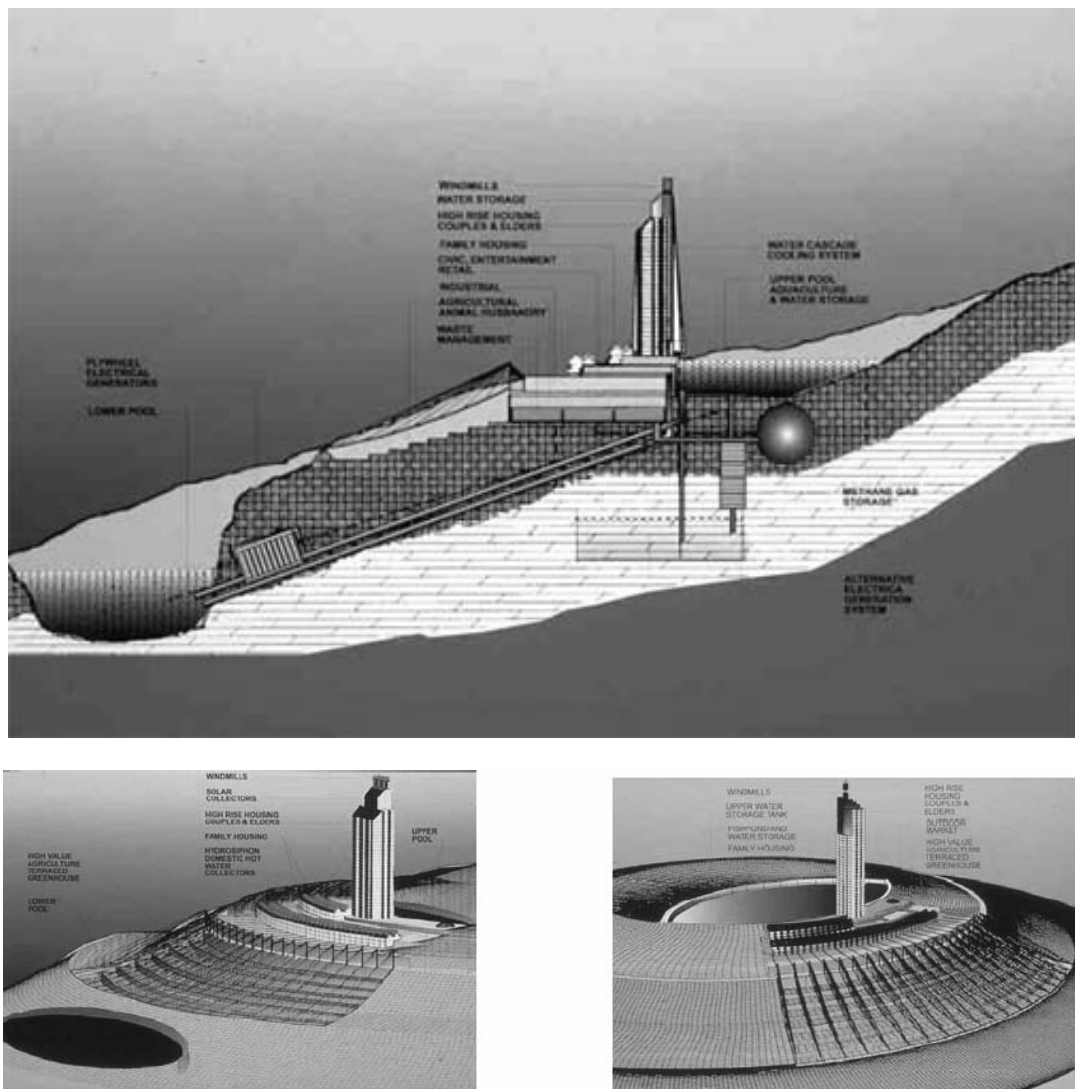


Fig. 4 Complete Sustainable Agricultural / Light Industrial Community (From Bennett, 2003)

Fig 4 illustrates a proposed design for a complete sustainable agriculture/light industrial community (Bennett, 2004). The community grows some of its own food in covered greenhouses on the slope, raises hogs and poultry for sale indoors in closed environments, and is energized by a combination of collected methane gas, wind, solar, photovoltaic and micro-hydroelectricity. Family housing and the market are at the top of the slope and pre-family and elderly housing is in the high-rise tower. It is a demonstration of what a sustainable agricultural community could be even in the near future if decision makers and society could look past traditional concepts and accept and implement innovative techniques.

The above concepts on sustainable development have been presented to the United Nations on two occasions on behalf of ITA.

## RETROFITTING CITIES FOR SUSTAINABLE DEVELOPMENT

Cities, especially in developing countries, tend to grow haphazardly and often as an urban sprawl. This means that infrastructure may not be constructed at the optimum time where construction can be efficient. To the contrary, infrastructure must be thrust onto an existing urban fabric. Underground construction provides ways that these essential services can be constructed beneath existing facilities with a minimum of disruption to the surface. Clearly this is a plus the tunnel industry, and especially for microtunnelling methods, all of which will flourish in the future.

## ROLE OF SUSTAINABLE DEVELOPMENT IN FUTURE DEMAND FOR TUNNELS & UNDERGROUND SPACE

A strong case can be made that the bulk of future tunnel demand can be attributed in some way or another to a desire by society and decision makers to improve the environment and sustainable development. However, our industry has not yet developed a convincing quantitative database showing just how important the Underground is to sustainable development and the environment. Mere suggestions that tunnels contribute to improve sustainable development will not be enough to increase the demand for tunnels either locally or worldwide.

Instead, our industry needs to fully embrace the concepts of sustainable development, as have many other professions and industries, and consciously use the strong benefits of tunnels to be the driving force in selecting the below-ground alternative. There will almost always be competing surface options which, at first glance, may appear to a decision maker or voter to be less expensive.

Our industry must begin to identify the specific quantitative sustainable development and environmental benefits of the Underground and collect and publish case histories that confirm these benefits giving specific quantitative environmental benefits. This would be in terms of how much less 1) pollution, 2) noise, 3) energy demand, and 4) space needs, etc. can be expected if the underground alternative is chosen. Particularly for water and wastewater, our industry needs to quantify just how much better the standard of living is and how much better health is improved by the use of the Underground. Our industry then needs to aggressively market the Underground as being the alternative that should be selected because of its superiority for sustainable development and the environment.

These include all of those listed in Table 1 and Table 2 but mostly the following:

- Lower energy used
  - Flat grades
  - Shorter distances
  - Less energy demand during operation
- Reduced noise
- Reduced air pollution
- Multiple use of land parcels
- Lower maintenance and Longer Life
- Reduced long term demand on renewable & non-renewable resources

Selected examples will be given in the paragraphs below. These are merely examples; the worldwide opportunities for more work through Sustainable Development are endless.

### Transportation

Transit Tunnels and Stations There is little doubt about the environmental benefits of transit versus other forms of transportation. It is reported that moving a person over a given distance by public transportation consumes on average, about half the energy of moving a person the same distance by private automobile.

Underground transit enjoys these advantages as well but suffers from a general perception that the cost of going underground is significant. ITA has recently published a report by Working Group 13 (WG 13) titled "Underground or aboveground: making the choice for urban mass transit systems." (ITA, 2003). Indirect advantages from underground mass transit listed in this report include several advantages that improve the environment.

Direct advantages listed by ITA's WG 13 include Visual/Aesthetic impacts as the major reason for locating transit underground. The indirect advantages listed include significant time savings and much reduced congestion on roads both of which translate directly to reduced energy usage. Also listed is more available space for other purposes and better utilization of space. Energy savings were reported by a dozen of the cities surveyed but most did not provide quantitative data. Finally, reduced air pollution was given as an indirect benefit with some limited data from a few cities.

Rail Tunnels Rail tunnels and underground stations generally provide significant environmental advantages. These advantages, including preserving environment and scenic views from industrial activities should be highlighted by planners when new rail lines are considered. Now, with renewed concern for the environment, rail lines are being increasingly placed in tunnels. In Stuttgart, Germany, the entire rail yard is being placed underground so that the land at the city center can be used for more noble purposes that will make the entire city more sustainable. The Stuttgart 21 project will create considerable open space and will also partially pay for the project by selling some of the newly created land to developers.

The Groene Hart tunnel in the Netherlands is an example where environmental and sustainable development issues carried greater weight than initial cost. As sustainable development becomes more important to society as a whole, more and more voters and decision makers will place rail projects underground even though initial cost may seem to be higher.

Road Tunnels Road tunnels provide the same type of environmental advantages as rail and transit but often to a different level or degree. Clearly, road tunnels eliminate the visual and aesthetic blight associated with highways wherever they are built. However, they can also drastically reduce noise, air pollution and energy usage. One example will suffice; the Hsuehshan Tunnel in Taiwan will be the longest highway tunnel in Southeast Asia at 12.9 km long. When completed, the tunnel will reduce travel time between Taipei and Ilan from two hours to 30 minutes and the energy savings will be enormous.

In urban areas, freeways constructed through a city (or any other urban fabric) divide the city into separate sectors. People do not want to live next to the freeway so land values are immediately depressed which is followed by other social problems that, over time, divide the social fabric of the city. This is not sustainable either socially or economically. In urban areas, road tunnels not only eliminate visual blight but they have been used to eliminate the problem of separating the areas on either side of the road from each other. A few examples will suffice.

In Seattle, the I-90 freeway was built in the mid to late 1980's. In response to public pressure, two major tunnel structures were constructed to avoid the visual blight and social interference of dividing the urban area into two separate parts. The first was the Mt. Baker Ridge Highway Tunnel, the largest diameter soil tunnel in the world with an inside diameter of 19.5 m and an equivalent outside diameter of 25.5 m. Also on the I-90 project, as the highway passed through Mercer Island, a multi-storey open cut structure was constructed as the future highway tunnel roadway structure. The open cut was then backfilled with soil so that little to no evidence of the tunnel below exists. Both the Mt. Baker Ridge tunnel portals and the entire Mercer Island tunnel were converted and landscaped to create beautiful parks with art and recreation facilities. No longer does the highway separate the city.

In Boston, the visionary Central Artery project consisted of removing a major surface and elevated freeway through downtown Boston and reconstructing the freeway in tunnel structures, allowing the surface to be reclaimed for more noble purposes including large open spaces, parks and recreation areas. This project is just now (2004) being completed and already the public is surprised at how much

improvement has already been achieved. No longer will Boston be divided and environmental improvements include dramatically reduced noise and air pollution.

Finally, in the last half of the 20th century, many cities throughout the world constructed roads and freeways as elevated viaducts, for many reasons, particularly cost. These structures also divided the city and became a blight on the city. Currently, there are planning and environmental assessment projects in several cities to replace these unsightly non-sustainable structures with an underground solution. One such project is the replacement of the Alaskan Way Viaduct along the waterfront in Seattle. The viaduct will be replaced with a major cut and cover structure which will also serve as a replacement for the deteriorated seawall. Similarly, there is a project to evaluate the replacement of the elevated Gowanus freeway in New York City with an underground tunnel. In both the Seattle and New York projects the tunnels would use the same right-of-way as the existing viaducts. In Bridgeport, Connecticut, a proposal has been made by a citizen group to demolish the unsightly viaduct along the waterfront and sell the land to partially offset the cost of a by-pass tunnel for the freeway along a different alignment.

There are abundant other projects throughout the world that can be constructed if the criteria for selection correctly takes into account the environment and sustainable development. None of these will happen without our industry being more active in the planning process. There will be a huge demand for underground transportation projects if the criteria properly include quantitative advantages for the environment and sustainable development.

### **Water & Wastewater**

Clean water is one of the most precious commodities in the world. Over 1.1 Billion people have no access to clean water and some 2.5 Billion people lack proper sanitary provisions. Water and wastewater is where our industry shines! Almost every major city in the world has a major tunnel supplying water to its inhabitants and even more urban centers manage wastewater by a network of tunnels. Some tunnel projects have just recently been constructed to provide badly needed water supply as is the case where the Lesotho project is now providing water to Johannesburg. Some cities around the world will soon need new major tunnel projects for expansion or redundancy and for replacement/rehabilitation. This is the case for New York City where City Water Tunnel No 3 has been under construction for decades and more tunnels are being planned and designed to provide more redundancy.

Moreover, the rapid development of new cities, particularly those of a million or more inhabitants, and especially the megacities of 10 Million or more will need abundant new tunnels to meet this demand. In fact, it is possible that if all the water and wastewater projects that need to be constructed in these new megacities were undertaken, that the demand for tunnels may exceed our industry's current capacity to design and build them.

Because tunnels are the best infrastructure for this purpose, there will be a huge demand for water and wastewater tunnels in the future. Also, as developing countries mature, their cities will need improved wastewater treatment and surely there will be many more mega-tunnel projects throughout the world such as the Chicago Deep Tunnel project (TARP) which has kept several tunneling companies in business for several decades. The project consists of a network of large tunnels which, during dry periods carry only very low flows. However, the tunnels are sized so that they become longitudinal holding tanks whenever storm flows exceed the capacity of the sewage treatment plants, allowing sewage from the combined sewer overflows to be held in the tunnels until it can be treated after the storm subsides. Similar projects have been proposed or constructed in several other cities around the world including Stockholm, Tokyo, and Paris.

The Scandinavian countries have pioneered the construction of entire sewage treatment plants underground. Not only do these facilities support sustainable development by putting an unsightly and generally odorous plant out of sight and out of mind but also there are significant energy savings. The

sewage treatment process is temperature sensitive and the constant temperature of the underground makes control of this process more energy efficient.

ITA Working Group No. 4, Subsurface Planning just published an important study of underground water installations. Their report, "Overview on Survey of Water Installations Underground: Underground Water-Conveyance and Storage Facilities" has been published. A summary of the report is published in Tunnelling and Underground Space Technology (TUST), (Nordmark, 2002). The report concludes that the worldwide demand for water has tripled since the middle of the 20<sup>th</sup> century and already the "supply of water cannot catch up with the demand."

Since tunnels are unquestionably the best infrastructure for water and wastewater facilities, there will be a huge demand for such tunnels beyond the foreseeable future. In water and wastewater, there is a need for tunnels of all sizes and capacity. Thus this future demand will be good not only for the traditional large tunnel industry but also for the microtunnel industry.

However, as with other underground projects, just because there is a need for water and wastewater infrastructure, there is no guarantee that the decision makers will make the decision to build more tunnels. Such is the case in Atlanta, Georgia. The water and wastewater infrastructure was known to be in poor condition and in need of expansion and repair for several decades. However, the problem was out of sight, out of mind until the situation became so bad that it forced the city leaders into action. The current mayor, Mayor Shirley Franklin, has taken upon herself the nearly impossible task to find funds to pay for the improvements which had been neglected for decades. She reported that the water distribution systems in Atlanta were losing a large percentage of water as a result of pipe ruptures etc. The author understands that an average estimate of the amount of fresh water lost in distribution systems in the US ranges up to 30%. Such situations likely exist in cities all over the world and, once the problem gets out of hand, abundant tunnelling is required to achieve environmental and sustainable development goals. One example is a New York City aqueduct which is leaking about 120 million liters of water a day. The city is currently evaluating how to repair or replace the section.

The American Water Works Association recently published a report (AWWA, 2003) which concludes that over the next 30 years, an additional \$250 Billion will be required to replace ageing drinking water infrastructure. Although not all of this would be tunnels, clearly there is a demand for additional traditional and microtunnels since the report also concludes that pipe replacement must triple over the next 30 years.

### **Utility Services and Utilidors**

This segment of our industry makes the most extensive use of the Underground worldwide and probably one of the strongest in support of sustainable development. The expansion and replacement of utilities is a multibillion dollar annual market worldwide (Sterling and Carmody, 1993). This demand will largely be met by the recent developments in microtunnelling.

There is an enormous demand for utilities in general as described above and as known from other utilities. Water and sewerage are not the only utilities that must be constructed to provide the needed infrastructure to a region. Not only do cities have a vast network of utility tunnels but many campuses of major university and industrial parks have significant networks of utility tunnels.

Placement of several different kinds of utilities in a common underground conduit, sometimes called a utilidor, is a goal of many city engineers but there are many legal and other constraints that prevent more common usage of utilidors (Sterling and Carmody, 1993) (Cano-Hurtado and Canto-Perello, 1999).

### **Bulk Storage**

Bulk storage of liquids, food, materials and equipment is another ideal situation where the underground provides obvious enormous benefits to the environment and to sustainable development while at the

same time providing a large potential market for the underground industry. Numerous examples exist but the most obvious is the storage of oil in huge underground caverns. These caverns not only allow safe storage of the oil but the use of the caverns replaces the construction of huge tank farms on the surface that would extend for many square kilometers. Again, the use of the underground promotes sustainable development while, at the same time, creates a significant demand for underground construction.

There are many other types of underground bulk storage including wine, frozen food products, grain, etc. A compilation of various uses of the underground for storage of products is given by Broch (1993). Nordmark (2002) also describes facilities for water storage and for storage of flood waters.

### **Food Storage**

The storage of foods underground is another use for the underground supporting sustainable development and has been discussed above with respect to the ITA UN proposals. Such uses are also described well by Sterling and Carmody (1993). The Underground has been used for storage of food for centuries. Underground storage of food will be extremely valuable to specific selected societies. But it is not now nor is it expected to be a major contributor to the overall demand of underground construction.

### **Energy Production, Storage, and Sharing**

In addition to bulk storage, there are a variety of special uses of the Underground that support sustainable development and conservation of energy. These include underground hydroelectric plants and underground pump storage plants that generate electricity full time and/or on demand. There are Compressed Air Energy Storage (CAES) projects that provide cyclic generation of electricity by release of previously-compressed air through turbines during peak demand periods. There are also thermal energy storage schemes which have been pioneered in Scandinavia. Finally, the use of district heating and/or cooling is another way the underground provides the means for using energy more efficiently. However, it is a specialty market and not likely to be a large demand for the general underground industry. These and other energy-saving schemes are described well by Sterling & Carmody (1993).

In the late 1970's, the author even worked on a conceptual design to place an entire nuclear power plant underground to avoid the potential environmental effects of an accident like the Three Mile Island or Chernobyl incidents. Obviously, the cost was considerably higher than an above ground plant but it was determined that releases could be contained if an accident were to occur.

### **Waste Disposal**

The Underground is the safest and most likely place to dispose of many hazardous wastes, especially nuclear waste. These projects are huge underground projects that address environmental and sustainable development issues directly. The projects, especially in the United States have been delayed because of differing opinions of environmental safety but the author is convinced that the best place to store and/or dispose of nuclear waste is underground. These projects are also huge and will challenge our industry whenever permission is granted for such projects to move ahead. Meanwhile, the waste, waiting to be stored safely, is stored in pools at each nuclear power plant.

### **Living and Commercial Spaces**

Many people live and work underground in facilities that are environmentally friendly and favorable to sustainable development. They range from individual residences and small facilities as described above in ITA's proposal to the United Nations to large complex underground living, office and industrial spaces. The author believes that these types of underground facilities will continue to be in demand for the foreseeable future. These facilities are well described by Bennett (2004); Hall (2004); Von Meijenfeldt, et al (2003), and Sterling and Carmody (1993).

## **Preservation of Archeological and World/National Heritage Sites**

There are many archeological and World and National Heritage sites that may need to be protected from modern day development and tourism. Examples include the Lourve extension as well as the Stonehenge Tunnel which provides a by-pass for the archeological site, and many others. These projects may not be large but they illustrate the versatility and tremendous importance of our industry to the overall goals of the environment and sustainable development.

### **EMBRACING SUSTAINABLE DEVELOPMENT: HOW DO YOU JOIN IN, AND WHAT IS ITS COST?**

Embracing the concepts of Sustainable Development requires a change in attitude from just agreeing that the environment is important or important enough to warrant considerations in the workplace. It requires an agreement to look at planning, design, construction, and operation in an entirely different light; that of actively looking for ways to conduct business that supports the principles of sustainable development.

To join in, one must become aware of what others are doing in the field of sustainable development. You may find that your clients or competitors are ahead of you. You must then decide how to convey internally to your employees and externally to your clients what is your commitment to Sustainable Development.

The good news is that embracing Sustainable Development is an *investment, not a cost*. Sustainable Development has been embraced by most of the multi-national companies not only because it opens new markets but because the perspective used by those engaged in supporting Sustainable Development makes one become more efficient and thus reduces the cost to your firm. If this were not the case, the Board of Directors of each of these firms on the Dow Jones World Sustainable Index would not embrace Sustainable Development so strongly. There are many papers and articles written about the fact that embracing sustainable development makes good business sense in terms of the bottom line.

If nothing else, for those trying to be selected for an engineering design project, the members on selection boards are not always hard lined non-environmentally-oriented engineers but may be someone who appreciates the fact that the company they are considering for a big job (your company) has already embraced Sustainable Development. For those trying to get a design-build project or even a traditional construction contract, the person making the selection for anything other than low bid will recognize your company has already embraced Sustainable Development. The same is true of equipment and material suppliers and all others involved in our underground industry

### **CLOSURE AND CHALLENGE TO OUR UNDERGROUND INDUSTRY**

From engineering and practical standpoints, there are costs and secondary effects for every move toward a cleaner environment and sustainable development. Those of us in the underground industry must understand that this is not all bad. Some costs are really "Investments" and often the secondary effects are beneficial. It should be the goal of our industry to make decision makers understand the benefits of the underground with respect to Sustainable Development.

The author suggests that all of us in our industry immediately take advantage of the strong environmental and sustainable development benefits that the underground offers. However, our industry needs the tools and database to support all the indirect claims that the Underground is, indeed, very environmentally friendly. It is not enough to say that noise will be less if you spend millions of Euros to place a structure underground. Our industry needs specific, credible and verifiable quantitative data on what the softer benefits are if a structure is placed underground. Interestingly, our

industry needs the same type of quantitative information with respect to Life-Cycle Costs. The author suggests that both of these be developed in parallel and synergistically by ITA.

The author represented ITA at the United Nations Habitat II conference in Istanbul in 1996. The author recognized that the people who are in charge of planning future societies and cities do not understand the importance of planning and construction of infrastructure and certainly do not understand or appreciate the Underground. Most city planners expected that infrastructure would “just evolve.” It is the job of our leaders to be pro-active at the earliest stage of any project, even when it is only an “idea,” to keep the underground option in the forefront of planners mind. We must demonstrate to planners and government officials that the earlier underground facilities are constructed, the more cost-effective they can be.

If the growth of cities, particularly the megacities, continues, they will all need abundant infrastructure and the demand for the Underground will be enormous. In fact, even if a fraction of the needed infrastructure is funded, the capacity of our industry will be challenged. We may not be able to build the required infrastructure fast enough. There simply may not be enough planners, designers, and contractors to do the work.

However, this work will not walk into the door by itself. We can not afford to wait for decision makers to become aware of the sustainable development benefits of the Underground. Instead we must be pro-active and let the world know that:

***Sustainability is Not Possible without Infrastructure and that, often, the best form of infrastructure involves the underground.***

## REFERENCES

AWWA (2004) AWWA website <[www.awwa.org](http://www.awwa.org)>

Bennett, David J. (2003) Personal Communication

Bennett, David J. (2004) “*Beyond Sustainability: The Case for Environmental Architecture*,” <<http://djbarchitects.home.att.net/sustainablebase.htm>>, 16 pp

Broch, Einer (1993), *Norwegian Underground Storage*, edited by Einer Broch, Publication No. 9, June 1993, Norwegian Soil and Rock Engineering Association, 108 pp

Brundtland, G (ed) (1987). *Our Common Future: The World Commission on Environment and Development*, Oxford: Oxford University Press

Cano-Hurtado, J. J. and Canto-Perello, J (1999), Sustainable Development of Urban Underground Space for Utilities, *Tunnelling and Underground Space Technology*, Vol. 14 No. 3, pp 335-340

Carson, Rachel L. (1962), *Silent Spring*, Houghton Mifflin Company, New York, 378 pp

Celik, Aliye P. (1996), “Challenge of Sustaining our Habitat in the Twenty-First Century,” *Tunnelling and Underground Space Technology*, Vol. 11, No. 4, October, 1996, p 377-379

Hall, Loretta (2004), *Underground Buildings: More than Meets the Eye*, Quill Driver Books, World Dancer Press, inc., Sanger, California, 215 pp

ITA (2004), Underground or aboveground? Making the choice for urban mass transit systems, Report of ITA Working Group 13, Direct and Indirect Advantages of Underground Structures, in *Tunnelling and Underground Space Technology*, Vol. 19, No. 1, pp 3-28

Nordmark, A. (2002) Overview on survey of water installations underground: underground water-conveyance and storage facilities, Report of ITA Working Group 4, Subsurface Planning, in *Tunnelling and Underground Space Technology*, Vol. 17, No. 2, pp 163-178.

Parker, Harvey (1996), Tunnelling, Urbanization and Sustainable Development: The Infrastructure Connection, Editorial in *Tunnelling and Underground Space Technology*, Vol. 11, No. 2

Ray, Kalyan (1998), Tunnels and infrastructure for metropolises: the Habitat Agenda Perspective, *Tunnelling and Underground Space Technology*, Vol. 13, No. 3, pp 313-315

Roberts, Don V. (1996), Sustainable Development and the Use of Underground Space, *Tunnelling and Underground Space Technology*, Vol. 11, No. 4, October, 1996, p 383-390

Sellberg, Bjorn (1996) Environmental Benefits: A Key to Increased Underground Space Use in Urban Planning, Editorial in *Tunnelling and Underground Space Technology*, Vol. 11, No. 4, October, 1996, p 369

Sterling, Ray and Carmody, John (1993), *Underground Space Design: A Guide to Subsurface Utilization and Design for People in Underground Spaces*, VanNostrand Reinhold, New York, 328 pp

Von Meijenfeldt, Ernst et al. (2003), *Below Ground Level, Creating New Spaces for Contemporary Architecture*, Birkhauser Publisher for Architecture, Basel, pp 264