Taking Urban Development Underground

Future-ready solutions for ensuring urban sustainability
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By 2050, the urban population will nearly double to 6.3 billion—two-thirds of all the people on the planet. Cities are gaining 77 million new residents each year, equivalent to the population of Turkey or Germany, and twice that of California. Much of this growth is sprawl. Over the first three decades of this century, the global increase in urban land cover is expected to be greater than all urban expansion so far in human history. Urban centres ranging in size from 500,000 to 10 million residents will continue to evolve, putting land in these high-density areas at a premium.

Underground construction is creating new opportunities and approaches to sustainability to address those realities. The potential economic, environmental and social impacts of underground construction are immense, with proper planning and development of underground space promising enhanced quality of life in compact, efficient and sustainable cities.

Key trends point to the growing recognition of underground’s possibilities, of future integrated cities where underground facilities link-up with infrastructure and make life above ground more enjoyable.

A previous WSP report focused on rail overbuild and the societal benefits that can accrue from creating new residential accommodation by decking over new and existing railway infrastructure. This can include rail/underground tracks and stations. Here we make a case for underground construction as a spatial asset that extends beyond transport tunnels and utilities to a host of facilities currently occupying surface space.

However, we must start planning for the underground city now if we are to maximize the livability and continued functioning of our increasingly congested, high-density cities.
Cities will be more pleasant, more livable and more efficient if they fully exploit the benefits of underground space. With global urban population densities set to rise dramatically, exploiting the underground realm will make cities less congested, less polluted, more sustainable, and greener places to live and work. Facilities that do not need to be on the surface can be located underground, resulting in more land available for crucial applications such as housing, schools and amenity space.

In addition to roads, railways and storage that often go underground, we can add cinemas, libraries, entertainment venues, department stores, supermarkets, parking lots, retail malls, pedestrian routes, factories, waste facilities and even support agriculture—the list is endless.

Once created, these spaces can be interconnected to form a holistic and sustainable underground system that complements the surface and results in a multi-level city. But to realize the extraordinary potential of underground space will require overcoming numerous structural, logistical and regulatory barriers as well as the synthesizing of planning, coordination and technical expertise.

There are many reasons why increased urban density can be regarded as sustainable environmentally, socially and economically. Cities offer far greater opportunity for the interaction and exchange that generates economic growth. According to the United Nations (UN), cities are responsible for 80 percent of global GDP. Greater density creates demand for social infrastructure such as hospitals, schools and nurseries, and cultural and leisure activities—and puts more people within practical reach of the services businesses provide.

Despite a plethora of advancements in technology that have rendered underground construction viable, there remain numerous structural, logistical and regulatory barriers to the realization of its full potential. Planning, coordination and technical expertise are all critical components required for success. However, issues of cost, ownership, safety and more continue to obstruct progress.

Underground development linked to existing city infrastructure will inevitably require the consensus and coordination of numerous government agencies, private sector interests, citizens and other stakeholders. Coordination of these stakeholder groups from the initial planning stage is critical. Governments at all levels must act now to ensure that integrated master planning addresses both future underground infrastructure development and surface-critical expansion.
Global urban and rural population (projected 2050)

Projections are based on the UN World Urbanization Prospects and its median fertility scenario.

Source: OWID based on UN World Urbanization Prospects 2018 and historical sources. Licensed under CC-BY-SA.

World population growth, 1750-2100

Annual growth rate of the world population

World population


Why we should build underground
What drives underground use

— Population growth and movement to urban areas (70% by 2050)
— Transportation needs
— Limited choice and congestion
— Surface space for people-centric activities
— Climate change and energy savings (up to 80%)
— Land costs
— Resilience
— Aesthetics
— Access

The state of the art
While the history of underground construction dates back centuries, evolution of technology and construction methods has expanded its horizons. A vision once reserved for transport, storage and utility solutions has grown to encompass limitless possibilities for future development, fueled by necessity in many cases.

Back to the future
In the early 1960s, Montreal, Canada embarked on a visionary project designed to cover exposed railway tracks connected to Central Station, located in the heart of downtown. The initial development connected an office tower, an underground shopping mall, a major hotel and Central Station via a pedestrian tunnel system. The RÉSO, commonly referred to as “The Underground City,” has since developed into a network spanning 33 kilometres that is used every day by as many as 500,000 people. The underground system links 10 metro stations, 2 bus terminals, 1,200 offices, 2,000 businesses, approximately 1,600 housing units, 200 restaurants, 43 indoor parking lots, 40 banks, 30 movie theatres, 10 major hotels, 10 university pavilions and much more.
What drives underground use
Repurposing of assets

While Montreal is uniquely advanced in its vision, stakeholders around the world today are examining ways to repurpose existing underground assets previously constructed to address other needs. In the UK, limestone mines in Corsham, Bath were converted into ammunition depots and cold war bunkers to address wartime needs. A new project underway to make innovative use of these empty underground facilities is expected to include a state-of-the-art communications centre, storage facilities, and much more. WSP experts are assisting government and private sector interests with this initiative.

In north-central Paris, a city council call for innovative proposals to repurpose an abandoned underground parking garage located below a 300-unit affordable housing complex is shining new light on the potential of urban agricultural production. Among the new tenants is La Caverne, a 3,500-square-metre subterranean farm that has become a model for the future of “underground permaculture,” adding productive new green space and a new dimension to city life. Owned and operated by Cycloponics, the farm aims to produce 54 tonnes of vegetables and mushrooms annually using hydroponic systems, LED lighting and 100 percent renewable energy.
The Lowline is a development plan to build an underground park on the Lower East Side of Manhattan in New York City. Using innovative solar technology to illuminate an historic trolley terminal, the vision is to create a four-season park and cultural attraction beneath one of the world’s most heavily trafficked urban districts. With a timeline focused on a 2021 opening, The Lowline could provide an inspirational example of how underground green spaces can be woven into the fabric of dense urban areas.

In 1996, Polish officials in the Kraków metropolitan area began repurposing the Wieliczka Salt Mine, a 13th century mine that has evolved over the course of its history into an underground salt city. With an infusion of wooden pillars, chocks, shores, anchors and epoxy glass, developers began securing existing salt pillars and petrified wood exposed to centuries of salt. Section by section, the mine has been converted into a Polish National Historic Monument, and today the site hosts more than a million annual visitors to its underground collection of statues, chapels, underground lakes, event space, wellness centre and more. In 1978, the repurposed mine became a UNESCO World Heritage site. ✍️

What drives underground use

Credit: Raad Studio

Credit: Davis Staedtler

Credit: Davis Staedtler
Stacking new developments

Sweden is well versed in the merits of rock engineering and its societal benefits. A concentration of underground construction projects and expertise has emerged in recent decades, feeding new ideas into development projects for the present and future. Dating back to the 1980s, Swedish cinema chain, Svensk Filmindustri, embarked on a visionary project to construct a large underground cinema complex within a rock cavity in central Gothenburg. A reinforced concrete frame comprising 450 prefabricated elements (beams, wall and roofing sections) was constructed within the rock cavity and bolted to the rock to house the complex. Additionally, when the National Library of Sweden needed expansion for book storage, a facility was constructed within a rock cavern directly beneath the existing building, as opposed to above ground construction on a separate site.

Sweden’s extensive experience has led to numerous spatial solutions for wastewater treatment plants, storm water reservoirs, hospital technical supply systems and more. Successes have given rise to innovative new urban planning projects focused on rock engineering as a means to an end for creating new underground spaces, and WSP experts in Sweden have played a critical role in the design and construction of some of the most ambitious projects.

In Stockholm, Hagastaden represents a strategic, progressive approach to sustainable development. The 2010-2025 timeline encompasses multiple projects that will ultimately transform former Norra Station—an area between Stockholm and Solna once dubbed a “no man’s land”—into “Hagastaden,” a vibrant new city neighborhood populated with housing, parks and knowledge-intensive industries.

The Norra Station/Over Decking Project plays a central role in making Hagastaden a reality. The project involves extending Norra länken (“Northern Link”), a 13-kilometre highway that relieves congestion in central Stockholm by tunnelling the E4/E20 European Highway and directing inner city traffic underground.

The Norra länken extension involves building a tunnel under Hagastaden, with complex and multi-story over decking connecting to the existing E4/E20 highway. The project will relieve congestion, reduce traffic noise levels and improve air quality, while also opening up much needed “high revenue” surface space. With a surface area of approximately 96 hectares, Hagastaden will accommodate an estimated 6,000 homes, 50,000 workplaces, multiple green spaces and more.

In Australia, officials looked below the surface for answers to parking issues facing the world-renowned Sydney Opera House and its surrounding...
region. The solution emerged in the form of the Bennelong Point Parking Station, opened in 1993 as a 12-story underground parking facility with a capacity of 1,100 vehicles. The double-helix concrete structure, constructed in sandstone, required excavation of 16 tunnels, including portions located beneath adjacent government buildings. More than 2,000 anchors and dowels were used to support the parking facility’s roof, forming part of a reinforcement system that gave rise to a new design method.

In the UK, WSP experts are researching innovative infrastructure development possibilities surrounding planned construction of a deep-tube project intended to relieve London’s overburdened metro system. With development plans to include construction of a series of new tunnels under the present system, WSP’s long-term view has expanded the vision to incorporate linked infrastructure that will include transport hubs, underground shopping and leisure facilities, and much more.

The London Underground system also has numerous disused stations. Plans are afoot to convert these stations into visitor attractions, such as night clubs and museums, ensuring that what is created underground will always have a use.
Deep thinking

As stakeholders around the world face the inevitability of future demands that exceed current land availability, a push to leverage international experiences, innovative ideas and emerging technologies is underway. As a global leader in innovative engineering practices, WSP draws upon the experience and expertise of an international workforce to offer solutions to clients in every corner of the world.

In the UK, the work of Think Deep UK is spreading across international borders, led by a group of built environment experts committed to creating resilient, sustainable and livable cities through smart use of underground space. Experts from WSP’s Sweden offices have participated in workshops sponsored by the group on such topics as Social Value, Future Infrastructure and 3D Urban Planning, complementing existing competencies and furthering our vision of underground construction as a core element of the planning process.

Among the international case studies being closely monitored by Think Deep UK is development of The Londoner, Leicester Square. Set for completion in 2020, the project includes a 350-room hotel with bars and restaurants on the surface, with two Odeon Luxe cinemas, event and leisure facilities spread across six underground levels. In addition to optimizing space in a trendy area of Central London, underground construction is also minimizing disruption in the highly populated neighbourhood.

Future visions

In 2009, Finland unveiled the Underground Master Plan of Helsinki and its vision for the long-term development of projects connecting underground spaces with important traffic infrastructure and commercial developments. The master plan identified more than 400 current and 200 prospective underground spaces available for future use, including potential dual-purpose cavern facilities currently funded by the National Civil Defence Department.

In 2014, the Singapore government opened the Jurong Rock Caverns (JRC) as the first commercial underground rock caverns facility for storage of liquid hydrocarbons (e.g. crude oil, condensates) in Southeast Asia. Located more than 150 metres below ground and 130 metres beneath Banyan Basin, the JRC underground infrastructure replaced unsightly surface facilities.

Singapore's Urban Redevelopment Authority (URA) is set to release pilot areas of its Underground Master Plan in 2019. The plan will incorporate electrical substations, bus interchanges, rail and road networks, deep tunnel sewage systems, pedestrian links and much more into future development plans. Initiatives relating to the master plan include the establishment of a national geological office, development of a subterranean land rights and valuation framework, and investment in underground development research and development.
Nearly all Singapore’s important infrastructures—such as airports, seaports and major industrial estates—were built on reclaimed land. Prior land reclamation expanded the island by some 100 square kilometres, and the URA estimates another 56 square kilometres of land will be required for further expansion from now to 2030. But development into deeper waters won’t work using conventional land reclamation methods.

From an initial concept titled NEUSpace, researchers at Singapore’s Nanyang Technological University are looking at ways to make land reclamation sustainable by not requiring the use of fill materials. One design creates a water-front city formed by seawalls, using the suction caisson method, which could reduce more conventional construction costs. An alternative design uses circular walls to build offshore islands, part of which could be built on land to integrate the newly created space to existing surface and underground space.

The use of underground space is also turning heads as a potential solution to issues surrounding water storage and conveyance. Scarcity of water, and transporting and storing waste and floodwater are pressing concerns for many major cities around the world. Going underground was London’s solution to major capacity issues related to a sewage system dating back to the 1850s and designed for an urban population of 2 million, not a record-breaking 8.5 million.

The Thames Tideway Tunnel or “super sewer” represents stage three of an extensive project to reduce sewage overflows into the river, improve water quality and address future demands.

The new tunnel will run nearly the length of the city, with completion by 2024.

In the aftermath of Hurricane Harvey, Houston, Texas authorities began researching underground tunnels as an option for the flood-prone US city that would divert stormwater and protect the city’s water supply. Looking forward, underground construction is also opening the door to a myriad of possibilities for energy applications, with potential savings of up to 80 percent. Work in this area could unlock new ground sources for heating, cooling and energy development.

In areas with higher levels of seismic activity, underground construction also offers resilience in the form of durability advantages in extreme environments.
Designing the future

As exploration of underground construction methods deepens, changes in technology and design are likely to emerge in parallel with a better understanding of the impacts on ground performance and related parameters. That may require greater systems integration on the design front, including development of geotechnical/geological data ownership and management systems that will enhance knowledge sharing, while reducing costs.

A finalist in the eVolo 2010 Skyscraper Competition, Bunker Arquitectura gained international recognition for Earthscraper, a 55-story inverted underground skyscraper. The visionary design proposed a mixed-use underground development for installation in Mexico City’s main plaza. The design concept, which addressed multiple urban constraints, included 10 floors dedicated to a Pre-Columbian museum; 10 floors of retail space and housing; and 35 floors of office space. Descending 1,000 feet below the surface, the inverted pyramid also featured a central void for natural light and ventilation, a glass ceiling and a variety of green spaces.

Reclaiming rural space

While this paper focuses on urban challenges driving more and more creative applications for underground construction, there may also be some fluctuation in the rural population that could stem from movement away
from city density to more open pastures—coupled with a desire for design that promotes sustainable living. Underhill House provides a look into what this transformation would look like in real life. The project took a crumbling 300-year-old stone structure located on a hillside in Warwickshire, England and effectively combined the best of heritage architecture with modern design to create a beautiful living space. A barn became an office, while a new building was added underneath and adjacent to it. Built into the hill, the house is invisible from the surrounding countryside. Design requirements included meeting Area of Outstanding Natural Beauty standards and earning certification as a Passivhaus—a German standard of 90 percent reduction in carbon emissions over an average home. ☺
As urban activities increasingly shift underground, human behavioral patterns will play a significant role in the future acceptance and success of underground projects. With global population growth in seemingly perpetual motion, society at large is headed for change as growing consumption of natural resources and evolving consumer demands inevitably hit a wall of non-sustainability. Forecasting future needs and demands is a daunting challenge. As urban activities increasingly shift underground, human behavioral patterns will play a significant role in the future acceptance and success of such projects. The advancement of electric vehicles and demand for their subsequent infrastructures; increased needs for arable land; and mass acceptance or denial of underground living as a viable option are just a few of the unknowns that will surely impact underground construction of the future.

Additionally, while advances in technology have proven underground construction to be viable, there remain numerous structural, logistical and regulatory barriers to the realization of grandiose projects. As issues regarding cost, ownership, fire life safety, ventilation, drainage, mechanical and electrical building services, and more continue to obstruct progress, WSP experts remain vigilant on all fronts and are dedicated to developing comprehensive solutions that will unleash the full potential of underground construction.
Cost justification

Cost has been a major barrier to the optimization of underground space, with rock construction incurring time-related costs that exceed the requirements of above ground construction. However, despite the relatively high cost of underground construction, research suggests that its resulting projects may offer cost-saving advantages that balance the scales by freeing up surface land for other projects, streamlining operational costs and reducing environmental impacts. Underground construction can also help reduce surface congestion, disruptions and travel times, thus offering additional cost benefits to the social infrastructure. Furthermore, with the state-of-the-art of technology in perpetual motion, underground excavation is becoming quicker, cheaper and more easily achievable.

Policy and stakeholder issues

Significant legal, administrative, safety and environmental concerns continue to hover above the advancement of underground construction projects. As planners and developers continue to wade into a new space, lack of governmental experience relating to all facets of underground construction is evident. Standardized legal processes are required, particularly for planning permissions for underground use in complex situations.

While underground facilities offer significant benefits, issues pertaining to the protection of surface and underground rights, business models, administrative responsibilities, financing, and more still need to be resolved at various levels of government.

The Underground Master Plan of Helsinki is a good example of the level of stakeholder involvement required to develop comprehensive legislation aimed at streamlining underground construction, A-Z. In Hong Kong, significant research and planning surrounding underground construction is also in full swing, and the government has stepped forward with a national standard regarding fire and safety requirements for underground spaces. While still in draft form, the standard is expected to be formally introduced in the next couple of years.
Lifecycle advisors for underground construction

Planning, coordination and technical expertise are all critical components to the future success of underground construction. Underground infrastructure that links with the existing infrastructure of city cores inevitably crosses the paths of numerous public and private interests. Global initiatives have already begun to take form, including the UN 2030 Agenda for Sustainable Development, which identifies 17 sustainable development goals and 169 targets.

However, as noted in a UN-Habitat report, successful implementation of urban planning aimed at developing more compact cities and synergies will require strong political leadership; comprehensive legal and institutional frameworks; efficient urban management; and improved coordination and consensus-building at all levels. Therefore, given the scope of master planning for the cities of tomorrow, early coordination of government agencies, private sector interests, citizens and other stakeholders is critical from the initial planning stage.

Experienced in all facets of underground construction, WSP possesses the in-house skillsets to assist governments and other stakeholders in moving toward comprehensive standards that address the complexities and concerns of all phases of subterranean development. Our experts have developed programs designed to educate both public and private sector interests on the importance of underground facilities, and the need to start planning for them now. With the urban population forecast to double by 2050, the sustainability of efficient urban centres offering enhanced quality of life for future generations depends on it.

Incorporating underground construction into master planning involves numerous considerations. WSP’s experienced global teams can assist clients across the full lifecycle of underground construction projects, from the critical planning stage through to design, repurposing, construction, operations, maintenance and decommissioning.

As governments begin a migration toward future visions of cities interconnected with underground infrastructure, WSP is well positioned to address both current and future challenges facing stakeholders. Our researchers and technical experts, experienced in the exploration of spatial assets, have long recognized the immense possibilities offered by underground construction. By promoting underground space as a developable asset, WSP is helping clients to prepare future-ready infrastructure designs that will be adaptable to change, ensuring more livable and viable urban centres that will endure well into the future.
WSP’s experience in addressing shortages in developable land is extensive, including in-depth research projects that have addressed the City of London’s complex housing crisis. In a report titled *Building Our Way Out of a Crisis*, WSP researchers presented the case that capitalizing on “air space” located directly above public facilities such as hospitals, schools and libraries had the potential to provide as much as 6,337 hectares of additional developable land, or enough space to build 633,700 new residential units in London. Further WSP research addressing the same issue resulted in *Out of Thin Air*, a report on rail overbuild that identifies sufficient land above London’s railway infrastructure to yield more than a quarter of a million new homes.

While the aforementioned projects have examined vertical development solutions from the ground up, WSP’s Global Tunnels and Underground Construction Network is applying its global expertise and capabilities to exploring underground construction. As new and emerging technologies reduce both the risks and costs of excavation, our experts are looking beyond current advances in underground transport tunnels and utilities and towards a futuristic vision where underground development of new housing, services, transportation, office space and even green space will transform the city landscapes of today.

WSP’s future-ready vision positions the firm to assist clients in identifying underground construction feasibility as part of master planning for the future, while our experts in the field continue to research and develop solutions that address tomorrow’s challenges today. Our global experts are experienced in both soft-ground space development and hard-rock construction, providing clients with viable solutions tailored to the specifics of their underground visions.

*Read Out of Thin Air*
*a WSP report on rail overbuild*
WSP project case studies

Slussen Bus Terminal
Credit: LINK arkitektur
WSP's Sweden team is involved in redeveloping the Slussen Bus Terminal in Central Stockholm into a central underground transport hub linking hundreds of thousands of daily commuters to buses, trains and metro lines. With surface space at a premium, the decision was made to excavate more than 250,000 square metres of rock to create caverns to house the new underground terminal. The underground terminal, scheduled for completion in 2023, frees up surface space designated for redevelopment as part of a dynamic new urban quarter design.

WSP is providing all engineering services for the project’s underground section, as well as multidisciplinary design elements including feasibility studies; preliminary and detailed design; rock mechanics; geotechnical; structural design; water and sewerage; M&E; traffic planning; risk management; fire and safety; acoustics; and environmental services.

In Australia, WSP has been a technical advisor to the Sydney Metro City and Southwest Project since 2014, assisting the client in creating a world-class transport system to bolster Sydney’s status as a global city and financial hub. Working collaboratively across a number of disciplines, the WSP team is providing engineering, rail infrastructure and architectural design support aimed at ensuring seamless integration between Sydney Metro and potential future developments. The project will also improve pedestrian access and free up corridor land.

One major issue addressed in Sydney Metro’s design is the significant risk posed by potential flooding of underground stations. Built for resilience, emergency access routes have been designed to exceed maximum expectations, while other considerations include automatic flood barriers and open channels and basins for drainage.
Garden Santa Fe
Mexico City, Mexico

The Garden Santa Fe project posed an innovative design challenge: how to bring natural daylight and greenery into a space that covers 231 metres and extends 33 metres underground?

Garden Santa Fe consists of an above ground park complete with a running track and terrace that surrounds a seven-level underground shopping centre housing retail stores, entertainment, a food court and three levels of parking. Central to Garden Santa Fe’s architecture are three inverted glass cones that project natural light and ventilation into the mall.

The complex is powered by highly efficient photovoltaic cells that convert sunlight into electricity to charge the LED lighting system. An 8,500-square-metre green roof and on-site water treatment and reuse plant further reduce operational costs and the complex’s carbon footprint.

WSP’s role was to provide structural solutions to accommodate the stability of the soil during the excavation process and to develop an optimal structural solution for the overall project to minimize excavation depth. WSP also provided field supervision during the construction stage and client fit out for the end users.

Snowdonia National Park
Wales, United Kingdom

The Visual Impact Provision (VIP) represents a major collaboration between UK electricity transmission network owner National Grid and an independent Stakeholder Advisory Group to reduce the visual impact of existing transmission lines in English and Welsh Areas of Outstanding Natural Beauty and National Parks.

Project funding draws from a £500 million provision made available by the Office of Gas and Electricity Markets. WSP works on two of the four projects approved for development, including the project in Snowdonia National Park, the largest National Park in Wales. Snowdonia’s varied landscape includes mountain scenery, glacial valleys, extensive moorlands, waterfalls, two coastal estuaries and 23 miles of coastline.

The Snowdonia project involves replacing a three-kilometre section of overhead line crossing the Dwyryd Estuary near Porthmadog with an underground tunnel below the estuary, permanently removing 10 towers from the landscape. WSP experts are engaged in tunnel planning, surveys, investigation and design, considering the area’s complex geology and the requirement to provide a visual improvement to the area.
**Waterview Connection**
*Auckland, New Zealand*

WSP in New Zealand was an Alliance partner in Auckland’s NZ$1.4 billion Waterview Connection Project, the largest road project ever undertaken in the country. The Waterview Connection includes 1.5 miles of road running through twin tunnels constructed under Auckland’s suburbs, as well as connections to the existing road network, six new bridges, new and upgraded cycling and pedestrian infrastructures, new recreational facilities, and a host of community and environmental improvements.

WSP was the lead designer providing tunnel, fire and life safety, geotechnical, mechanical and electrical systems design services, as well as design support during the construction phase. Our team will also continue as a partner during the project’s initial operation and maintenance period.

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**East Side Access Project**
*New York State, United States*

WSP is providing design and construction services to the Metropolitan Transportation Authority’s East Side Access Project as the managing partner of a general engineering consultant joint venture.

The project will extend the Long Island Rail Road from Queens to a huge new underground station being constructed adjacent to the existing Grand Central Terminal in Manhattan. Trains will travel from Queens to Grand Central via four new tunnels on the East Side of Manhattan. The new station will serve more than 160,000 daily commuters from Long Island when it opens in December 2022.

With surface space in the area extremely limited by the historic Grand Central Station and the established Park Avenue infrastructure above, the design incorporates the innovative use of underground space. The design accommodates eight tracks and four platforms, along with 33,000 square metres dedicated to retail and dining. Nearly 50 escalators and 20-plus elevators will facilitate quicker, easier movement between the surface, the trains and the retail/dining areas. South of the station, eight tracks (four tracks on two levels) will merge underground into two, 520-metre-long storage tracks—a purpose typically reserved for at-grade surface facilities.
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