

UNDERGROUND AGRICULTURE:
REPURPOSING ABANDONED TUNNELS IN COAL-MINING SYSTEMS

BY

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THESIS

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ABSTRACT

Underground agriculture is a way to reclaim abandoned tunnels in coal-mining systems, putting them to new, productive uses. Underground agriculture is also a way to help revive the economy of mining districts, transforming their basis from a limited-lifespan extraction industry to an unlimited-lifespan generative industry. This method could help address a major problem facing cultures and economies today: sustaining food production in the face of systematic failures, growing urban populations, and climate change.

This project starts with a specific concern for post-industrial coal mining areas, which suffer economic depression and environmental pollution. Many abandoned coal mine tunnels are now being repurposed as landfills or, after cleaning, as storage facilities. This project is an opportunity to rethink how we might treat such situations productively, taking advantage of existing infrastructure. This project also sets up system-specific approaches for dealing with similar situations, in which economic growth and co-operative engagement are sought.

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CHAPTER 1

INTRODUCTION

1.1 Background Information

Subterranean spaces always seem mysterious and difficult to access. In *Notes on the Underground* (1990, revised edition 2008), historian Rosalind Williams argued that one of the most interesting aspects of the world that humans have constructed is the creation of mock or artificial underworlds as places meant to exclude organic life—places where everything is meant to be a creation of human artifice rather than given from the larger universe. (Williams, 2008) The idea of uncovering underworld potentials became a point of departure for me in research about abandoned coal mines and their potential for preservation, remediation, and reuse.

In the United States, coal mines are distributed throughout the Appalachian Mountains (Figure 1.1). That region is the main source of coal in the US, and the products are used in large-scale energy generation—specifically, of electricity. As a limited-lifespan industry, coal production leads to a large amount of abandoned underground coal mine tunnels.

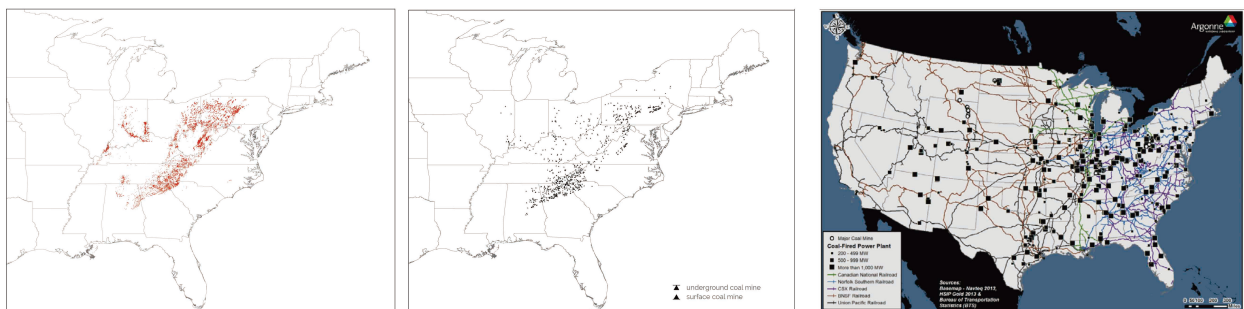


Figure 1.1 Map of coal mine distribution and railway transportation system (source: author, based on USGS)

Figure 1.1 shows the distribution of coal mine sources along the Appalachian Mountains, the location of existing underground coal mine digging operations and surface coal mine

operations, and the national railway transportation system, which is mainly used for transporting coal.

Underground mines provide coal, and burning coal provides energy in the form of electricity. That production brings temporary economic benefits to a country. But once the coal is extracted, each mine is abandoned. Also, as the coal-based energy industry falters, other forms are rising up to replace it and will start providing new sources of energy and economic benefits. Consequently, a vast infrastructure of mine tunnels could be put to other purposes.

1.2 Research Purpose

Inspired by the relationship between economic growth and the reuse of existing infrastructure, this thesis aims to envision and describe new opportunities for agriculture in abandoned coal mine tunnels, with attendant economic and community benefits. The goal of the research is to identify an alternative way to make use of abandoned coal mine tunnels and to expand the vision to other abandoned underground tunnel systems. Under the above circumstances, my research is not limited to one specific location or site but addresses instead a widely-distributed type with specific characteristics of value to agricultural production: integrated ventilation, electrical, and water systems plus integration with a functioning transportation network.

Whether working with “brownfields” or “greenfields,” landscape architects not only transform sites physically; they can also bring economic transformation keyed into new

markets. Underground agriculture is pertinent to problems of population growth and climate adaptation and can help fulfill global demands for food production, safety, and security. This thesis will optimize the organization of existing underground infrastructure to maximize profits. Former industrial land now acts as an essential point of leverage contributing to underground urbanism (in this case, through urban agriculture), as an interface between repurposed infrastructure and “natural” growing processes.

1.3 Conceptual Framework

According to Rosalind Williams,

Subterranean surroundings, whether real or imaginary, furnish a model of an artificial environment from which nature has been effectively banished. Human beings who live underground must use mechanical devices to provide the necessities of life: food, light, even air. Nature provides only space. The underworld setting therefore takes to an extreme the displacement of the natural environment by a technological one. It hypothesizes human life in a manufactured world. (Williams, 2008)

This proposal engages with that artificial, subterranean world and seeks to make it a better place. Research in landscape architecture is about finding invisible aspects and potentials, such as facts, flows, or systems. The process for this thesis began with a study of general coal mine tunnel conditions, including size, temperature, and humidity, and how changes in the latter are regulated. Analysis of case studies resulted in an alternative design concept for the site. Through business-based foundation scenarios for underground fungiculture, the thesis provides a vision for reuse of abandoned coal mine tunnels and related community development. The thesis also makes reference to other kinds of underground space that might be considered for similar development. This thesis offers a provisional theoretical framework for how to grow underground in abandoned coal mine tunnels and

suggests potential regional energy flows, such as distribution and consumption, with diagrams.

CHAPTER 2

LITERATURE REVIEW

2.1 Theoretical Strategies

There are four general categories of use of underground space, namely:

1. Storage (natural gas/oil storage; storage of H₂, compressed air);
2. Deposition (Carbon Capture and Storage (CCS)); underground waste disposal including storage of radioactive waste, brine injection);
3. Productive activities (mining; use of geothermal energy as geothermal heat pumps/shallow geothermal systems, hydrothermal geothermal systems, petro thermal systems/ hot-dry rock technology; storage of heating and cooling energy; utilization of mineral springs and groundwater);
4. Underground structures (tunnels, technical structures; underground pumped hydroelectric power plants). (S. Bartel & G. Janssen, 2015)

This thesis proposes a potential reuse scenario that encourages productive activities with minimal threshold cost and impact.

Climate changes are always the biggest factors influencing the production of agriculture. If the growing process were moved underground, then environmental conditions such as temperature, humidity, and ventilation could be more fully under control. In such a case, production and product cycles would no longer be influenced by climate and season, so production could be more consistent in meeting market demands. Controlled Environment Agriculture (CEA) offers an instructive model related to testing and examining tunnel situations and conditions. CEA is "an integrated science- and engineering-based approach to provide specific environments for plant productivity while optimizing resources including water, energy, space, capital and labor," according to professor of agricultural

and biosystems engineering Gene A. Giacomelli. (Madden, 2013, Website) More specifically, the CEA system “is an advanced and intensive form of hydroponically based agriculture. Plants are grown within a controlled environment so that horticultural practices can be optimized.” (Cornell Biological and Environmental Engineering, Website) When possible, switching from traditional farming to Controlled Environment Agriculture, for environmental and economic reasons (Despommier, 2010), and when combined with other technologies, has greatly improved the agriculture industry.

In this thesis, the Controlled Environment Agriculture systems model has been considered from three aspects: the automation system, the cultivation process, and the growing environment. The objective is to define a high standard of enclosed environment for growing crops, starting with broad control of the whole growing environment. A wireless communication system at the coal mine, with integrated audio, video and high-speed data transmission (Tian, Yang, and Yang, 2005), helps monitor and regulate sensory control of the growing situation.

Automation means that machines can be equipped with human-like capabilities of information processing and task execution. Automated machines can take responsibility for perception, inner-logistics, communication, and integration of all systems. With the aid of automation and surveillance technology, people can monitor and control conditions inside tunnels without needing to enter them. However, the main challenge for implementation pertains to market conditions. Can return on investment make this approach attractive? Automated systems need to be safe for operation and to allow for continuous improvement

of research and development capabilities. In the meanwhile, some systems need to be flexible or adaptive, with appropriate levels of pertinent machine intelligence. On the other hand, there are many great opportunities to engage automated systems to help build agricultural mechanization and modeling capabilities, increasing the potential for spin-off technologies, which could help facilitate the implementation of high-tech. (Ting, 2015)

During the cultivation process, automated systems can be used to determine how water circulates and nutrients are distributed and to recycle materials in order to help reduce environmental impacts, such as through composting for mushroom cultivation. As crops grow, every change in the subterranean microclimate can be monitored and controlled by automated system to ensure the best results.

This method of underground cultivation can provide year-round food production, disconnecting agriculture from volatile outdoor situations in which “the scientific evidence points to increasing risks of serious, irreversible impacts from climate change associated with business-as-usual (BAU) paths for emissions”. (Despommier, 2010) Growing underground can therefore both evade and help resolve environmental problems.

CEA systems model

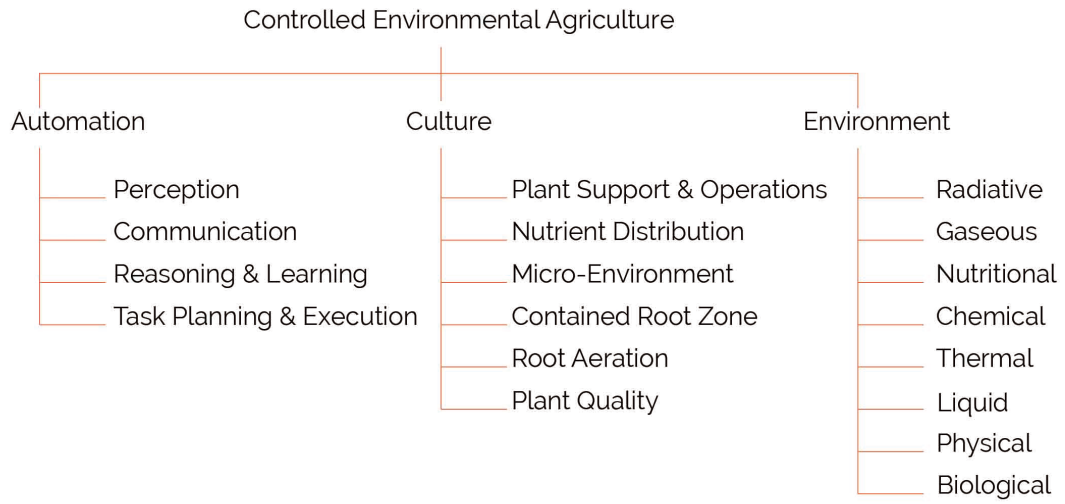


Figure 2.1 Controlled Environment Agriculture (CEA) Systems (source: Ting, 2015)

2.2 Case Studies

Underground spaces are always somewhat mysterious because one cannot observe directly what happens in them. For that reason, and as places removed from “surface” conditions, underground spaces have long been used both as security zones and for infrastructure, such as water and energy supplies and fast and easy transportation. In the nineteenth-century’s narratives of the underworld, there are two types of catastrophe that send society underground: massive warfare and ecological disaster so severe that the earth’s surface no longer supports life. In our own time, the specter of disaster has not changed much. Space underground is still thought of as a possible refuge from warfare (especially nuclear warfare and fallout) and from environmental collapse. During the past half-century, use of underground spaces has become multipurpose, especially in metropolitan areas with dense populations; for example, some markets or malls are located underground as connection corridors between subway stations.

Abandoned tunnels have been repurposed as landfills or and storage facilities, especially in rural areas. For example, the Heilbronn Underground Repository in Germany turned a former mine site into a landfill operation. The facility receives waste from Austria, even though the materials must be transported over long distances. In Austria, waste is divided according to three types: slag, ash, and hazardous waste. Hazardous waste is transported abroad to designated storage facilities across the European Union (EU). Figure 2.2, below, represents the trans-national waste shed in Europe that converges on facilities in Germany.

During two centuries of mining, 45 million cubic meters of tunnel and shaft space were created in Heilbronn. According to the standards of the European Atomic Energy Community, this vast underground complex is geologically isolated from groundwater and the biosphere by existing strata of salt and clay, making it safe for storage of hazardous materials. Overall, there are more than 1 billion cubic meters of storage capacity below Germany, enough for the storage of hazardous waste during the next 150 years. (Südwestdeutsche Salzwerke AG, 2008)

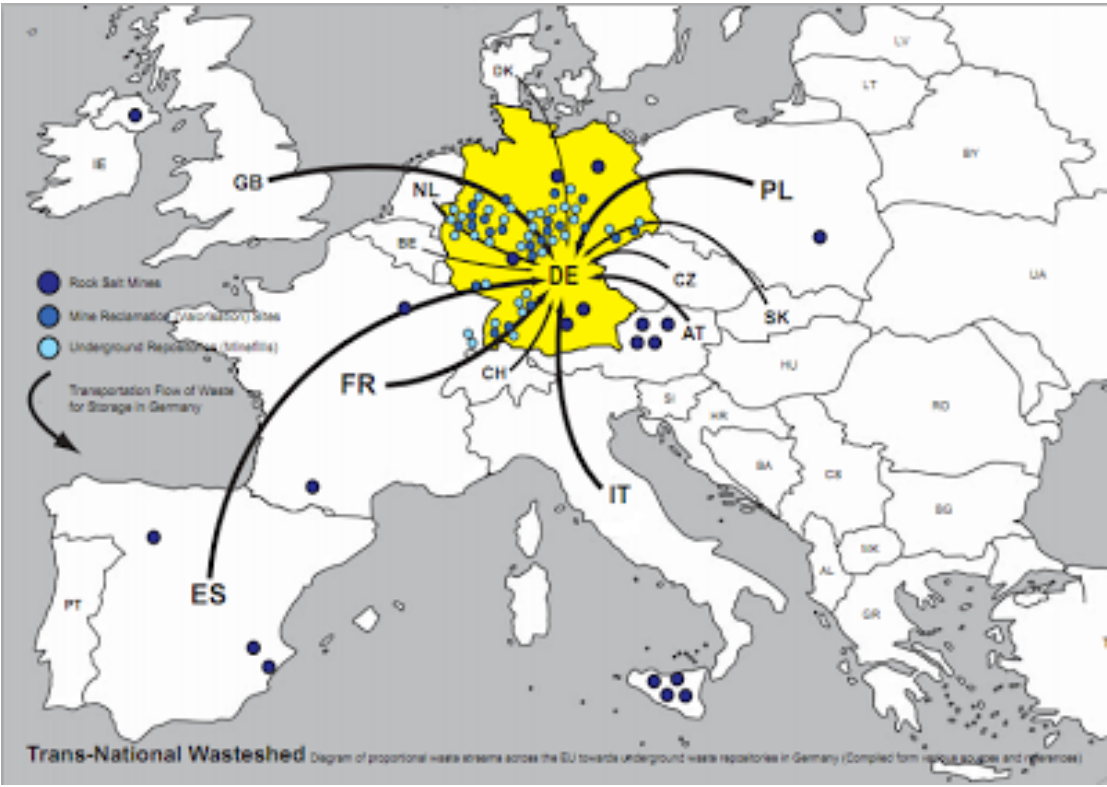


Figure 2.2 Heilbronn Underground Waste Repository Trans-national Waste Shed (source: Xiaoxuan Lu)

33 meters below London, England, an abandoned air raid tunnel built during the Second World War could accommodate 8,000 people. Now it has become a subterranean farm. With sophisticated lighting and irrigation systems, and after eighteen months of

experimental research, development, and growing trials, the facility began to supply vegetables to markets. It is said that the hydroponics system used there requires 70% less water than traditional open-field farming. Also, the closed-loop system guarantees that nutrients are retained and recycled rather than contributing to agricultural run-off. In the meanwhile, a constant temperature of 16 degrees Celsius and a fan-driven air circulation help crops grow strong. (Growing Underground (website)) The most obvious advantage of this system is that crops are available year-round without being influenced by seasonal or climatic changes. Also, the pesticide-free environment means that crops are grown in a healthy way. Yields per unit area are much larger than those in traditional agriculture. Developed as a business, the underground farm consistently provides fresh food to urban retail markets and restaurants with minimal time and energy expended transporting produce from farm to table. Given the fast pace of harvesting and delivery, people can enjoy fresh produce year round. In Figure 2.3, the image on the left shows the original condition of the underground tunnel, the middle image shows installation of LED and trestle table systems there, and the image on the right shows the set up of growing surfaces.



Figure 2.3 London Underground Agriculture (source: Growing Underground (website))

In New York City, the Low Line Park envisioned for the Lower East Side of Manhattan will become the world's first underground park. The one-acre space is anchored in the

abandoned Williamsburg Bridge Trolley Terminal, a “hidden historic site [...] located in one of the least green areas of New York City—presenting a unique opportunity to reclaim unused space for public good.” (Low Line Lab (website)) The aim of the project to activate a new space for public life while drawing people’s attention to the potentials of abandoned areas.

The Low Line Park makes use of innovative technology to translate sunlight above ground to the underground park: Designed by James Ramsey of Raad Studio, the proposed solar technology involves the creation of a “remote skylight.” In this approach, sunlight passes through a glass shield above the parabolic collector, and is reflected and gathered at one focal point, and directed underground. Sunlight is transmitted onto a reflective surface on the distributor dish underground, transmitting that sunlight into the space. (Low Line Lab (website))

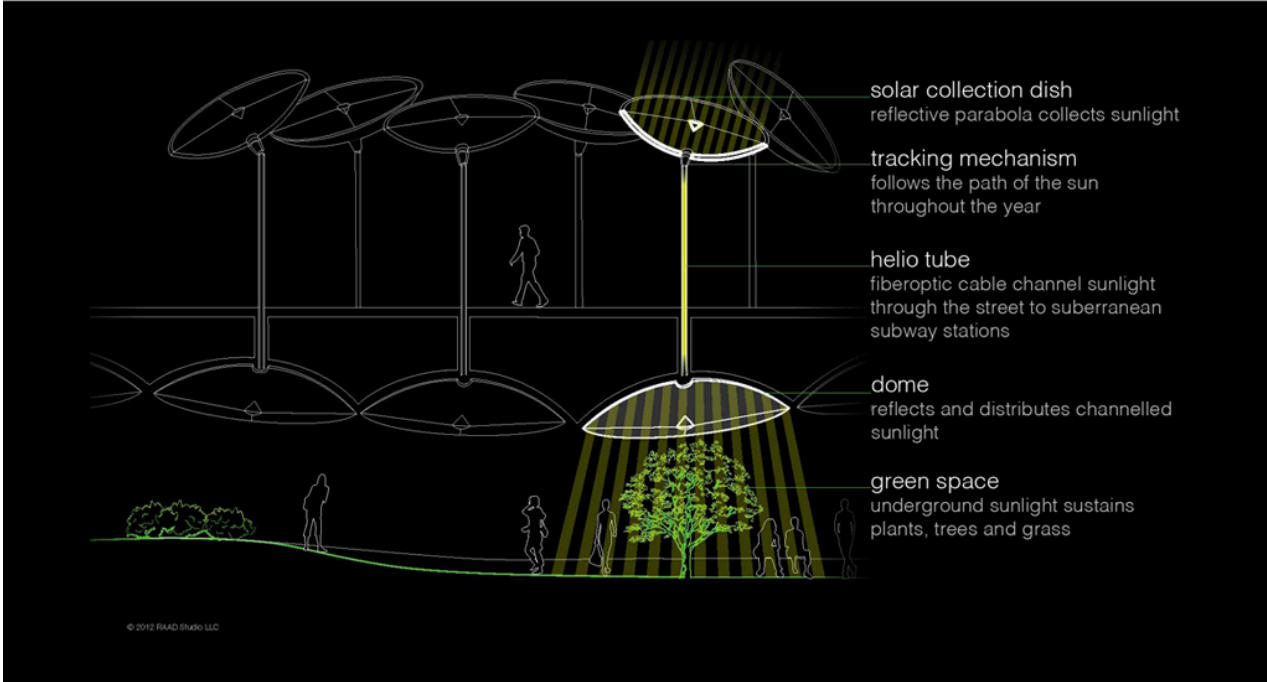


Figure 2.4 Technology translates solar energy to underground site (source: The Low Line Park)

Remarkably, the solar technology allows plants to undertake natural photosynthesis because it transmits the necessary wavelengths of light. Figure 2.4, below, shows the light transmitters installed in the space, with plants installed. During periods of sunlight, electricity is not necessary for lighting the space. (Low Line Lab (website)) The next step in the experimental development of the Low Line Park is to try to grow food. As technical capacities are understood and interest grows, the area will become an innovative public park. The process is a powerful, publicly visible example of creative thinking, public/private collaboration, and motivated practice.



Figure 2.5 View of Low Line Lab (source: The Low Line Park(website))

The tunnel farm in London and the Low Line Park in New York City show the agricultural potentials of underground spaces and inspired me to consider the potentials of similar use of abandoned coal mine tunnels. In *Notes on the Underground*, Rosalind Williams examines

how actual and imaginary underworlds have shaped our attitudes toward the manufactured environments that we inhabit. All of the case studies and examples described gave me inspiration, and, through synthesis and analysis thereof, I envisioned potential reuses for existing infrastructure in underground spaces, from small-scale ventilation, electrical, and water circulation systems that could be repurposed for horticulture, to large-scale systems, such as railway transportation, that could be used to transport food.

CHAPTER 3

DESIGN RESEARCH

This chapter discusses the steps required to transform a coal mining tunnel into an agricultural farm, taking typical existing conditions and situations into consideration. The proposal sets up a scenario that integrates infrastructural development, site remediation, and agricultural production, repurposing existing systems in a way that leads to economic growth and ecological benefits. Agriculture is a way to redefine and extend the original function of underground sites as economic engines, but now with an endless lifespan linked to economic and environmental benefits.

Integrate Separate system

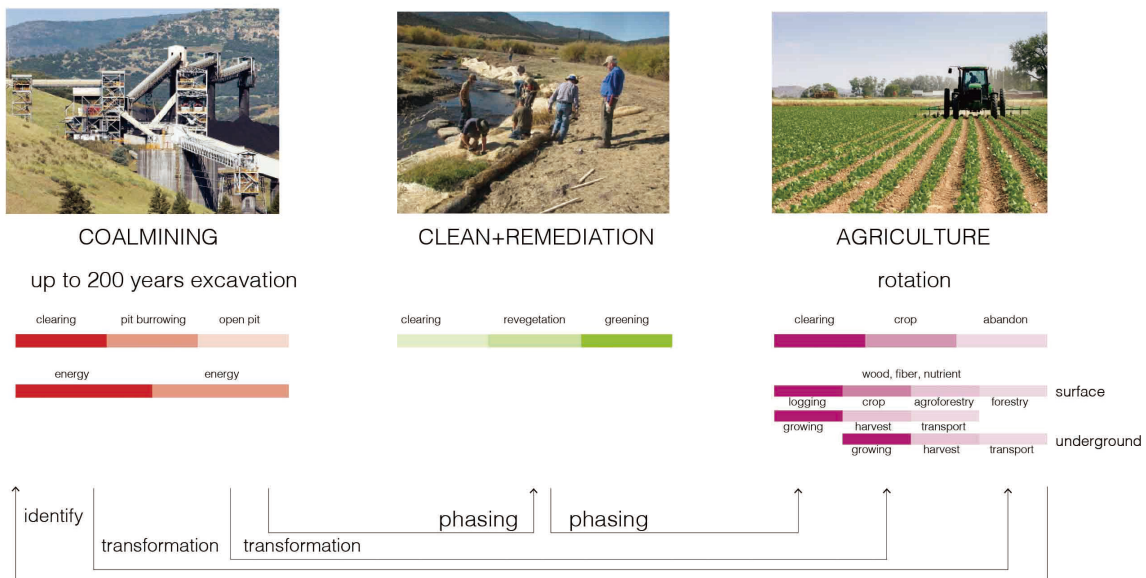


Figure 3.1 Integrate System (source: author)

3.1 Regulating Ideal Environmental Conditions for Fungiculture in Abandoned Coal Mines

Planning underground systems calls for an integrated approach, which considers the interests of many parties, the dynamics of different activities, and potential threats posed by hazardous materials. (Beroggi, 2000; Delmastro et al, 2015)

Understanding existing conditions is very important to establishing and regulating ideal environmental conditions. With GIS technology and existing data, it is possible to build three-dimensional models of coal mine tunnels. Being able to monitor and control temperature, ventilation, humidity, and access, as well as wireless connectivity, is essential. Modeling is a way to understand the coal mine vector, as well as to provide strong support for planning, design, and production. (Qiang and Fu, 2011)

Temperature within coal mine tunnels depends not only on subsurface temperature but also on air expansion and compression and surface temperatures. When air flows downward, as the depth increases, the temperature increases at a rate about about 1°C per 100m. When air flows upward, expansion will cause it to cool at a rate of about 0.8 to 0.9°C per 100m. Subsurface temperature will also influence temperature in tunnels. Rocks below the surface are divided into three temperature bands:

- 1) Variable temperature zone. From 0m to about 15m deep, ground temperature changes significantly with the surface temperature. In summer, rock absorbs heat from warm air; in winter, rock releases heat to the cool air.
- 2) Constant temperature zone. From about 20m to about 30m below the earth's surface, ground temperature is not affected by surface air temperature. This layer is perennially steady, with temperatures approximately equal to or slightly higher than the average local surface temperature.

3) Temperature increasing zone. Below the thermally stable, and depending on the types and properties of rocks present, ground temperature increases with depth, though the rates of increase vary widely, 10m ~ 15m / 1°C to as much as 40m ~ 50 m / 1°C (Wang, et al., 2004)

Regulating change of humidity depends mainly on ground temperature. This change in temperature is most obvious when the seasons change, affecting air intake systems (ventilation). For instance, in summer, the air temperature at ground level is higher than in winter, but the air in the tunnels is relatively stable, thus the airflow from ground level going into the tunnel will affect the underground air temperature and humidity. In summer, the temperature of the air at ground level is higher than in the tunnels; when the ground higher temperature going into the tunnel and meet the lower temperature, it leads to the decline of saturation capacity, thus the relative humidity is increased. As the relative humidity reaches 100%, drops of water emerge as the increasingly humid air fills the air intake lane. In contrast, in winter, the cold air on the ground that goes into the same hole, affected by the difference in temperature, will rise relative to the ground air temperature. Thus, the saturation capacity becomes greater, and the relative humidity level will decrease. The air in the tunnel will become relatively dry. As for the main return airway, regardless of the summer or winter season, the relative humidity is higher and very humid. The reason for that difference is that the mine's horizontal working surface offers a relatively high temperature when compared to the vertical intake lane. The total return airway finds a constant cooling airflow, while the humidity finds a relative increase (Wang, et al., 2004).

The four main types of mine form excavation include the following: shaft, drift, slope, and open cast (Figure 3.2). The open cast mine mainly includes mountain top removal, which is

the easiest way to harvest the coal; however, it is the most harmful method of coal extraction for the environment, when compared to the potential and limited economic benefits. The open cast mine will not be discussed further for the purposes of this thesis. Underground mining conditions will remain the primary focus in the sections that follow.

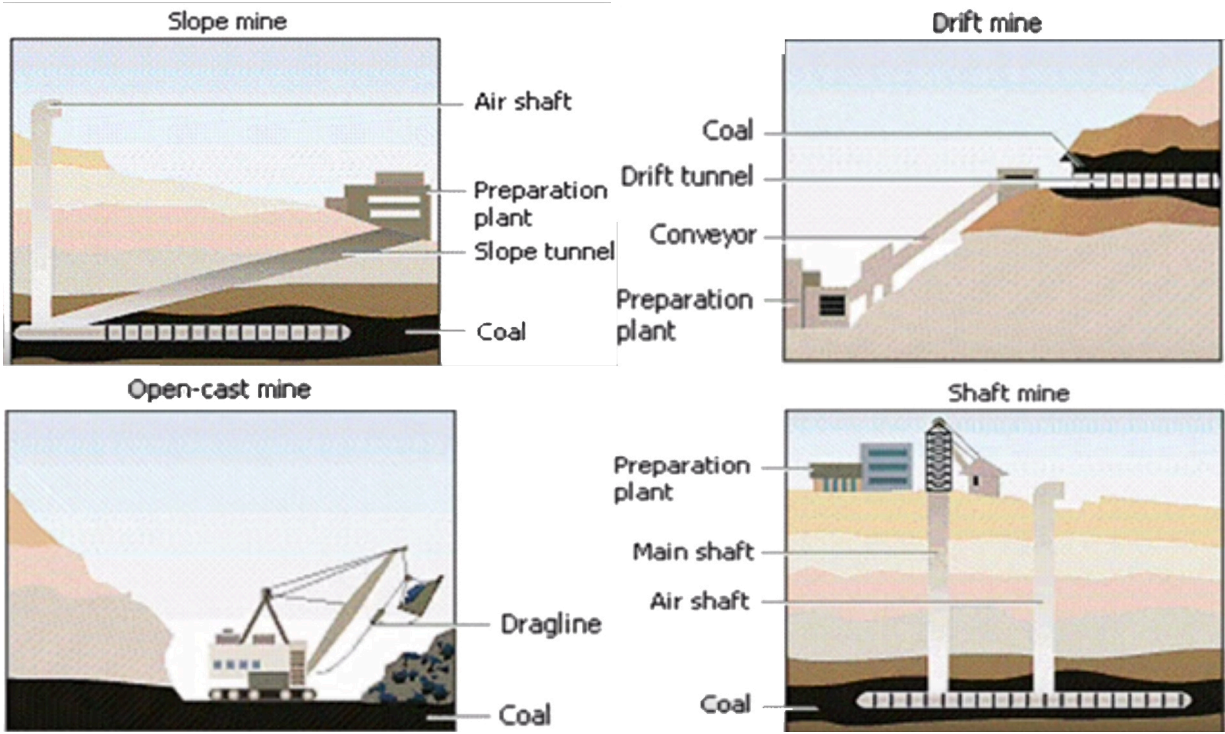


Figure 3.2 Coal Mine Type (source: Geocaching (website))

First, this thesis offers an investigation of the sectional changes of underground coal mine tunnels that occur in relation to horizontal properties as well as the vertical layers of the tunnels. Abandoned tunnels may help us to understand how materials are transported underground on the vertical layers. The reason that we consider these sections is to understand how the transportation system within the underground coal mine tunnels can be adapted or built for agriculture. To gain such an understanding, we must study the relationship between the layers as it relates to such a transportation system. Consequently,

three different drift zone mining conditions have been analyzed based on engineering master plans and sectional drawings found in the *Mining Engineering Design Manual* (Figure 3.3). (Zhang, He, and Li, 2003) Although the three different coal mine plans indicate different slopes, the sections show the tunnels developing in a straight direction, although directional changes may occur. Given the grounded speculation strategy, the coal mine layer distributions among the strata are not parallel to ground level. The underground mining tunnel going straight and with a limited slope may be ignored.

The sectional diagram (Figure 3.4) illustrates the speculation process. It shows the changes from the original condition of the earth, which was covered with trees, to the start of the mining process and focuses on the changed surface. In particular, when the mining begins, the earth will be influenced and some of the trees will be removed in order to dig a hole. After a clearing and cleaning process, all many devices installed for mining can later be used for growing mushrooms and other crops underground. At the entrance to the underground tunnel, an elevator may be installed, which would function to transport food as well as workers. The tunnel on each coal mine stratum is constructed with transport tracks for delivering coal as well as workers. The transport system from the top to the bottom has a special conveyor, which is controlled by a machine. That machine could further be used for transporting mushrooms and other crops while also functioning as a sensory-control mechanism. Specifically, the ideal space for underground tunnels is at least 2.5 meters in width and 2 meters in height, which will enable the smooth passage of workers and supplies.

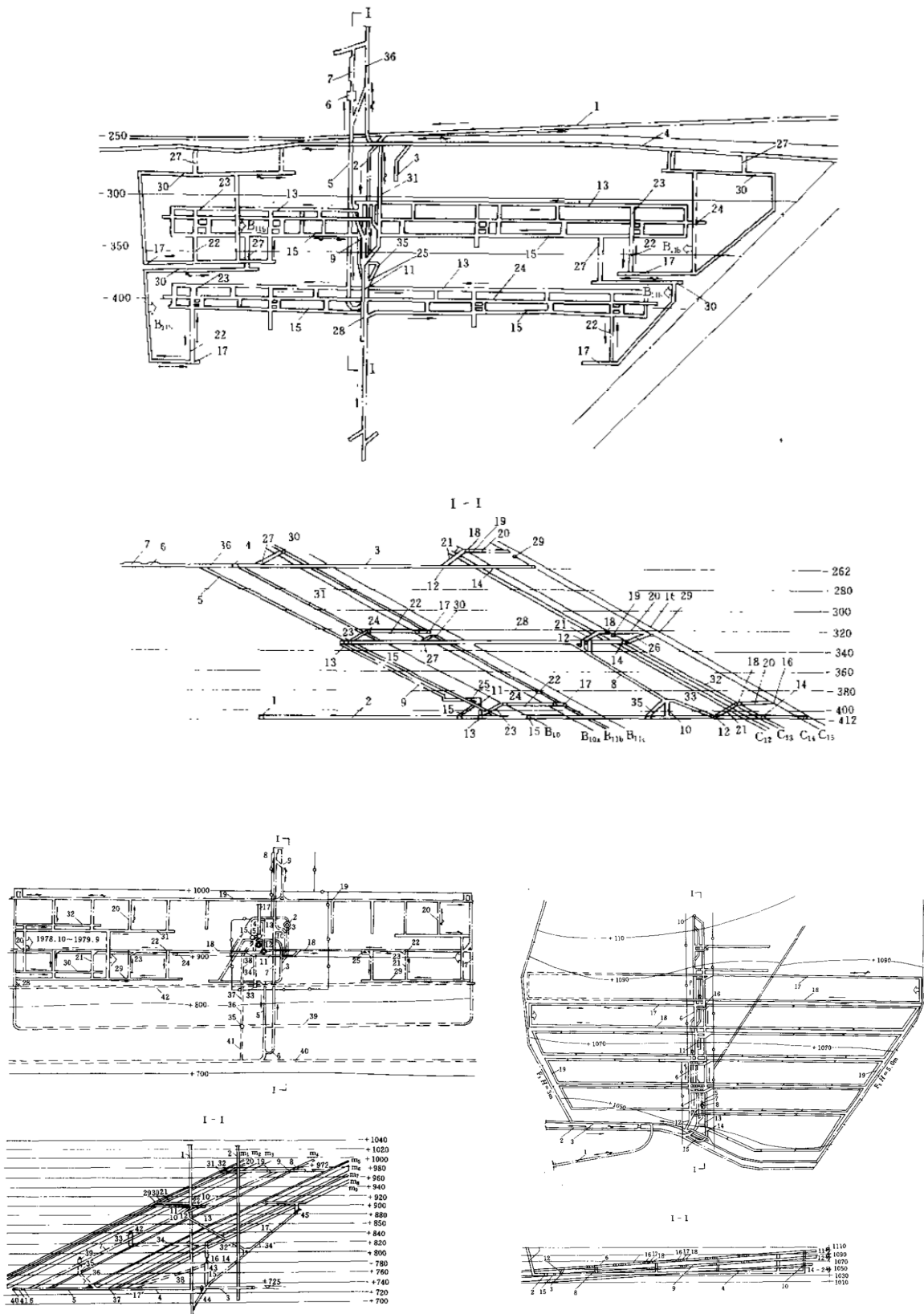


Figure 3.3 Master Plan and Sections of Coal Mine Tunnel (source: Mining Engineering Design Manual)

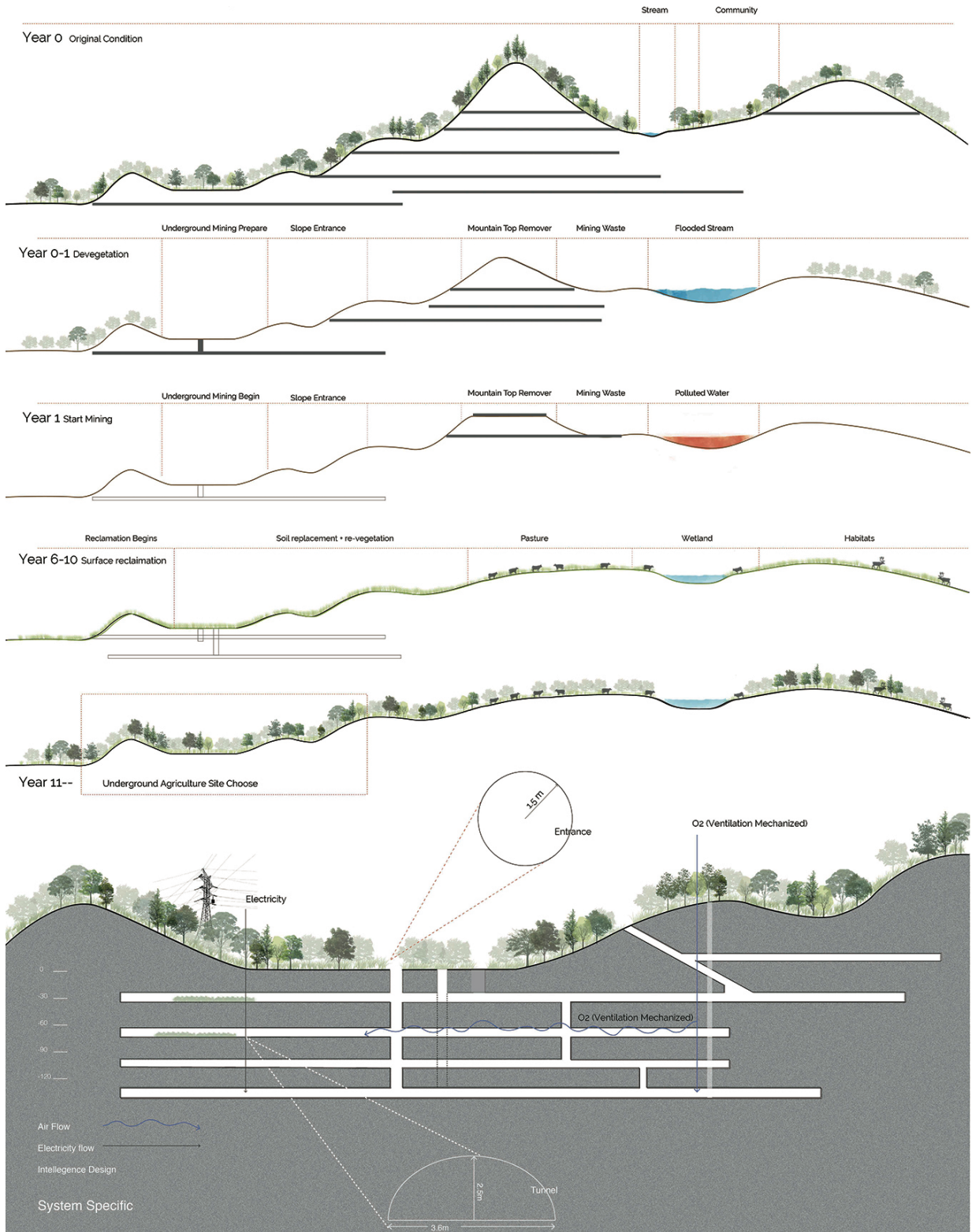


Figure 3.4 Diagrammatic Sections (source: author)

3.2 How to Grow and What to Grow?

3.2.1 Mushrooms

Underground agriculture can be divided generally into two types. One is fungiculture, in which fungi such as mushrooms are cultivated on compost to produce food, medicine, and other products. The other type is growing green crops using hydroponics, which requires more equipment, such as special planting beds with multiple layers, and watering systems to provide nutrition. A plan for developing underground agriculture could be phased to start with fungiculture and, later, after revenues have grown, upgrading to grow green crops.

In Phase 1, the start-up cost for fungiculture is lower because the technical requirements are less complex. Mushrooms and other fungi generally prefer damp, cool, and dark environments. Many abandoned coal mine tunnels are already well-suited to fungiculture. Each level within a mine has a distinct, relatively stable temperature, and different species of fungi prefer distinct temperatures for growth. Accordingly, the specific temperature in a tunnel determines the species of mushroom to be grown there.

Logs, wood chips, and sawdust are commonly used as growing media for mushrooms. Compost could be made of wood sawdust mixed with additional plantation waste such as coffee pod waste or even cocoa pods, as long as it could provide necessary carbon nutrition for mushroom growth. Any species of wood, whether soft or hard, except pine can be used as the medium so long as it does not contain any extractive substances that might inhibit

the growth of fungi. (Santoso, 1992; Mudakir and Hastuti, 2015) After being pasteurized, the compost can be inoculated with mushroom spores.

The growing time for different species varies significantly. Edible mushrooms typically required from 25 to 40 days, while medicinal mushrooms need from 8 to 10 months.

Until recently, a mushroom production facility, owned by the largest mushroom company in the world, was located in 150 miles of abandoned limestone caves near Pittsburgh, Pennsylvania, and was the only underground mushroom farm in the United States. (Zhang, 2014) Though no longer in operation, it is a good case study for the viability of underground fungiculture as a business—particularly for understanding real costs, requirements, productivity, and profitability, given specific conditions.

GROWING METHODS FOR TWO KINDS OF VEGETATION

FUNGICULTURE

For Food (Compost)

For Medicine (Log)

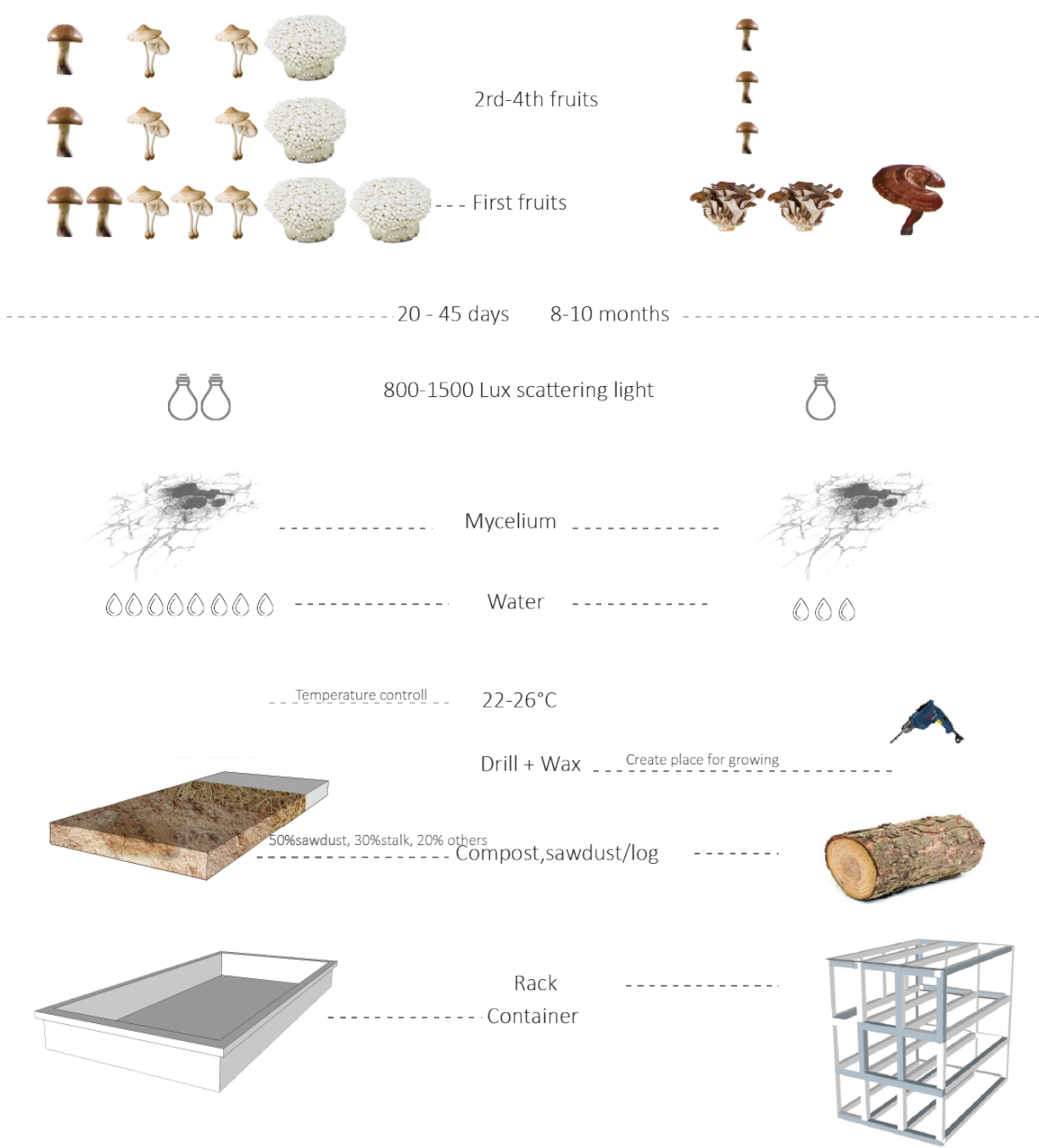


Figure 3.5 Growing Fungiculture (source: author)

3.2.2 Commercial Function

“Fungi have provided food for man, primarily in the form of fruit bodies of basidiomycetes and a few ascomycetes, for thousands of years.” (Wiebe, 2004) Presently, mushrooms serve a plurality of functions and hold multiple values. The edible parts of mushrooms provide fresh produce that is ready to eat. Additionally, through processing, dried mushrooms, mushroom juices, mushroom coffees, among others products, are possible. Further potential uses of mushrooms vary broadly. For example, mushrooms that are grown in natural conditions for medicinal use could be cultivated more readily under controlled, artificial conditions. In such instances, growing high-value mushrooms could lead to high profits.

Myco-protein is a type of food and a substitute for meat. Specifically, because myco-protein provides a source of healthy protein, it is a viable replacement for the nutritional benefits of meat products. “This product meets what the nutrition community thinks a product should be and in addition, it tastes good! Modern science can fabricate anything. We can imitate anything, but we always run into problems on how to have it taste good. Not taste all right, but taste good. This product does that” (Peregrin, 2002). This comment describes a product that is full of potential.

Beyond food and medicine, mushrooms have many industrial applications, such as cosmetics, perfumes, shampoos, and face creams. A company called Ecovative Design is undertaking research to construct packaging, furniture, and building materials using “mushroom materials” by combining mycelium and agriculture waste. In other words, the

task of growing mushrooms may be regarded as a market- driven option. It holds great profit potential and possible benefits for human health and the environment.

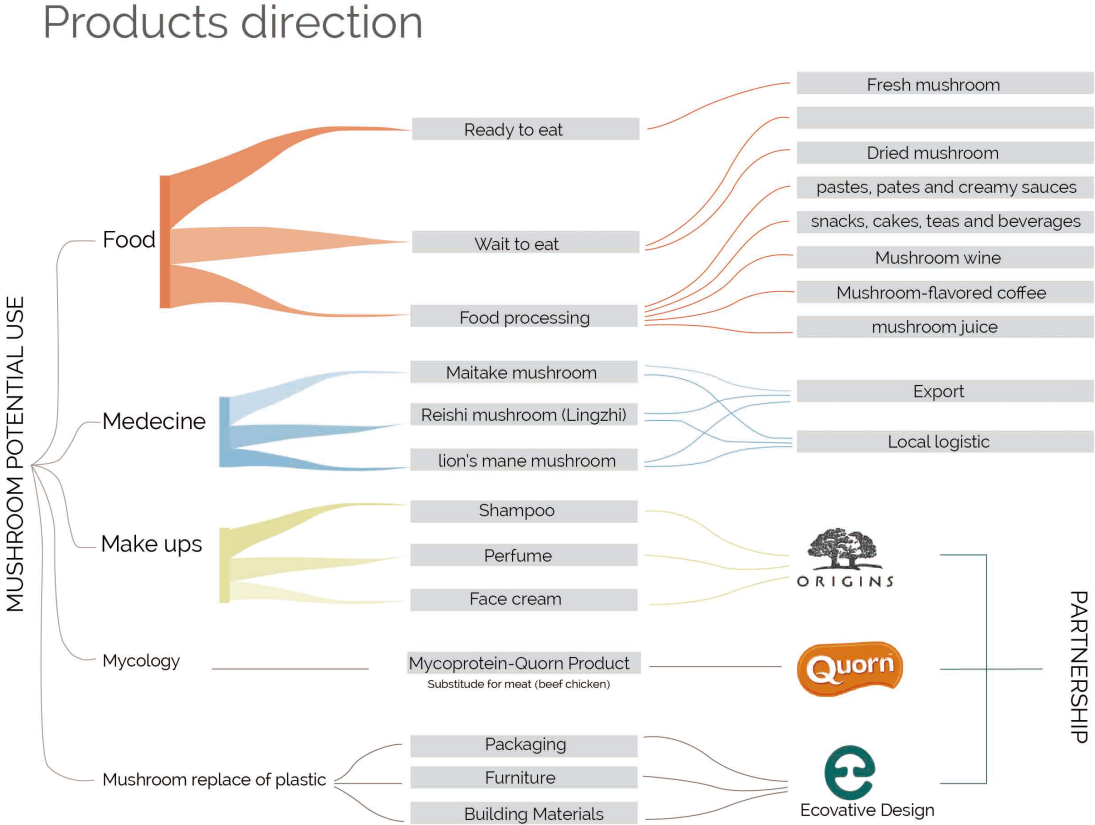


Figure 3.6 Mushroom by-production (source: author)

3.2.3 Hydroponic Growing Crops

In Phase 2, the necessary equipment for hydroponic growing is installed. LED lighting is the most essential new requirement at this stage. This lighting provides the radiant energy that is necessary in order for green leaf vegetation to grow. Since temperature and humidity are constantly monitored, and controlled by fans, crop growth will not be affected by weather changes. Through this process, crops and plants are able to grow strong year-round regardless of seasonal changes.

Hydroponics does not rely on soil. Instead, it is supported by substances, such as fabrics and circulating water provided with enough nutrition in a pesticide-free environment. Mist can also provide the moisture that is necessary for many crops. LED lights are often installed as a movable device, enabling vegetables to maintain constant exposure to sufficient lighting. Further, electricity may be sourced from electrified wire netting or through the use of solar technology. Solar energy may be transformed into electric power that is used to generate light.

Lettuce, tomatoes, radishes, celery, and basil are good options for hydroponic cultivation because they grow quickly in controlled conditions. Also, they are easily packaged, which enables them to be shipped ready for use by restaurants, retail stores, and other markets. Rapid turnover means that sustainable food can be sourced locally.

AGRICULTURE

Vegetable (Hydroponic)

Hydroponics is a method of growing plants using mineral nutrient solutions, in water, without soil.

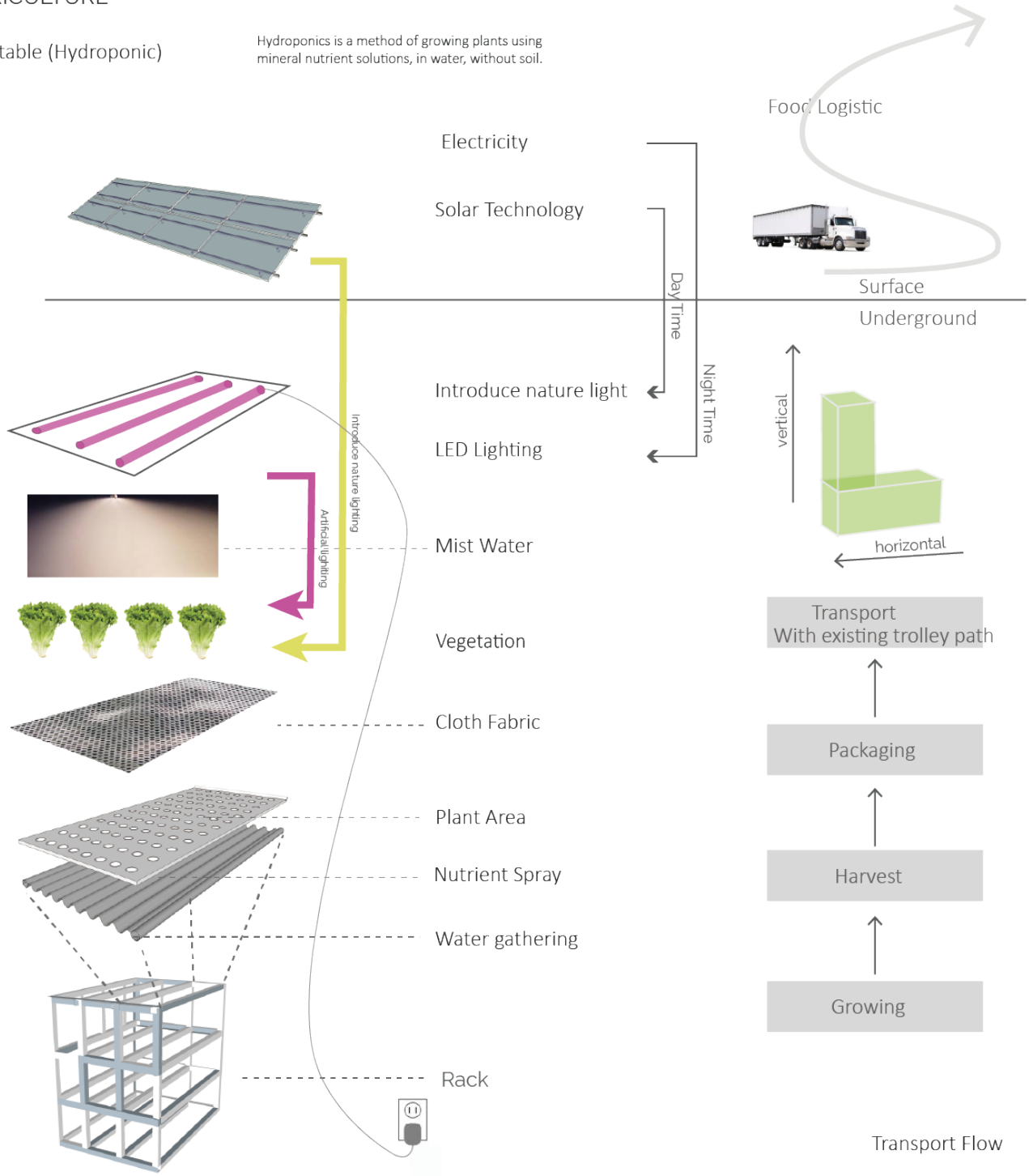


Figure 3.7 Hydroponic Growing Processes (source: author)

3.3 Comparison

To be considered properly, it is necessary to compare underground agriculture with conventional agriculture generally. Nevertheless, such a comparison needs to focus specifically on conventional mushroom cultivation from the perspectives of energy requirements and production costs. Preliminary investments for infrastructure and growing environment set-up are not accounted for at this stage because such investments vary, depending on the existing conditions of each site. Instead, this section offers a comparison related to manual work output as well as applied energy and production gains.

The largest cost for growing mushrooms, according to conventional methods, pertains to controlling temperature as much as possible. Such an effort is a great challenge, given the unpredictability of climate change as well as greenhouse effects. Such instabilities may eventually force a shift of the mushroom industry to more controlled environments, such as underground spaces. Given more stable growing conditions, mushroom-based industries may experience more stable economic return. Arguably, among controlled environment options, underground spaces are the best choice.

For growing green leaf vegetation, hydroponic systems compare favorably with conventional agriculture in many categories (Figure 3.8). For example, food waste in hydroponic agriculture is only about 3%, while ranging from 30% to 40% in conventional agriculture. Also, the harvest cycle and growing rotation of underground, hydroponic agriculture can be highly controlled and intensive, producing as much as 20 to 30 times more per unit of growing area than conventional agriculture. In the meanwhile, the

growing period for conventional farming follows the natural and seasonal patterns that are largely influenced by weather and climate change. Consequently, hydroponic production may reach levels that are 80 to 100 times greater than conventional agriculture. Also, in terms of demand for water, hydroponic systems require far less than conventional farms. Although the amount of electricity required is 3 to 4 times greater for hydroponics than for conventional agriculture, the ratio of energy consumption to production is highly competitive. Thus, it provides sufficient justification for adopting the controlled growing method. Relative to conventional farming, hydroponics has a very small ecological footprint. Given its benefits—fast growth, less disease, little to no pesticides, and significant conservation advantages—hydroponics can work well in underground environments, such as coal mine tunnels.

Energy/Production Calculations

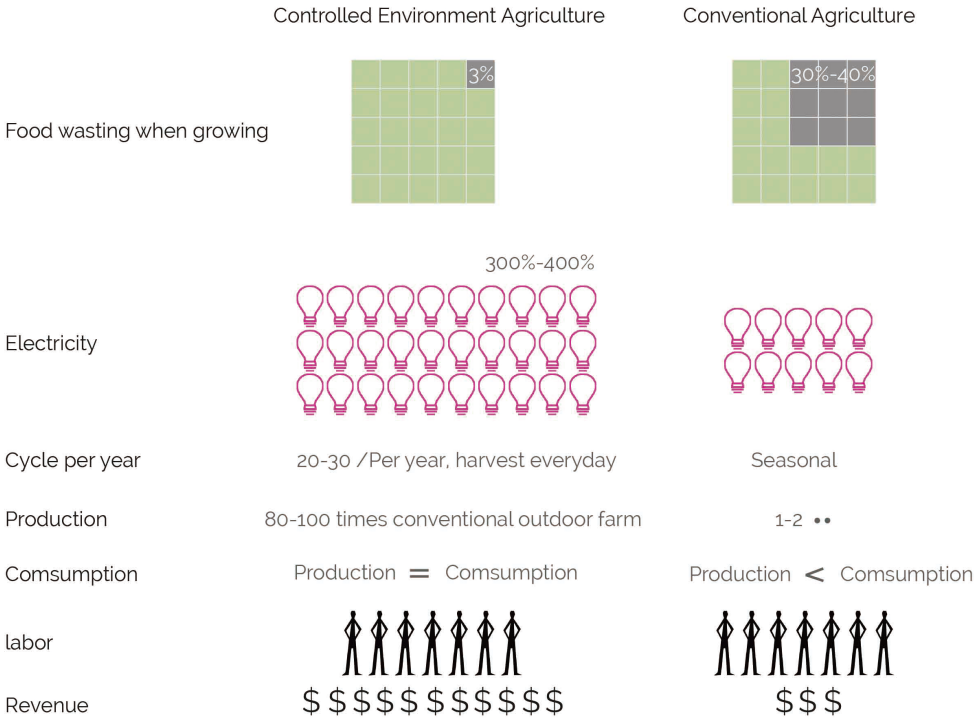


Figure 3.8 Comparisons (source: author)

3.4 Community Benefit

The proposed initiative would have significant benefits to the public. For instance, it may offer jobs to local residents and offer financial investment opportunities, such as co-operation financing methods. Moreover, it provides continuous employment opportunities for skilled people who previously worked as coal miners. Additionally, this initiative provides fresh produce for the local food markets. With collaborative participation from mining companies, academic programs, departments of conservation, and natural resource and environmental protection bases, the underground coal mine tunnels function as a growing site and economic incubator (Figure 3.9).

With minimal intervention, mining tunnels may be adapted and repurposed for underground agriculture. Production can meet the local demands for fresh vegetables. Further, with expansion, the demands of larger markets may be met by following a farm-to-table strategy. Following a regional or national market retail strategy is also a possibility. Underground agriculture may serve multiple functions beyond production, such as cultivating networked knowledge, providing economic opportunity, stimulating education and research, and engaging agency stewardship, which activates communities.

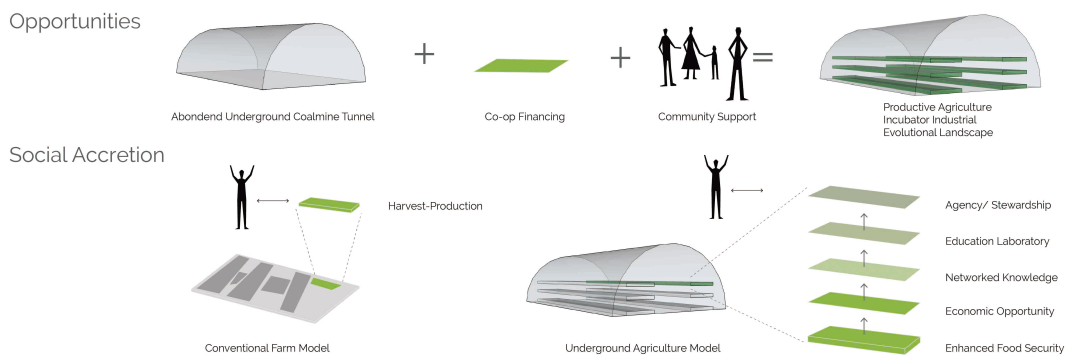


Figure 3.9 Community Steward (source: author)

Underground fungiculture can also link to or catalyze other economic developments, such as tourism and dairy farming. For example, waste from dairy farming can supply nutrient energy in fungiculture: “the waste from the dairy farm is recovered to produce energy as a larger integrated system.” (Scott, Rutzke. & Albright, 2005) Organic, manure-based compost is a viable growing medium for mushrooms. Underground agriculture could also stimulate interest among tourists. As with other forms of agriculture, tourism is linked to wide ranging economic and energy flows. What at first might seem to be unrelated programming can in fact be linked through an integrated system (figure 3.10, 3.11).

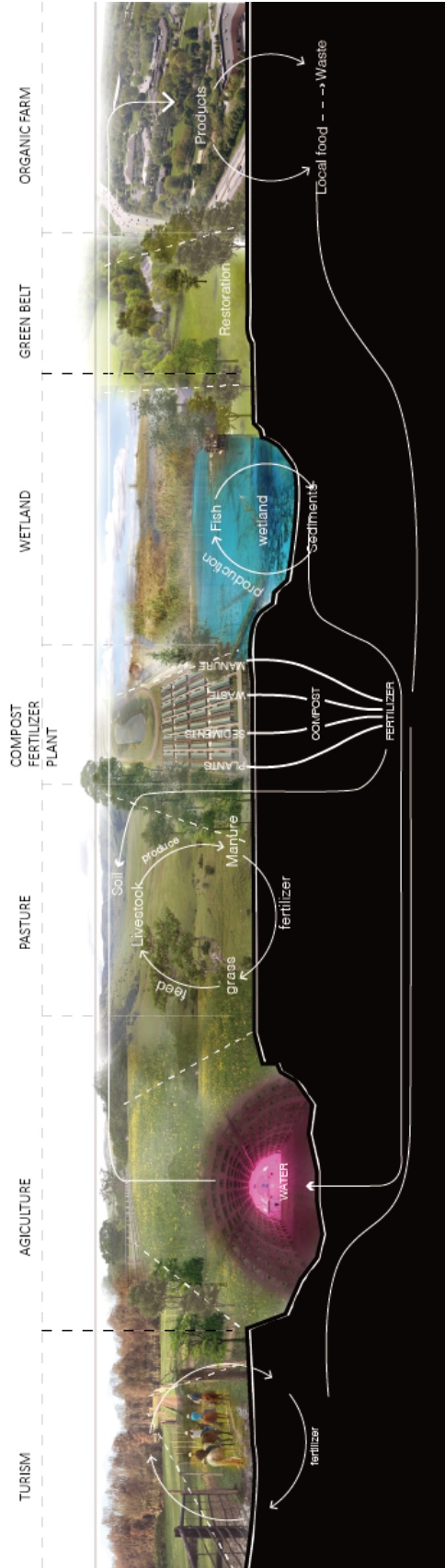
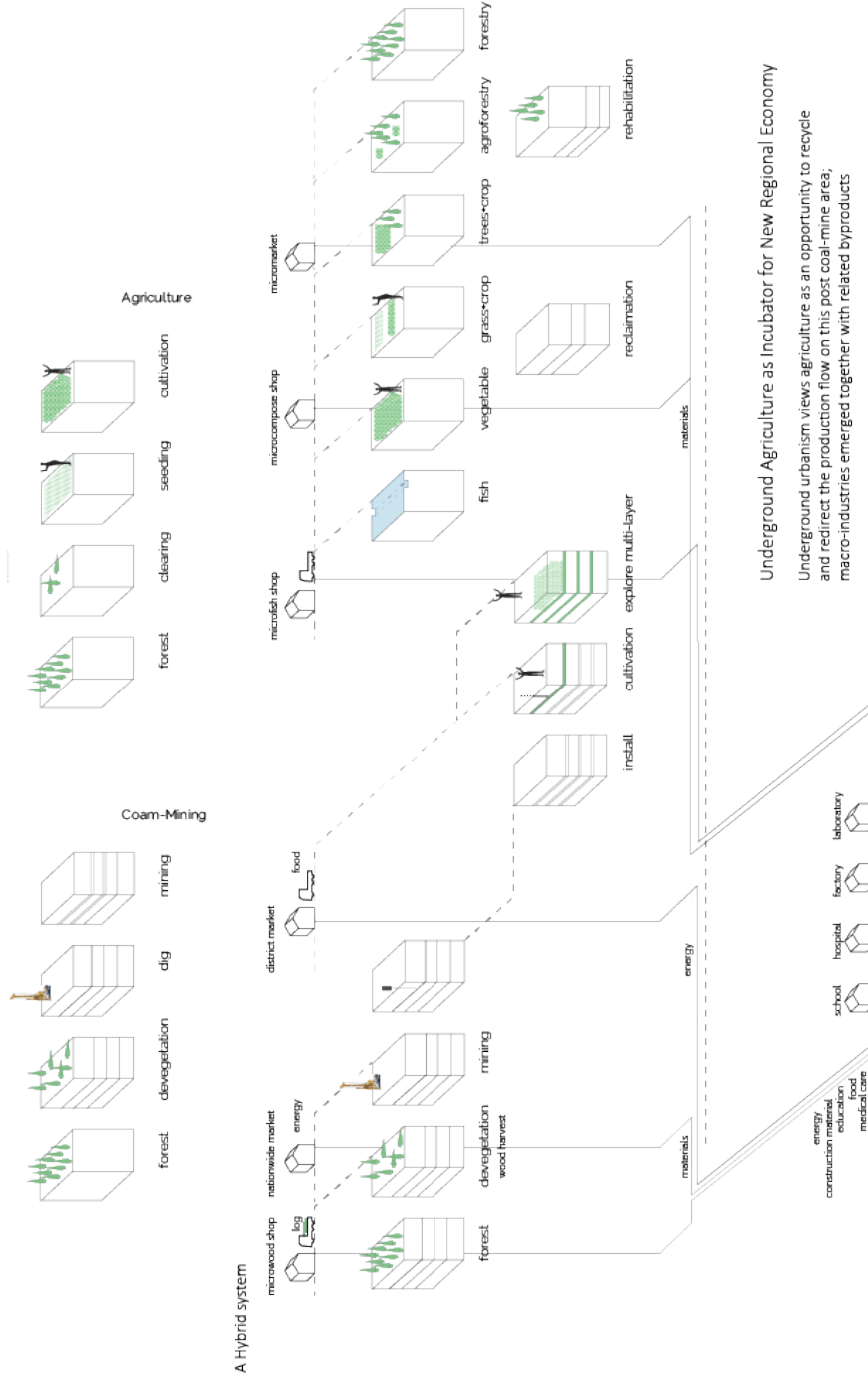


Figure 3.10 Potential Values to Community (source: author)

SYSTEMATIC WORK FLOWS

Seperate systems

With minimal intervention, mining tunnels can be adapted and repurposed for underground agriculture. In this condition, enclosed controlled environment agriculture systems take into use. Production could meet local demand, but it could also be scaled to serve larger markets for fresh vegetables, following farm-to-table and regional or national market retail strategies. Underground agriculture can contribute to, and activate, whole systems.



Underground Agriculture as Incubator for New Regional Economy

Underground urbanism views agriculture as an opportunity to recycle and redirect the production flow on this post coal-mine area; macro-industries emerged together with related byproducts

Figure 3.11 Material Flows (source: author)

CHAPTER 4

DISCUSSION

4.1 Opportunities

This proposal describes ideal conditions for agriculture in underground coal mine tunnels that could also serve as criteria for choosing a site in practice. It is important to recognize temperature and humidity changes and regulation and to know how the controlled environmental agriculture (CEA) system functions. Methods used for the purposes of growing provide opportunities to choose species and offers suggestions for markets, which will benefit the community at large.

Moreover, from the perspective of safety and security, underground agriculture provides an alternative approach, which can help reduce or eliminate food crises. The environment for growing food is highly controlled and without any pesticide. The compost used for growing mushrooms is recycled from other usable waste products. Hydroponic nutrition processes for growing vegetables is fully used, which offers an environmentally friendly approach. Such production output would not be affected by climate changes, and it may, in fact, help to alleviate food crises experienced in particular locations.

In ways that are similar to urban vertical gardening, greenhouse farming, and repurposed abandoned buildings, researchers continue to think of ways to implement urban agriculture production sites. We can also speculate about their potential in terms of underground sites. Many cities have abandoned tunnels, such as aqueducts and subway stations that have fallen into disuse. If an abandoned underground subway tunnel could be

used as a site for urban fungiculture or other forms of agriculture, the benefits for the community and public would be significant. Another related opportunity is to improve environmental and living conditions by applying this development model broadly.

4.2 Challenges in Proposed Design Research

Given that the abandoned coal mine tunnel is an unfamiliar setting to most of the general public, it is likely that people would doubt the stability and utility of those underground spaces. Indeed, problems might occur, such as the collapse of constructed underground tunnels. That would seem more likely if the tunnels were located on or near an active earthquake zone, but would such movements of the earth affect their stability? Such potential problems warrant further discussion, but grounded speculation suggests that, if the tunnels were constructed well, the only factor likely to cause collapse would be irregular operation during the mining process. Later, any action following the rules would not affect the stability of the constructed tunnels. It would be expected that the transport system, ventilation system, and monitor control system would be installed or checked before manipulations began.

Regardless, not every tunnel is suitable for the growing methods described above. Further, preparations for this business would require an appropriate length of time for experiment (1-3 years to test). The preliminary work and investments devoted to this project would not generate income immediately. Later, however, when the business was established and in operation, contributions and benefits can be expected.

CHAPTER 5

CONCLUSION

The application of agriculture in abandoned coal mine tunnels proposed in this thesis explores the technical possibility of agriculture in abandoned coal mine tunnels, making use of existing infrastructure as much as possible. Such an approach would have economic, social, and environmental benefits and could be implemented wherever tunnel-based mining has occurred.

The coal mining system produces, and then abandons, large amounts of infrastructure that could be put to new purposes; that includes rail networks used to transport materials at local and regional scales, tunnel conditions with distinct environmental properties (stable structure, temperature, and humidity), and pertinent mechanical systems (electricity, water, and ventilation) that are well suited to controlled agriculture. As one industry—mining—falls away, another—agriculture—can take its place.

With minimal intervention, mining tunnels can be repurposed for underground agriculture. In that adaptation, enclosed and controlled environment agriculture systems are put into operation. Production could meet local demand, but it could also be scaled to serve larger markets for fresh vegetables, following farm-to-table and regional or national market retail strategies. Underground agriculture can contribute to, and activate, whole systems.

Fungiculture has low requirements for lighting, and production for food (including mycoprotein) and medicine could build a financial basis that would support other vegetable types that require more lighting and therefore have a higher threshold cost. Similarly, as

the economic basis grows, higher cost systems for growing vegetables quickly, such as hydroponics, could become viable. Of course, production scenarios would depend on market demands—meaning, patterns of consumption. However, a strictly controlled system could help to ensure the quantity and quality production.

The proposed initiative would have significant public benefits by inviting participation from all members of the affected community through co-operative financing and work opportunities. With participation from mining companies, academic programs, departments of natural resources and conservation, and environmental education initiatives, such sites could function as educational and environmental protection bases, as well as economic incubators.

In summary, the main goals of this proposal are:

- 1: to reclaim post-industrial sites for new economic uses,
 - 2: to revive community-based industry,
 - 3: to design a systematic approach that could be applied in related situations,
- and
- 4: to help address a significant contemporary challenge—namely, meeting the demands of food production.

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