35 years
PRESSURIZED FACE: EPB OR SLURRY SHIELD
1 to 3 bars
100 ft
SOIL
ROCK

COMPRESSED AIR

TIMELINE
35 years

PRESSURIZED FACE: EPB OR SLURRY SHIELD

1 to 3 bars.

100 ft

TIMELINE

COMPRESSED AIR

SOIL

100 ft

DRILL AND BLAST

ROCK

200 ft

TBM

GROUT OR DRAIN

6 bars
Supergrid facilities

- **Power generation**
  - Nuclear plants underground: technology exists: 100-ft-wide + caverns. Find good rock

- **Transmission lines**

- **Distribution line connections**
  - Electrical
  - Hydrogen

- **Mechanical**
  - Coolant plants
  - Hydrogen-electrical exchangers

- **Service, maintenance access**
Super conducting mainline:

- Length of line between stations (distribution points or mechanical access points).
- Tunnel access for:
  - Maintenance
  - Replacement of sections of the line.
- Tunnel size alternatives
  - Single cable
  - Personnel access
  - Single cable and replacement cable installation
  - Two operating cables
  - Additional space for mechanical lines – coolant.
- Stations: shafts or laterals
  - Distribution lines
  - Mechanical support: cooling plants
Requirements

Redundancy
- Multiple lines in a single tunnel
- Multiple tunnels and lines (grid)

Security
- Controlled access
- Hardened: adequate depth
- Location uncertainty
- Redundancy

Access for maintenance, repair, replacement while tunnel is operating

Access for replacement cable
- Curvature, Length

Replacement after shutdown?: pulling cable.

Tunnel environment
- Leakage - Drainage - Humidity - Temperature
Tunnel with two cables and access:
10- to 15-ft diameter

Pipe with single cable pulled through: HDD or micro-tunneling
Multiple use corridors: large tunnels

- Rail:
  - Freight, double stack
  - Passenger, twin tunnels: 20-ft-dia: limited additional space
  - Passenger, single tunnels: 35-ft-dia
- Fire Life Safety concerns
- High speed corridors: high population density
- Portion of tunnel cost supported by supergrid? Major cost of mainline is for transportation.
Tunnel Depth

- Below utilities and foundations
- Below stream beds
- Dependent on frequency and depth of access shafts and laterals
- Dependent on geology
  - Uniform ground conditions are desirable
  - Avoid rock-soil interface
  - Avoid high groundwater pressures
  - Avoid other difficult ground conditions: solution caverns, faults, oil and gas, extremely high permeability zones
  - Advances in TBM technology extend range of ground conditions that can be efficiently tunneled.
Tunnel Method and Lining

- Short shield tunneling in rock
  - Initial rock bolt support and channels
  - Final lining: cast in place concrete or pipe with grouted backfill

- Shield tunneling
  - Initial lining and final cast in place concrete lining or pipe with grouted backfill
    - Consistent with open shield
  - Segmental concrete lining placed in tail of shield
    - Consistent with EPB or Slurry shield.

- Pipe jacking (Micro-tunneling): (Lining installed in jacking shaft and pushed into the ground)
  - Concrete or plastic pipe sections
    - Consistent with Slurry shield.
Face support and muck removal

- Open face -- rock
  - Muck removed by conveyor or rail cars

- Pressurized face support
  - Earth pressure balanced shield
    - Muck removed by conveyor or rail cars
  - Slurry shield
    - Muck removed by slurry pipeline
    - Common method for micro-tunneling
    - Also used for larger diameter tunnels
Drill and Blast
Chattahoochie Tunnel, Atlanta
Two 18-ft-dia. tunnel boring machines: 47,000 ft
Cutter head
Back-loading (recessed) disk cutters
cutting tracks approx. 4 in. apart
Thrust:
1960: soft rock
1980: 30,000 lb/cutter
2000: 70,000 lb/cutter
...the result of improved tool hardness, bearing design & metallurgy.

Disk Cutters

Penetration rate
- - in proportion to Thrust/cutter & rpm

Advance Rate = Pen. rate x % Utilization
(% of workday machine is penetrating)
GRIPPERS: AGAINST ROCK.

THRUSt CYLINDERS
SHOVE CUTTERHEAD FORWARD

(Photo shows machine being assembled in drill and blast section)
Pressurized face tunnel boring machines

... now the standard tunneling method for soils that would otherwise flow or run into the tunnel face. Now used in rock. Allows tunneling through water-bearing soils without dewatering.

- EARTH PRESSURE BALANCED (EPB) SHIELD (Common for large tunnels in soil)

  Chamber at front of shield is filled with excavated muck mixed with conditioners (foam, polymers, bentonite) to provide a pressure against the face. Muck is removed from chamber with a screw conveyor.

- SLURRY SHIELD (Common for micro-tunnels)

  Chamber at front of shield is filled with a bentonite slurry mixed with excavated muck to provide a pressure against the face. Slurried muck is removed from chamber and pumped out of the tunnel through a return slurry pipe.
Earth Pressure Balanced Shield

- Muck pressurized in chamber
- Screws remove muck and provide back pressure
- Segmental Lining is installed in tail end of the shield.
- Shield is advanced by pushing against the installed lining
Soap foam, polymer is injected to reduce friction and fluidize muck so that face pressure can be developed.
Disk cutters to cut boulders, rock

Grizzlies to limit size of boulders passing through the head
1. Cutter wheel with picks
2. Pressurized Chamber, with slurry
4. Bentonite line into chamber
5. Stone Crusher
3. Compressed Air Cushion
6. Slurry of bentonite & muck is pumped out of chamber and out of tunnel, then separated
1. Shove jacks to advance shield as wheel cuts ground

2. Concrete segments erected to form a ring, every 4 or 5 ft, after shield is shoved forward.
MICRO TUNNEL       SLURRY SHIELD

- Rotating cutterhead, bentonite slurry supports face
- Slurry is circulated out of tunnel to remove excavated muck
- After muck is separated, slurry is recirculated to tunnel face
JACKING PIT: START OF MICRO TUNNEL

Figure 3.18  Photograph of Double-Entry Ring Seal with Guillotine Closure Used for Retraction and Grouting Tests
JACKING FRAME IN STARTING PIT

- Place 10 to 12-ft-long pipe, with slurry lines attached
- ~ 30 minutes to install pipe section
- Jack pipe string to advance the shield
Figure 3.19  Concrete Pipes Used for Retrievable Machine Reaming Driv...
Pipe jacking (micro-tunneling)

- Small crew or no crew in tunnel
- Straight runs or very large radius curvature
- Short runs (300 to 1000 ft)
- Additional length achieved with:
  - Access and multiple ports along pipeline for injecting bentonite and floating the pipe
  - Intermediate jacking stations inserted in pipe string: earthworm motion

Pump bentonite into annulus
HORIZONTAL DIRECTIONAL DRILLING (HDD)

PILOT HOLE DRILLING

PREREAM
HDD CAPABILITIES TO DATE

- Maximum distance: 6000 ft at 24 in. dia.
- Maximum diameter: 48 in. over distance of 3000 ft

Excavation and Steering

- EM signal transmitted to surface or through single hard wire line in casing: inclination and magnetic azimuth
- Circulating fluid pumped to mud motor or jets to excavate ground. Steering controlled by small rotations of pipe to adjust attack angle of motors or cutting tool.
3 Ways to be more efficient/cost effective

1. Increase advance rate
2. Reduce crew size
3. Reduce Risk
   - To Bidder/Construction Contractor
   - Better Contracting Practices
   - Reduce delays/ cost overruns
   - Robust tunneling equipment
   - Methods insensitive to variable ground conditions
## Order of magnitude

<table>
<thead>
<tr>
<th>Fiber optic conduit: trenching</th>
<th>$50-100/ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduit: pipe jacking,</td>
<td>$200/ft</td>
</tr>
<tr>
<td>directional drilling:</td>
<td></td>
</tr>
<tr>
<td>Larger: 2- to 4-ft-dia micro tunnel:</td>
<td>$500/ft</td>
</tr>
<tr>
<td>Optimum-sized TBM tunnel</td>
<td>$1500/ft</td>
</tr>
<tr>
<td>Larger TBM tunnels</td>
<td>$3000/ft</td>
</tr>
</tbody>
</table>
Supergrid Opportunities

- Long-term project
- Large capital costs for installation
- Special requirements for installing the grid: tunnel size, lengths of runs, ranges of ground conditions to be encountered.
- Trend with time: less space and more difficult access for installing utilities. Less public tolerance for disturbance
- Increasing use of tunneling and trenchless technologies rather than trenching and open excavation.

Focus for improving tunneling technology for supergrid:
- Contracting practices: mitigation and assignment of risk
- Joint efforts with research groups, engineering firms, contractors, and machine manufactures to develop and demonstrate excavation and tunneling systems that will fit the requirements of the project
- Link directional drilling, micro-tunneling and larger tunnel boring machine technologies.
- Support demonstration projects using advanced technologies for driving tunnels.
EPB & Slurry Shield Opportunities

- Ability to change cutters, maintain face, particularly in ground with high pressure, high permeability ground water and gas.
  - Flood doors
  - Back loading cutters
  - Robotics: New technology
  - Wear sensors on cutters and rolling disks

- Maintain circulation and minimize loss of slurry into voids, high permeability zones

- Reduce risks of large local ground losses
  - Improve EPB conditioners used to mix soil and develop pressure on the face
  - Improve monitoring of volume in and out of head.
  - Real time readout of machine functions and grout and conditioner volume and pressure, link readout to control of machine
  - Sensing of conditions ahead of shield requiring adjustment in slurry or conditioners.
  - Reduce dependence on operator’s control
Segmental lining opportunities

- Automate lining installation procedures
- Improve seals
- Improve tail grouting techniques
- Improve remedial measures for chasing down and sealing leaks.
- Improve toughness of concrete: fibers, reduce corner cracking.
- Longer segment lengths
- Install while tunnel is advanced
Pipe jacking (micro-tunneling) opportunities

- Extend total length of runs
- Develop for larger diameters (10-15 ft)
Hole through