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Geosynthetic Applications in Modern Mining Practice

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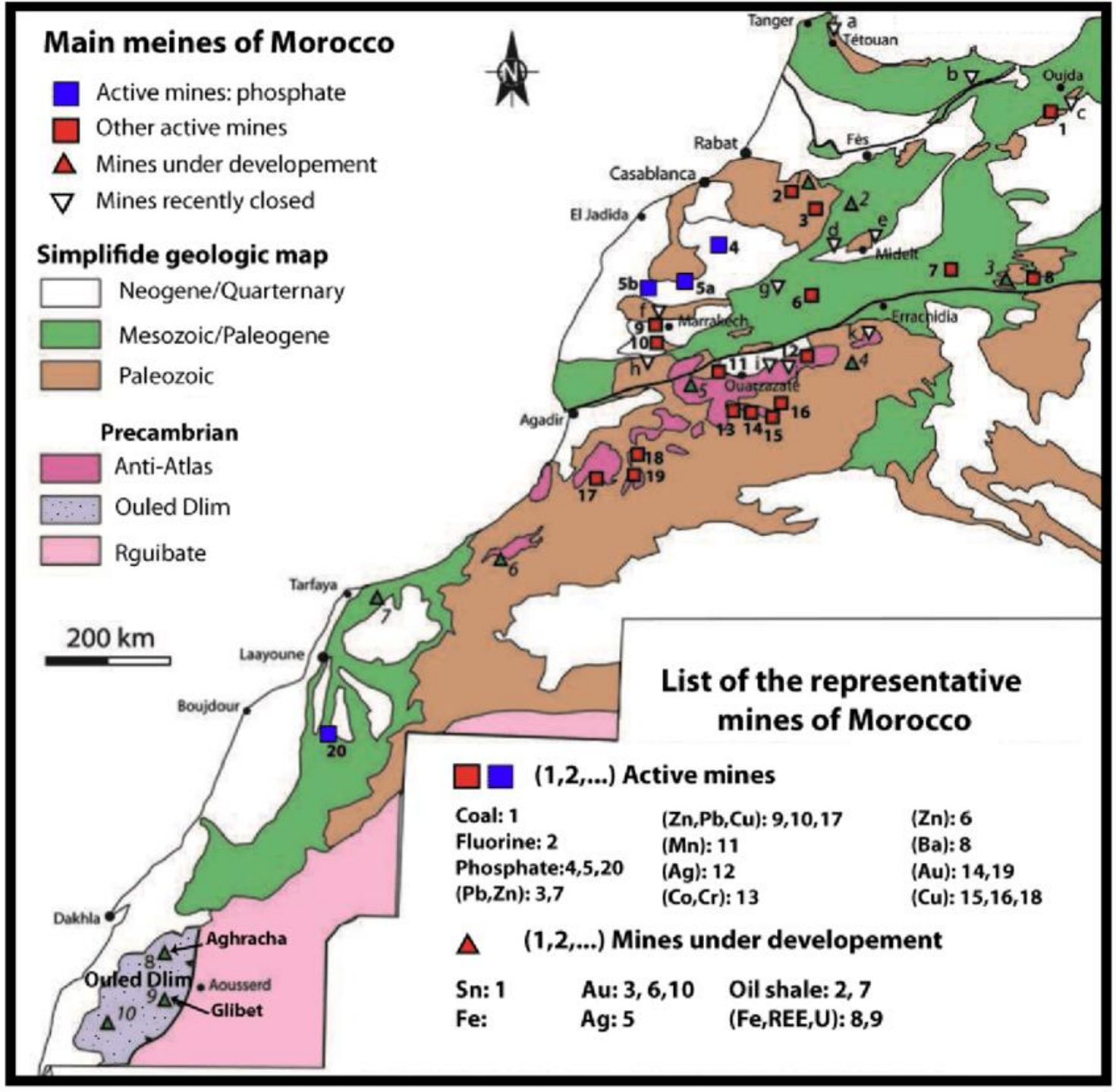

Main meines of Morocco
Active mines: phosphate
Other active mines
Mines under developement
Mines recently closed
Simplifide geologic map
Neogene/Quarternary
Mesozoic/Paleogene
Paleozoic
Precambrian
Anti-Atlas
Ouled Dlim
Rguibate
200 km
N
Tanger
Tétouan
Oujda
Rabat
Fès
Casablanca
El Jadida
Meknès
Marrakech
Errachidia
Ouarzazate
Agadir
Tarfaya
Laayoune
Boujdour
Dakhla
Aghracha
Ouled Dlim
Aousserd
Glibet
List of the representative mines of Morocco
(1,2,...) Active mines
Coal: 1
Fluorine: 2
Phosphate:4,5,20
(Pb,Zn): 3,7
(Zn,Pb,Cu): 9,10,17
(Mn): 11
(Ag): 12
(Co,Cr): 13
(Zn): 6
(Ba): 8
(Au): 14,19
(Cu): 15,16,18
(1,2,...) Mines under developement
Sn: 1
Fe:
Au: 3, 6,10
Ag: 5
Oil shale: 2, 7
(Fe,REE,U): 8,9

Name	Mine Production (mmtpa)
Khouribga Mine	22.45
Benguerir Mine	5.95
Mzinda Phosphate Mine	3.05
Youssoufia Mine	2.83
Hajar Mine	2.27

Khouribga Phosphate Mine

Benguerir Phosphate Mine

Outline

- Understanding the mining industry
- Traditional uses of geosynthetics in mining
- Newer uses of geosynthetics in mining
- Best practice with geosynthetics

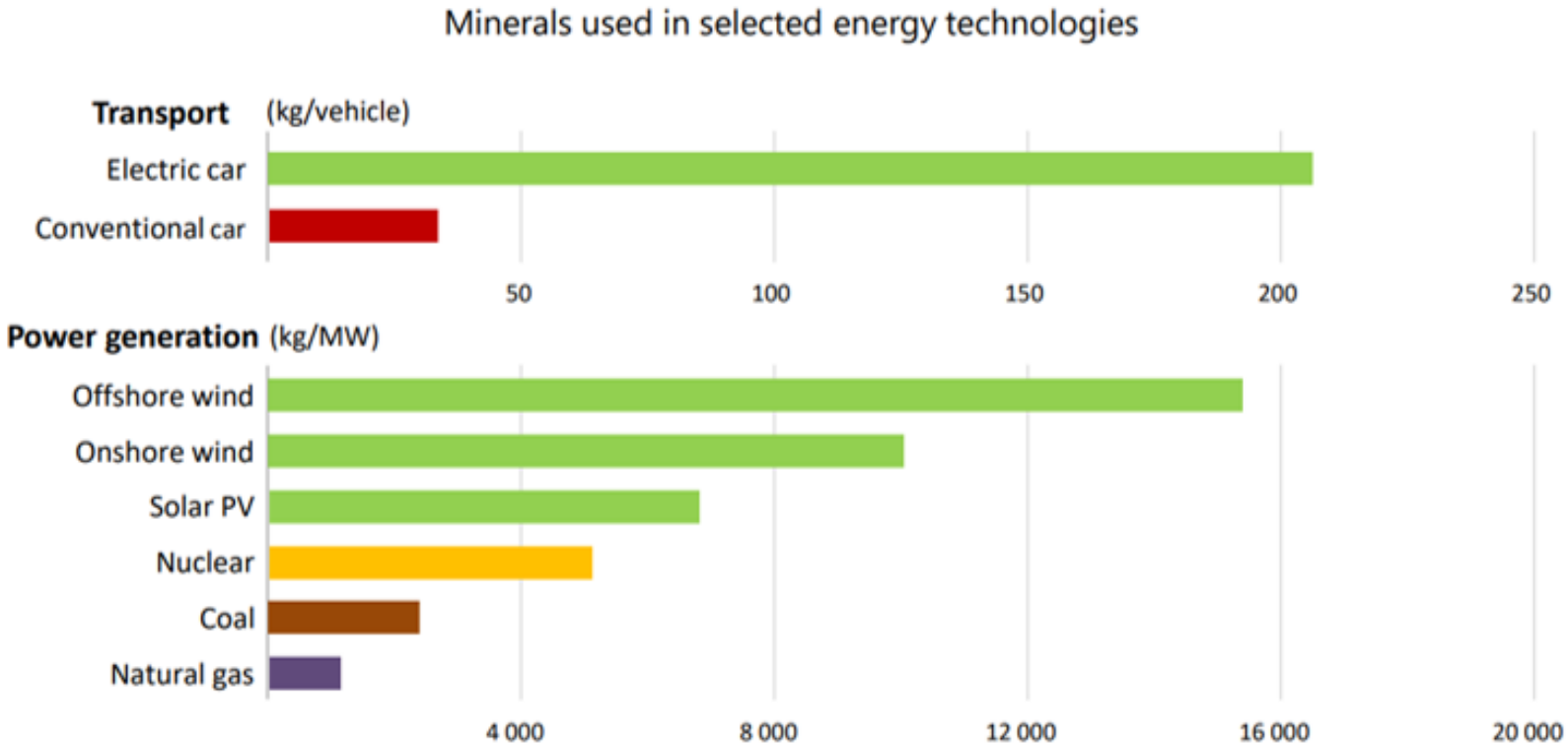
Mining risks

- NOT SUSTAINABLE!
- High energy consumption
- Environmental contamination
- High water consumption
- Dangerous /
  employee safety concerns
- Expensive
- Wary public
- Policy risks

Environmental hazards associated with mining

Risk	Affected compartments	Relevant toxic compounds
Overtopping of tailings dam	groundwater, surface water, soil	**Water emissions:** • in most cases radionuclides, mainly thorium and uranium; • heavy metals; • acids; • fluorides; **Air emissions:** • in most cases radionuclides, mainly thorium and uranium; • heavy metals; • HF, HCl, SO_2 etc.
Collapse of tailings dam by poor construction	groundwater, surface water, soil	
Collapse of tailing dam by seismic event	groundwater, surface water, soil	
Pipe leakage	groundwater, surface water, soil	
Ground of tailing pond not leak-proof	groundwater	
Waste rock stockpiles exposed to rainwater	groundwater, surface water, soil	
Dusts from waste rock and tailings	air, soil	
No site-rehabilitation after cease of mining operation	land-use, long-term contaminated land	
Processing without flue gas filters	air, soil	
Processing without waste water treatment	surface water	

The shift to a more mineral-intensive energy system



A typical electric car requires six times the mineral inputs of a conventional car, and an offshore wind plant requires thirteen times more mineral resources than a similarly sized gas-fired power plant

Minerals in

ELECTRIC VEHICLES VS GAS CARS

Electric vehicles require a wider range of minerals for their motors and batteries compared to gas cars.

In fact, an EV can have 6 times more minerals than a gas car and be on average 340 kg heavier.

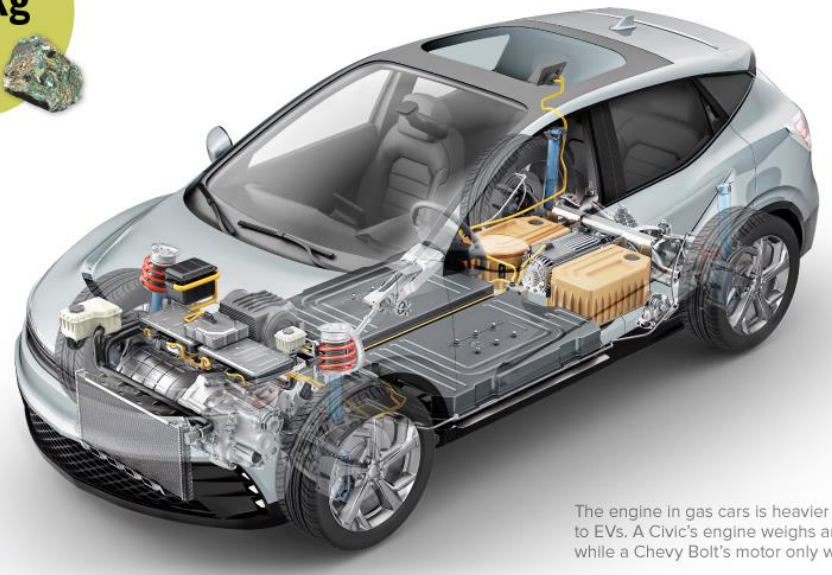
Mineral content kg/vehicle *Steel and aluminum not included.*

Electric Vehicle | Gas Car

EVs can contain more than a mile of copper wiring inside the stator to convert electric energy into mechanical energy.

	Electric Vehicle	Gas Car
Graphite	66.3 kg	0 kg
Copper	53.2 kg	22.3 kg
Nickel	39.9 kg	0 kg
Manganese	24.5 kg	11.2 kg
Cobalt	13.3 kg	0 kg
Lithium	8.9 kg	0 kg
Rare Earths	0.5 kg	0 kg
Zinc	0.1 kg	0.1 kg
Others	0.3 kg	0.3 kg

Many EV motors use magnetic materials typically made with rare earths.

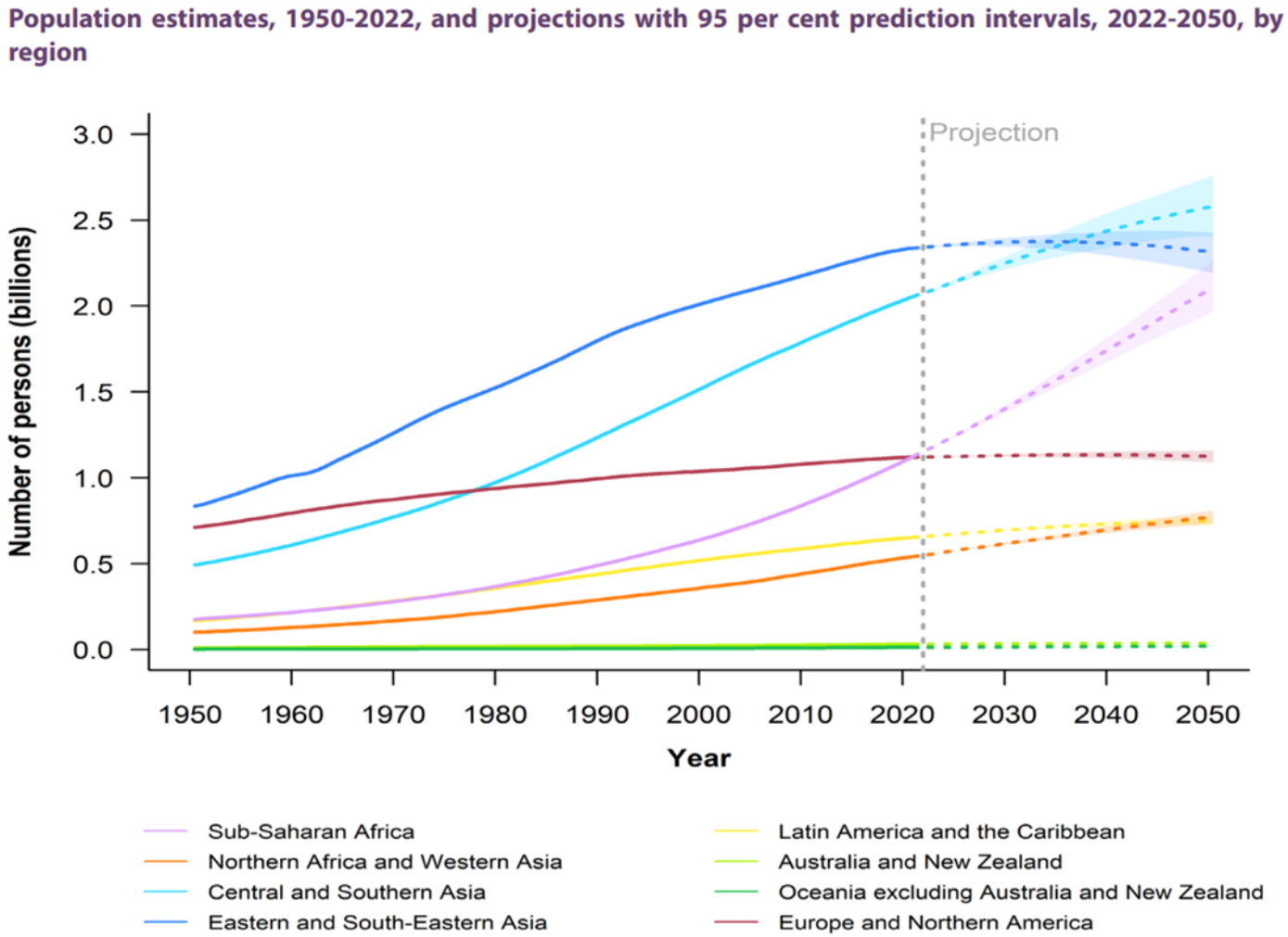


Graphite is the anode material in a lithium-ion battery and is the single largest component by weight.

The engine in gas cars is heavier compared to EVs. A Civic's engine weighs around 184 kg while a Chevy Bolt's motor only weighs 76 kg.

Source: IEA
The values are for the entire vehicle including batteries and motors. The intensities for an electric car are based on a 75 kWh NMC (nickel manganese cobalt) 622 cathode and graphite-based anode.

Around 70% will live in Asia or Africa



Source: UN Dept Economic & Social Affairs: World Population Prospects 2022

Global Mining Outlook 2022

The survey reveals a resilient sector responding to a rapidly shifting environment of complex and diverse risks.

72%

of respondents expect a disruption in the mining sector due to ESG in the next three years.

84%

agree that success in the long run will become increasingly dependent on defining success in broader than just financial terms

62%

are confident in the growth prospects for their organization over the next 12 months

Mining

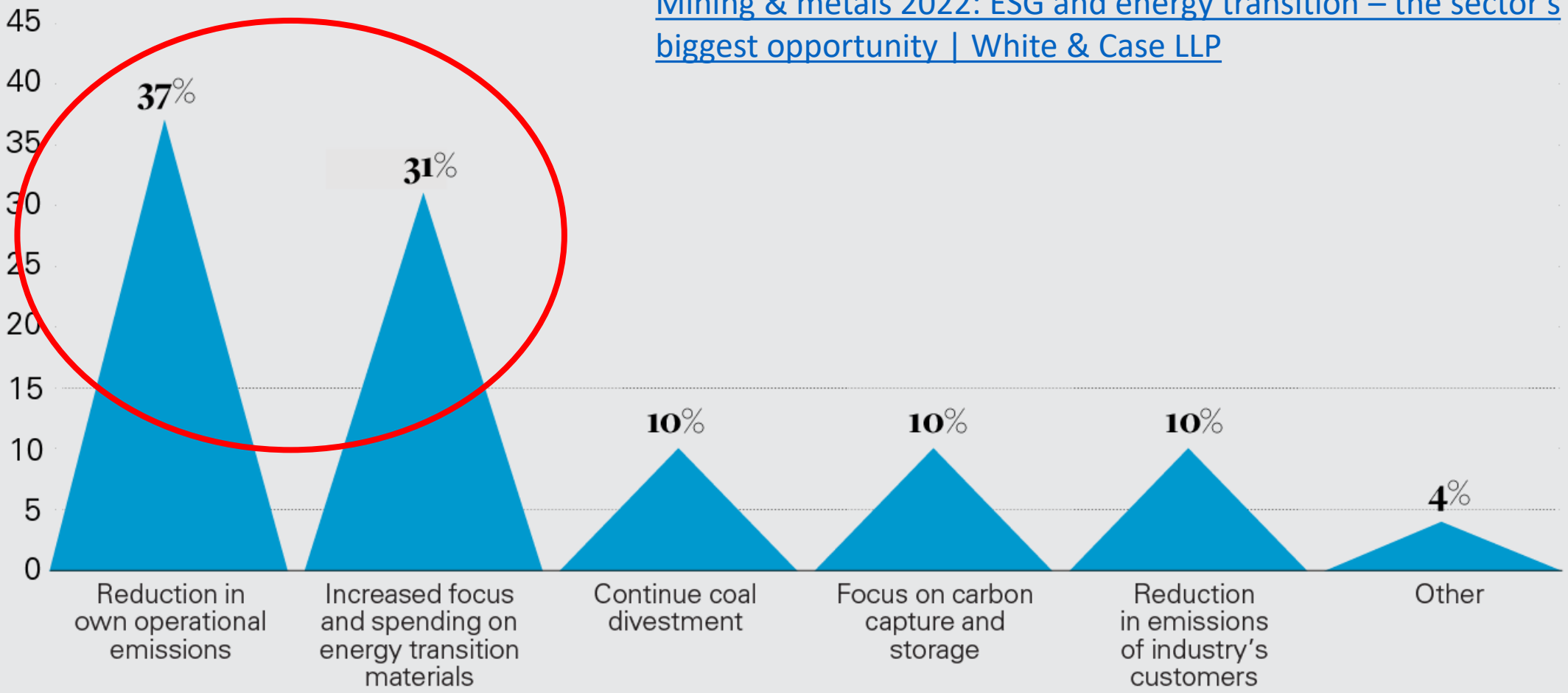
KPMG:

Leading mining risk has been commodities for past 12 years…

…now replaced by ESG

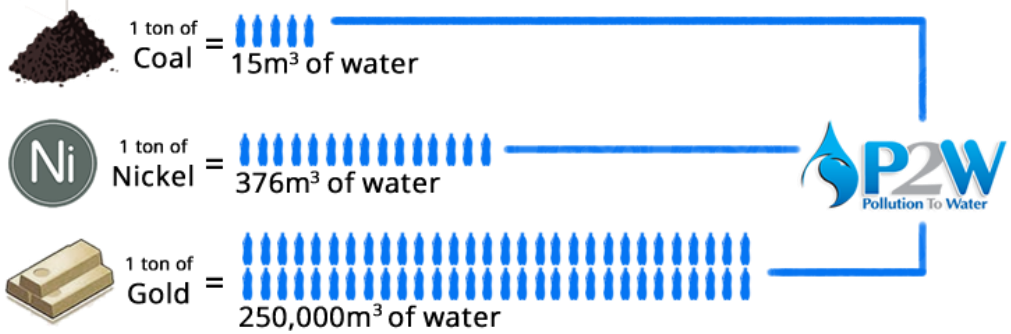
How will the mining industry respond most effectively to climate change policies and investor pressure?

[Mining & metals 2022: ESG and energy transition – the sector's biggest opportunity | White & Case LLP]



Source: White & Case 2022 Mining & Metals market sentiment survey

Water Consumption for Mining



[Gold Mining Wastewater Solutions | Pollution to Water]

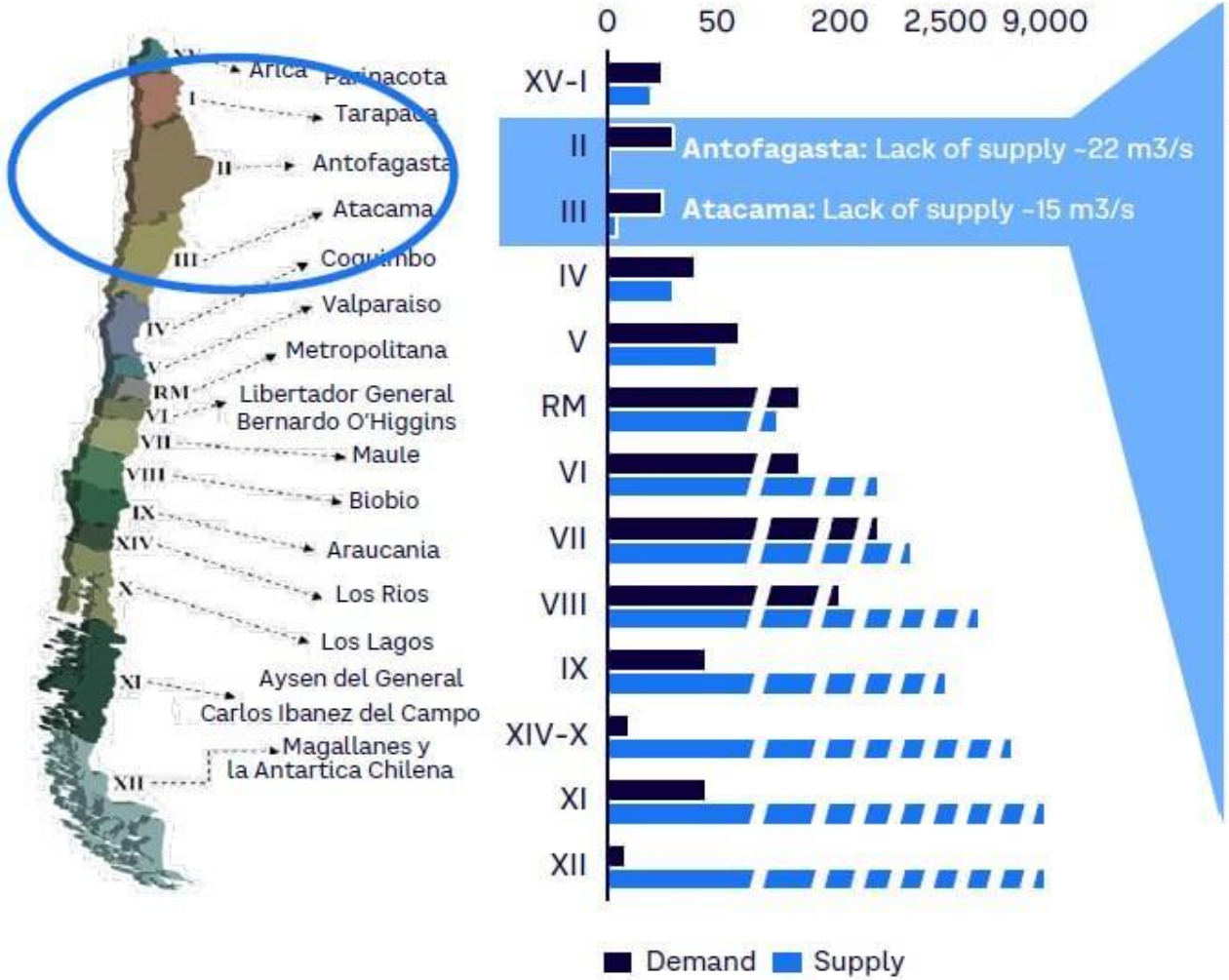
Mineral/metal type	Water use for processing and extraction
Coal	💧💧
Copper	💧💧💧
Diamond	💧
Gold	💧💧💧
Nickel	💧💧
Iron Ore	💧💧
Platinum	💧

Key

High 💧💧💧

Medium High 💧💧

Medium Low 💧



Large copper mines create high demand

Copper mine	Region	Owner	Production
Escondida	Antofagasta	BHP	1,126kt
Collahuasi	Tarapaca	Anglo American	630kt
El Teniente	Libertador	Corporacion Nacional del Cobre de Chile	445kt
Chuquicamata	Antofagasta	Corporacion Nacional del Cobre de Chile	400kt
Los Pelambres	Atacama	Antofagasta Plc	360kt

Arid climate causes weak water supply

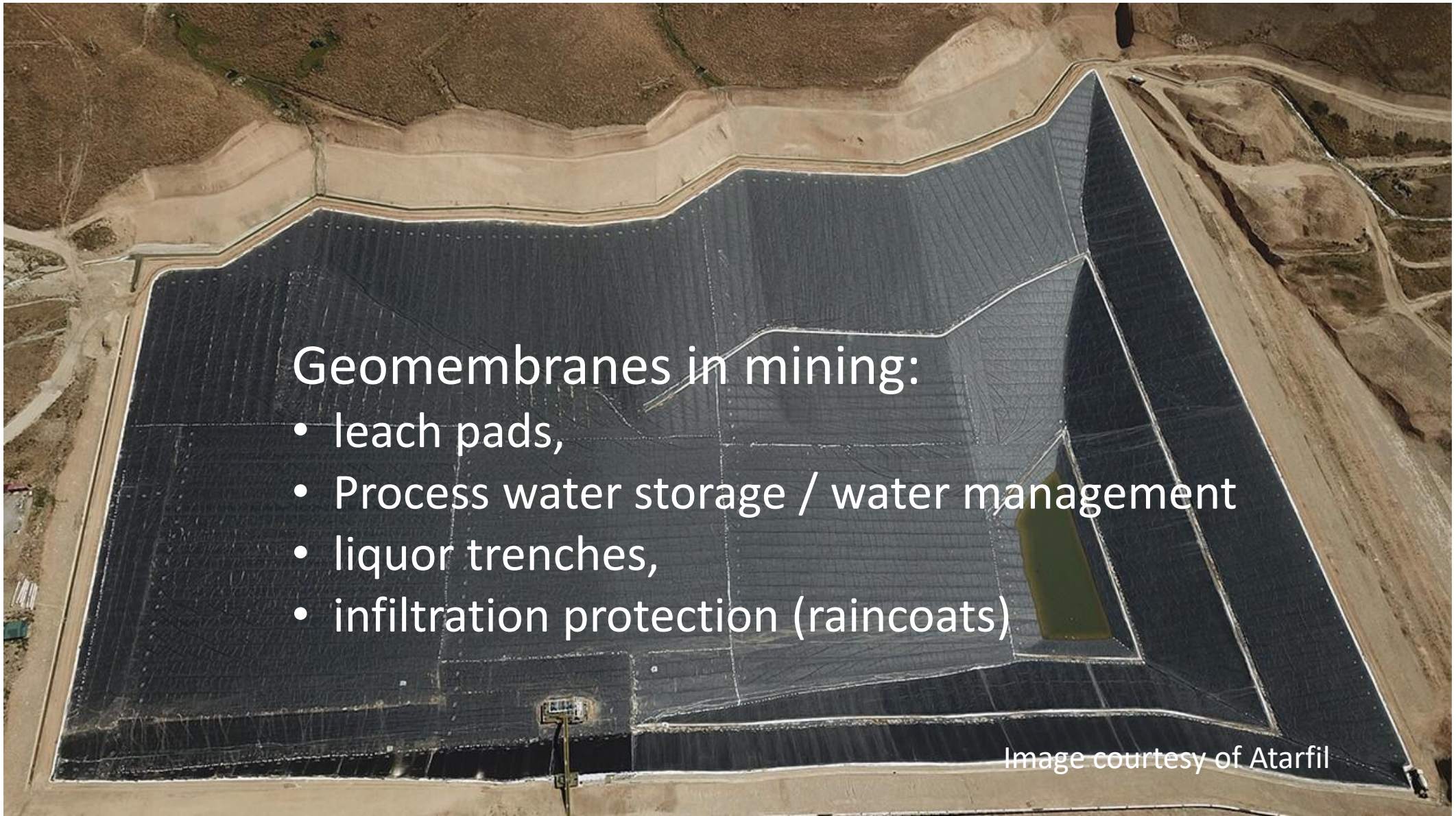
- The Atacama Desert is one of the driest places on earth.
- The average annual rainfall is about 15 mm per year, with some locations receiving only 1 to 3 mm.

Source: Arthur D. Little

A Job for Geosynthetics!!

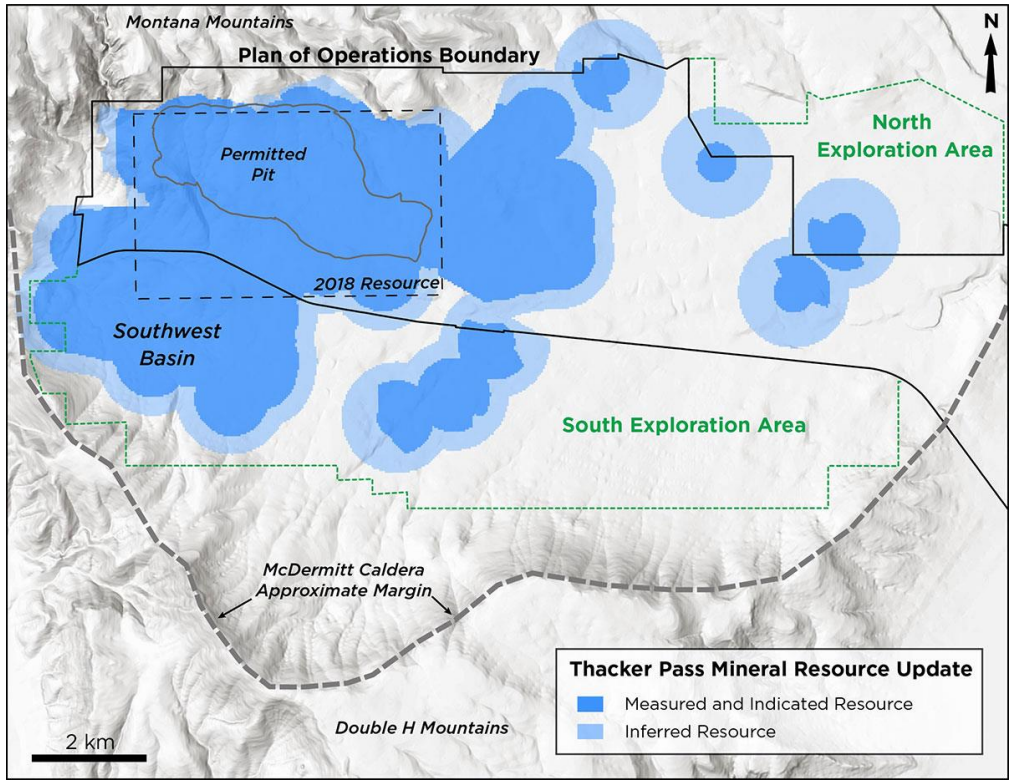

Geomembranes are the answer

Traditional geosynthetic applications in mining: containment



Are geomembranes are important to mining?

- Mining consumes ~40% of global geomembrane production.
- Largest liner systems are now >15M m2
- Waste volumes are escalating



according to **<u>Lithium Nevada Corporation's Plans of Operation</u>**, the mine would entail:

- excavation of a large open pit roughly 3.7 km long by about 0.8 km at the widest
- removal of 17.2 million tons of rock and ore per year
- direct surface disturbance of 2,304 hectares (total project size would be 7,257 hectares) (**total GM: > 30M m2**)
- on-site sulfuric acid plant - 5,800 tons of acid per day during leaching
- ultimately pumping up to 1.7 billion gallons of water per year
- estimated lifetime of 41 years and 5 years of reclamation

Escalation of Mining

Daily mining rates in kt/d:	
0.1s	1900
1s	1930s
10s	1960s
100s	2000s
1,000s	2030s?

Growth every 30 years:	
Volume of waste	10x
Area of waste	5x
Max height	2x
-Dams in 2000	240m
-Dams in 2030	480m?

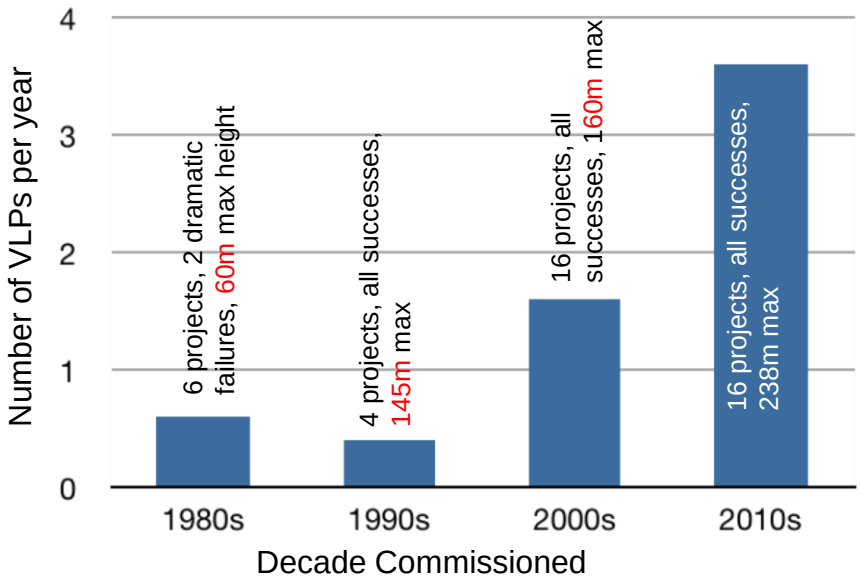
Largest oil sands and copper mines are already at about 1,000 kt/d

M. Smith adapted from A. Robertson, 2011

Geomembranes are important to mining?

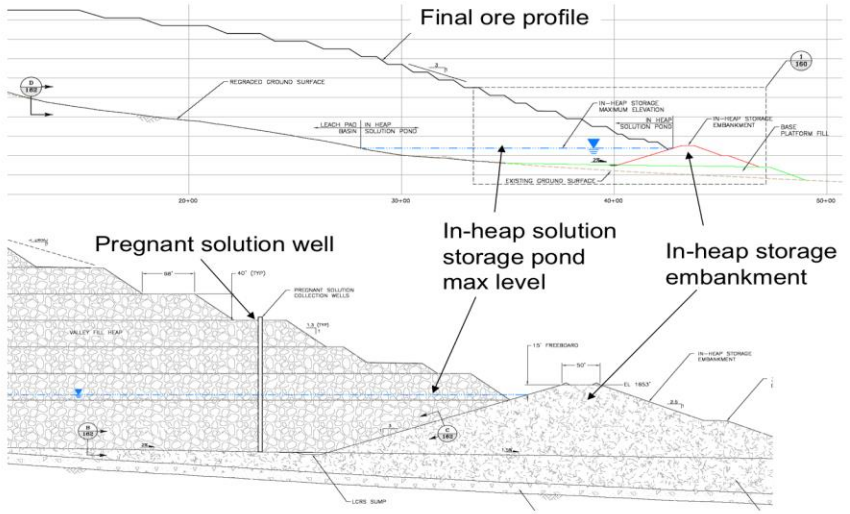
- Valley leach pads
- New ore types
- Heap covers
- Liability & risk management

Valley Fill Heap Leaching (Valley Leach Pads)



- ✓ Everything about VLPs is harder & more expensive than conventional pads!
- ✓Costs can be 2-3x conventional pads

Fort Knox Gold Mine, Alaska



Geomembrane Raincoats

- First used in Costa Rica at 2 small gold mines, circa 1988
- First large-scale commercial test, Peru, 1994 - 1997
- First full-scale commercial application, Peru, 2000 – present

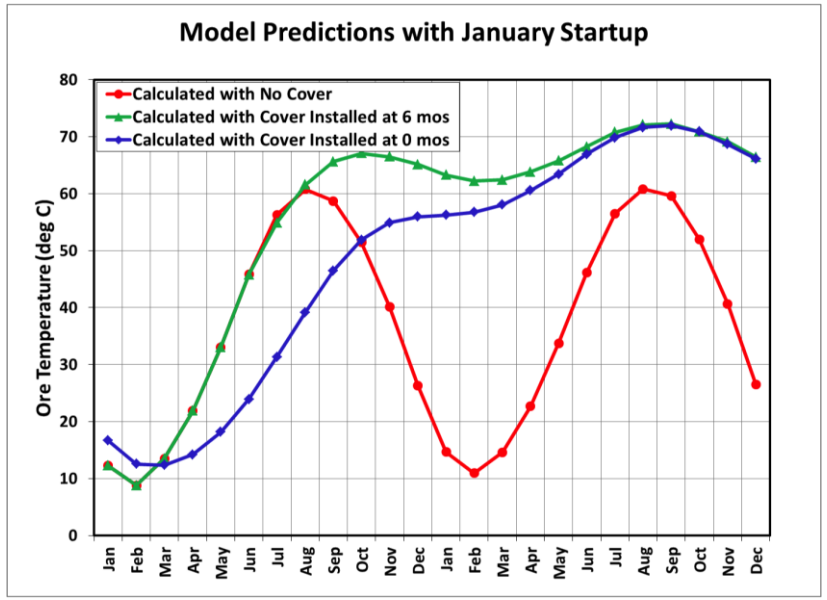
Images courtesy Tetex

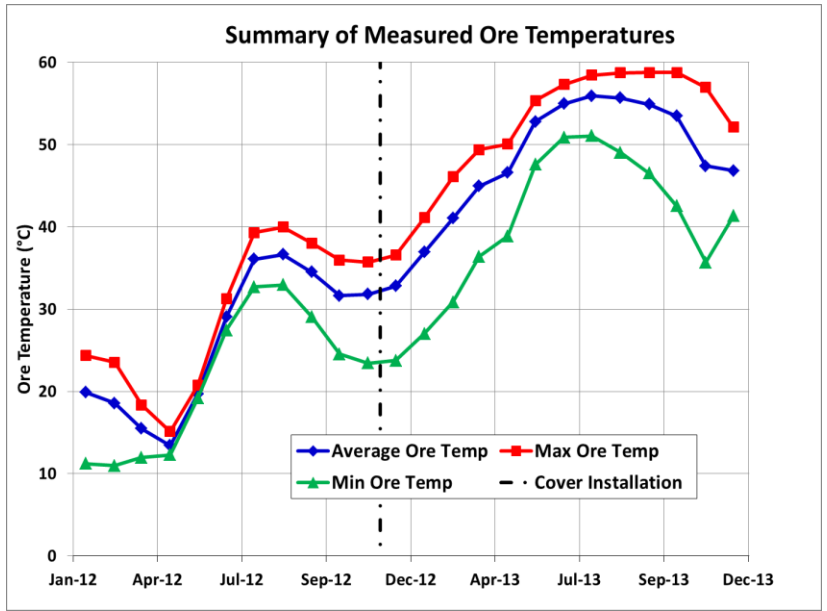
Raincoats for Water Management

Two gold VLPs in Peru

Geomembrane Thermal Cover Pilot Test

- Chalcopyrite ore
- 90,000t two-year test
- Results:
  - cover increased internal temperature >20c
  - longer operating season, faster leach kinetics, better economics





From Mark Smith

- First large-scale test was in Chile, funded by the federal government
- Mid-sized copper mine
- Results: 50 L/s water consumption saved

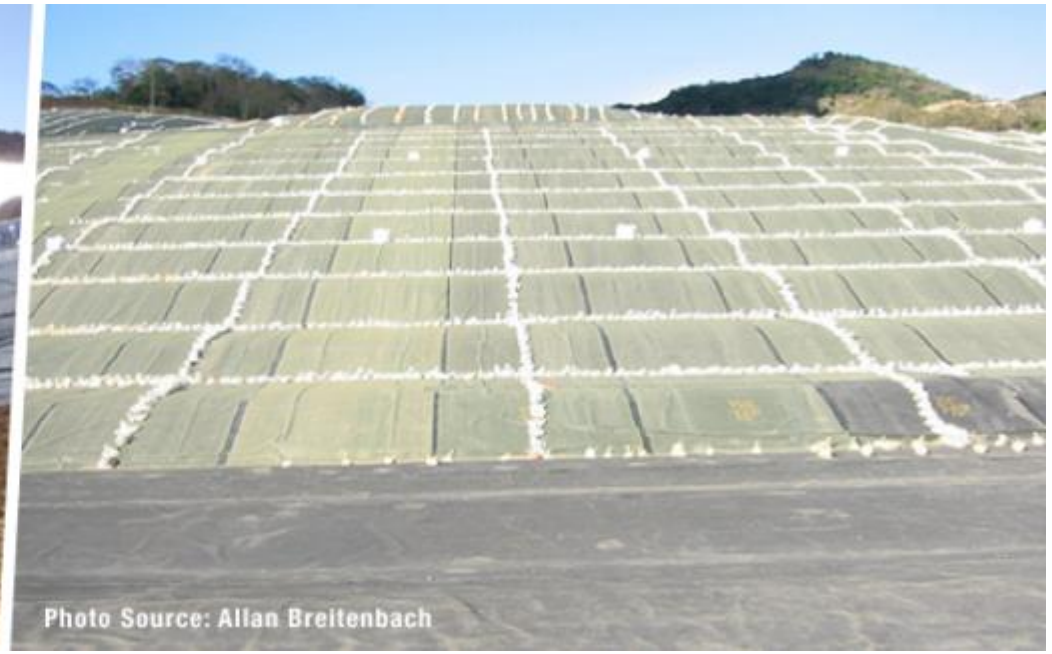
  - Gross Savings = $7.1M/yr
  - Cost = $4.8M initial + $1.2M/yr after 1st yr
  - Payback = 8 months
  - Add'l benefits:
    - heat gain, faster leach kinetics
    - more uniform leaching of upper +/- 1 m of ore
    - less correction, plugging
    - social acceptance & public support for mining

From Mark Smith

Geomembrane Lined interim benches: serving triple duty:

- ✓Construction access
- ✓Anchorage of geosynthetics
- ✓Management of seepage and surface waters during construction & operations

Example stability berm configuration from a heap leach pad liner project. The scale of heap leaching today is dramatically different than just 20 years ago.



Example “stair step” stability bench configuration on a composite lined heap leach pad.

Geomembrane Covers for Water Preservation

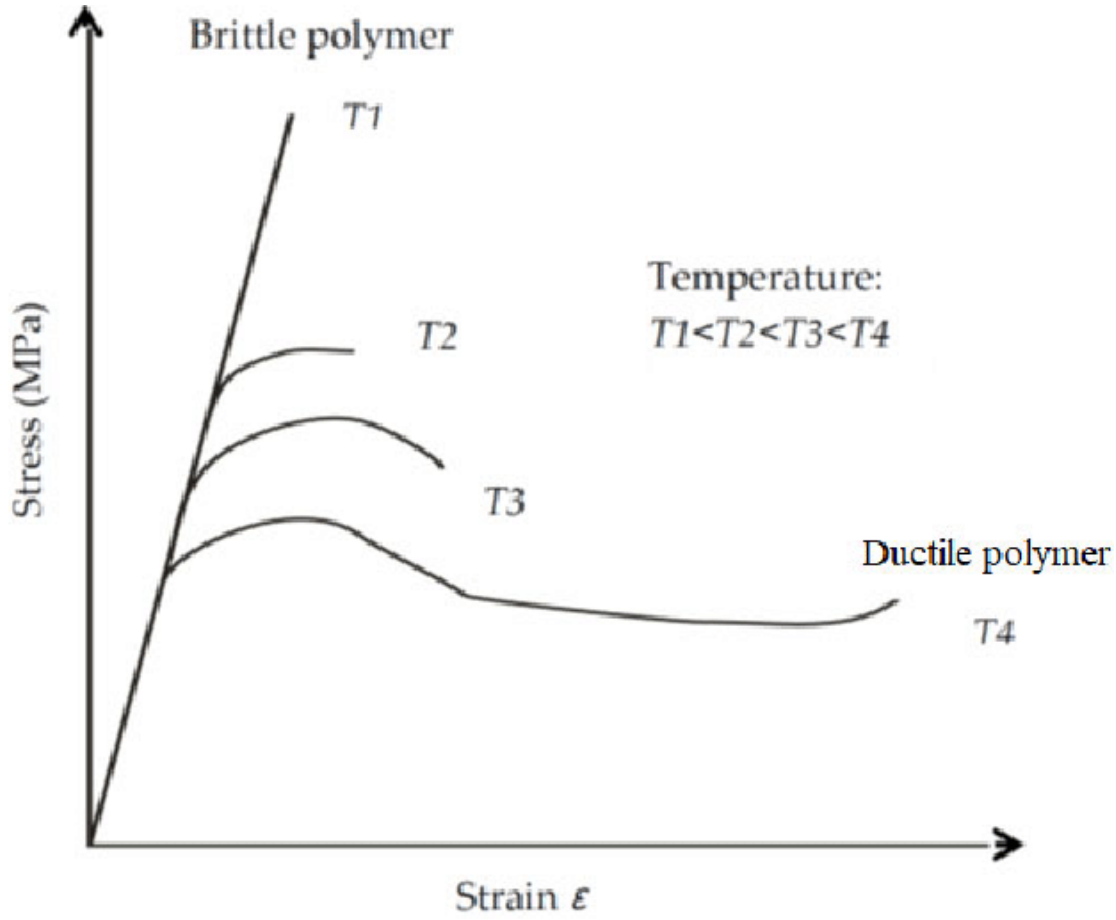
Images courtesy of Mike Sadlier

Geosynthetic Durability Issues in Mining

- Aggressive chemistry
- Elevated temperatures
- UV Radiation exposure
- Thermal expansion / contraction
- Down drag (ex: as tailings dry out)

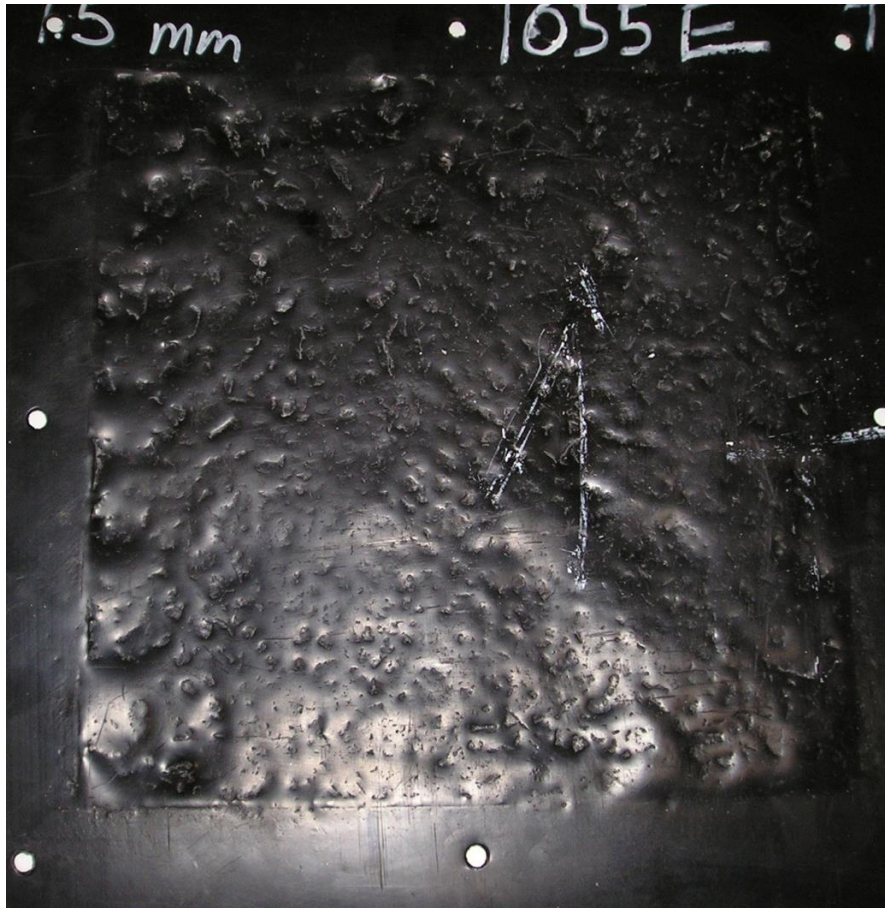
Large tailings pond with geomembrane (Sadlier)

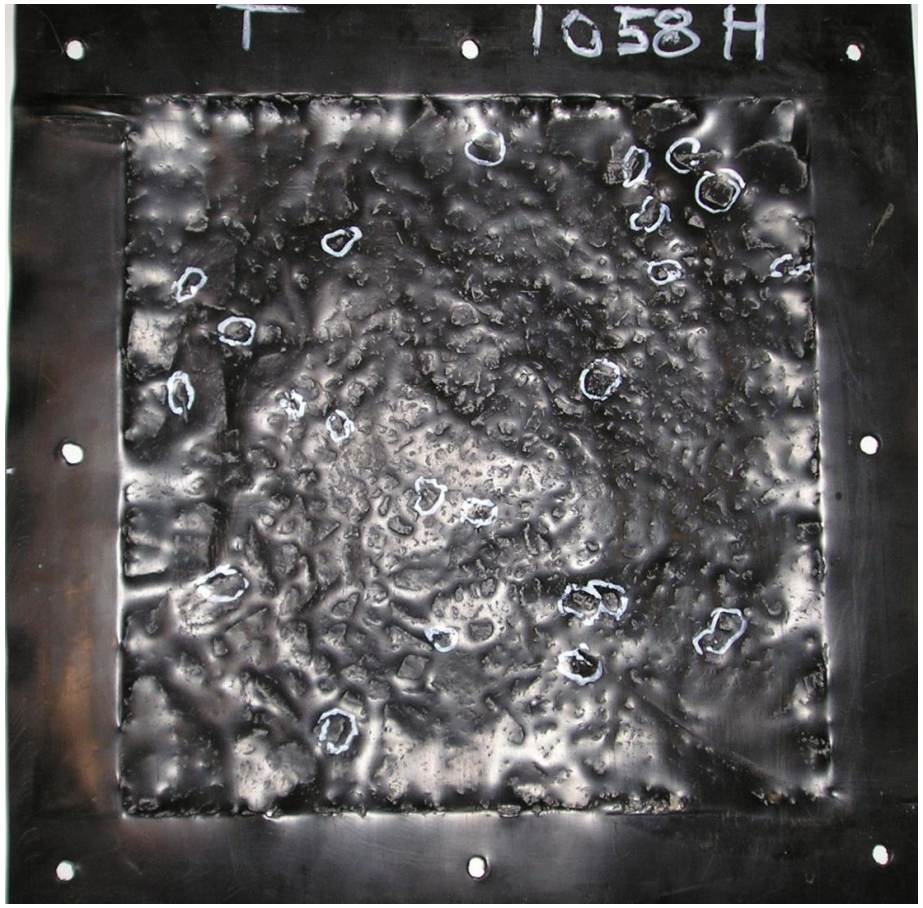
Geomembranes & Operating Temperatures



Geomembranes & Operating Temperatures

1.5mm LLDPE: 120 m ore depth; 48 hour load, 20° C (L), 60° C (R)





Drainage Pipe Performance vs Operating Temperatures

Heap Height, meters	Vertical Deflection @ 20ºC	Vertical Deflection @ 50ºC
20	5.0%	8.0%
40	8.6%	13.3%
60	11.6%	17.6%
80	14.3%	21.5%
100	16.8%	24.9%
120	19.2%	28.1%
140	21.4%	31.0%

Material: Corrugated dual wall polyethylene drain pipe

Drainage Pipe Failure

Mining presents unique challenges for GMs

Geomembrane in a PLS Pond with tailings at about 30C

SX tanks used to effect a separation of a warm mixture of sulphuric acid and an aggressive organic liquid (similar to kerosene) into its two components

Images courtesy of Mike Sadlier

Additional geosynthetic applications in mining

- road & slope stabilization
- erosion control re-vegetation
- Filtration / dewatering
- Heat management
- Reinforced soil structures / walls / berms
- …..on and on

Geomembranes	**Process solution pond lining** **Heap leach pads/liner systems** **Tailings impoundment lining system** **Encapsulation of contaminated waste rock**
Geosynthetic Clay Liners	Encapsulation of contaminated waste rock Barrier layer below geomembrane (composite lining system
Geotextiles	Filter layer for underdrains and collection pipes Cushion layers over geomembranes Ground stabilization Erosion control
Geogrids	Ground stabilization Remediation of mine workings / safety
Geopipes	Process solution collection and conveyance Solution recovery Leak detection and monitoring

Mining site transportation needs

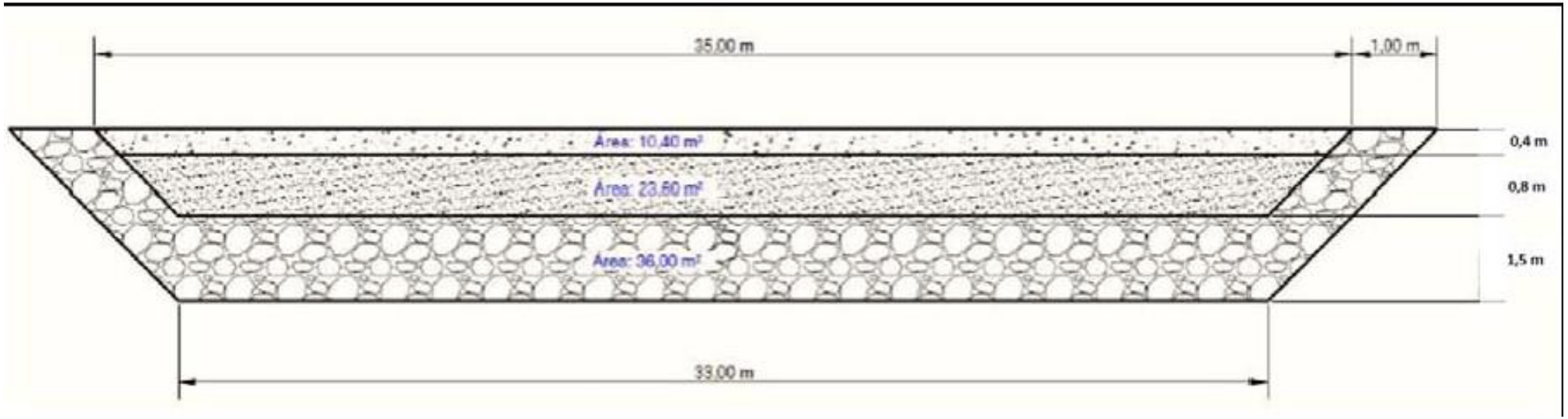
- Heavy loads
- Dynamic loads
- Rain / moisture
- Isolation / proximity to infrastructure assistance

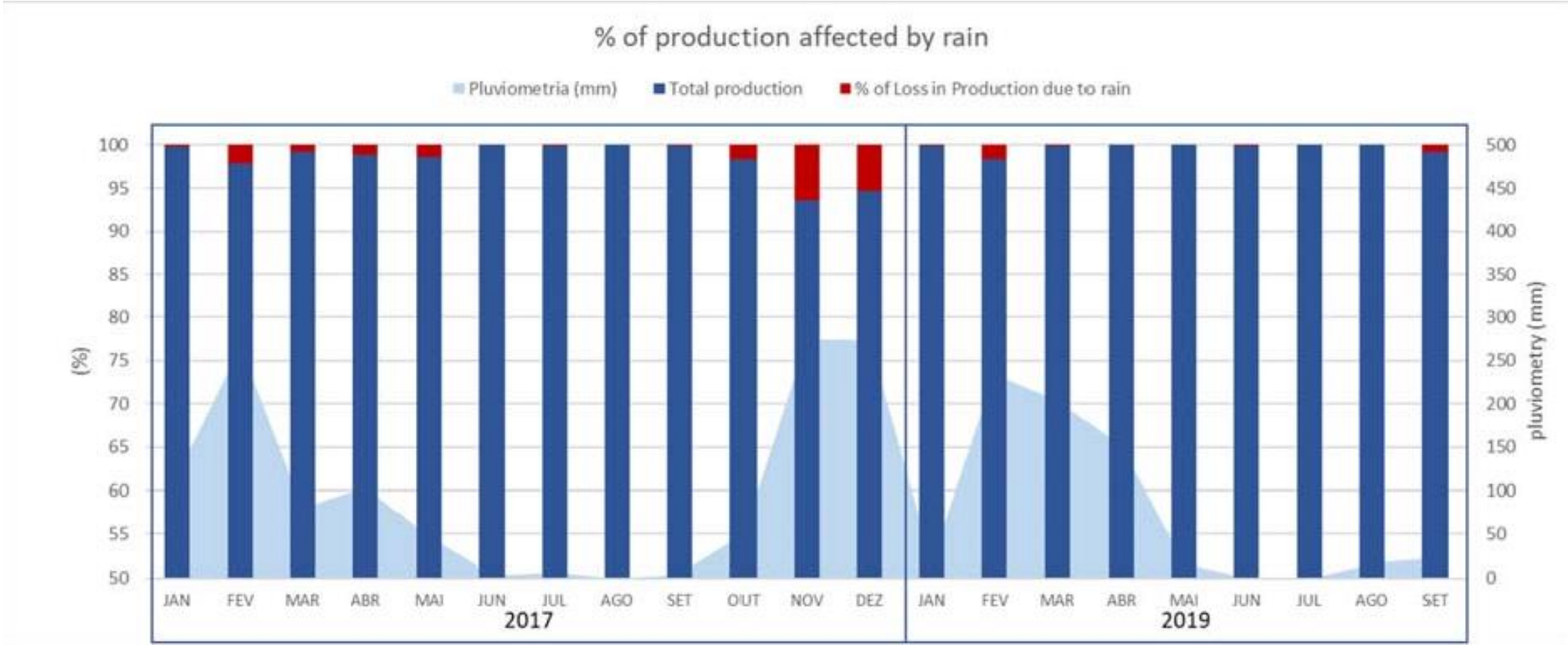
Case History: Diamond Mine in Gerias, Brazil

Diamond Mine in Gerias, Brazil

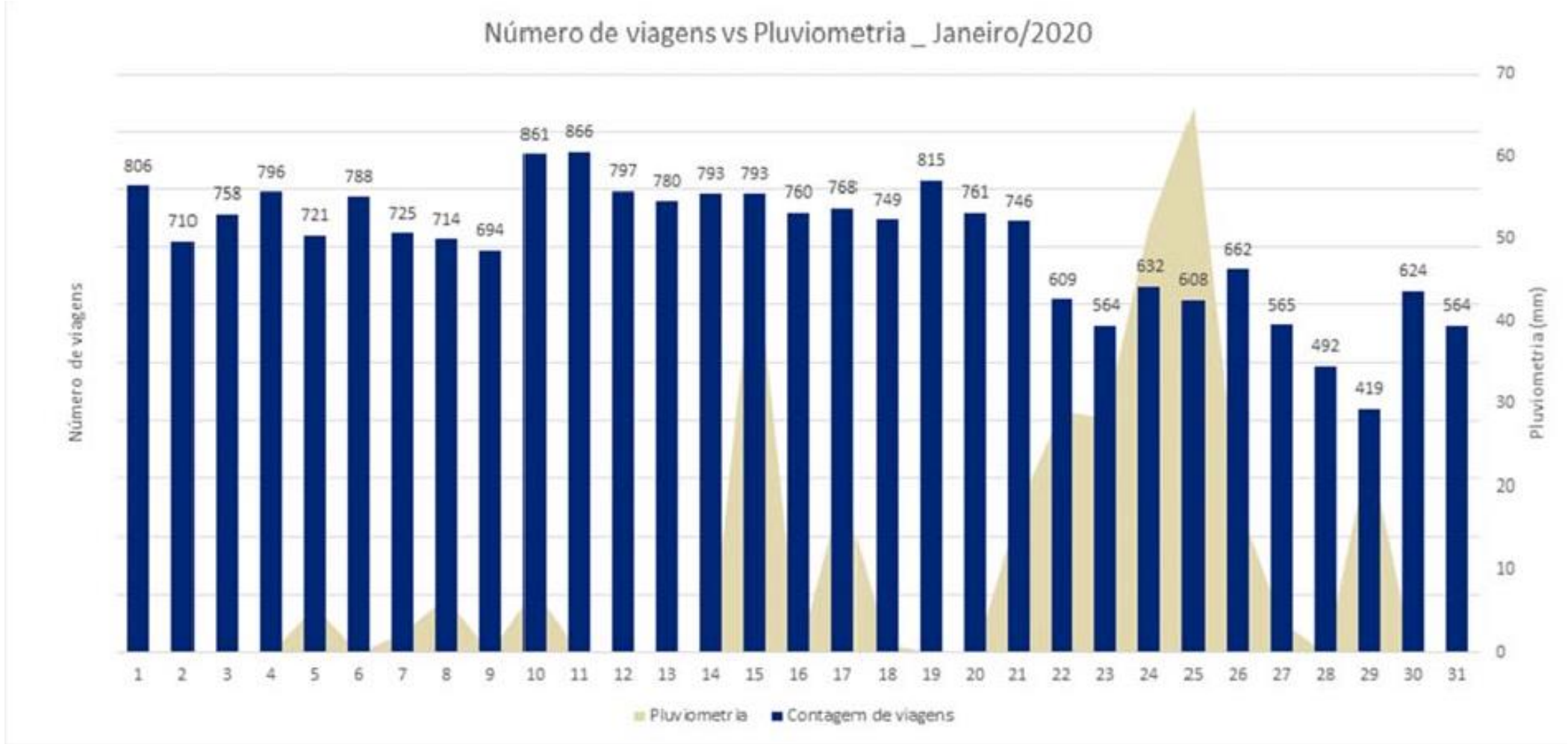
- Internal haul roads
- Kontasu 830E-AC trucks: 400 tons when full, 650-800 trips per day, empty and loaded.
- Roads composed of on site materials, compacted only by traffic:

- 1.00 meter composed of fragments of rocks
- 0.7 meter of thickness of the sub-base
- A 0.30m thick wear layer

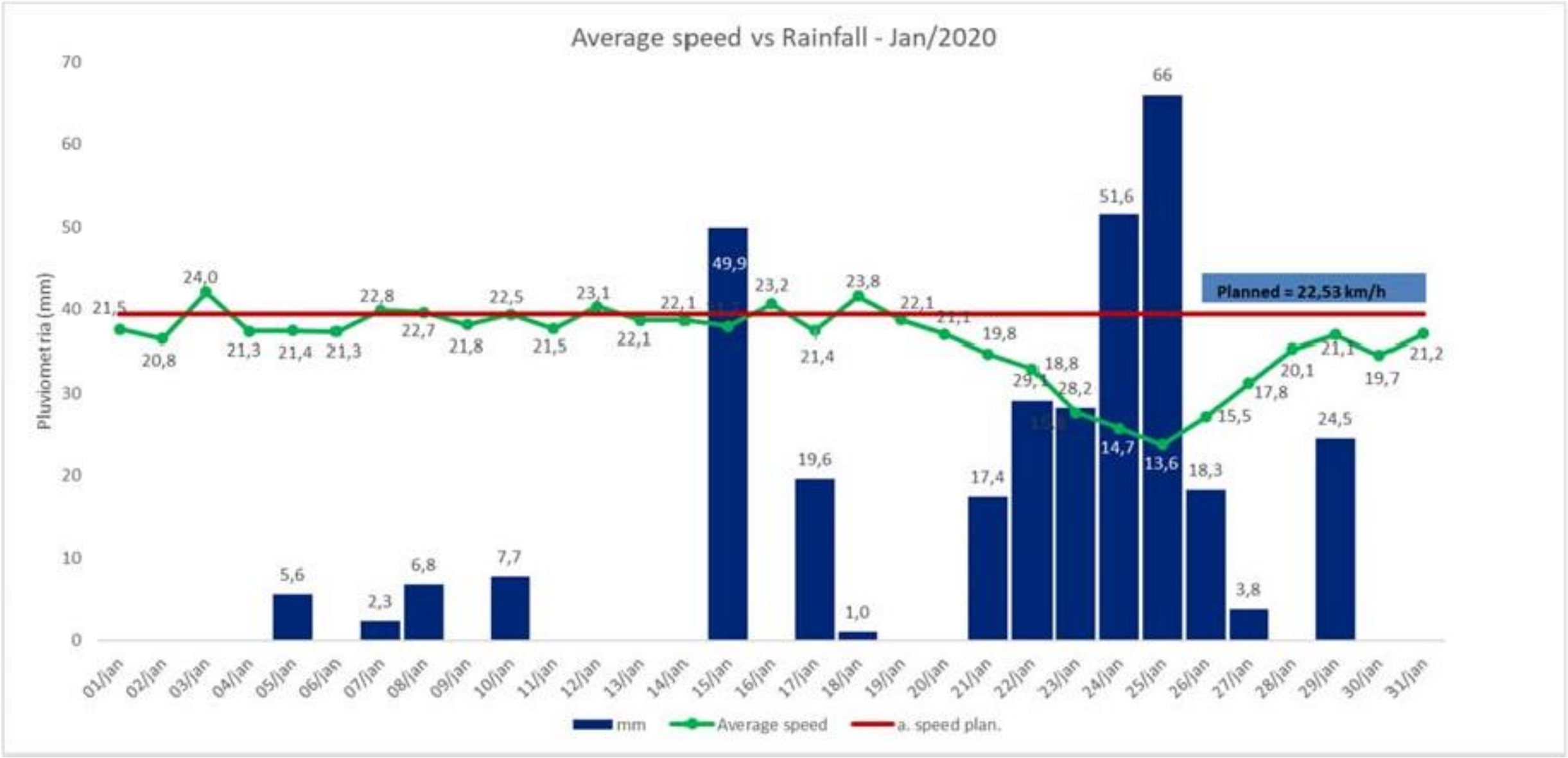




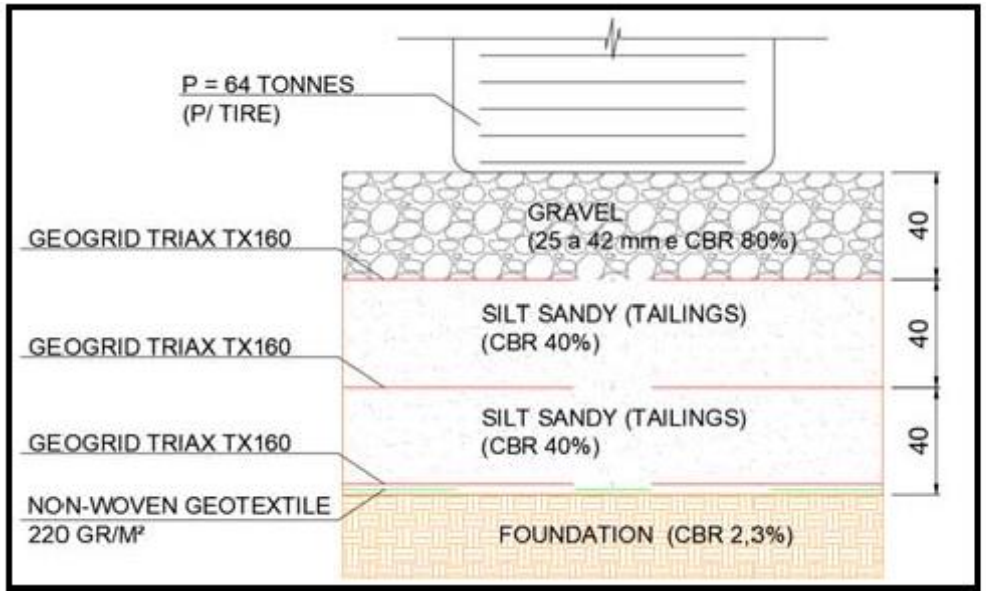
Percentage of haul trip production impacted by rain



Number of haul trip versus precipitation

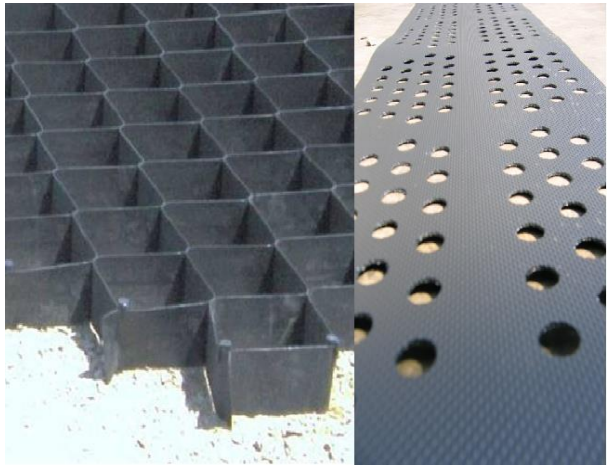


Average speed vs rainfall – Jan/2020

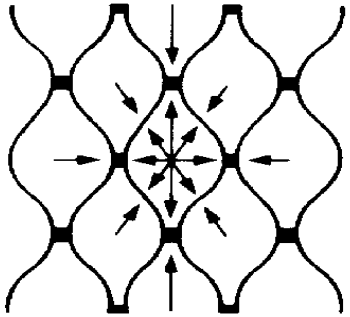


A geosynthetic solution

Geocells



Geocells are honeycomb products manufactured by joining polymeric strips or geotextile strips by welding, gluing or stitching.



Function as lateral confinment: movements of the soil infilled in the cells is prevented or limited

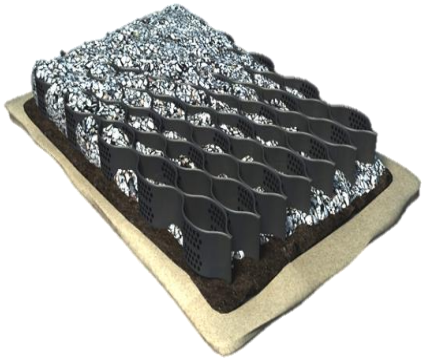
Cannot prevent soil erosion alone.

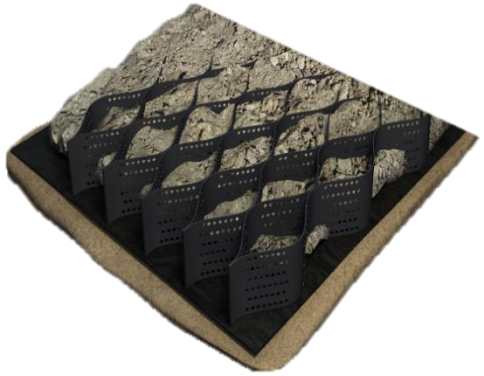
The top surface is protected against erosion by placing a geomat or biomat.

Used on arid slopes, when a thick topsoil layer is required for allowing vegetation growth.

Geocell – Infill Material

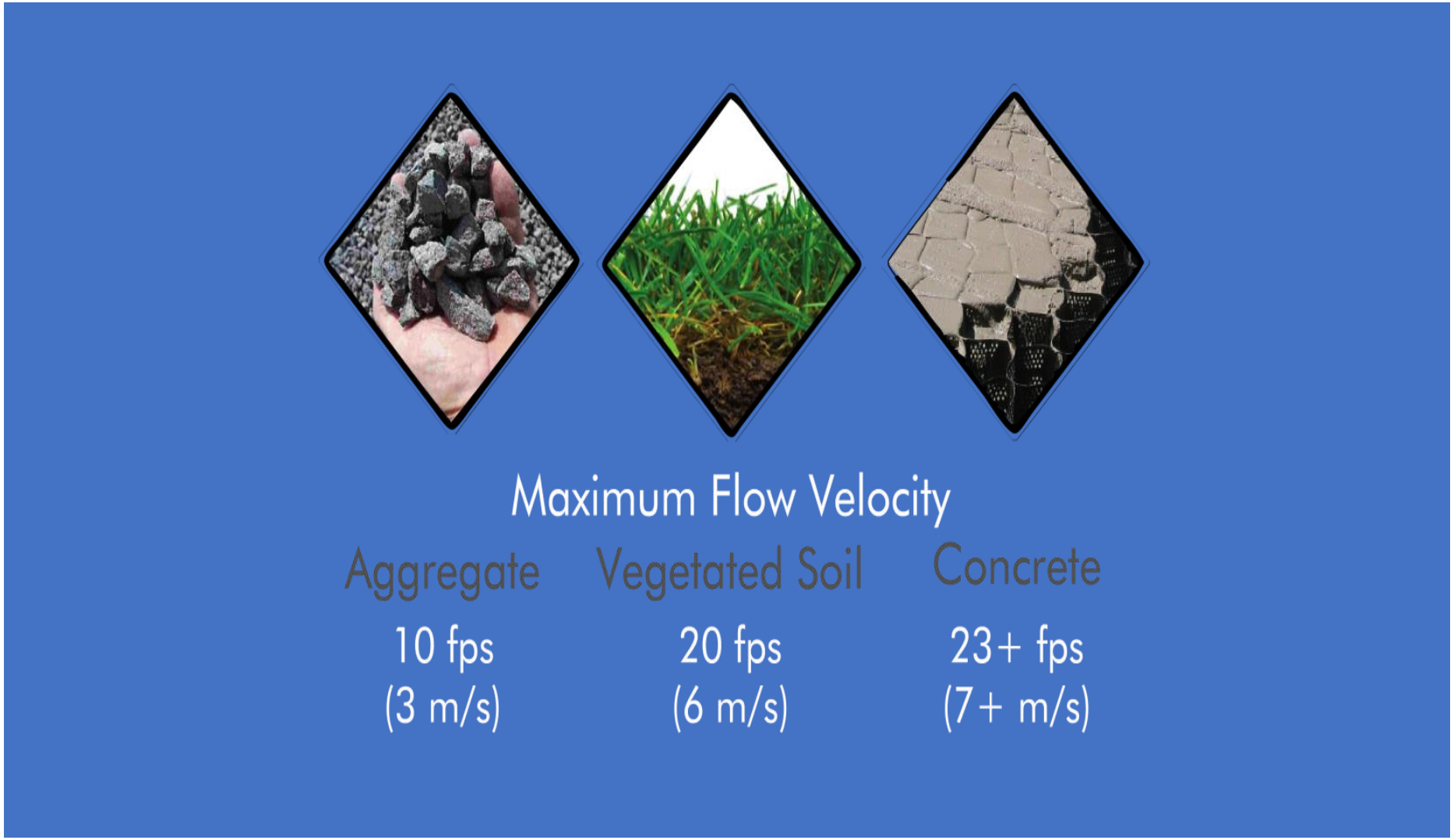
- Topsoil and Vegetation: Steep slopes, berms, levees, chutes, aprons and spillways.
- Structural/Growth Fill: Vegetated slopes that experience traffic loads
- Sand and Granular Fill: Suitable on gradual slopes.
- Aggregate: Channels, slopes, except for severe grades, moderate sheet flow.
- Concrete: Around bridges, severe slopes, high flow rate channels, spillways and chutes





Courtesy of Geo Products

Geocell –
Infill Recommendations For Channel Erosion Control



Courtesy of Geo Products

Geocell slope restoration project

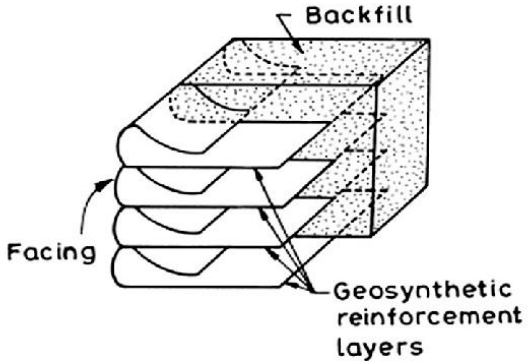
Geocell slope restoration project

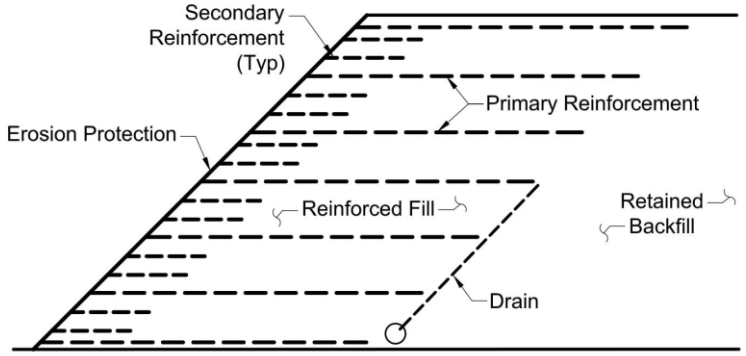
Images courtesy
Presto Geosystems

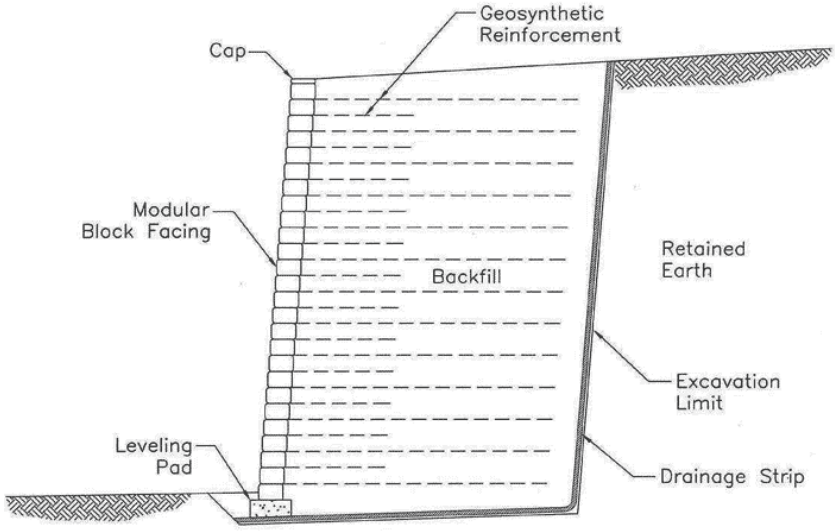
Geocell storm water channel construction

Geocell storm water channel

Geosynthetic reinforced soil structures

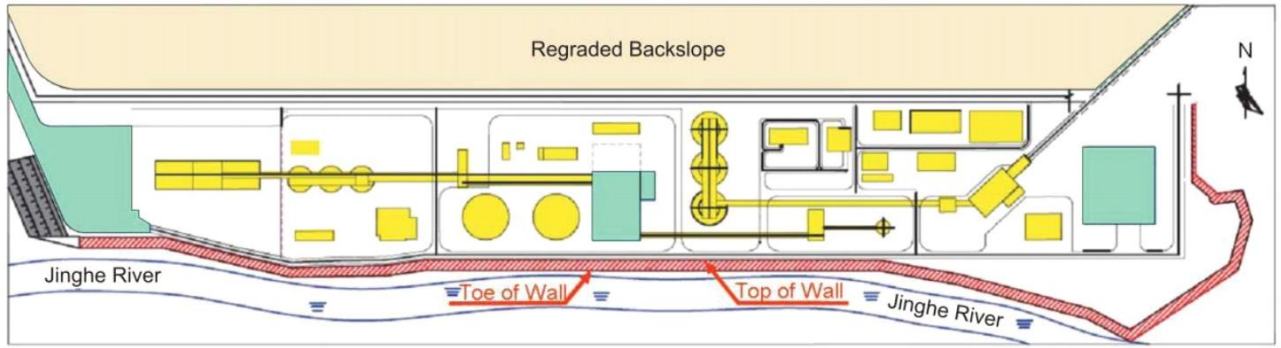


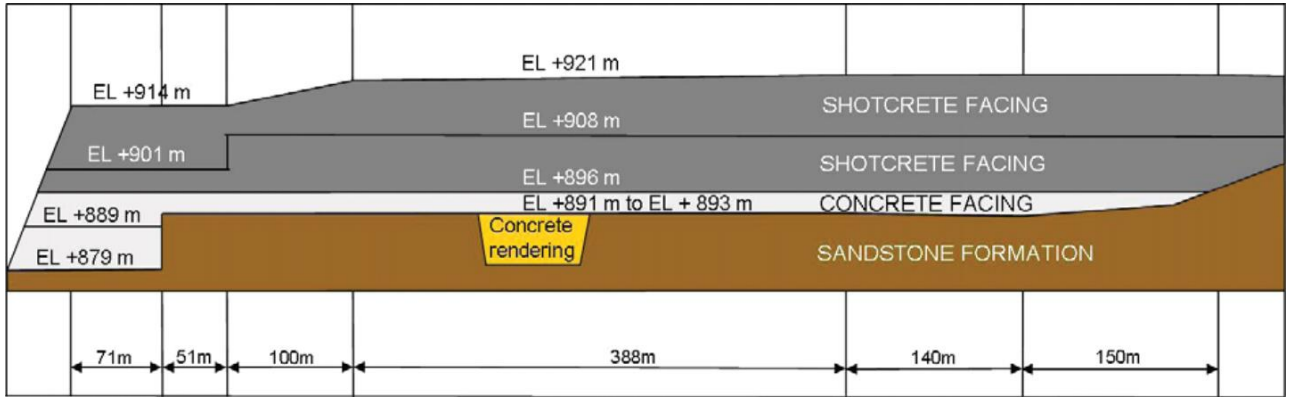




Case History: Hetaoyu coal mine complex in Zhengning County, Qingyang City of Gansu Province in China

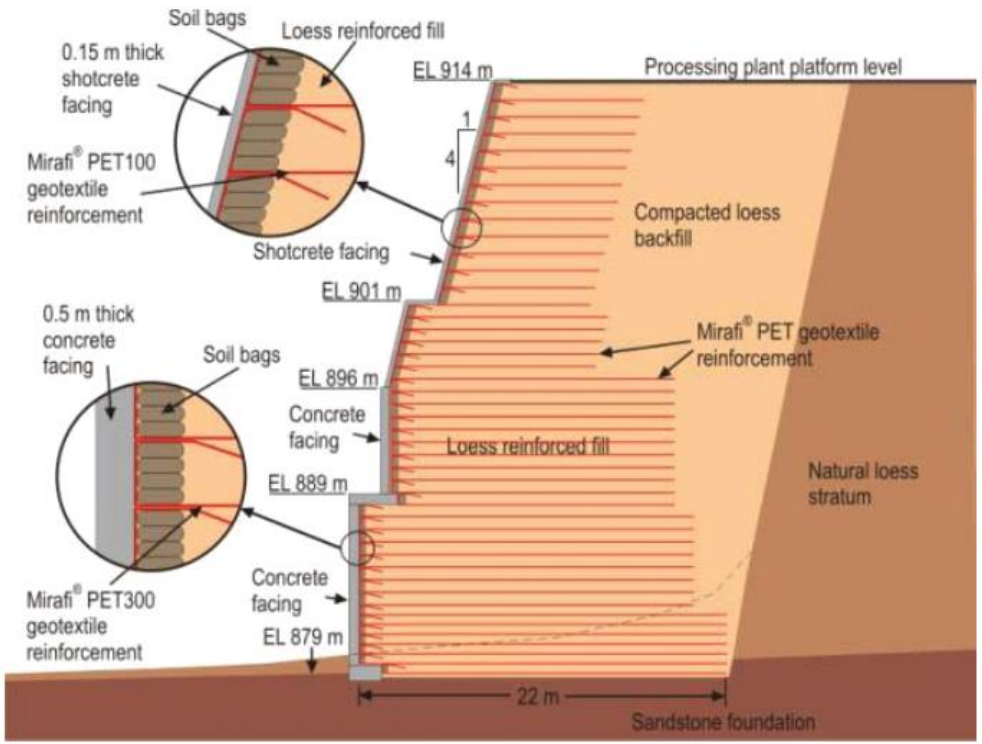
- To optimize the creation of useable land a retaining wall was constructed beside Jinghe River
- 1 km long and averages 25 m in height but is 35 m at its highest section
- high tenacity polyester geotextiles as reinforcing elements laid horizontally between layers of soil bags



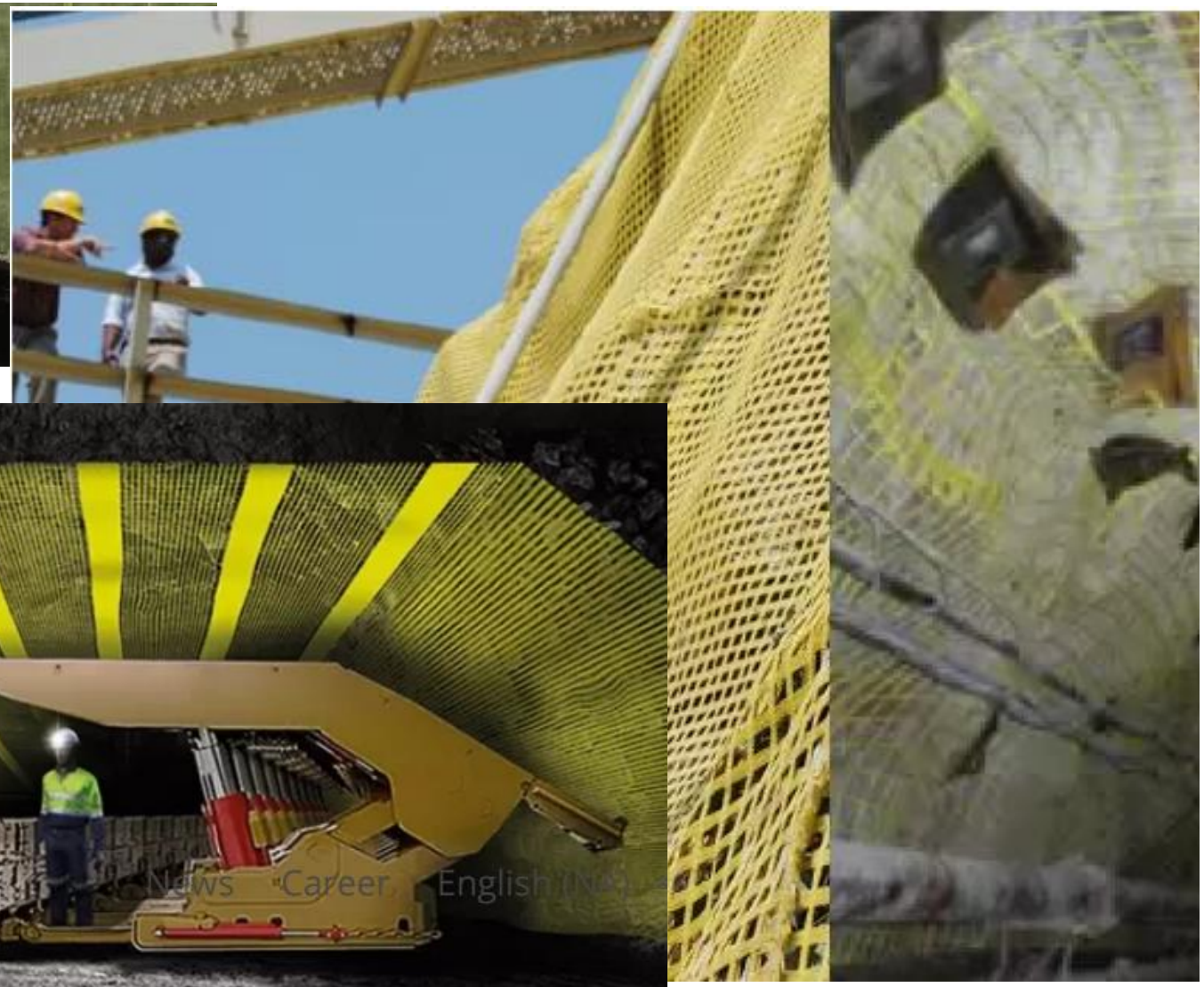


High Strength Geotextiles

Almost always woven structures


Soil bags
Loess reinforced fill
0.15 m thick shotcrete facing
Mirafi® PET100 geotextile reinforcement
Shotcrete facing
EL 914 m
Processing plant platform level
1
4
Compacted loess backfill
EL 901 m
Mirafi® PET geotextile reinforcement
0.5 m thick concrete facing
Soil bags
EL 896 m
Concrete facing
Loess reinforced fill
EL 889 m
Natural loess stratum
Concrete facing
Mirafi® PET300 geotextile reinforcement
EL 879 m
22 m
Sandstone foundation

Geogrids for Longwall recovery, highwall and Rib support

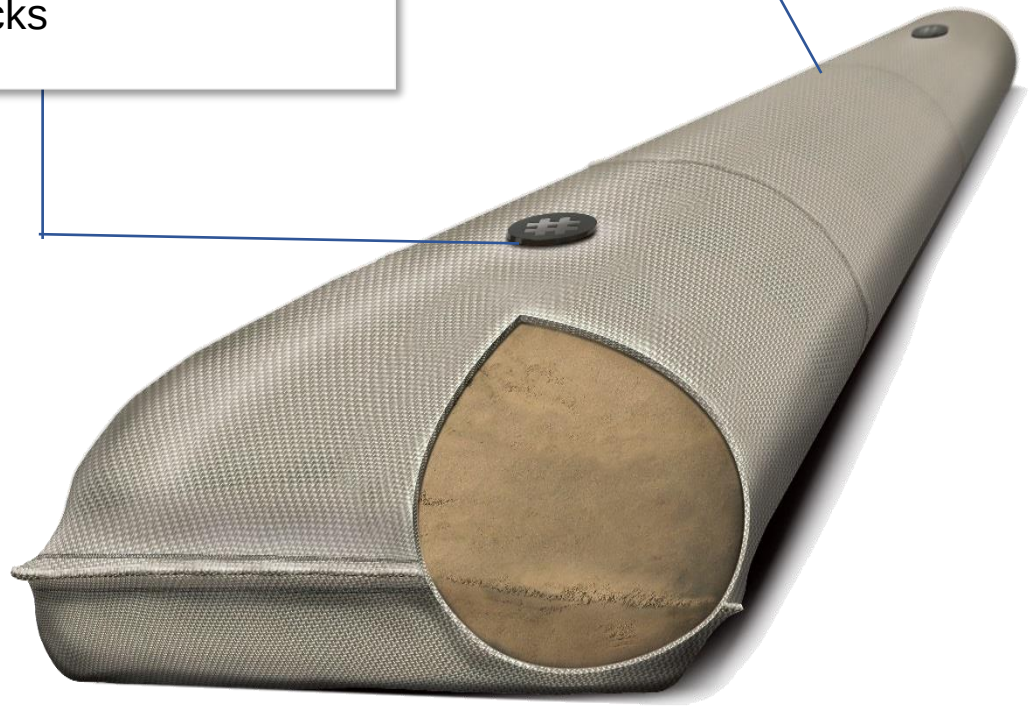


Pictures courtesy of Huesker

Geosynthetic Tubes

Geotextile tube Prefabricated unit made from wovens or composites

Tailings filling
Filling with tailings/water slurry via filler necks



Geotubes in Mining

El Mochito Mine – series of tailings dams in Honduras

Check Dams

Tailings treatments facilitated by initial dewatering

Dewatering Tailings

Images courtesy of Solmax/Tencate

Woven geotextile dewatering tubes in operation in Brumadinho, Brazil (river water remediation)

Some Observations

- While heap leaching is currently the principal consumer of geosynthetics, other applications are becoming increasingly important
- Growing focus on risk management to reduce cost over-runs & failures
- Highest risks: closure & tailings

Optimistic Closure Estimates

- Actual closure costs can be 10-30% of initial capital cost in real dollars
- Australian U: actual costs were 6.8x the estimate
- Total US mine closure liability: $12 billion un-bonded
- Two major closure studies: 75% of 84 projects were over budget
- Earthworks costs are the most common culprit
- Unfunded costs create risk of company insolvency or transfer of liability to the local community

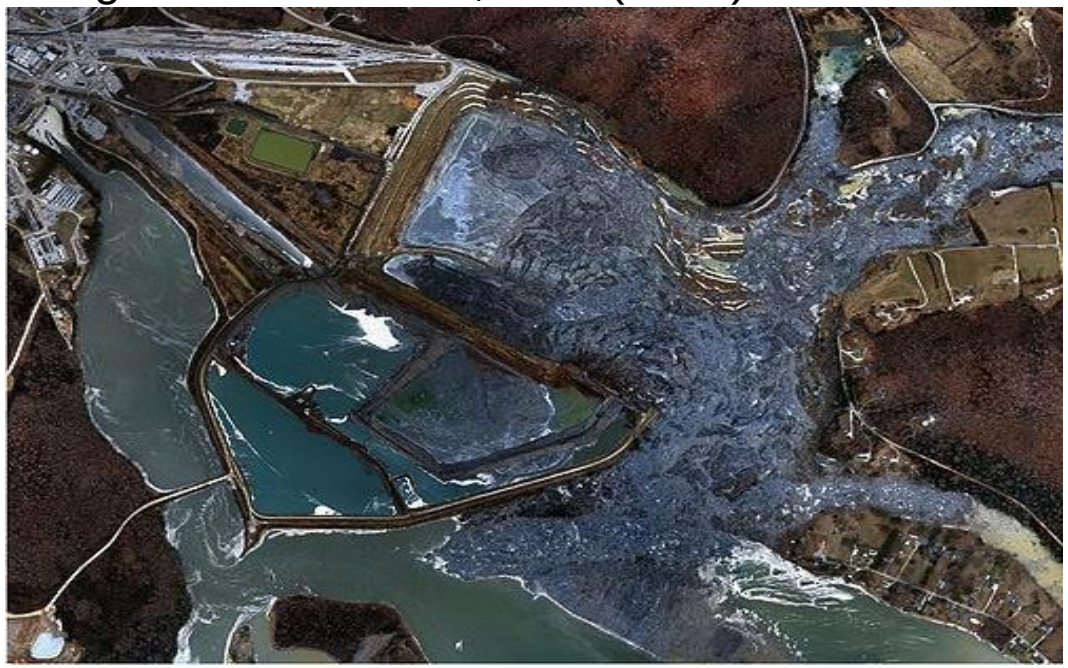
- **The solution:**
  - **More effort in closure design early in the project**
  - **More and better use of modern technology**

From M.E. Smith (2012), “Emerging trends in mining,” GeoAmericas, Lima, Peru.

Mining Tailings Dam Failures

- 220 documented failures; ~9% of all facilities
- Tailings dams are ten times more likely to fail than water reservoirs
- All major failures have been unlined facilities
- An average of 2 significant failures with a combined 10 fatalities per year

Kingston Fossil Plant, USA (2008)



Hungary Aluminum (2010)

Mt. Polley, B.C. (2014)

Brumadinho, Brazil (2019)

Summary

- Mining is NOT going away.
- The mining industry is expanding to products needed for electrical energy
- There is new focus on Environmental Social Governance (ESGs)
- Environmental Protection emphasized
- Environmental resource preservation emphasized
- Geosynthetics are not optional, they are MANDATORY, for modern day mining practice.

TRI ENVIRONMENTAL

5ème RENCONTRE GÉOSYNTHÉTIQUES SOUS LE THÈME

08 > 10 JUIN 2023 MARRAKECH

Thank You!
Merci!

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