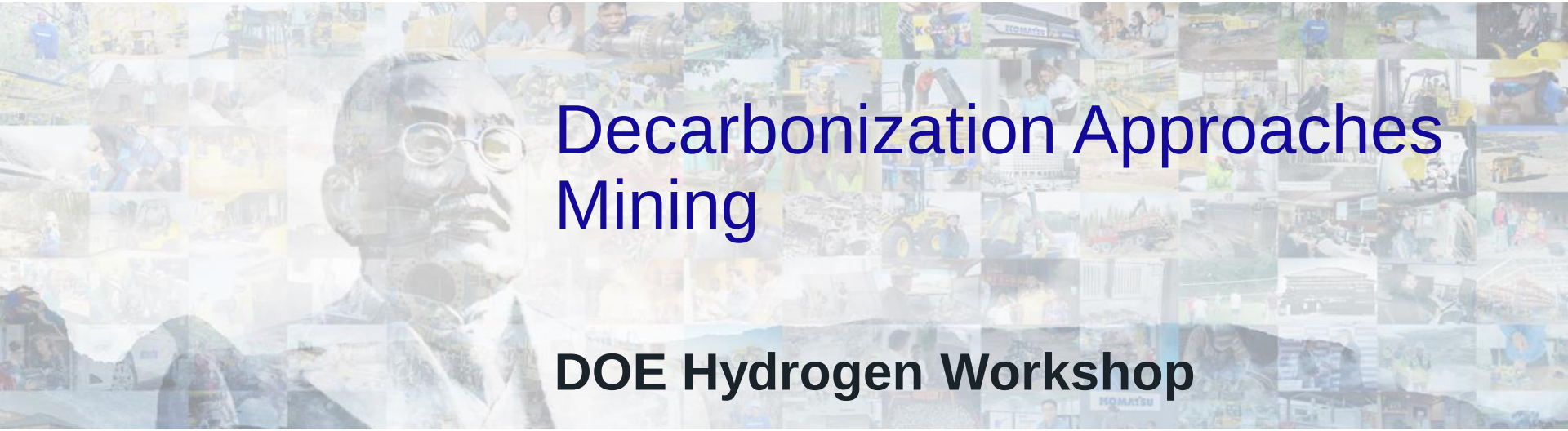


Decarbonization Approaches Mining

DOE Hydrogen Workshop

Michael Lewis | Technical Director – Komatsu

September 2021 - Virtual

Mining product offerings

KOMATSU


Haul trucks


Mining hydraulic excavators and shovels


Hard rock trucks


Hard rock loaders


Dozers


Motor graders


Hard rock drills


Hard rock shaft sinking


Mechanical drive wheel loaders


Hard rock bolters


Hard rock mechanical cutting

P&H


Electric mining shovels


Electric drive wheel loaders


Hybrid shovels


Draglines


Rotary blasthole drills


Track blasthole drills

JOY


Longwall systems


Room and pillar systems


Entry development systems


Underground crushing

MONTABERT

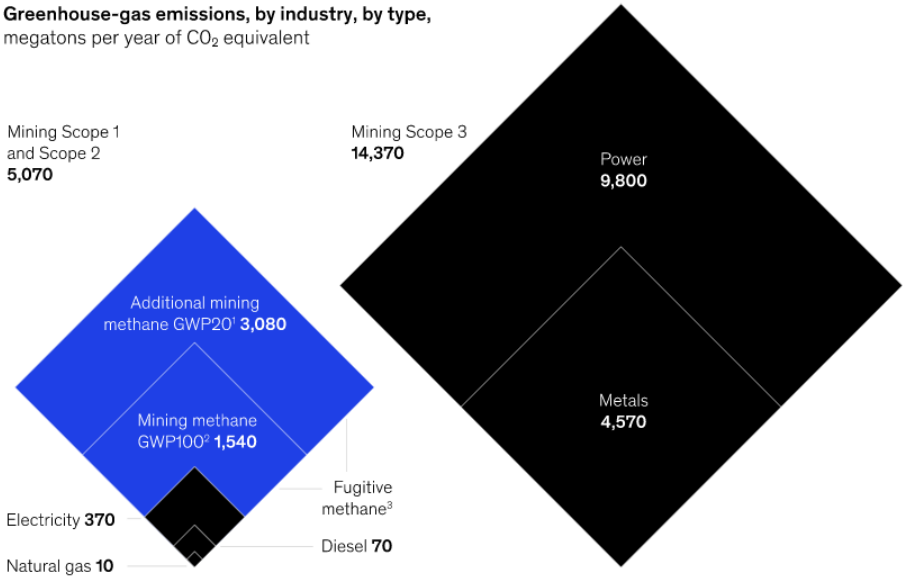

CPAs


Breakers


Hydraulic drifters

The Decarbonization Challenge in Mining

The majority of greenhouse-gas emissions in mining are generated in downstream industries (Scope 3) and during coal mining (fugitive methane).



Source: McKinsey & Company: Climate Risk and Decarbonization What Every Mining CEO Needs to Know

- Fugitive Methane is by far the largest source of emissions at mines (Scope 1)
- Haulage accounts for the majority of diesel consumed at mines, typically ranging from 50 to 80% (varying based on mine profile and equipment selection)
- Decarbonizing haulage and mining overall is challenging but feasible
- Many low or zero carbon solutions are available today, however adoption has been uneven – **Do We Have to Wait to Start Decarbonizing?**
  - Tier 4 engine technology
  - Trolley Assist
  - Electric rope shovels, electric hydraulic excavators, and electric drills

The Road to Zero Emission Haulage

Tier 1
MCRS Advantage

Pre-Electrification

Fuel Consumption
100%

*Emissions
100%

Today

Stage I Electrification
+ Tier 4

Migration of several supporting systems to all electric.

Fuel Consumption (Stage I + Tier 4)
98%

Emissions (Stage I + Tier 4)
1.9

Mid-term

Stage II Electrification
+ Trolley

Transition of remaining systems to all electric and introduction of an innovative future proof platform that supports multiple propulsion systems.

Fuel Consumption (Stage II + Trolley)
48%-68%

Emissions (Stage II + Trolley)
.17%-.46%

Future

Stage III Electrification
+ Battery/Hybrid/Hydrogen

- Selectable Option Power Systems
- Choose from:
  - Diesel
  - Trolley
  - Electric Hybrid
  - Battery
  - Hydrogen Fuel Cell

Diesel/Trolley

Fuel Consumption
48%-68%

Emissions
.17%-

Electric/Hydrogen

Fuel Consumption
0

Emissions
0

Note: Emissions reduction includes; NOx, Hydrocarbons, and Particulate Matter. Emissions reductions are a result of improvem ents made in Fuel Consumption and Engine Design including the addition of SCRs and DEF.

Key Issue to Consider Regarding the Energy Transformation

- Long life of mining equipment (up to **25 years**) – need to enable technology transitions throughout lifecycle
- Significant investments in R&D are required for development of zero emission mining equipment, **all ICE equipment will have to be redesigned.** (Diesel Electric Dump Trucks are well positioned for this transition)
- Development of Battery Electric and Hydrogen Fuel Cell are competing for the same resources, prioritization is mandatory. Serialization of development may result in a slower than desired transition of key models. **Government incentives will be necessary to increase pace of equipment development.**
- Significant investment is required for supporting technology and systems such as:
  - Green Energy (wind, solar, geothermal…) and storage
  - Hydrogen Production, Distribution, Storage, and Filling
- Uncertainty in market demand, **Mine Operators need to support a specific decarbonization strategy/approach** (i.e. BEV, HFC, Trolley Assist) and **make long lead investment decisions** (i.e. green energy production & storage, hydrogen production, distribution, and storage…)
- The maturity of key decarbonization technologies are low for mining applications:
  - Battery Systems
  - Hydrogen Production
  - Hydrogen Fuel Cells
- The Total Cost of Ownership (TCO) of Zero Emission mining equipment will likely start out higher compared to current solutions but will reduce over time and with sufficient scale and technology maturity it may reach a point more competitive than existing models. **Expectation is the TCO needs to be competitive with current offerings**.

Challenges Associated with Adoption of Hydrogen for Mining

- **Mine Profile**
  - Most mines are very remote and in challenging environments
  - Availability of green energy is variable but generally poor to non-existent
  - Skilled technician availability can be poor, no current capability around hydrogen
  - Varying profiles due to ore body configuration (i.e. relatively flat, uphill loaded, downhill loaded). Rolling resistance varies considerably to >10% for severe applications
  - 24/365 operation, typically >6000 hours per year
- **Equipment**
  - Ultra class haulage trucks range in size from 205 tons payload / 745k lbs GVW / 2,000 HP (1500kW) to 400 tons payload / 1,384k lbs GVW / 3,500 HP (2,600 kW)
  - Lifetime ranges from 60k (10 years) to greater than 100k hours (15 years)
  - Diesel engines or diesel engine / trolley provide the energy that powers wheel motors
  - Diesel engine life typically varies from 18k to 30k hours (3-5 years) – **green technology expectations are similar**
  - Number of equipment in service varies by mine, largest operations have greater than 400 trucks, smaller <10, and average about 40
  - Refueling of ICE equipment once every 12 – 24 hours (generally 15-20 minutes per event) - **green technology expectations are similar**
- **Regulatory**
  - Fire suppression
  - Not well governed for Off-Road machines (ISO process in infancy)

Challenges Associated with Adoption of Hydrogen for Mining - 2

- **Application**
  - Wide range of environmental conditions ranging from Artic/Northern Latitudes **(<-40C**), desert**(>50C**), rainforest (**>90%RH**), to high altitude (**>4000m**)
  - Most severe – uphill hauls of several kms at **10% grade**
  - Many profiles exist at each operation and vary over time as the mine develops
  - General expectation of mine operators – **zero-emission equipment should have similar performance to current (ICE)**
- **Onboard Systems**
  - **Safety is of prime importance**
  - Space claim of FC and battery
  - Hydrogen tanks physical size and capacity
  - Dust resilience
  - Availability, reliability, and maintainability/serviceability
- **Infrastructure**
  - **Safety is of prime importance**
  - Generally, no experience with H2 or cryogenics
  - **Fast fueling is a must**, H2 requirements will be ~800-1200 kg/day/truck.
- **Commercials**
  - TCO must be competitive!

Thank You

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