Geoscience Perspectives on Technology Development in Energy Storage and Implications for Strategic Mineral Exploration*

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Abstract

In May, 2018, the US Department of Interior released its list of 35 critical mineral commodities, most of which are used in energy storage or electronics. As the cost of lithium ion batteries drops, electric vehicles are becoming the preferred new purchase of car-buyers in Europe, China and parts of the US. Lower cost of operation will accelerate this trend and enhance the need for new batteries and their mineral components. Storage associated with the dramatic growth in off-grid baseload power, such as solar, wind, and hydro, will also increase the pressure on battery manufacturers. Minerals such as cobalt, graphite, lithium and vanadium, along with rare earth elements, are seeing an uptick in demand. Economic geologists are needed to explore for and sustainably extract them in ever increasing volumes. A review of the landscape of mineral exploration and extraction reveals similarities to the fossil fuel production business. A small group of major multi-national integrated corporations are supported by a plethora of “junior” exploration companies who provide a feedstock of leases and prospects.

Mining geologists use 3D geologic models to explore for and assess reserves of metals and are now expanding the use of geophysical techniques, including 3D seismic. The concept of ore trends, similar to petroleum play fairways, can be adapted and refined to better predict exploration corridors and future areas of extraction. Data employed by economic geologists are similar to those used to find hydrocarbons and include borehole records, surface geologic maps, rock mineralogy, and size statistics. Predictive models of ore accumulation rely on mass transport calculations at assumed heat, pressure, brine composition and mineral equilibria. As exploration geoscientists, we can readily transfer our skills from one hunting ground to the other. Geoscientists can also maximize energy efficiency for development of new mineral deposits via the use of low carbon energy resources. We can apply our environmental experience to minimize the footprint of the mine itself. We can utilize our industry strengths in risk assessment, environmental remediation, social license, and greening the oil field to become leaders in sustainable mineral development. As with all disruptive technologies, the plates will likely shift rapidly. Battery innovations will continue to redefine our concept of strategic minerals.

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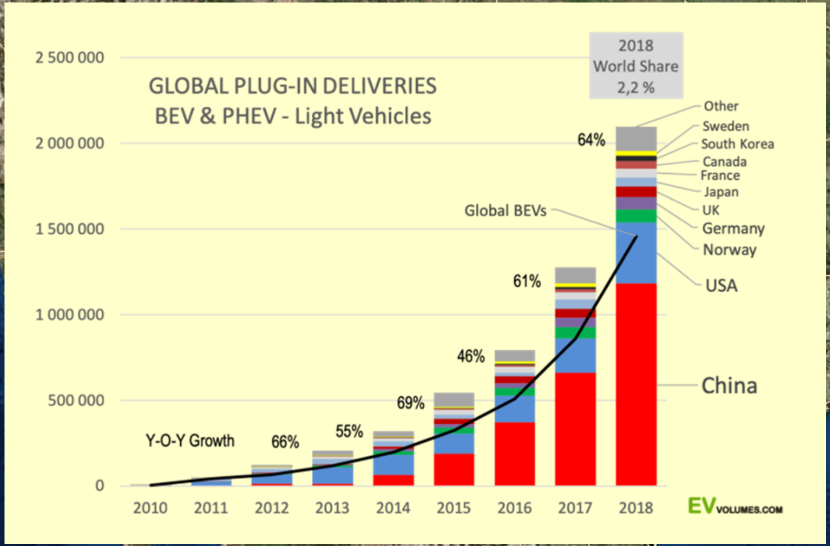
Geoscience Perspectives on Technology Development in Energy Storage and Implications for Strategic Mineral Exploration

Photo courtesy of Ty Dinwoodie

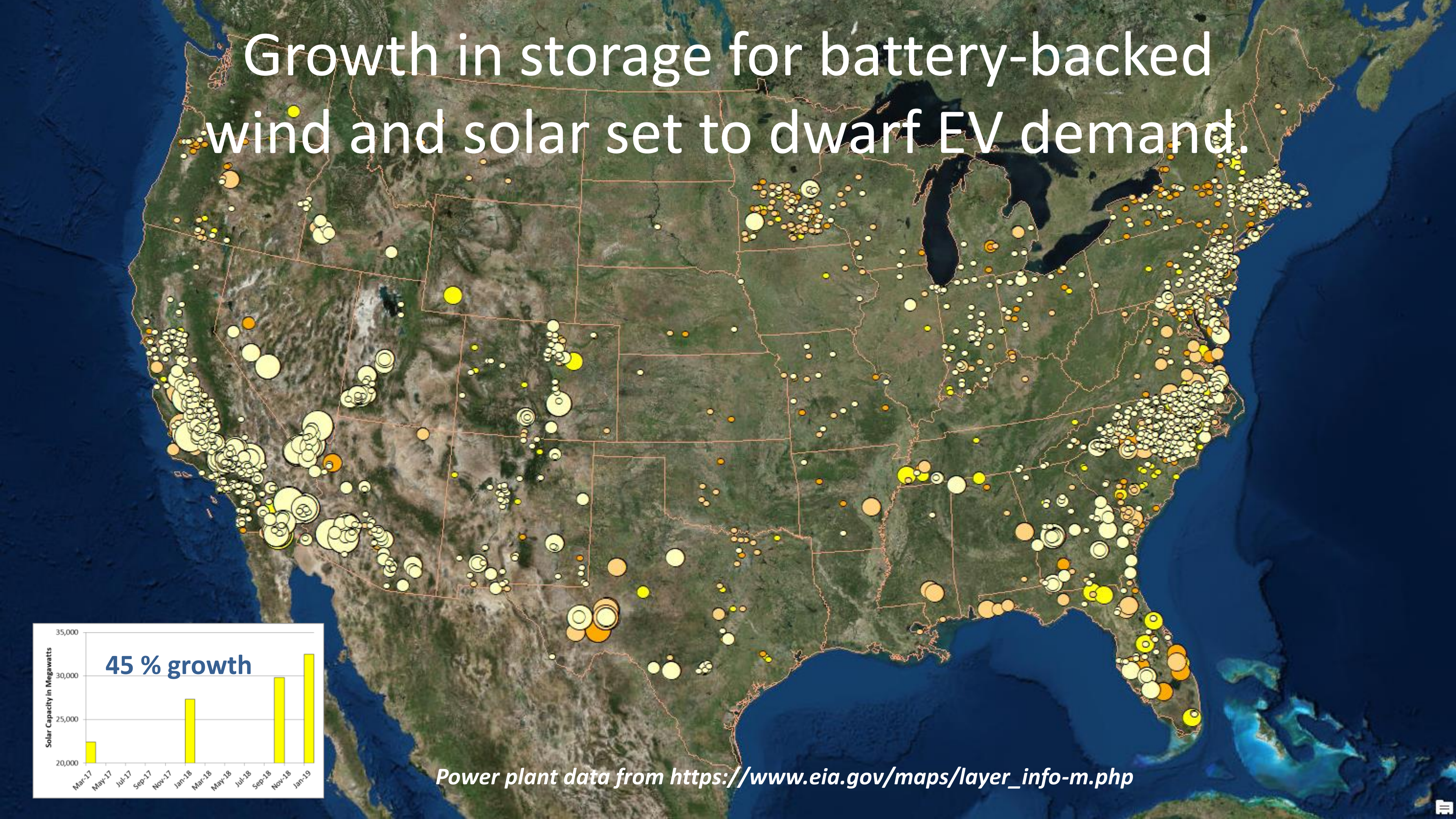
Edith Newton Wilson and Jesse Edmondson

AAPG ACE, May 20, 2019

What's driving this?



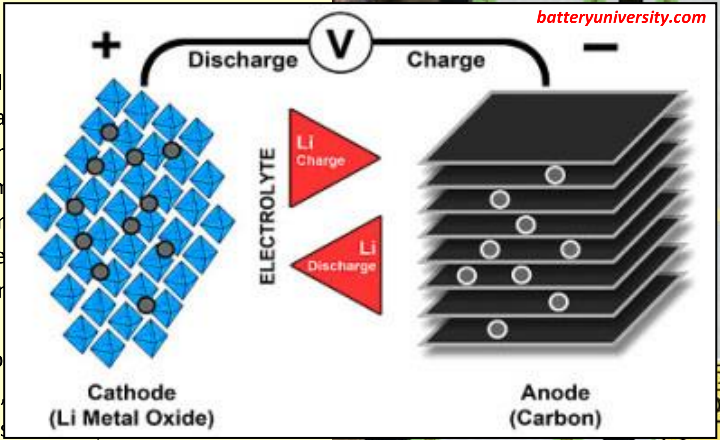
Growth in storage for battery-backed wind and solar set to dwarf EV demand.

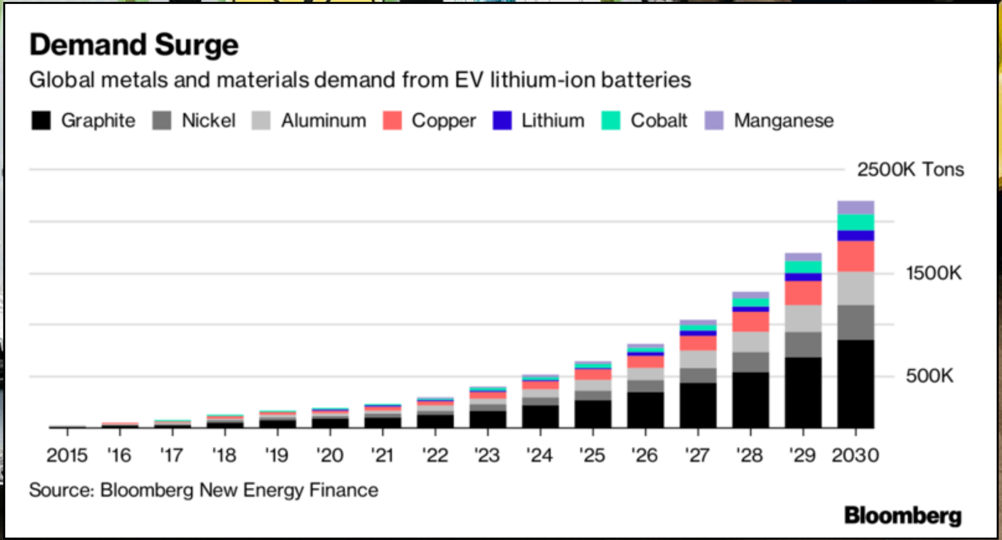


Power plant data from https://www.eia.gov/maps/layer_info-m.php

There's antimony, arsenic, aluminum, sel
And hydrogen and oxygen and nitrogen a
And nickel, neodymium, neptunium, gerr
And iron, americium, ruthenium, uranium
Europium, zirconium, lutetium, vanadium
And lanthanum and osmium and astatine
And gold and protactinium and indium ar
And iodine and thorium and thulium and
There's yttrium, ytterbium, actinium, rub
And boron, gadolinium, niobium, iridium,
And strontium and silicon and silver and s
And bismuth, bromine, **lithium**, beryllium, and barium.
There's holmium and helium and hafnium and erbium,
And phosphorus and francium and fluorine and terbium,
And manganese and mercury, molybdenum, magnesium,
Dysprosium and scandium and cerium and cesium.
And lead, praseodymium, and platinum, plutonium,
Palladium, promethium, potassium, polonium,
And tantalum, technetium, titanium, tellurium,
And cadmium and calcium and chromium and curium.
There's sulfur, californium, and fermium, berkelium,
And also mendelevium, einsteinium, nobelium,
And argon, krypton, neon, radon, xenon, zinc, and rhodium,
And chlorine, **carbon**, **cobalt**, copper, tungsten, tin, and sodium.
These are the only ones of which the news has come to Harvard,
And there may be many others, but they haven't been discovered.

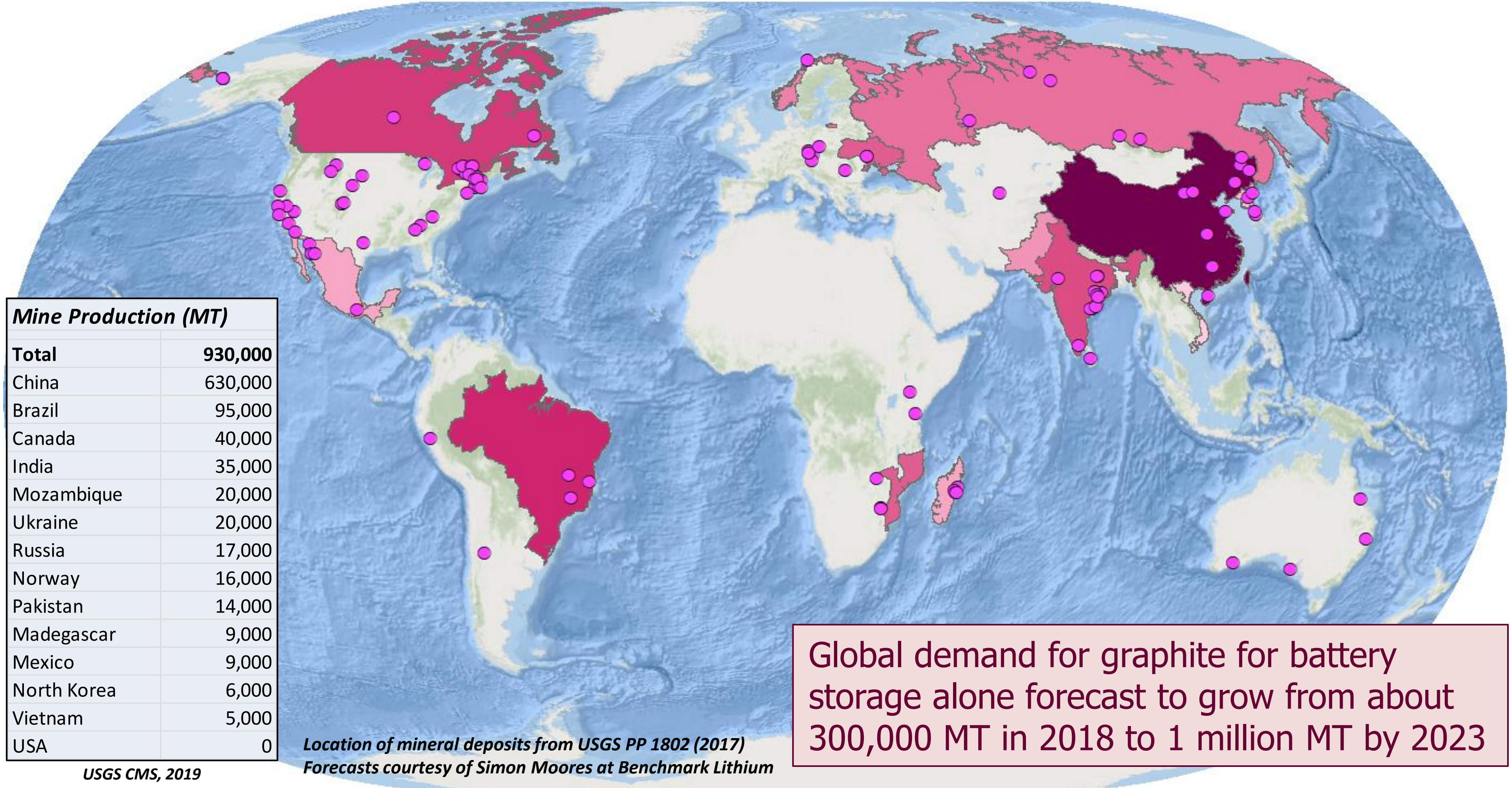
- Tom Lehrer, 1959 (102, nobelium)





from teslarati.com

Global Graphite Deposits and Production



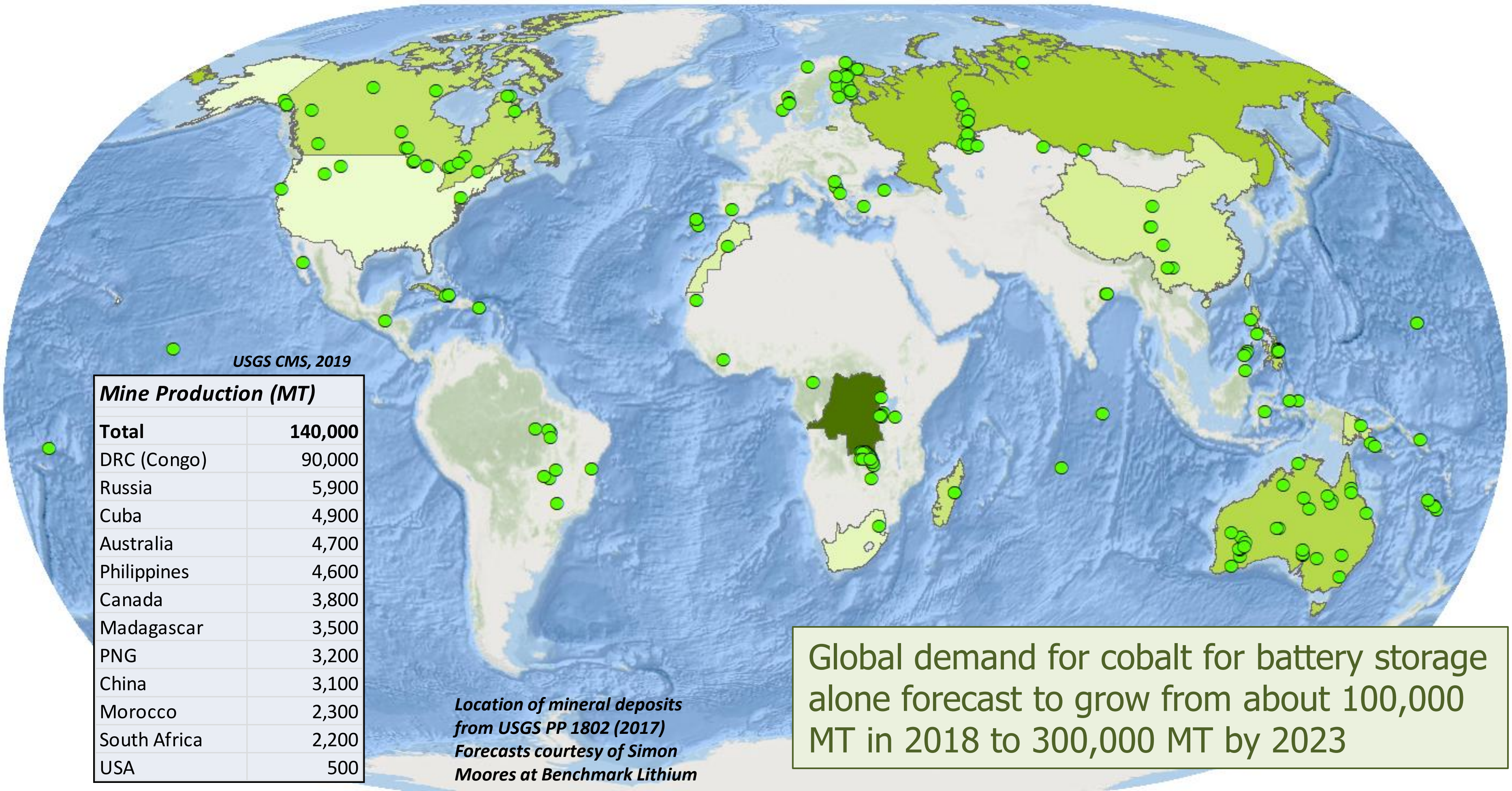
Mine Production (MT)	
Total	**930,000**
China	630,000
Brazil	95,000
Canada	40,000
India	35,000
Mozambique	20,000
Ukraine	20,000
Russia	17,000
Norway	16,000
Pakistan	14,000
Madegascar	9,000
Mexico	9,000
North Korea	6,000
Vietnam	5,000
USA	0

USGS CMS, 2019

Location of mineral deposits from USGS PP 1802 (2017)
Forecasts courtesy of Simon Moores at Benchmark Lithium

Global demand for graphite for battery storage alone forecast to grow from about 300,000 MT in 2018 to 1 million MT by 2023

Global Cobalt Deposits and Production



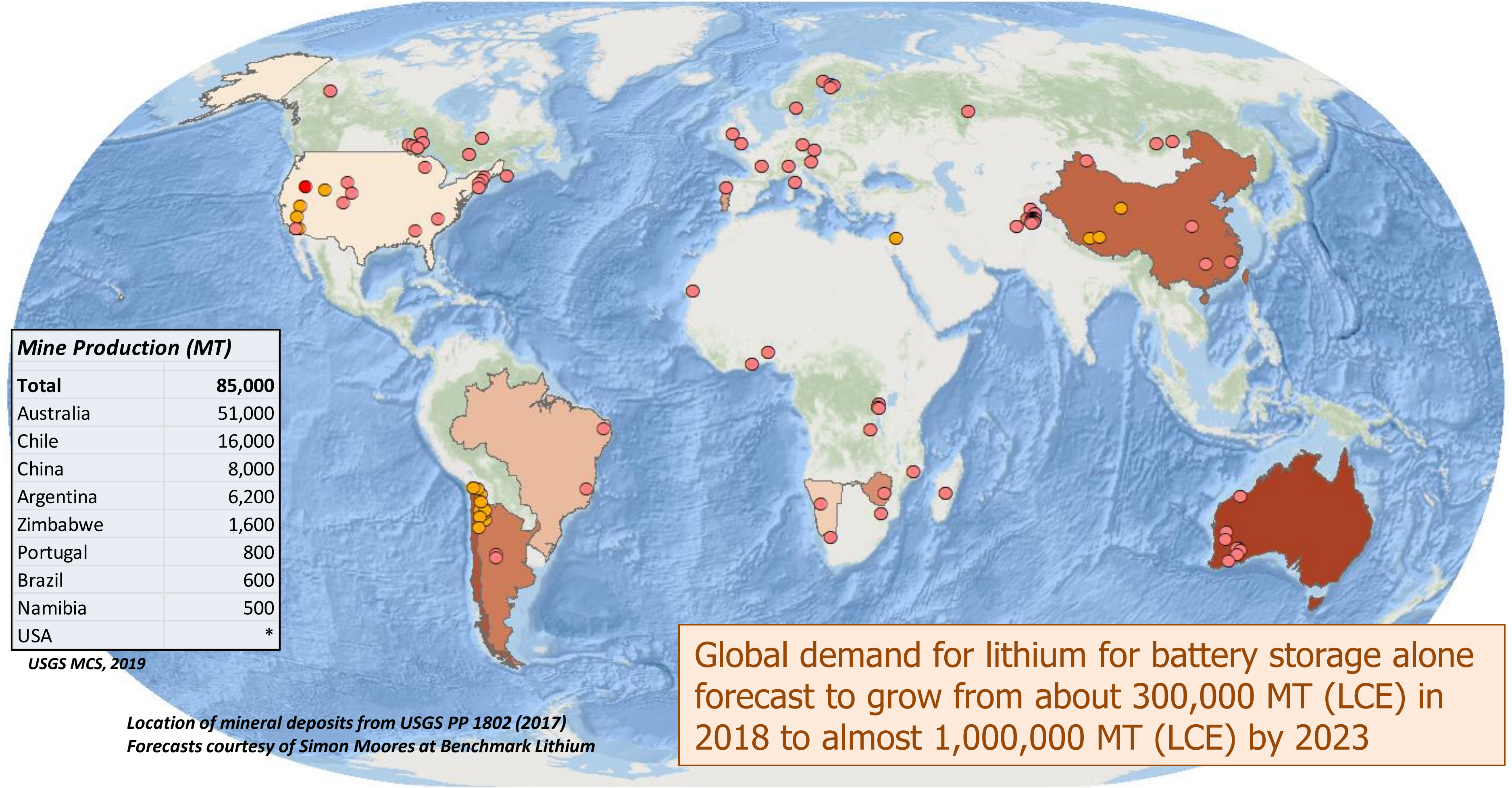
USGS CMS, 2019

Mine Production (MT)	
Total	**140,000**
DRC (Congo)	90,000
Russia	5,900
Cuba	4,900
Australia	4,700
Philippines	4,600
Canada	3,800
Madagascar	3,500
PNG	3,200
China	3,100
Morocco	2,300
South Africa	2,200
USA	500

Location of mineral deposits from USGS PP 1802 (2017)
Forecasts courtesy of Simon Moores at Benchmark Lithium

Global demand for cobalt for battery storage alone forecast to grow from about 100,000 MT in 2018 to 300,000 MT by 2023

Global Lithium Deposits and Production



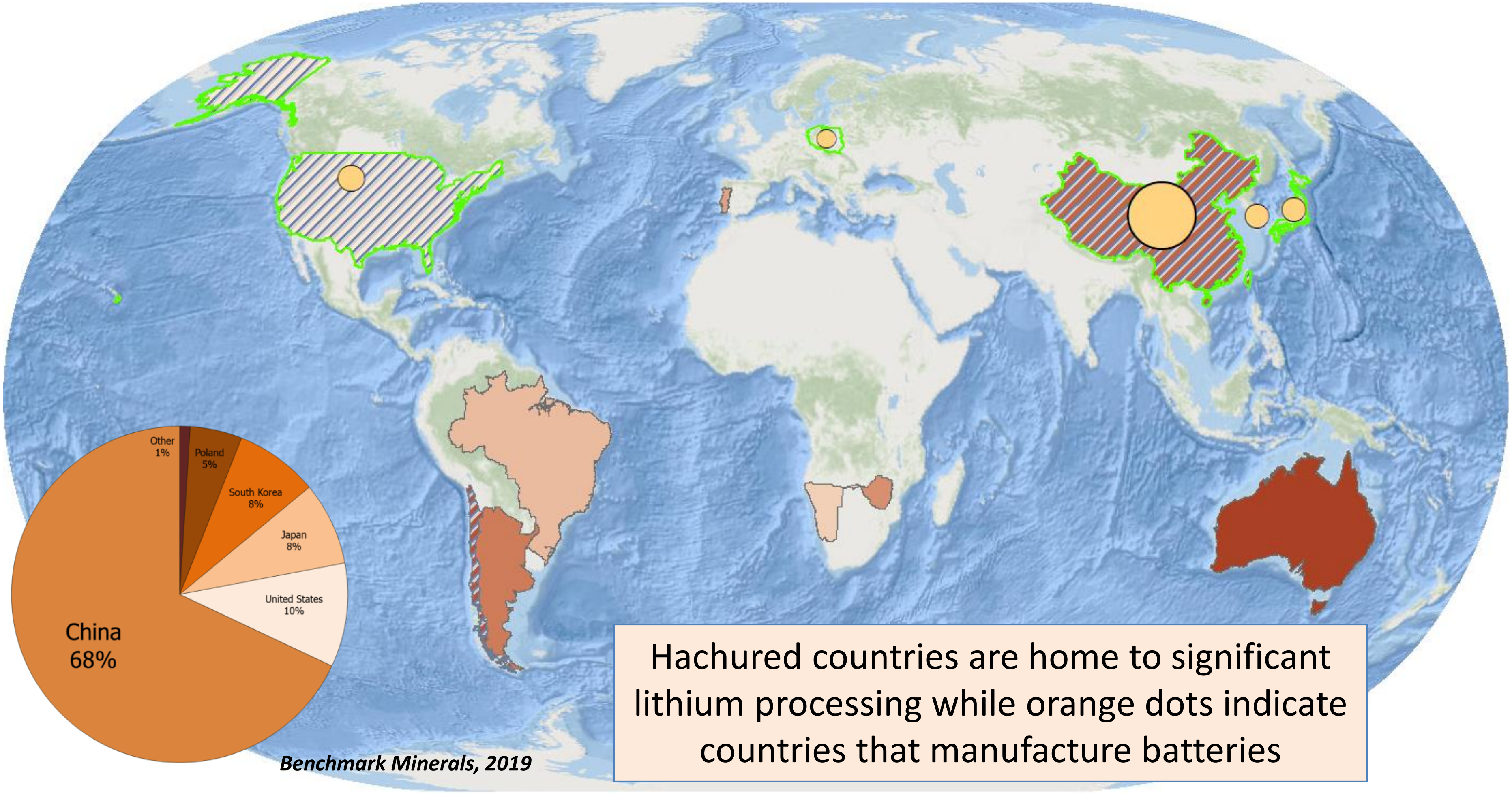
Mine Production (MT)	
Total	**85,000**
Australia	51,000
Chile	16,000
China	8,000
Argentina	6,200
Zimbabwe	1,600
Portugal	800
Brazil	600
Namibia	500
USA	*

USGS MCS, 2019

Location of mineral deposits from USGS PP 1802 (2017)
Forecasts courtesy of Simon Moores at Benchmark Lithium

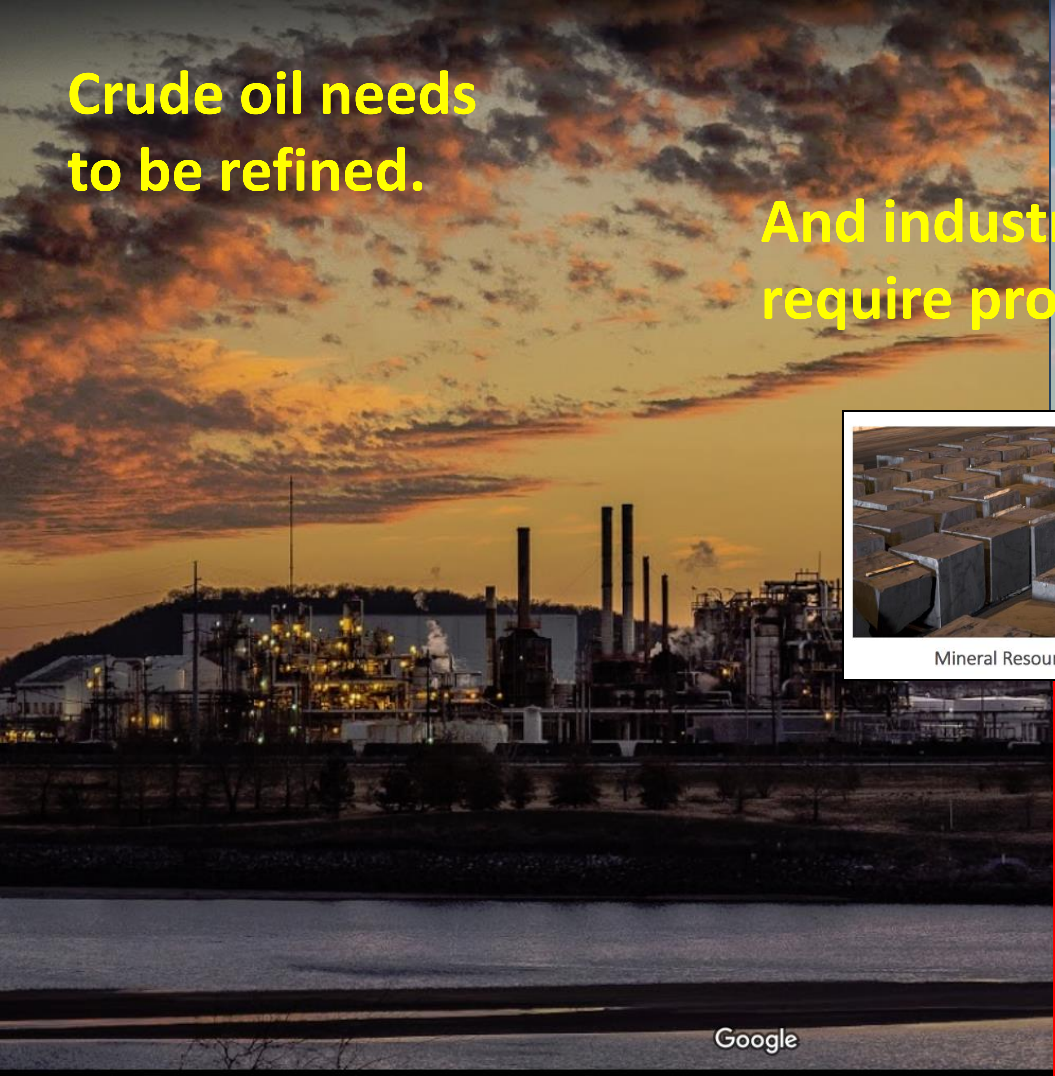
Global demand for lithium for battery storage alone forecast to grow from about 300,000 MT (LCE) in 2018 to almost 1,000,000 MT (LCE) by 2023

Global Lithium Processing and Battery Capacity



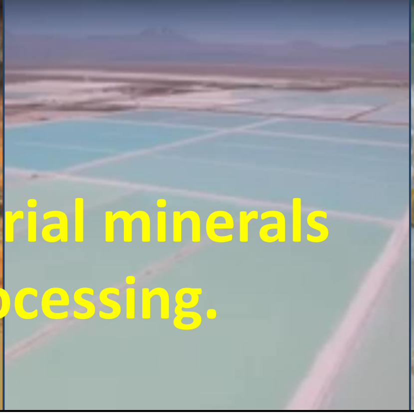
Benchmark Minerals, 2019

Hachured countries are home to significant lithium processing while orange dots indicate countries that manufacture batteries

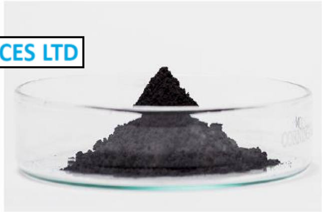


Crude oil needs to be refined.

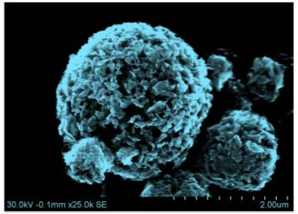
And industrial minerals require processing.



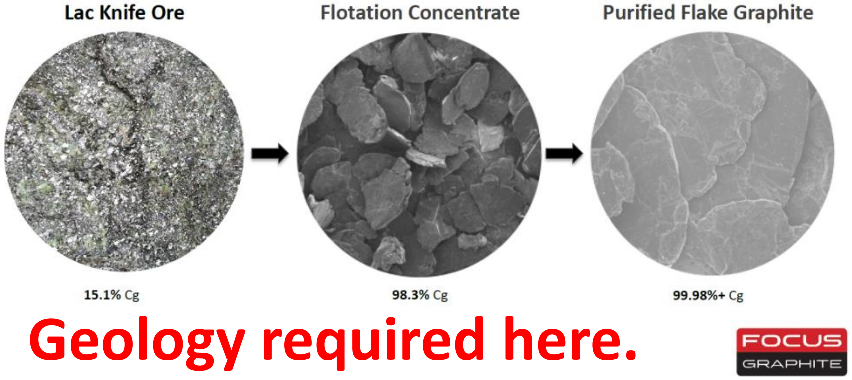
Mineral Resources



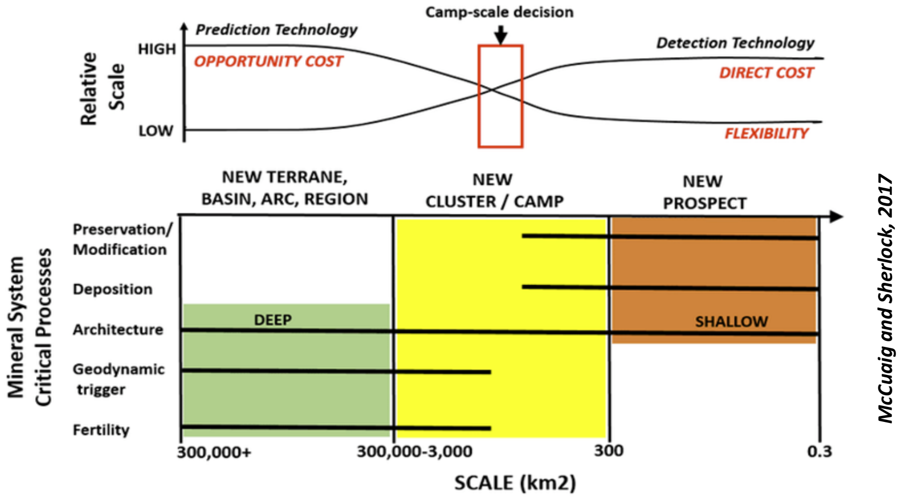
Processing Technologies



Product Technologies and IP



Geology required here.



Sediment-hosted copper system

COMMODITY SYSTEM CRITICAL PROCESSES

	NEW BASIN – Process	NEW BASIN – Geology	NEW BASIN – Spatial proxy	NEW CLUSTER, CAMP or PLAY – Process	NEW CLUSTER, CAMP or PLAY – Geology	NEW CLUSTER, CAMP or PLAY – Spatial proxy	NEW PROSPECT – Process	NEW PROSPECT – Geology	NEW PROSPECT – Spatial proxy
Preservation/ modification	Not at this scale			Mineralization preserved at mineable depth	Redox boundary close to surface	Basin GDE; post-mineralization 4D models	Mineralization preserved at mineable depth	Redox boundary close to surface	Sub-basin GDE; post-mineralization 4D models
Deposition/ accumulation	Formation of redox boundary or reduced S source	Extensive reduced sequence – basin depocentre style	Paleogeographic reconstructions	Formation of redox boundary or reduced S source	Volume of reduced sequence or HC trap; basin depocentre style	Basin GDE, 3D structural model, analogues	Redox boundary effectiveness	Volume and composition of reduced sequence	Sub-basin GDE and 3D model; geochemistry; drill hole control
Architecture	Seal formation to throttle P_f and fluid flow	Not at this scale		Seal formation to throttle P_f and fluid flow	Thick low-permeability strat above ox seq	Basin-scale temporal 2D and 3D structural, basin and hydrodynamic models	Seal formation to throttle P_f and fluid flow	Permeable stratigraphy; X-strata fault network; alteration patterns	Basin-scale GDE, temporal 2D and 3D structural, basin and hydrodynamic models
	Focusing of fluid flow in permeable pathway	Not at this scale		Focusing of large fluid volumes	Permeable stratigraphy; X-strata fault network; alteration patterns	Basin-scale temporal 2D and 3D structural, basin and hydrodynamic models	Formation of fluid exit pipes vs convection cells	Permeable stratigraphy; X-strata fault network; alteration patterns	Basin-scale GDE, temporal 2D and 3D structural, basin and hydrodynamic models
	Permeable pathway source-deposit	Not at this scale		Permeable pathway source-deposit	Permeable stratigraphy; X-strata fault network; alteration patterns	Basin-scale temporal 2D and 3D structural, basin and hydrodynamic models	Permeable pathway source-deposit	Permeable stratigraphy; X-strata fault network; alteration patterns	Basin-scale GDE, temporal 2D and 3D structural, basin and hydrodynamic models
Geodynamic trigger	Spatial and temporal P-T variation	Basin depocentre style, tectonic history	Plate models, paleogeographic reconstructions	Spatial - temporal P-T variation driving metal extraction/fluid flow	Local basin to sub-basin depocentre style, tectonic history	Temporal 2D and 3D structural, basin and hydrodynamic models	Spatial - temporal P-T variation driving metal extraction/fluid flow	Local basin to sub-basin depocentre style, tectonic history	Temporal 2D and 3D structural, basin and hydrodynamic models
Fertility	Generation of highly oxidized, saline fluid	Oxic environment Arid paleolatitude	Plate models; paleogeographic reconstructions	Generation of abundant brine	Evidence of evaporites	Basin GDE	Generation of abundant brine	Evidence of evaporites	Sub-basin GDE
	Availability of Cu	Thick oxidized clastic pile ± basement rich in Cu	Geology maps Tectonic reconstructions	Formation of oxidized Cu source	Thickness and composition of oxidized clastic pile ± basement	Basin GDE; Cu showings	Formation of oxidized Cu source	Thickness and composition of oxidized clastic pile ± basement	Sub-basin GDE; Cu showings

300000+ | 30000-3000 | 300 | 0.3

SCALE (km²)

McCuaig and other8, 2018

Common Elements

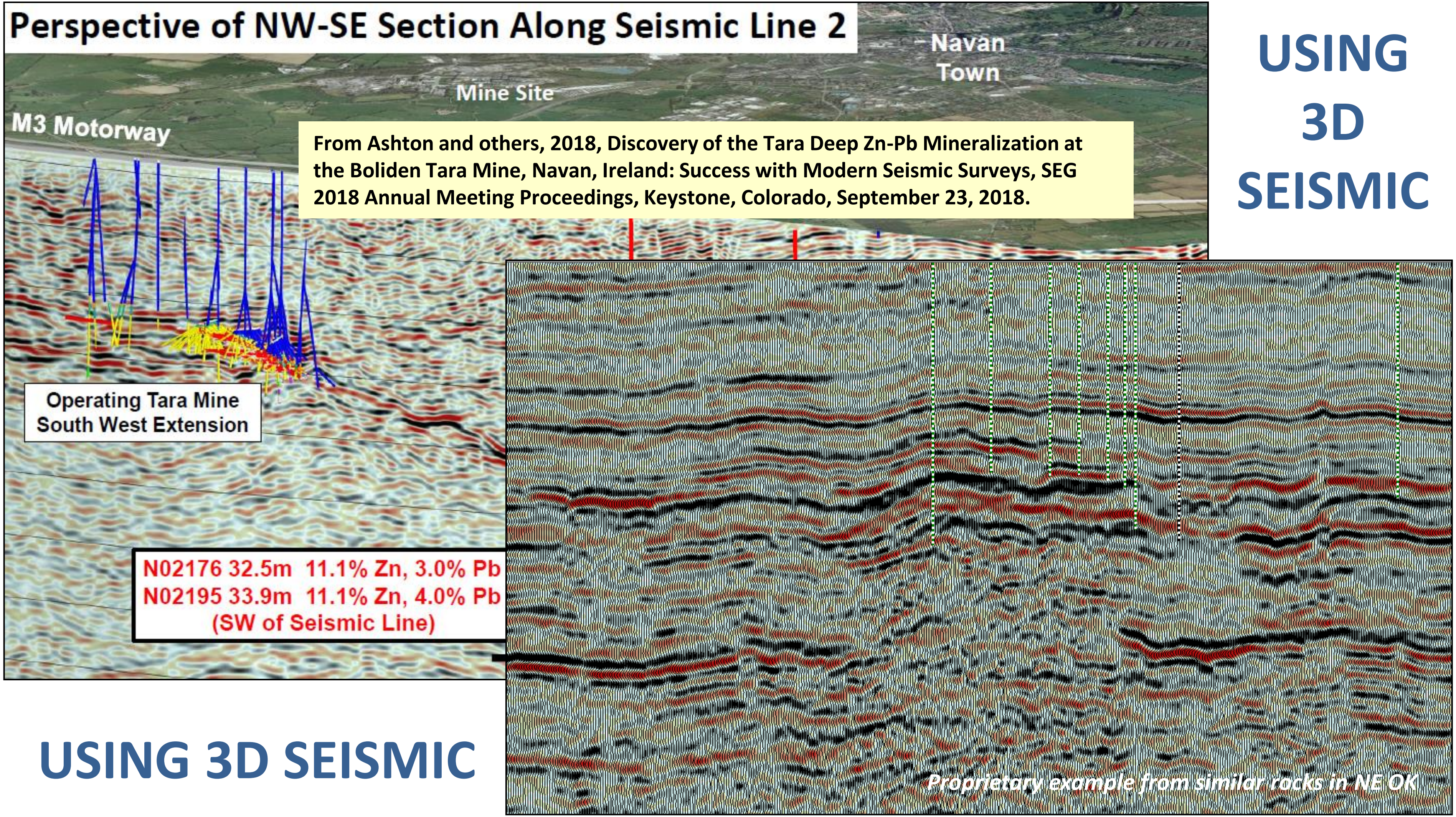
Technical

- Resource estimation, asset valuation
- Hydrodynamic modeling of mass balance and transfer
- Tectonic element mapping and structural restoration
- Mineralogy and petrophysics
- Core, log and well analysis
- 3D seismic imaging
- Geochemistry

Strategic

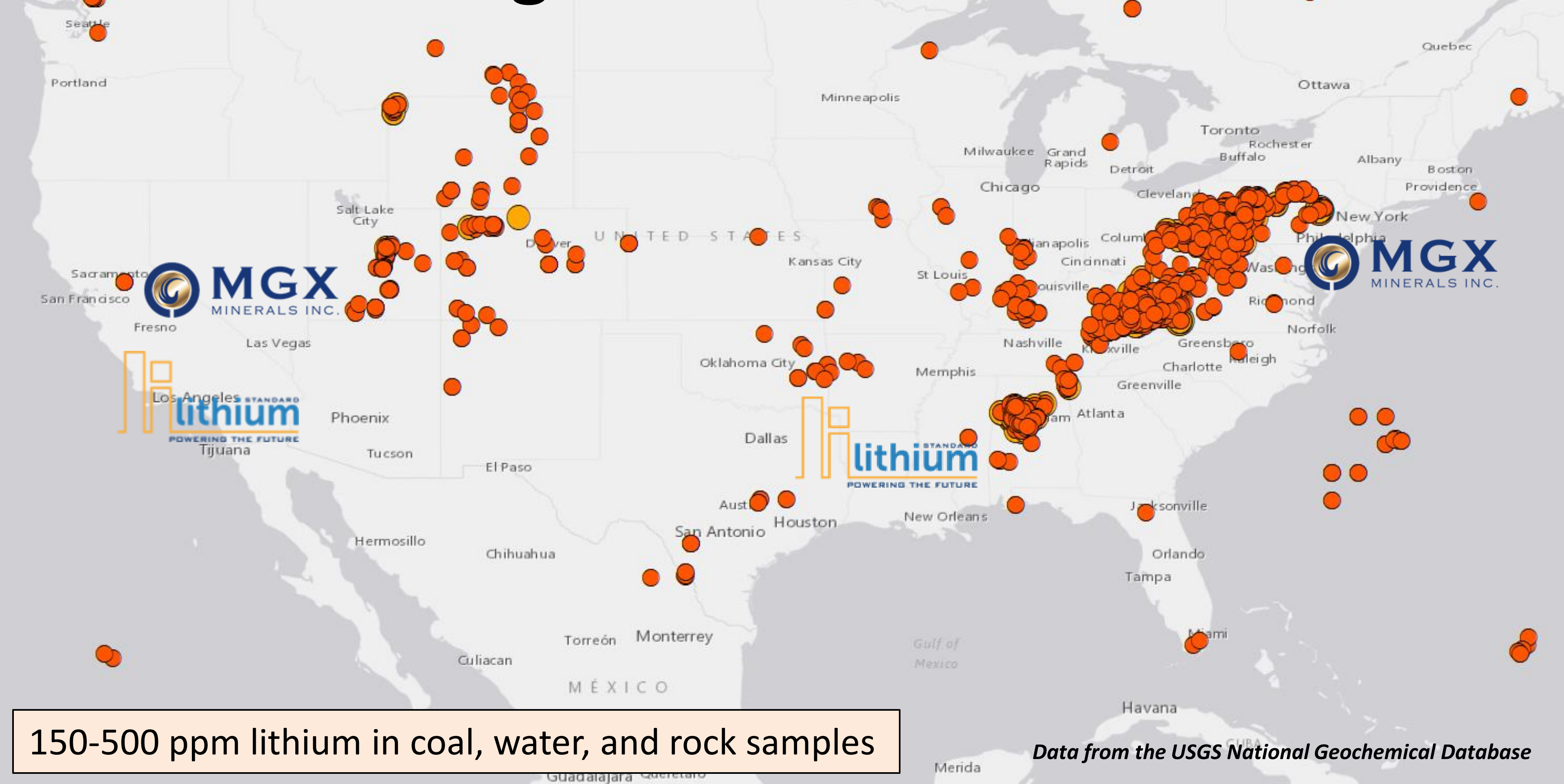
- Secondary production
- Looking deeper in old basins
- Plethora of “juniors” feeding majors
- Future of ML, AI and sustainability supporting creative geologists

USING 3D SEISMIC



USING 3D SEISMIC

Using Geochemical Data



150-500 ppm lithium in coal, water, and rock samples

Data from the USGS National Geochemical Database

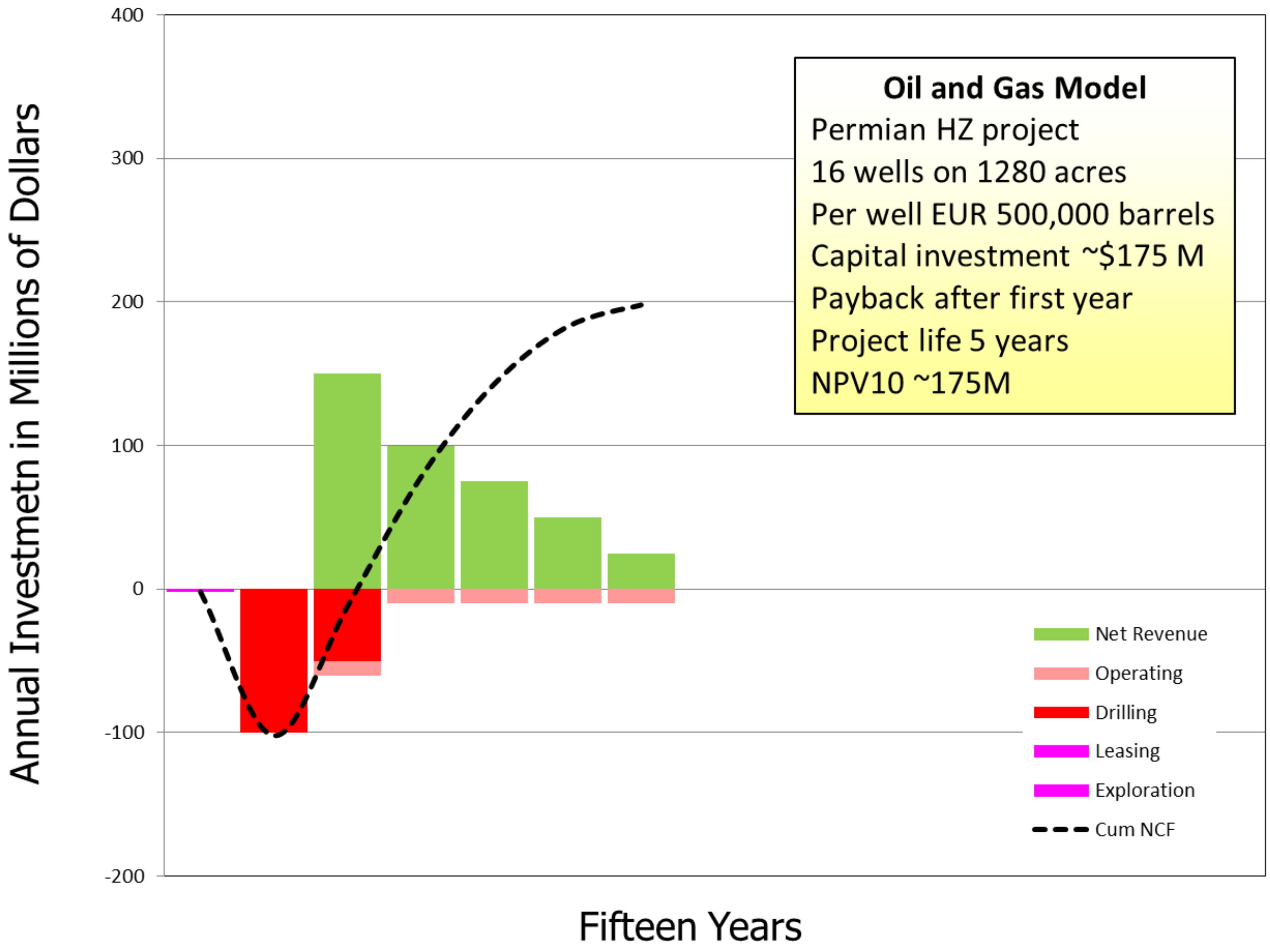
This figure from mining.com/web article "How much will it cost?" published August 30, 2107

FIGURE 1

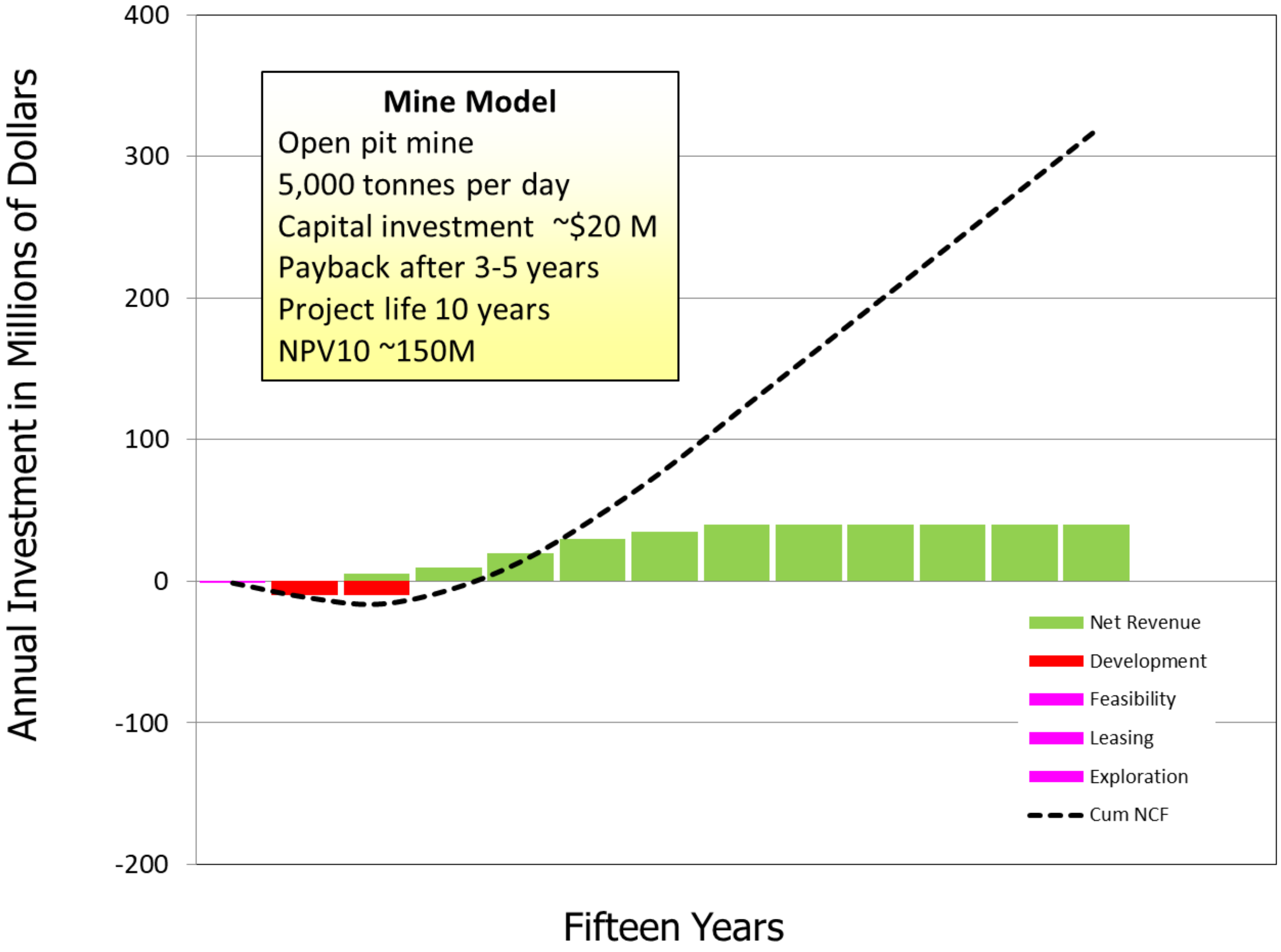
Criteria	Technical & Economic Studies		
Study	Preliminary Economic Assessment (PEA)	Prefeasibility Study (PFS)	Feasibility Study (FS)
Concept	"What it could be"	"What it should be"	"What it will be"
Objective	Early stage conceptual assessment of the *potential economic viability* of mineral resources	Realistic economic and engineering studies sufficient to *demonstrate economic viability* and establish mineral reserves	Detailed study of how the mine will be built, used as the basis for a *production decision*
Cost Accuracy	+/- 50%	+/- 25%	+/- 15%
Engineering	<1%	1–5%	5–25%
Mineral Estimate Inputs	Inferred/Indicated/ Measured Resources	Indicated & measured resources	
Mineral Estimate Outputs	Inferred/Indicated/ Measured Resources	Probable & Proven Reserves	

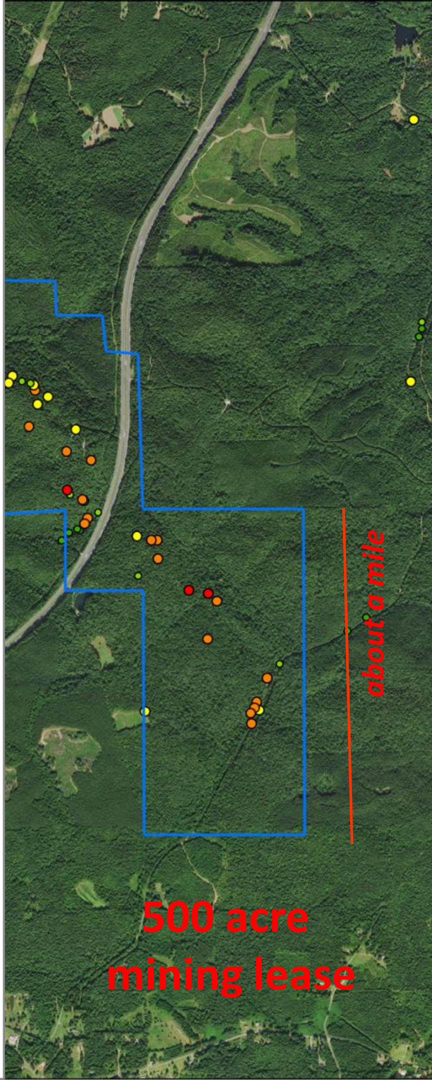
Adapted from a March 2015 PDAC presentation by the Ontario Securities Commission and the TSX.

Reserve assessments are rigorously controlled and regulated according to national standards in three steps, PEA, PFS, and FS, and require an independent report and third-party monitoring.

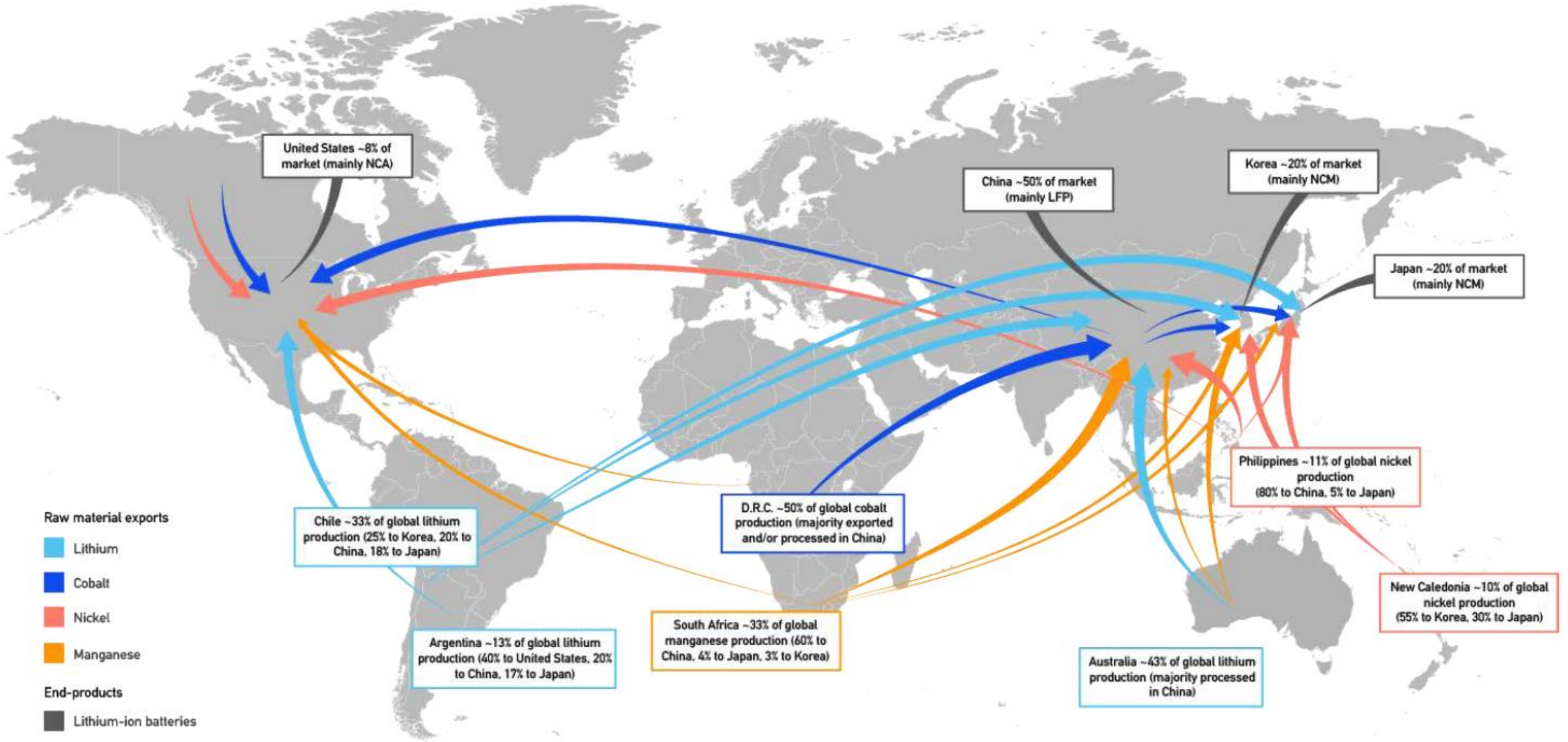

Oil and Gas Model
Permian HZ project
16 wells on 1280 acres
Per well EUR 500,000 barrels
Capital investment ~$175 M
Payback after first year
Project life 5 years
NPV10 ~175M
Annual Investmetn in Millions of Dollars
400
300
200
100
0
-100
-200
Fifteen Years
Net Revenue
Operating
Drilling
Leasing
Exploration
Cum NCF


3D
20
erms
Send feedback
1 mi


Mine Model
Open pit mine
5,000 tonnes per day
Capital investment ~$20 M
Payback after 3-5 years
Project life 10 years
NPV10 ~150M
Annual Investment in Millions of Dollars
400
300
200
100
0
-100
-200
Fifteen Years
Net Revenue
Development
Feasibility
Leasing
Exploration
Cum NCF


about a mile
500 acre
mining lease

BUT IS IT CLEAN AND SUSTAINABLE?



Dominish and others, 2019, Responsible Minerals Sourcing for Renewable Energy

Critical minerals - a new energy frontier

Worldwide market demand
Global distribution trends
Basin to play to prospect
Exploration technology
Valuation and economics
Sustainable development

BUSINESS NEWS MAY 14, 2019 / 1:28 AM / UPDATED A DAY AGO

U.S. Senate moves forward on plan to develop electric vehicle supply chain

Ernest Scheyder 6 MIN READ

CAD rig drilling in Clayton Valley, 2017, from nextsmallcap.com

AAPG Energy Minerals Division

THANK YOU