ACE 2020 AAPG ANNUAL CONVENTION & EXHIBITION INCORPORATING SEPM & GCAGS
29 SEPT – 1 OCT ONLINE AND ON DEMAND

Critical Minerals, the Petroleum Geoscientist and the Wider Application of Hydrocarbon Exploration and Development Techniques and Business Practices

Strategic economic and environmental opportunity from adoption of unconventional hydrocarbons E&P approach by leveraging available geoscience and engineering skills to generate technological competitive advantage by the Hydraulic Production of Critical Minerals

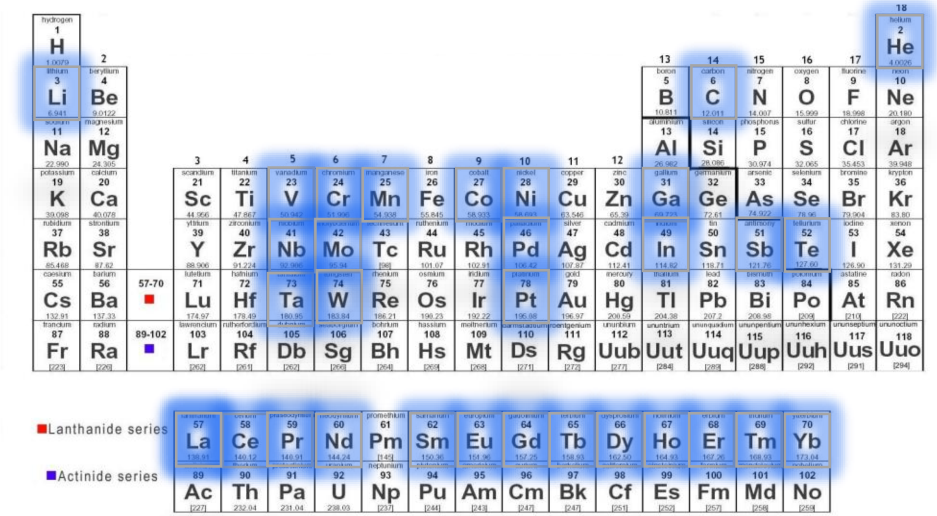
CHERRYVALE PARTNERS
Lindsay Ross
Director

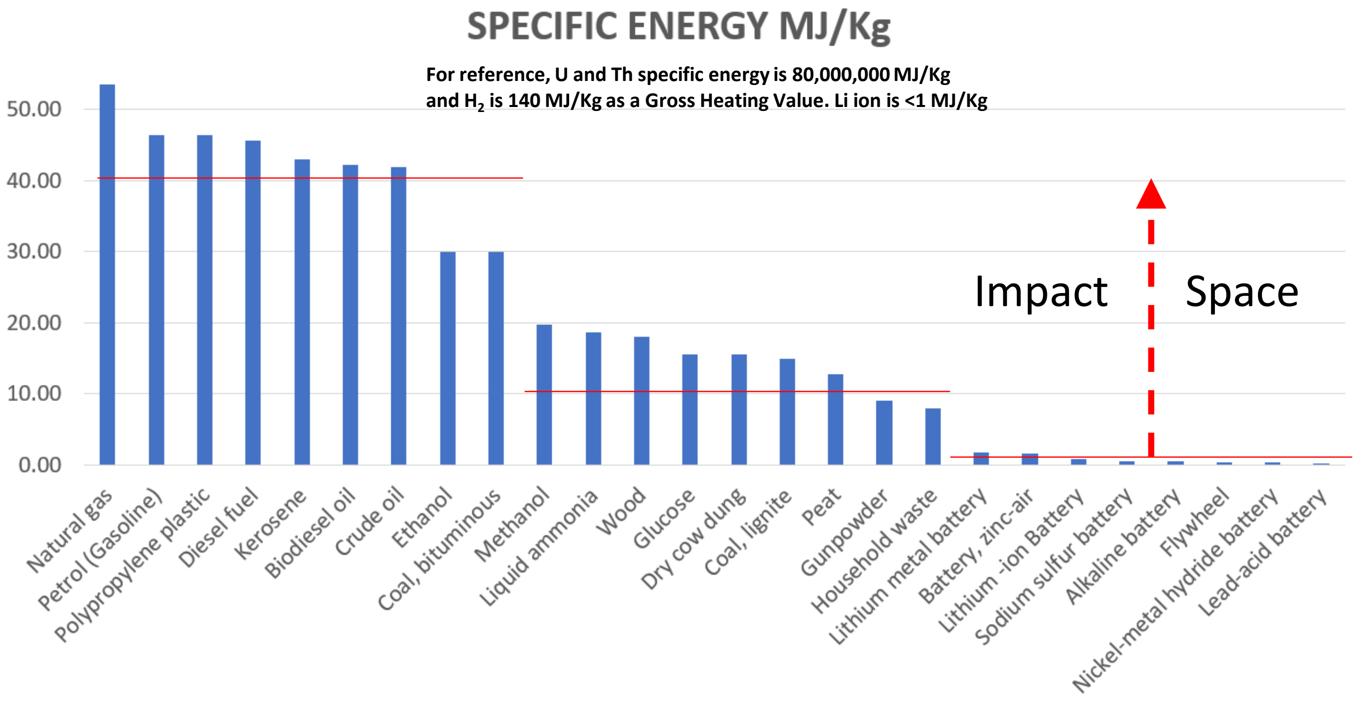
Rockleigh Energy
Advisory | Assurance | Consulting
David Beckett
Director

THE PETROLEUM BUSINESS AND CRITICAL MINERALS

-CRITICAL MINERALS IN CONTEXT

A strategic mineral is a critical mineral, but a critical mineral is not necessarily a strategic mineral



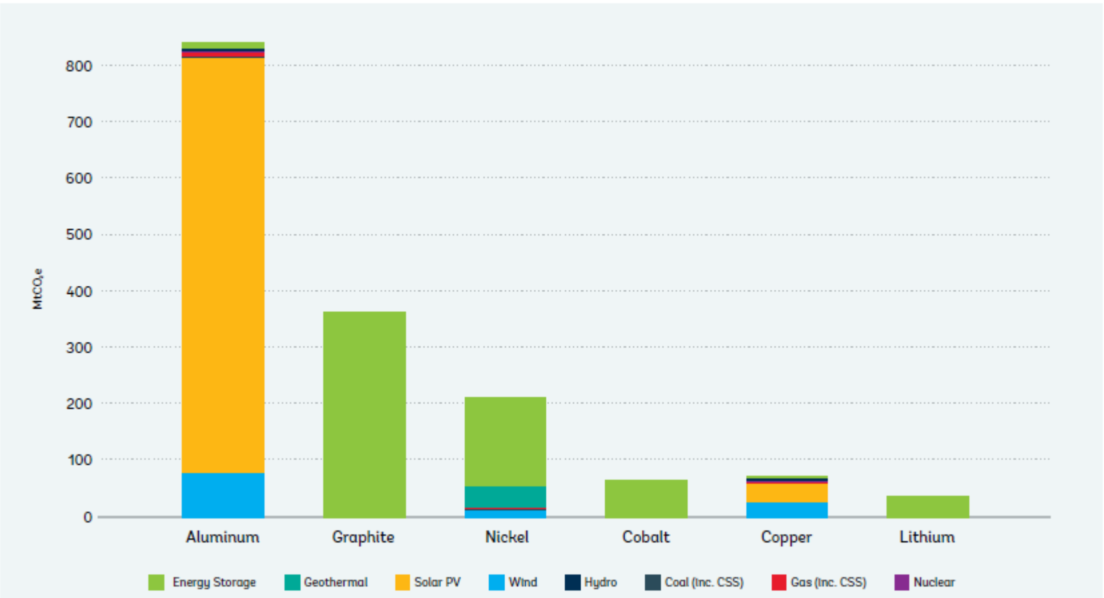


According to one definition in the Energy Mineral Division's *Critical Minerals Committee*, a critical mineral is a naturally occurring and extractable-from-rock commodity (exclusive of petroleum and uranium), that is vital to current and emerging energy technology, and at the same time, limited in supply by current or forecast requirement. Petroleum and Uranium are excluded from the CMC focus because they are the attention of significant effort elsewhere in the AAPG.

THE PETROLEUM BUSINESS AND CRITICAL MINERALS

-E&P IN THE DECARBONISING ENERGY ECONOMY

Figure ES.5 Cumulative Global Warming Potential from Extraction and Processing of Minerals, Not Including Operations, Using Cradle-to-Gate Through 2050 Under 2DS

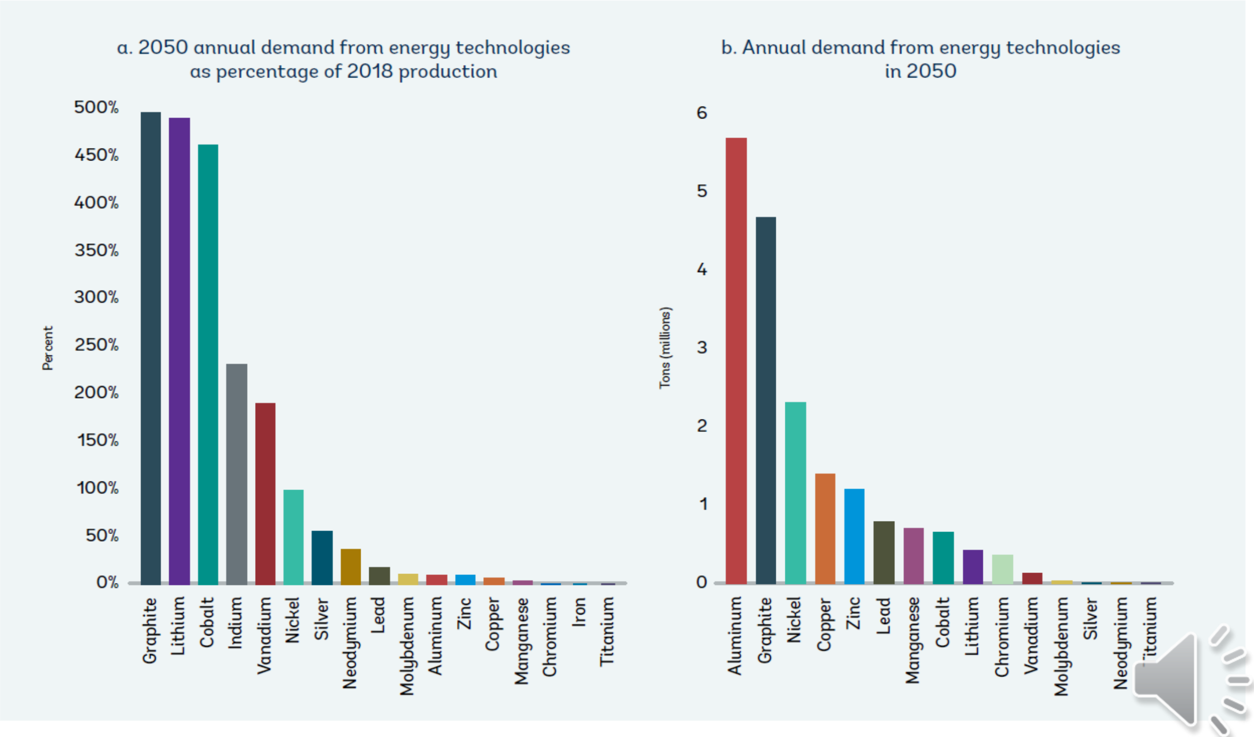


Source: World Bank Group

To their credit, mining houses are aiming for zero net emissions by 2050 and to that end are exiting Coal and entering commercial solar PV, wind and bioenergy and applying these technologies to mining operations.

Typically in mining greater than 50% of the carbon budget per tonne of metal produced is allocated to excavation, hauling, crushing and grinding the ore. Using Copper as an example, these operations account for more than 400 Kg CO2 / ton Cu concentrate.

Beyond a GHG perspective, the environmental impacts of mining include significant effort to manage health and safety, water use, airborne particulates, land management and social licence to operate. Whilst these issues are the subject of serious and ongoing effort, we speculate that the burden on mining could be lifted were the extraction and handling processes of ore production to be supplemented by the Hydraulic Production of certain mineral deposits. The concept is analogous to the differentiation between conventional and unconventional aspects of hydrocarbon production and has the potential to deliver the comparable outcomes to the minerals industry



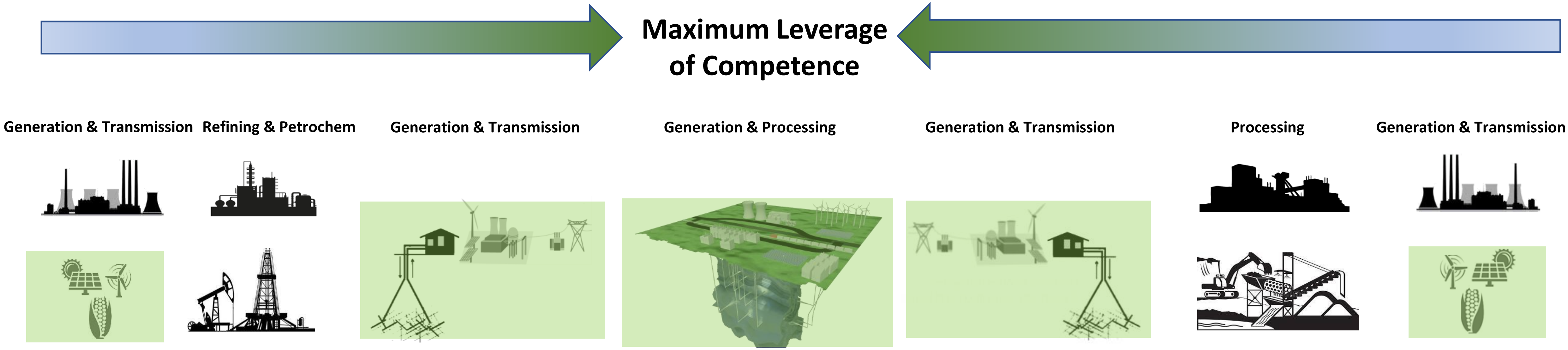
Note: 2DS = 2-degree scenario.

Source: World Bank Group

THE PETROLEUM BUSINESS AND CRITICAL MINERALS

-Tomorrow's Integrated Energy Resources Company

The integrated energy resource business model is achievable by both the Mining Houses and the Oil & Gas Companies, each pathway made achievable by increasing leverage upon intrinsic technical competencies and potentially, more effectively in strategic partnership.



Traditional Oil & Gas with Solar, Wind and Bio Addition

Enhanced Geothermal

Integrated Future Energy Resources

Enhanced Geothermal

Traditional Mining with Solar, Wind and Bio Addition

Many Elements are Common – but the Future Integrated Energy Resources company encompasses and is accountable for the Energy, Structural & Critical Minerals inputs to drive its renewable/sustainable energy elements and leverages core and common geoscience engineering skills to explore and produce in an acceptable and sustainable model.

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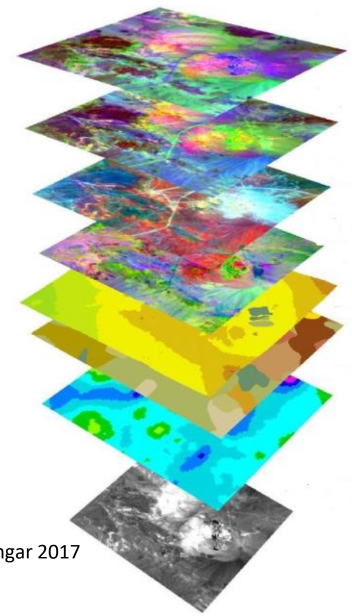
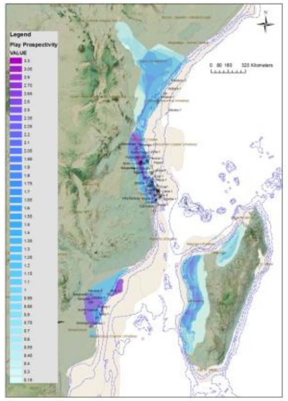
-COMMODITY EXPLORATION SCHEMES



After Sengar 2017

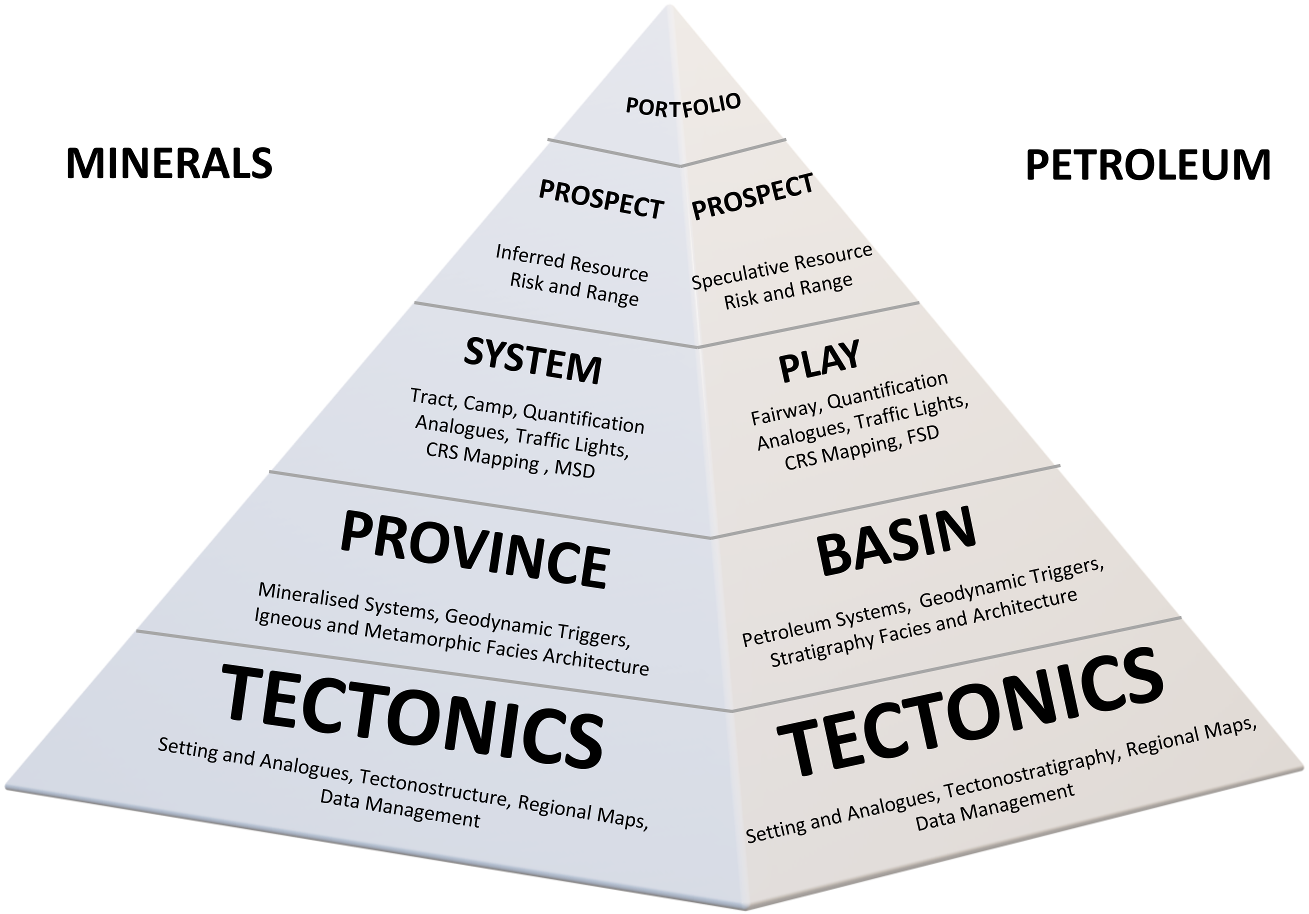
System elements modelling for probabilistic economic distributions and decision analysis

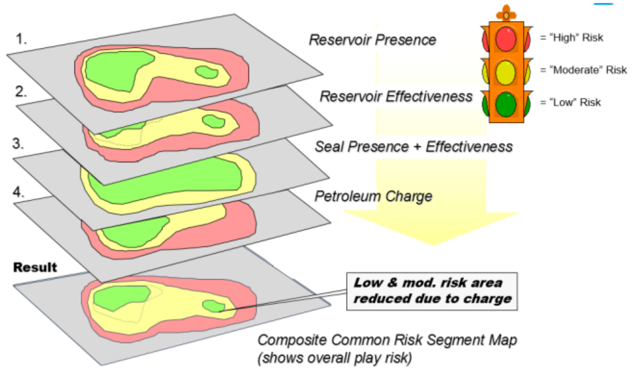
- **Considerable of overlap of evaluation process and products**
- **Skills of experienced petroleum geoscientists readily transferable to minerals exploration**



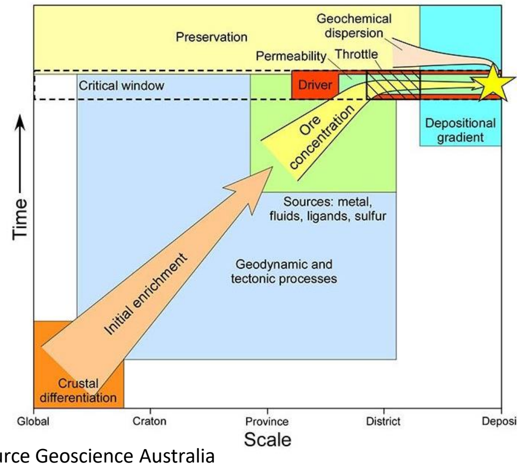
MINERALS

PETROLEUM

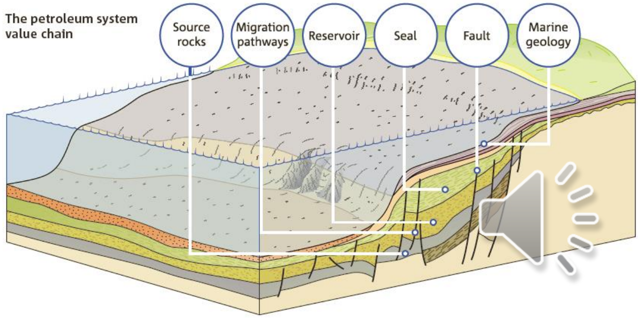




after Fraser 2012



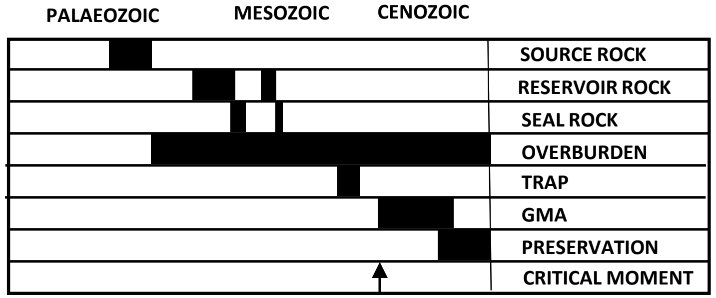
Source Geoscience Australia



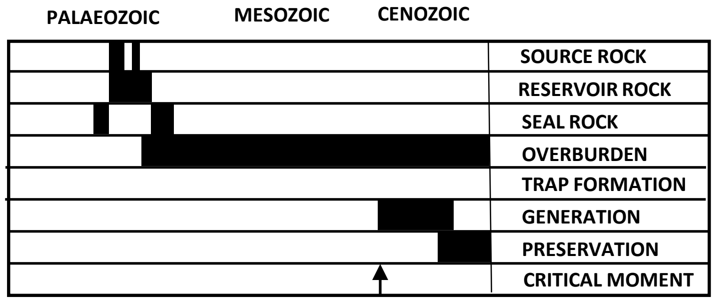
THE PETROLEUM BUSINESS AND CRITICAL MINERALS

CRITICAL THINKING, PARALLEL PROCESSES AND COMPARABLE OUTPUTS

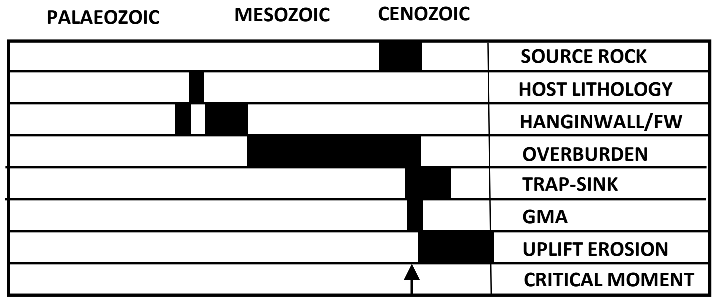
PETROLEUM
CONVENTIONAL SYSTEM EVENT CHART



PETROLEUM
UNCONVENTIONAL SYSTEM EVENT CHART



MINERAL
HYDROTHERMAL SYSTEM EVENT CHART



MACRO IMAGERY
GEOLOGICAL MAPPING AND ATTRIBUTES
PETROPHYSICS
ROCK MECHANICS
RADIOMETRICS AND ISOTOPES
PALAEONTOLOGY AND PALYNOLOGY
ORGANIC GEOCHEMISTRY
INORGANIC GEOCHEMISTRY
NON SEISMIC GEOPHYSICS
2D 3D SEISMIC INTERPRETATION AND ATTRIBUTES
MICRO IMAGERY

MODEL THEORY
MODEL RESEARCH
INTERPRETATION THEORY
MACHINE LEARNING
SPATIAL MODELLING
DATA ANALYTICS
GEOSTATISITICS
PROBABILISTICS

ANALYSIS

- FLUID ROCK INTERACTION CPVT
- THERMAL & FLUID HISTORY
- STRUCTURAL ANALYSIS
- PETROGRAPHY & FACIES
- BASIN AND PROVINCE ANALYSIS
- SPATIAL DISTRIBUTION

OIL AND GAS

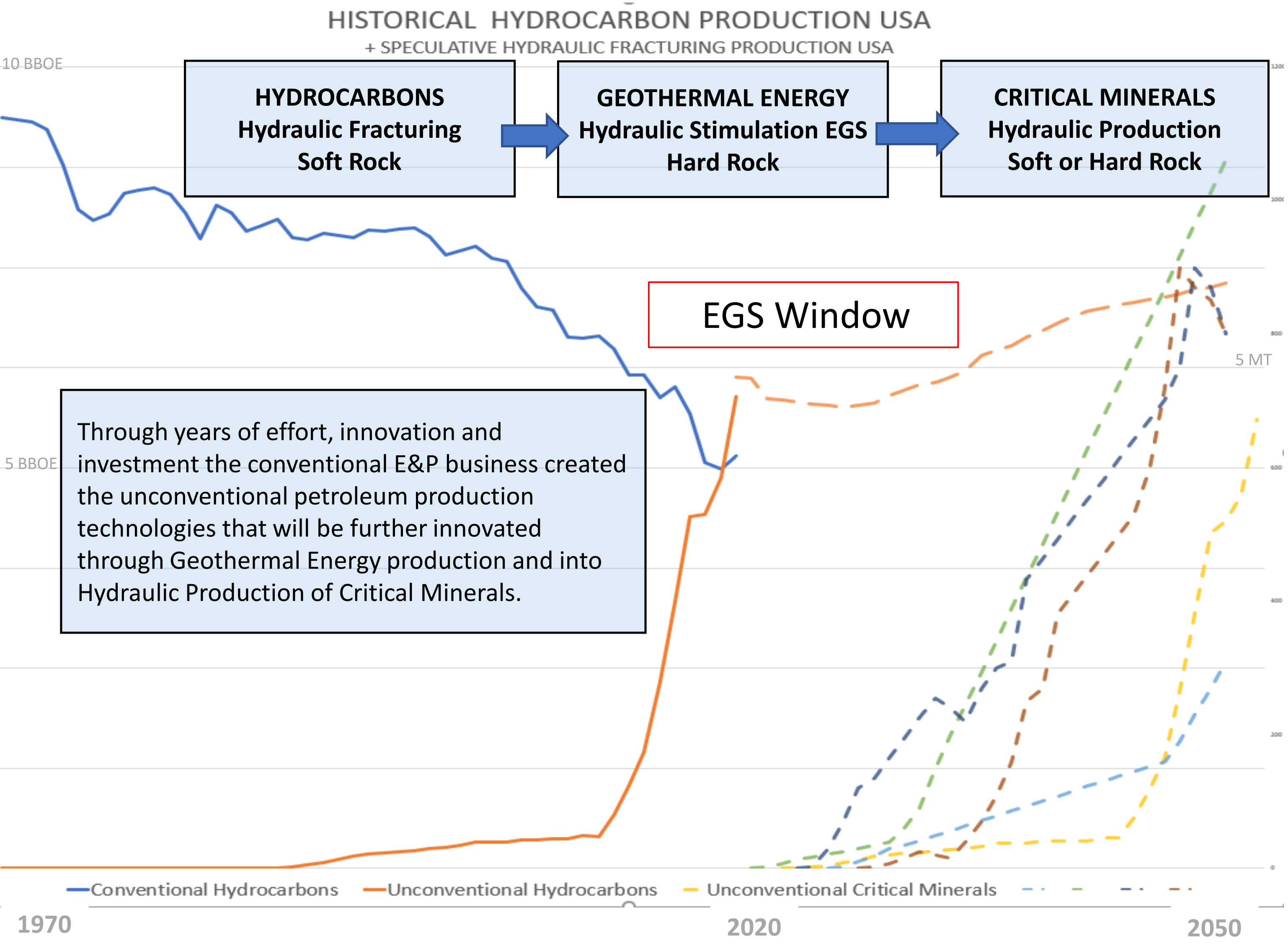
- DIAGENESIS
- SOURCE ROCK MODELLING + MIGRATION TO TRAP
- NON-PENETRATATIVE STRAIN / BRITTLE
- SEDIMENTARY STRATIGRAPHY
- TECTONOSTRATIGRAPHIC RECONSTRUCTION
- PLAY, PROSPECT OR FIELD
  MMBBL OR MMSCF
  P_{90}-P_{50}-P_{10} DISTRIBUTION OR 1P-3P + C
  SPE/WPC/AAPG

MINERALS

- ALTERATION MAPPING
- SOURCE TO TRAP AND SINK METALLOGENESIS
- BRITTLE TO POLYPHASE DUCTILE
- METAMORPHIC AND IGNEOUS TERRAINS
- TECTONOSTRUCTURAL RECONSTRUCTION
- PROSPECT OR MINE
  Mt @ GRADE
  MEASURED-INFERRED -INDICATED OR PROVED-PROBABLE
  JORC

THE PETROLEUM BUSINESS AND CRITICAL MINERALS

-PATHWAY TO THE HYDRAULIC PRODUCTION OF CRITICAL MINERALS



INNOVATION TRIGGERS HYDRAULIC PRODUCTION

Hydraulic Fracturing of Granitoids for Geothermal Energy

- Targeted poro-perm generation by exploiting mechanical properties of orebody versus wall rock
- Managing fluid-ore interaction in foliated fabrics
- Extension on Hydraulic Fracture preconditioning

Microbes in mineral beneficiation or advanced Lixiviants

- Microbial beneficiation of minerals in-ground
- Ecologically sustainable solvent extraction, electrowinning and re-cycling of process water

Continuous Hydraulic Production eliminates the considerable earthworks involved in open cut and underground operations whilst delivering a safer workplace. Tailings dams, evaporation ponds, waste hauling and dumps, digging operations no longer required and replaces conventional mining impacts with producer and injector wellheads, pipe and a renewable energy sourced electrowinning process plant.

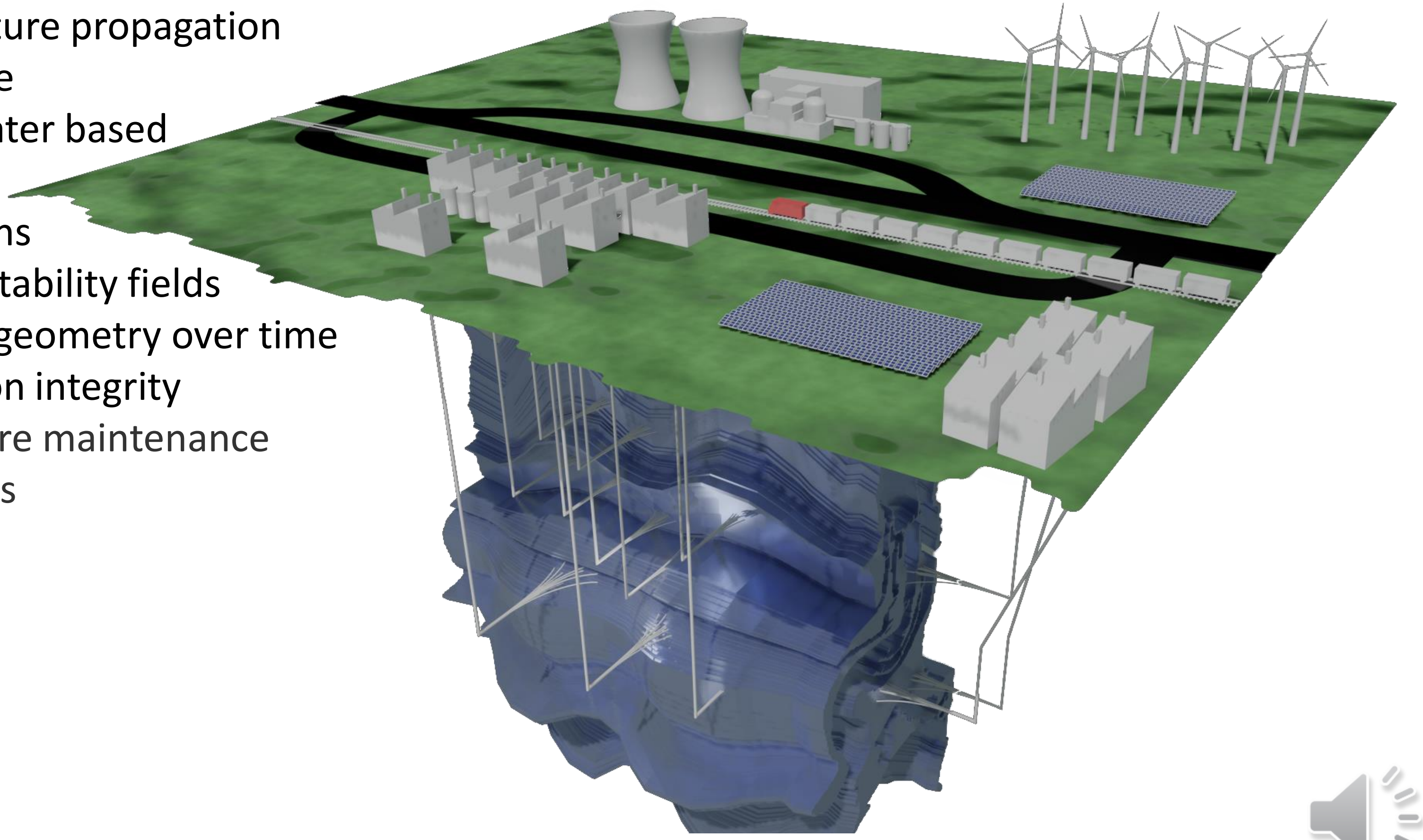
Continuous Hydraulic Production offers opportunities to:

- Leverage the considerable technical capabilities of the unconventional Hydrocarbon production model
- Produce stranded mineral resources, uneconomic for conventional mining. Go deeper into proved mineral systems
- Improve the environmental and social outcomes of mineral resource extraction over existing operations

THE PETROLEUM BUSINESS AND CRITICAL MINERALS
-CHALLENGES FOR CONTINUOUS HYDRAULIC PRODUCTION

- Ore-gangue-host deposit ranking metrics
- Scale of testing: in mine, near-mine stranded resources or greenfield
- Orebody imaging, grade distribution and development drilling
- Modelling fracture acoustic emissions in heterogeneous rock
- In-situ stress variations, anisotropic fabrics and fracture propagation
- Porosity, permeability and the accessible ore volume
- Liquid CO2, exotic fracture fluids or conventional water based
- Production scheduling and optimisation
- Orebody zonal isolations, cementing and completions
- In-ground leach efficiency and multimetal-lixiviant stability fields
- Measurement of extraction efficiency and orebody geometry over time
- Corrosion and maintenance of subsurface production integrity
- Chemo-mechanical orebody degradation and fracture maintenance
- Interactive geomechanics of fractures and proppants
- Fines production and waste disposal
- Containment of production fluids and microbes
- Induced seismicity effects
- Treadmill effect

Which technical competitive advantages does an E&P company have in Solar PV, Wind, Tide or Hydrogen technologies versus the current players?



Drafting Credit: Christopher Ross

Why The World Still Needs an Oil & Gas Industry

- Predictions vary – but under Stated Policy criteria IEA forecasts indicate oil demand growth (marginally exceeding production) at a declining rate out to 2040, with a similar profile at a steadier growth rate and larger production shortfall for gas.
    - As expected – strong steady growth in demand and supply for renewables across the same period
- In general terms, a steady growth in demand for plastics across the comparable period is forecast despite a corresponding increase in recycling.
    - Plastics are, and will continue to be, essential components of green energy systems
- However – even assuming a universal effective substitution of renewables for hydrocarbon fuels in power generation (baseload and transmission considerations notwithstanding) some essential fuel types and feedstock for plastics must still be derived from fossil fuels.
- Global integrated transport networks based on fossil fuel derivates will continue to be an essential enabling factor in any effective transition to renewable energy.

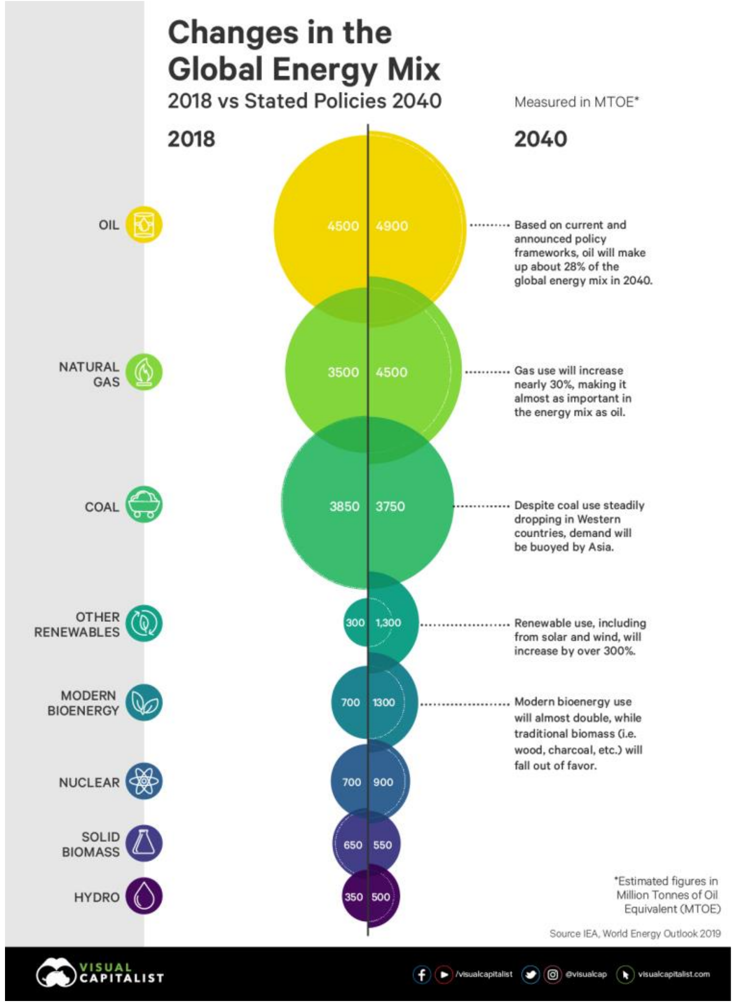


Diagram sourced from Visual Capitalist website:
https://www.visualcapitalist.com/the-worlds-projected-energy-mix-2018-2040/

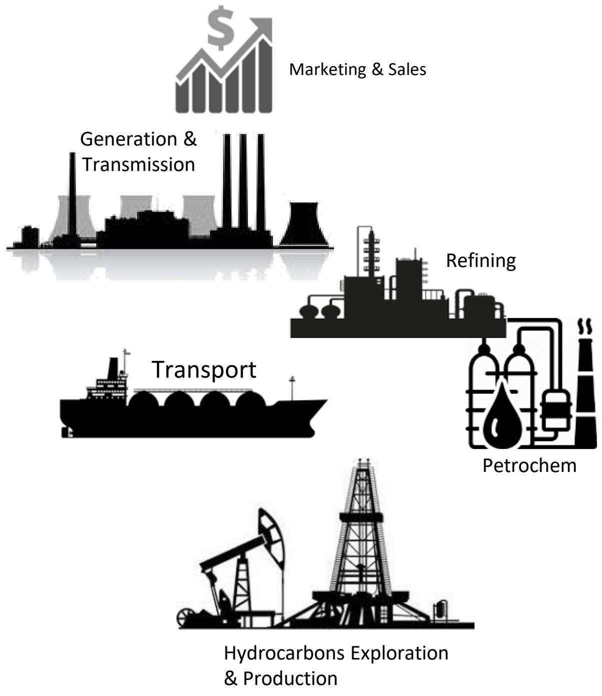
Evolve to Prosper – Future Integrated Energy Resources Companies

- Advocacy & Education - not Apology.
  - Absolutists and activists can't effectively be appeased – but the general public will recognise a rational argument
- Oil and Gas companies and hydrocarbon products are integral to the transition to effective universal sustainable energy by substituting clean gas for other fuels and supplying fuel types not easily replaced.
- Publicly owned oil and gas companies, in particular, have a role as exemplars in clean, safe exploration and production – and the full-cycle energy business. Whilst NOCs are more likely to main their current trajectory in developing and transitioning economies.
- Virtue from Vice? To maintain social licence, the transition to future integrated energy resources companies should encompass and account for all elements of the energy chain and not outsource critical components of the value or supply chain to less capable or responsible third parties.
- Evolution sees increasingly complex systems and new hierarchies based upon entities which demonstrate greater efficiencies and resilience over competitors. Evolution by leveraging competitive advantage is the key for energy companies, not devolving by discarding hard won corporate experience and knowledge.
- Positioning by some Supermajors in response to CO_2 abatement and other green schemes game may jeopardise shareholder returns as competitive advantage is eroded – likely to impact the service sector adversely.

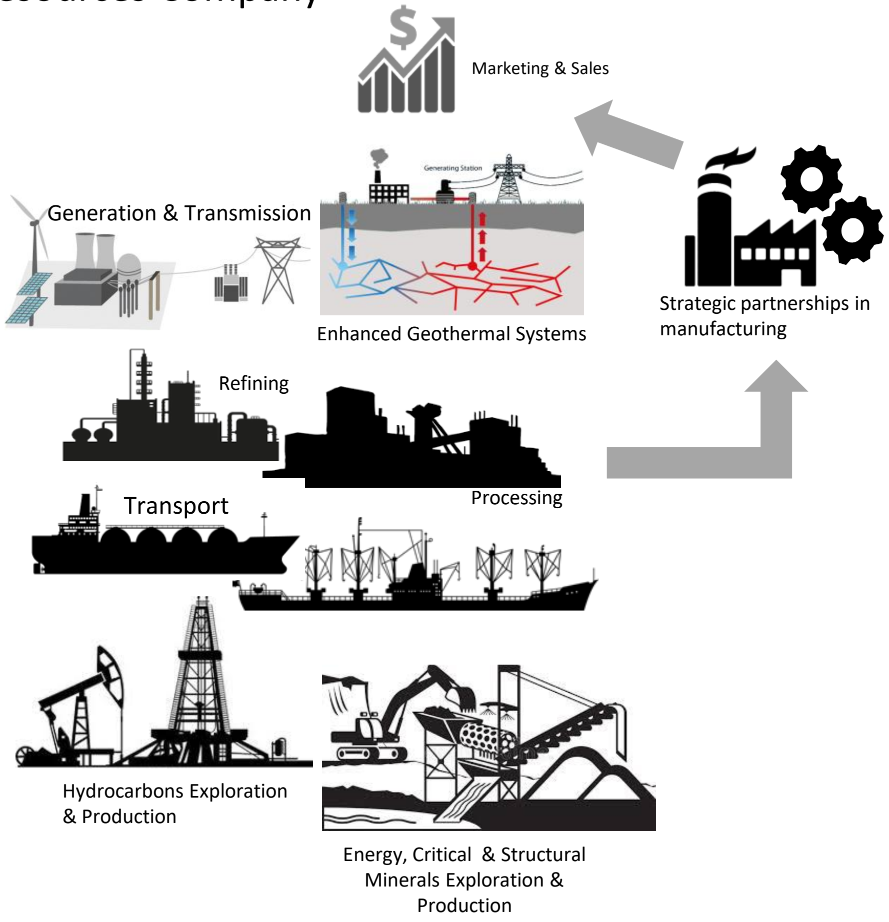
The extraction of critical minerals for "green" energy sometimes isn't……

Evolve to Prosper – Tomorrow's Integrated Energy Resources Company

The Traditional Vertically Integrated Oil & Gas Company



The Integrated Future Energy Resources Company



Many Elements are Common – but the Future Integrated Energy Resources company encompasses and is accountable for the Energy, Structural & Critical Minerals inputs to drive its renewable/sustainable energy elements and leverages core and common geoscience engineering skills to explore and produce in an acceptable and sustainable model.

Workforce & Technology Strategies

- Build cultural and future workforce resilience
  - More to more responsive, flexible working practices – including retained talent pools
  - Cultural strength – based on advocacy and education
- Capability components based on talent and transferable skills profiles
  - Robust competency mapping across petroleum and minerals disciplines supported by mutual recognition and certification across professional bodies to support enhanced energy resources minerals capability.
  - Enhanced and standardised professional practice and ethics framework
  - Certified skill sets
  - Participants not passengers
- Leadership becomes an applied function and skill - not a status symbol
- Shift to military-inspired flexible and configurable mission-oriented combined task group approach to projects
- R&D driven application of unconventional petroleum technology and practices to solution minerals extraction to leverage industry phase shift
  - Tax and reputation advantages
  - Scalable pilots

Geoscience Competency Mapping Example – Hydrocarbons to Minerals: Play Analysis

Hydrocarbon Play Analysis: Competency and Metrics

Sets of known or postulated hydrocarbon accumulations sharing similar temporal, geologic and geographic and basin properties such as hydrocarbon type, trap mechanisms, source rock/s and migration fairways

Evaluate regional datasets, incorporating all analogue and available information in order to generate predictive play concepts and produce comprehensive fairway maps leading to the development of hydrocarbon resource and risk estimates for that play. At all stages integrate machine learning and AI.

1. Assemble and collate disparate and sometimes incomplete datasets to generate predictive fairway component maps (Source, Reservoir, Seal and Tectonics) for each play element that are not necessarily limited to areas of data coverage.
2. Collate superimposed and layered fairway component maps to derive migration and charge window maps and identify prospective trends
3. Generate and apply uncertainty and risk element layers to component mapping and construct summary traffic light maps to identify play sweet spots.
4. Estimate potential prospect and lead frequency and density within mapped fairways and identify shared risk and charge limitations between interacting or linked fairway components.
5. Apply best-practice resource estimation techniques to derive potential play resource potential incorporating both discovered and Yet-to-Find components.
6. Identify and highlight areas for acreage capture or further evaluation.

Minerals Play Analysis: Competency and Metrics

Sets of known or postulated mineralisation systems sharing similar temporal, geologic and provincial and camp properties such as mineral associations, alterations, ore body configuration, metal origin and in the case of hydrothermals, fluid pathways.

Evaluate regional datasets, incorporating all analogue and available information in order to generate predictive play concepts and produce comprehensive fairway maps leading to the development of ore resource and risk estimates for that play. At all stages integrate machine learning and AI.

1. Assemble and collate disparate and sometimes incomplete datasets to generate predictive fairway component maps (Fluid nature and origin, ore body geometry & configuration, and tectonics) for each play element that are not necessarily limited to areas of data coverage.
2. Collate superimposed tract component maps to derive fluid migration and emplacement window maps and identify prospective trends
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Very high congruence in application

THE PETROLEUM BUSINESS AND CRITICAL MINERALS

-LITHIUM BRINE

Lithium resources inferred and measured in Continental surface Li Brine deposits (Lithium Triangle) Hardrock LCT Pegmatites (Greenbushes) Geothermal Li Brine (Salton Sea) Oilfield Brines (Smackover) (MGX Sturgeon Lake) AND Clays Hectorite, Sepiolite, Jadarite.

Speculative resource potential is considered for the megahalite Amadeus and Officer Basins of central Australia's Neoproterozoic as:

- **Source** Archaean, Paleoproterozoic, Mesoproterozoic cratonic Igneous and Metamorphic terrains
- **Reservoir** Neoproterozoic Evaporites, Dolomites and Sandstones of the Bitter Springs Group

Resource extraction is speculated as:

- Deep Solution Mining
- Production of Brine. Molecular sieve Lithium extraction + reinjection of processed water

ONSHORE SALT BASINS

AMADEUS AND OFFICER

Greenbushes mine in Western Australia, jointly owned by China's Sichuan Tianqi Lithium Industries

Source: Forbes

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-LITHIUM PLAY CONCEPT

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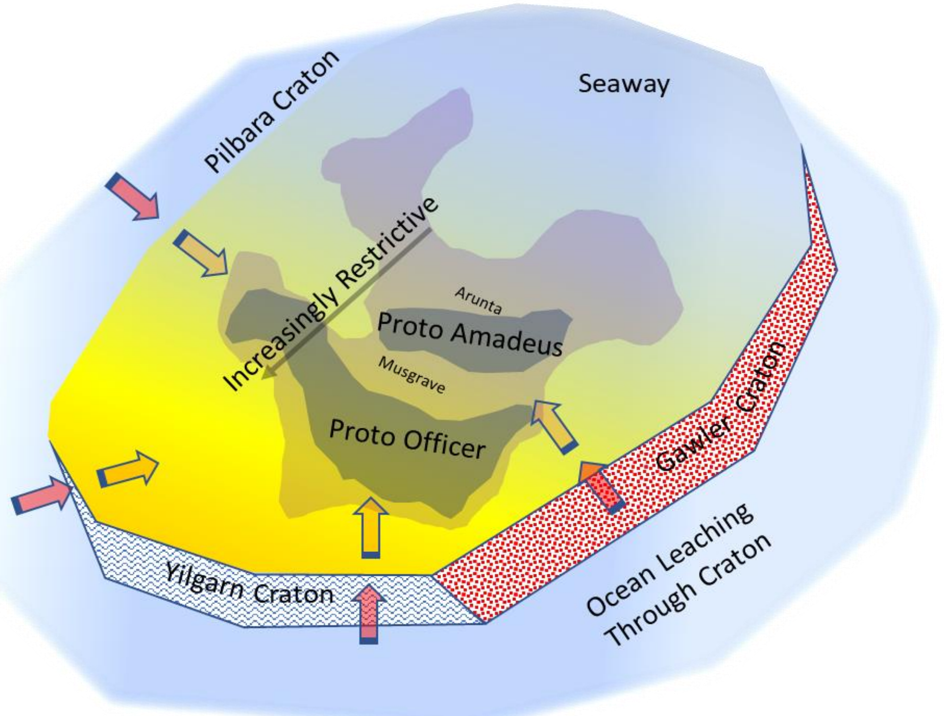
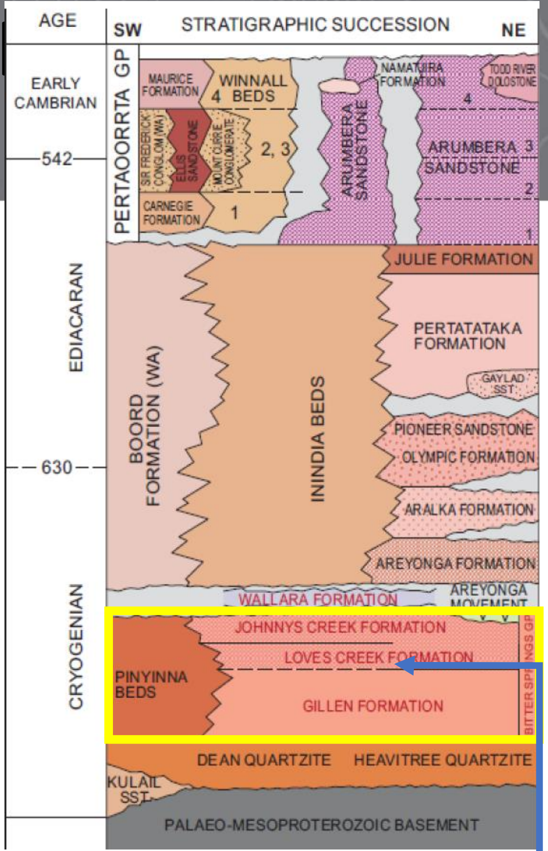
Centralian Intracratonic Sag Basin 830- 750 Ma





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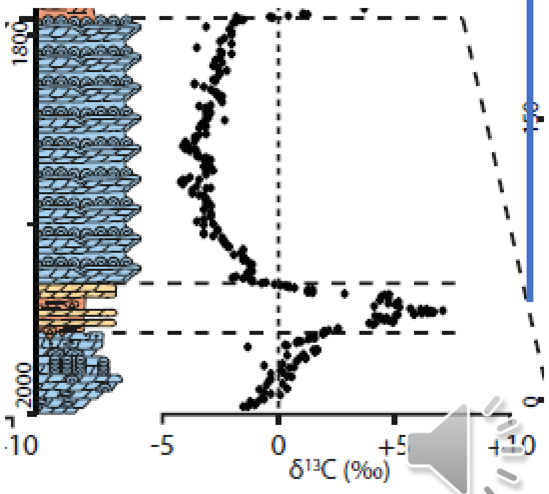


Source Klaebe

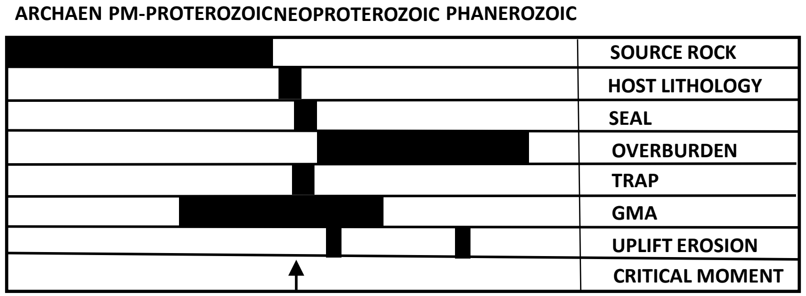
	OFFICER BASIN
Buldya Gp	Upper Browne Mbr
	Woolnough Mbr
	Lower Browne Mbr
Townsend Quartzite	

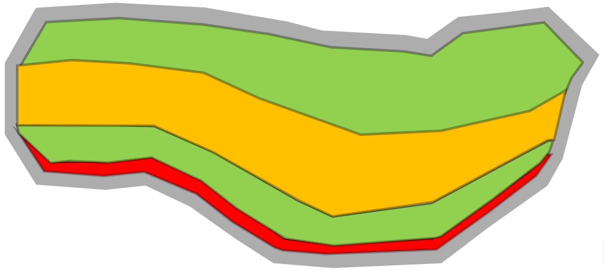
	AMADEUS BASIN
Bitter Springs Gp	Johnnys Creek Mbr
	Loves Creek Mbr
	Gillen Mbr
Heavitree Quartzite	

THE PETROLEUM BUSINESS AND CRITICAL MINERALS

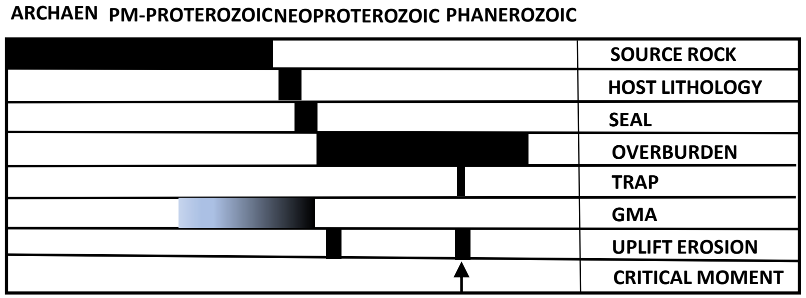
-NEOPROTEROZOIC HALITE BITTER SPRINGS LITHIUM

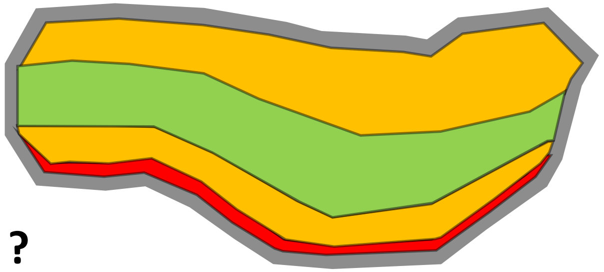
LITHIUM SYSTEM EVENT CHART STRATIFORM





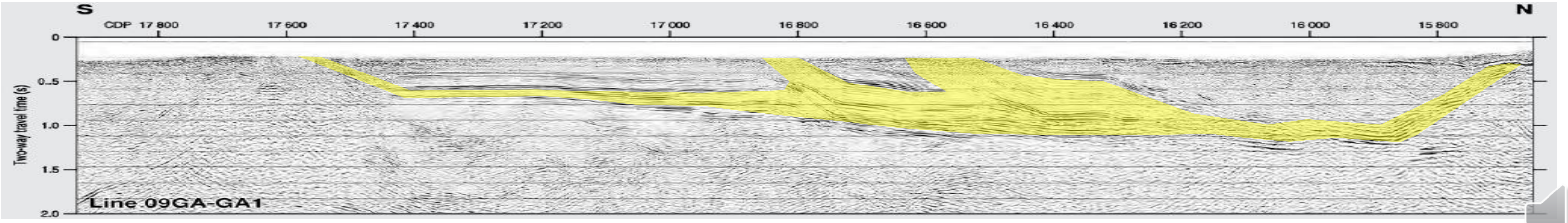
LITHIUM SYSTEM EVENT CHART HALOKINETIC





Amadeus Basin

Bitter Springs – Bitter Springs ?

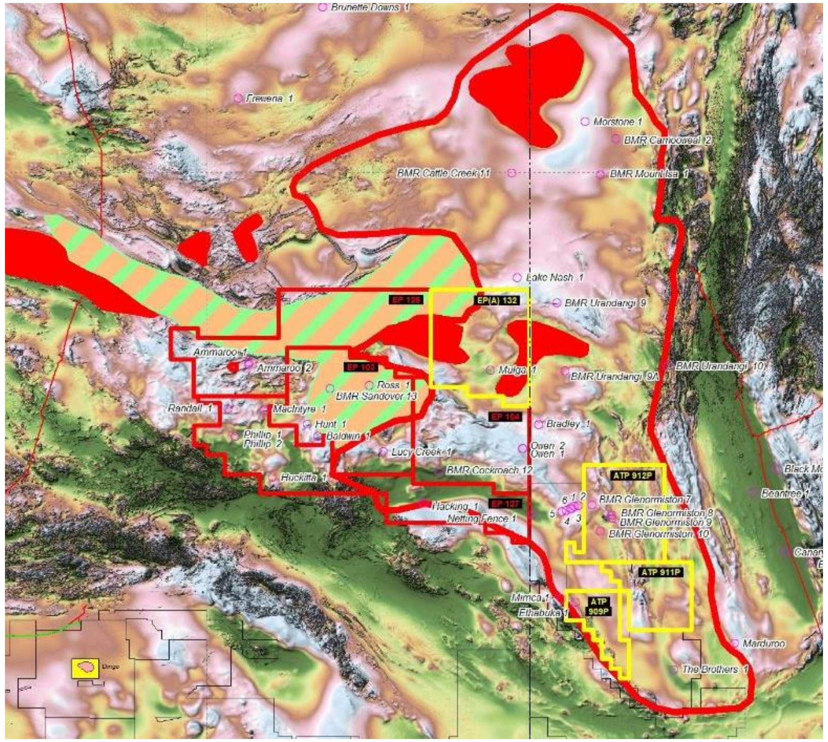


THE PETROLEUM BUSINESS AND CRITICAL MINERALS

-RADIOGENIC HELIUM

Helium produced from radioactive alpha emitters in the U-Th series, by molecular diffusion in local migration or longer migration within carrier beds and faults ultimately to be trapped in a reservoir beneath a competent top seal. Helium in the context of PBE steps beyond the method only in the source rock origin of Helium, in the most simplistic terms a Uraniferous source. Late stage microfractured Granitoids approaching pegmatite composition, Uranium primary or secondary deposit, asphaltic sandstones, entrained in hydrocarbon or connate waters via leaching or in unconventional terms a Uraniferous petroleum source rock. Other potential sources include metamorphic and sedimentary sequences, long stable, uplifted and subjected to high heat flow due to the onset of magmatism and/or rifting.

Increasing Helium diffusivity with depth (pressure and temperature) indicates the top seal efficiency decrease with depth and that (under) geopressure considerations are attention worthy. Anhydrite top seal is the logical candidate though other high density top seals should be considered.

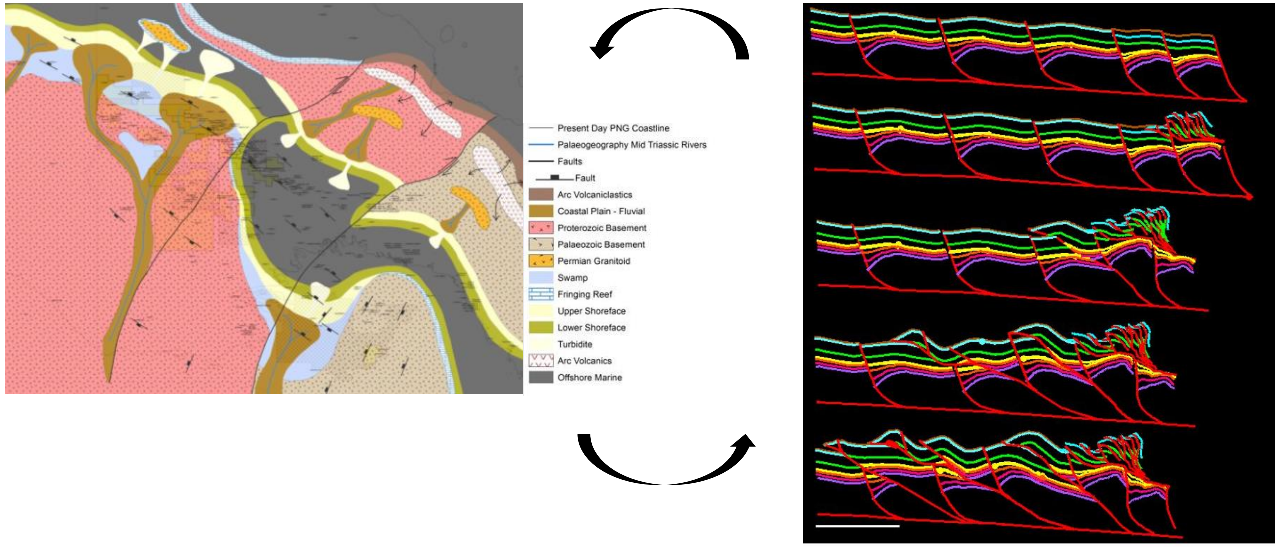


THE PETROLEUM BUSINESS AND CRITICAL MINERALS

-IT'S NOT ALL ABOUT PBE, SOMETIMES IT'S EXPLORATION TECHNIQUE

Graphite Mineralisation

Greenschist facies contact or regional metamorphosed coal (or other high TOC – kerogen rich source rock) is typically the source of *amorphous* or **microcrystalline graphite**. Microcrystalline graphite is not a critical mineral and is therefore not considered further. Disseminated crystalline syngenetic **flake graphite** is produced from a high TOC sedimentary rock subjected to amphibolite-granulite facies metamorphism, and epigenetic high crystalline or **vein graphite** is produced in amphibolite-granulites, from carbon-bearing fluids such as CO2 or CH4 as product of methanogenesis be it biotic or abiotic in origin. Syngenetic graphite conversion commences at 280^{O}C and graphitisation is complete at >650^{O}C. Graphite is a peak palaeothermometer (Raman Spectra), not subject to retrograde metamorphism.



Flake Graphite Play Based Exploration Introduction

Flake graphite plays may be initially classified (temporally) according to faunal criteria for the source of the organic carbon:

1: Palaeoproterozoic and Mesoproterozoic
2: Neoproterozoic
3: Phanerozoic

1: Palaeoproterozoic and Mesoproterozoic

From a palaeogeographical perspective the originating sequence would have resulted from cyanobacterial production and preservation in broad epicontinental pro-delta slope to distal settings, and Intracratonic anoxic marine platform settings, subsequently amphibolite-granulite facies, multi-phase metamorphic and igneous settings. At the most basic levels of consideration the intersection of the originating Proterozoic source rock facies within the present-day amphibolite-granulite metamorphic facies belts defines the bounding flake graphite play fairway (spatial) limits.

The next step is the deconstruct the (polyphase) deformations to the precursor sedimentary basin setting, determine palaeogeographic reconstructions and identify the locations and extents of high TOC source rock deposition. From this reconstruct the sedimentary basin back to the present-day and formulate the speculative target areas in the context of depth of burial, location under cover sequences, for example. Appropriate technology is then applied to the exploration for the prospective resource.

Sustainability and Evolution in the Industry & Market

- Why do oil & gas companies need to evolve? The business and energy climate is changing – investor activism – even on an institutional level is increasing and markets reward ethically conducted and environmentally sound practices.
- Controlling the integral components of the energy resources value chain will drive environmentally sound best practices, bolster reputation and facilitate wider access to an informed investor pool.
- Companies outsourcing critical components of their business value chain to less responsible third parties in cheaper operating environments risk being held accountable for their environmental harm.
- Investors can be encouraged to support a pricing premium supported by internationally recognised accreditation for environmentally sound best practice across the value chain that will also facilitate energy and strategic minerals security in an increasing fractured and insecure world.
- Governments have a geostrategic interest in supporting the exploration and development of reliable sources of strategic and critical minerals and should be willing to pay a security premium.
- The transition to renewable energy can reward responsible regionalism to replace globalism in a declining geostrategic climate.
- **Options:**
  - Do nothing and risk a dwindling investor base and increased vilification
  - Diversify without accountability and risk continuing or worsening adverse investor pressure
  - Discard core technical and business competencies and enter new business without clear competitive advantage
  - Reconfigure to control all essential components of energy resources value chain, influence public perception and shape the transformation of energy supply

THE PETROLEUM BUSINESS AND CRITICAL MINERALS:

SOME CONCLUSIONS

- Despite the increasing importance of renewables, Hydrocarbon fuels and derivatives will remain essential to the global community and industry for the next few decades at least
- Oil & Gas explorers will need to evolve with care, retaining core skills and competitive advantage whilst moving to integrate essential minerals and resource exploitation and generation into their portfolios or ambit of control
- Future integrated energy companies will need to be prepared for increased scrutiny of the entire energy chain and control all aspects of their involvement to ensure environmentally and economically sustainable best practice
- The integrated energy resource business model is achievable by both Mining and Oil & Gas Companies - each pathway made possible by increasing leverage of intrinsic technical competencies and more effective by strategic partnership

CHERRYVALE PARTNERS

Lindsay A. Ross
Director and Exploration Geologist
Cherryvale Partners Pty Ltd

Lindsay@Cherryvale.com.au

https://www.linkedin.com/in/lindsaycherryvale/

Rockleigh Energy
Advisory | Assurance | Consulting

David Beckett
Director
Rockleigh Energy

david.beckett@rockleigh-energy.com

https://www.linkedin.com/in/david-beckett-bb699810/
https://www.linkedin.com/company/rockleigh-energy/?viewAsMember=true