REMIX
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Georesources Cornwall

Recommendations for development of the Georesources sector in Cornwall

REMIX project

The aim of this Georesources Cornwall document is to advise Cornwall Council and Cornwall and Isles of Scilly Local Enterprise Partnership on the mining and related opportunities in Cornwall and how best they might be encouraged and facilitated. It is an output of the REMIX project.

REMIX was funded by Interreg Europe to encourage resource efficient and environmentally and socially acceptable production of raw materials by working with regional policy instruments. It brought together partners and stakeholders across nine European regions, at different stages of the mining cycle, to share knowledge and develop best practice guidelines. Camborne School of Mines, University of Exeter was the partner for the region.

In Cornwall we brought together stakeholders, especially Cornwall Council and the companies in the Cornwall Mining Alliance for workshops on specific topics and facilitated travel to European partners to a series of peer review meetings to learn from their activities and experience. A peer review visit of European partners to Cornwall was held in May 2018. Various interviews were also held with individual businesses. Expertise external to the university was used to help compile information, especially on mineral rights, mine water geothermal energy, the Cornwall Mining Alliance business cluster and potential economic development through growth of this sector.

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Summary Recommendations

Georesources are an important part of the region's Natural Capital and can bring economic development through Clean Growth. Current exploration projects could generate an additional £1 billion GVA over the next 20 years in a world-leading, highly specialist sector. Minerals, geothermal energy, heritage and the natural beauty of the region need to be considered together.Using the local industrial strategy, an ecosystem of geothermal energy, tin, tungsten and lithium exploration, production and refining can be created in the southwest, centred in Cornwall.

Recommendations from each section have been consolidated into six key suggested actions for Cornwall Council and Cornwall and Isles of Scilly LEP. The first three are particularly relevant to the Minerals Planning and the second three to economic development.

1. Set up a Georesources data and information centre 'one stop shop' for geological, surface and social information, starting from the research project planned in the Digital Mining ERDF proposal which is currently under development at second stage.

2. Create a strategy to develop Georesources in Cornwall, implementing high standards of responsible sourcing. Use this to enhance the mineral planning process, including 'syn-mining' generation of additional economic activity and public outreach.

3. Include geothermal activities in the minerals planning and safeguarding remit. Join/form national working group to create national legislation regarding protection of deep and shallow geothermal energy and extraction of metals from deep and surface mine waters to encourage inwards investment in these businesses.

4. Invest in the Cornwall Mining Alliance cluster to expand productivity and the number of businesses, including staff time to pursue business opportunities for the cluster. Consider an enterprise zone for this sector (Wheal Jane, Camborne-Redruth).

5. Invest in/ facilitate major research and innovation initiative(s) such as Strength in Places or similar to:
   a) accelerate the understanding of regional sub-surface geology using state of art geophysics techniques and geological concepts. Mine waste can be included in this study, both as a future resource, and as environmental contamination.
   b) improve local processing/refining and manufacturing value chain opportunities for lithium, tin, tungsten.
   c) expand the number of businesses in digital mining, including business incentives to relocate and start up in Cornwall.

6. Continue support for deep geothermal electricity and heat projects but also invest in mine water geothermal energy for domestic and commercial heating. The use of underground heat has become more sophisticated in the last five years and is an important opportunity as an alternative to gas central heating.

1. Georesources Cornwall – an integrated approach

The Georesources of Cornwall include the mineral wealth, geothermal potential and spectacular geology that shapes the landscape. Together these are Cornwall's underground natural capital. They give the region a unique opportunity to contribute to the low-carbon, high-technology world through sustainable economic development.

Georesources in Cornwall include:

- World class kaolin mines and associated research centre
- Granite-related minerals of economic interest, including world class deposits of tin and tungsten plus the potential for (hard rock) lithium, and copper, zinc, indium, cobalt, uranium, and the potential to rework waste deposits
- Potential for lithium production from deep brines
- Quarrying sector – building and decorative stone, aggregates
- Highest geothermal gradient in the UK high potential for a range of geothermal energy including geothermal electricity generation and mine water geothermal
- Cornwall Mining Alliance business and innovation cluster of over 100 organisations, the only such cluster in the UK, exporting goods and service worldwide
- The Cornwall and West Devon Mining Landscape UNESCO World Heritage Site and National Trust heritage attractions demonstrate the long history, pride in the sector and famous name of Cornwall, synonymous with mining in many parts of the World.

Figure 1: Wheal Coates (photo courtesy of Ainsley Cocks).

- Museums with internationally important collections to inspire and educate about the natural world.
- Active groups including geoconservation and geological societies
- University research, innovation and education in the sector, including the Camborne School of Mines, the UKs only multidisciplinary mining school and a world leader in education and research for the georesources sector
- A coast line with superb geological exposure, tourist and heritage value

An integrated approach to georesources is essential because:

- The technical considerations including a better understanding of subsurface geology are equally relevant to both mining and geothermal energy. Many of above ground considerations, as well as the expertise and equipment provision are also common to the whole sector.
- Geological resources are part of our natural capital (natural capital is simply those assets provided by nature which have the capacity to generate goods and services. Natural capital can be regarded as the source of all other types of capital: whether manufactured, financial, human or social) along with the ecosystems of landscapes, wildlife, soils, air and natural waters. They need to be looked after and used wisely in balance with each other.
- Stakeholder partnerships are key to using georesources well and essential in gaining public support for major industrial initiatives such as opening new mines or geothermal energy production.
- There is a need to inspire, interest and educate people in the sub-surface natural world in order to produce the next generation of employees, entrepreneurs and innovators in the sector, as well as an informed public.

Opportunities

- Maintain networking opportunities, like those facilitated by the stakeholder meetings in REMIX.
- To lead best practice in a partnership approach to using the georesource natural capital of Cornwall.
- Coordinate Georesources educational activities and museum collections that can be carried out at multiple venues.

Figure 2: Collaboration between the Mining World Heritage site, Cornish Lithium and University of Exeter to meet the public at Royal Cornwall Show (photo courtesy of Ainsley Cocks).

Barriers

- There are many relevant activities already happening but rather piecemeal and relies on projects such as REMIX with external funding to bring stakeholders together.

Recommendations

1.1 - Encourage cluster and networking opportunities, e.g Cornwall Mining Alliance, which already includes mining and geothermal sectors, mainly Cornwall but also Devon and Southwest Georesources Partnership that aims to include a wider range of stakeholders.

1.2 - Catalyse activity to coordinate outreach and education activities

2. Technology metals and minerals in Cornwall

Figure 3: Cornish cassiterite (Photo courtesy of Calum Beeson, Camborne School of Mines, University of Exeter).

The transition to a low carbon and digital economy, coupled with the increasing global population who can afford energy, consumer goods and transport, means that we need to mine more raw materials and a wider range of raw materials than ever before.

A low carbon economy = A minerals economy

Cornwall already has world class kaolinite mines and associated research centre. It also has quarries for building and decorative stone, aggregates and a large cluster of other georesources-related businesses.

Metalliferous mining finished in Cornwall when it was no longer economic to mine the ores. There is still certainly ore in the ground, and with higher prices and new technologies, metals mining could start again in Cornwall.

Estimated past metal production in Cornwall: Tin, 2.5-3 million tons; copper 2 million tons; tungsten concentrate, >8000 tons; arsenic oxide, 0.4 million tons; iron ores, 2 million tons; zins, 0.2 million tons; lead, 0.5 million tons; silver 1000 tons + minor uranium, antimony, nickel, cobalt, bismuth

Opportunities

- Cornwall has world class deposits of technology metals and a role to play in providing these raw materials to manufacturing industry.
- Lithium is an essential battery material.
- Tin is one of the most important technology metals, in all electronic devices as a component of solder[1] and the indium tin oxide that makes touch screens work[2].

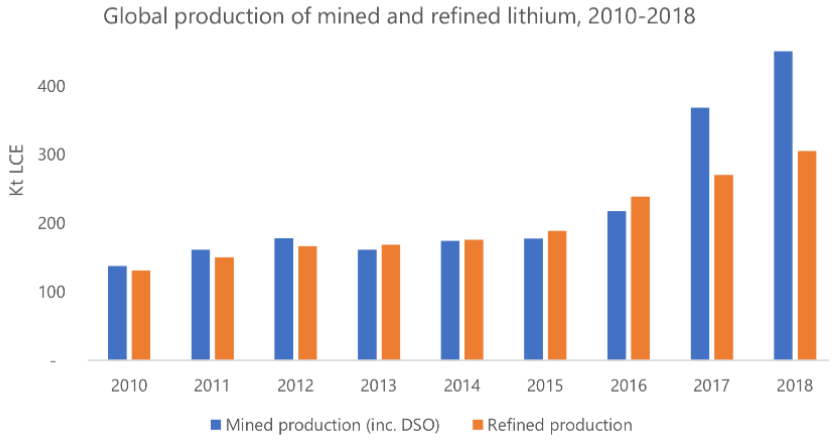
> Roskill: 'The **tin** market is entering an interesting phase with the diversification of applications in high and new technologies. Established major producers are investing in expansions and new producers have commenced or will be commencing operations in the near future to help supply catch up with the forecast demand increase. These however might be insufficient, potentially leaving enough space for new suppliers to enter the market.'
>
> https://roskill.com/market-report/tin/ Accessed 21.6.19

[1] https://www.internationaltin.org/how-is-tin-used/ Accessed 2.7.19
[2] https://www.chemistryworld.com/podcasts/indium-tin-oxide-ito/3008984.article Accessed 2.7.19

- Tungsten is a critical raw material for Europe[3], essential in tools (tungsten carbide) for many manufacturing processes.
- There are current tin and tungsten exploration projects – including two of the highest grade deposits in the world at South Crofty and Redmoor.
- Lithium is being sought in 'hard rock' mica deposits in granite, as by-product and in waste mica from China Clay operations and in sub-surface brines.

Roskill 2019 – 'Demand for **lithium** is expected to increase five-fold over the coming decade, driven principally by demand for lithium-ion batteries and their use in electric vehicles, energy storage systems and portable electronics. Lithium demand is forecast to increase by over 20%py, with demand from battery applications increasing by over 25%py through to 2028. [We] expect the lithium market to enter a period of sustained supply deficit in the early 2020s.' Lithium outlook to 2028, 16th edition. https://roskill.com/market-report/lithium/ Accessed 21.6.19

KtLCE – thousand tonnes of lithium carbonate equivalent



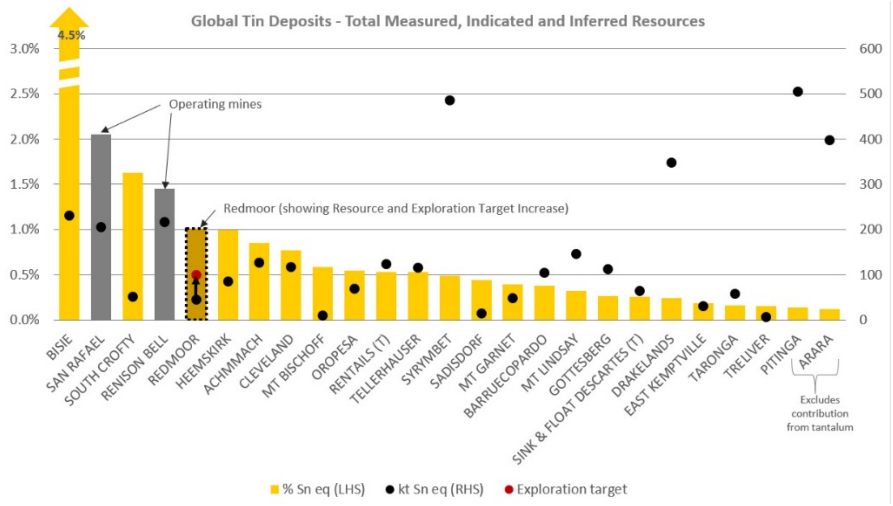


Figure 4: Exploration company illustration that Cornwall has some of the highest grade (i.e. richest) tin deposits in the World[4].

- Nearshore marine and estuary deposits of waste contain tin ore from previous mining and ore washed out of the rock by natural processes and deposited at sea.

[3] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en Accessed 3.9.19
[4] https://www.strategicminerals.net/projects/redmoor-tin-tungsten-exploration.html accessed 21.6.19

- Copper, indium, zinc, lead, and cobalt are also present but not yet of economic interest in the region unless mining technologies and prices change.

- It is possible to imagine a new ecosystem of minerals production; a mixture of open pit and underground mining and bore holes to extract lithium, linked to geothermal energy and other renewables, done to world-leading standards.

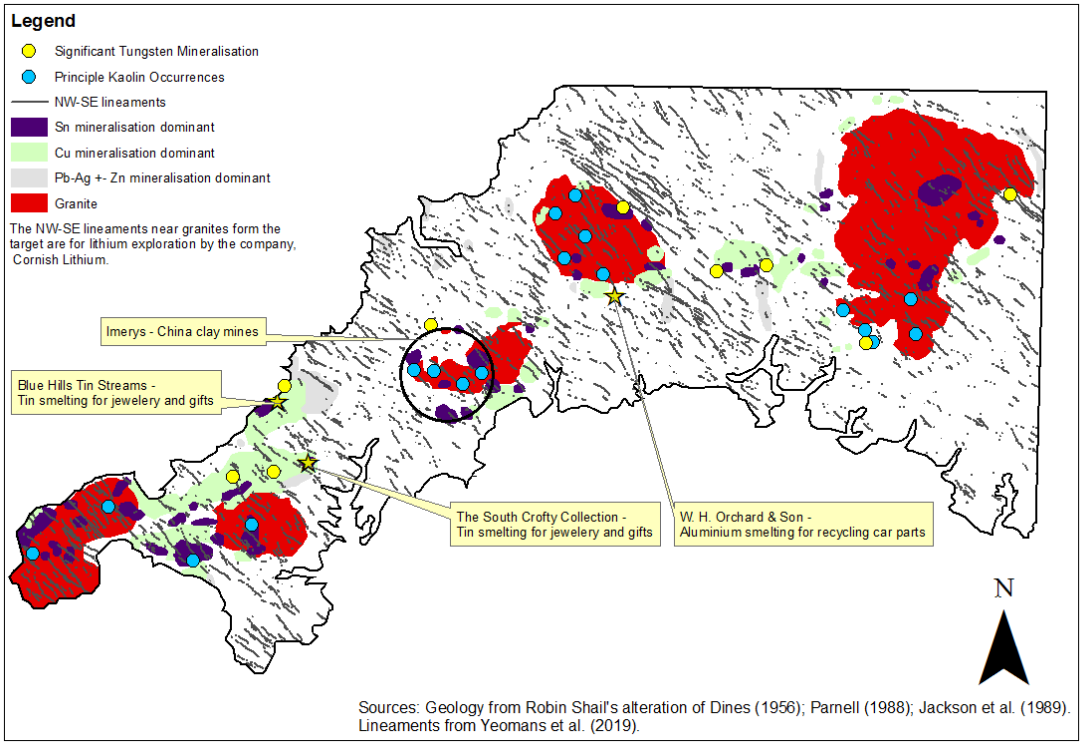


Figure 5: Mines, metallurgy (smelting) and mineral deposits in Cornwall. The lineaments are of interest for lithium and geothermal energy.

Barriers

- Despite the current scientific knowledge, we still do not know where exactly ore deposits are in the subsurface. Finding them requires expensive drilling and many years of work.
- It usually takes at least ten years to develop a new mine through the exploration, permitting and construction phases. The projects in Cornwall are all at early stage.
- Most exploration companies, especially for specialist technology metals are small (junior) companies, who are reliant on external investment to progress through the stages of exploration and development of the mine. Raising this investment can be slow, or even impossible and is dependent on many factors in addition to the technological features of the deposit.
- Minerals exploration is a high risk business. When it succeeds the reward is high but the reality is that most exploration projects do not come to fruition as mines.

- Extraction of lithium brines is a new technique and requires a different kind of exploration and extraction, as well as new processing technology. Extraction of lithium from mica is not yet done in a commercial mine.
- The UK, and Cornwall in particular has a reputation that securing mineral rights is difficult, expensive and time consuming. The can discourage exploration companies from coming to Cornwall and act a barrier to investment in exploration projects.
- Cornwall (and the UK in general) is almost unknown as a jurisdiction interested in mining. There is so little activity in the UK that it does not feature on any of the international mining indexes (such as the Fraser Institute Annual Survey of Mining Companies). There is no 'shop window' for Cornwall.
- Public support for mining (the 'social licence') in Cornwall is generally good. However, there has been more opposition to proposed marine and coastal operations. Social Licence cannot be taken for granted if lost can greatly hinder operations (cf. fracking in the UK).

Recommendations

2.1 - Create a shop window for the sector in Cornwall and promote this internationally by setting up a georesources information and data centre. If a new ERDF-funded project on 'Digital Mining' is contracted successfully, this will provide the R&I activity needed to set up this facility, including a new visualisation suite for local businesses to use. Delivery partners are University of Exeter, British Geological Survey, Cornish Lithium, Cornwall Resources, SW Satellite Applications Catapult. By joining with Cornwall Council, Cornwall Development Company, Department for International Trade, and local companies including mineral rights owners, this project can form the heart of a 'One Stop Shop' information centre. It can contain state of the art visualisation of the sub-surface geology showing the links to mineral rights and all the surface information such as land ownerships and designations, mine workings, current projects. The centre would provide easy access to advice on planning and permitting, Cornwall Council and LEP support for investment, R&I, staffing, internships, networking, services, offices/incubator, and exploration services. Representatives (such as Cornwall Development Company would attend PDAC Prospectors and Developers Association of Canada, Toronto in March and other similar events each year.

2.2 - Cornwall Council can help to make mineral rights more transparent and easier for companies to navigate. The Mining Alliance has taken a first step by setting up a page for mineral rights owners and agents to list on the Alliance website https://cornwallminingalliance.org/mineral-rights-companies/. Information on mineral rights can be integrated with other data as part of the Digital Mining research and innovation project, and with the cooperation of rights owners, a substantial amount of information may be gathered. If this initiative is not successful, the suggested route is to seek legislation change to create a national administration of mineral rights, similar to the systems in the Republic of Ireland or Northern Ireland (see appendix for more information).

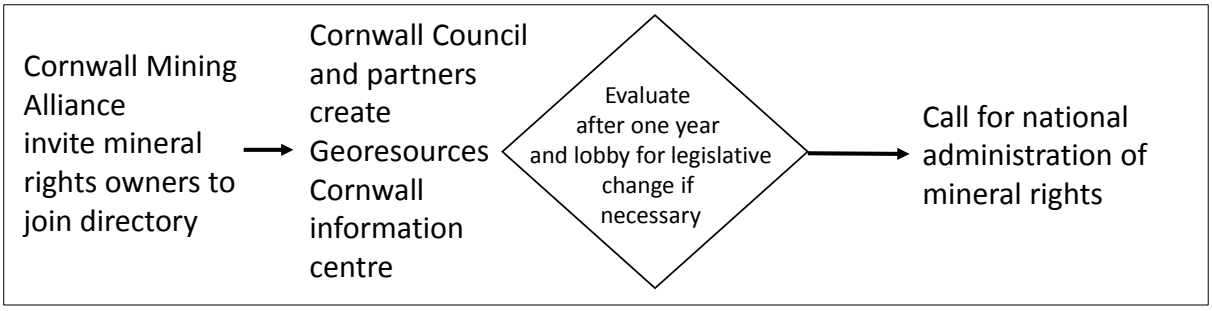


Figure 6: A route to make mineral rights information more transparent and accessible.

2.3 – CioS LEP and Cornwall Council can support major research and innovation funding bids, e.g. to UK Research and Innovation or regional development funds, to improve knowledge of the subsurface. The South West was the first mainland region of the UK to have a high resolution 'Tellus South West' geophysics survey in 2013. This has been very helpful to exploration and active Georesources projects. However, there is more pre-competitive geophysical and geochemical work that needs be done to aid further exploration and de-risk minerals and geothermal projects.

2.4 - Mining and processing techniques also would also benefit from major research and innovation investment to speed up development of lithium projects, especially granite-related brines, but also mica processing.

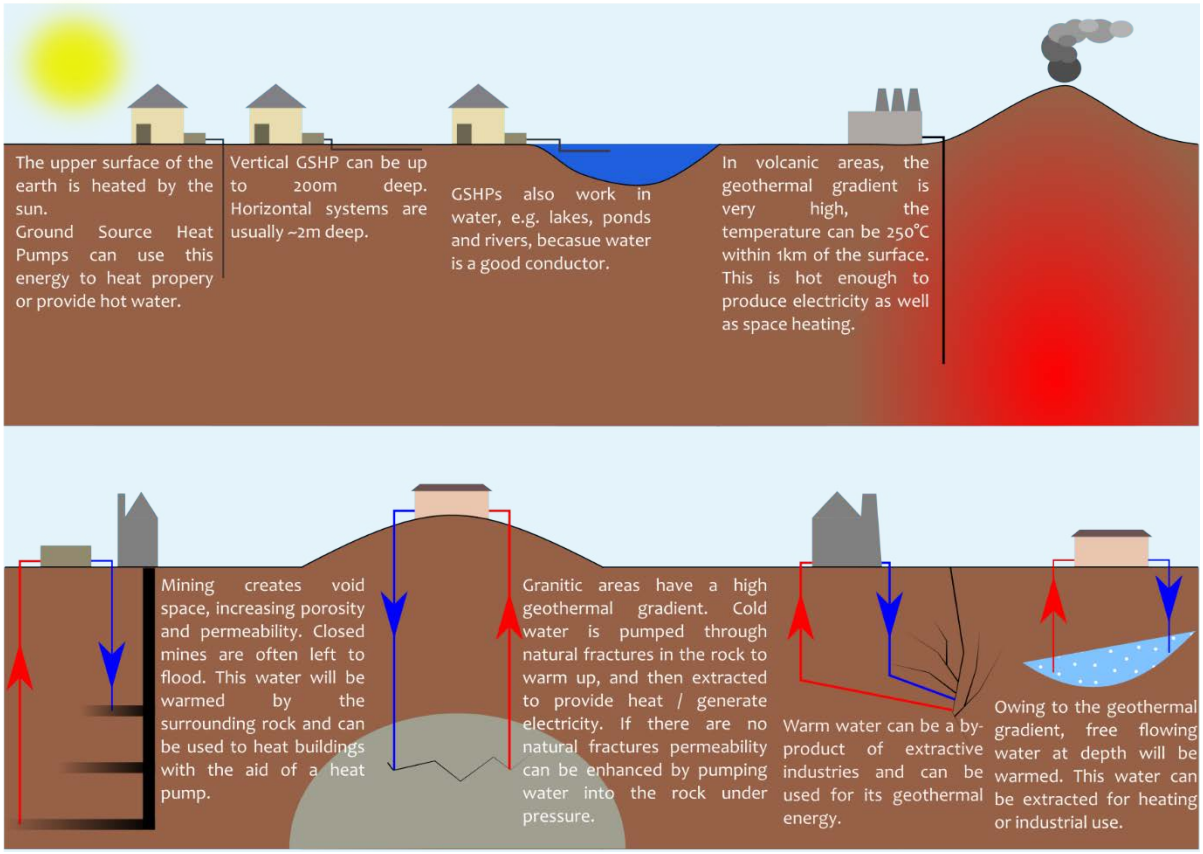
2.5 - Be ready for failure. If exploration projects fail to move onto the next stage of exploration, it is important to retain data and expertise ready for future projects.

2.6 - Cornwall Council, through the Mineral Planning Authority can help to ensure best practice – preferably world leading best practice - including linking minerals, quarrying and geothermal sectors since perceptions are easily transferred between them. Social licence (public acceptance and support) is excellent for land-based projects in the region but needs to be retained and should not be taken for granted. Investors are increasingly looking for higher standards and assurance.

2.7 - Environmental research on near shore marine environment and best technologies would help the companies here gain public acceptance by being seen to be at the forefront of good practice and able to design an extraction system that will cause least disruption, and potentially have some positive effects.

3. Geothermal Energy

Geothermal energy comes from within the Earth's crust, in the form of heat and is a renewable resource. Cornwall is well endowed with a variety of geothermal heat sources – it has everything - except volcanoes.



- 'Hot Rocks' – in granitic areas the rocks are hot because granites contain radioactive elements (potassium, uranium, thorium), and when these decay, they produce heat. The Southwest's granites have the highest geothermal gradient in the UK (up to 35 °C/km, giving heat flows of +125 mW/m^2 , compared to the UK average of 54 mW/m^2 [(5)]). While solid granites do not have free-flowing water, water can flow along natural fractures, along faults for example, or the granite may be fractured artificially. This allows water to be pumped through the rock to be heated and then extracted. If the system is hot enough, the water can be used to produce electricity via steam, with heat as a co-product.
- Deep groundwater – heat from the Earth's interior raises the temperatures of all rocks at depth. In the UK the average geothermal gradient in 26 °C/km. Groundwater at depth (e.g. 500 – 2500 m) will be heated and can be extracted and used as heat.
- Mine water – in abandoned and flooded mines there is void space is below the water table and the water in the flooded chambers is slightly warm and can be used as a heating or cooling source.
- Shallow geothermal – ground source heat comes from the upper 1.2 - 200 m of the Earth, which is heated by solar energy and acts as a heat store. Ground source heat pumps exploit this heat store to warm buildings in the winter, and in some cases cool them in the summer.

[5] http://science4cleanenergy.eu/wp-content/uploads/2018/10/An-Overview-of-the-United-Downs-Deep-Geothermal-Power-UDDGP-Project.pdf Accessed 5.7.19

Opportunities

Cornwall is the most prospective area in the UK for electricity generation from geothermal energy. The United Downs Deep Geothermal Power Project has found water at ca. 190°C at 5 km depth. The potential is recognised in Europe where there is a European Technology and Innovation Platform on Deep Geothermal[6].

- Heat as a by-product from power generation or dedicated heat projects can facilitate new industries in Cornwall as well as providing renewable heat for domestic application.

- Mine water geothermal can be used for heating and cooling. This may be from underground water or water flowing out of adits, such as at the treatment plant at Wheal Jane. The leaders in use of mine water, such as Heerlen in the Netherlands[7], now have sophisticated urban energy management systems to balance heating and cooling with a deep underground mine water buffer. Prospective areas have been identified in Redruth and St Austell (Appendix 3).

- There are many more opportunities to install ground source heat schemes for domestic and commercial properties. Cornwall has the business expertise to expand in this area.

- Geothermal energy may link directly to minerals production, with either lithium extraction from hot waters or metals and heat extraction from mine waters that need to be cleaned prior to discharge.

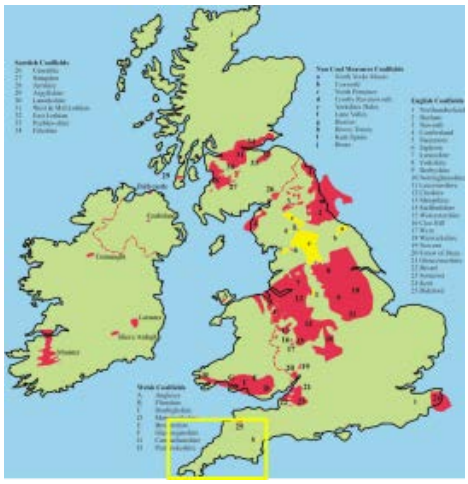


Figure 7 Maps of UK mine water potential for geothermal energy often omit Cornwall (British Geological Survey map)

Barriers

- Deep geothermal electricity generation is still experimental in the UK and needs a demonstrator (or two) and better geological understanding to attract private investment.
- The law regarding protection of heat near deep wells and in mines is unclear[8], as are regulations regarding extraction of metals from these waters.
- Mine water in metalliferous mines is usually omitted from UK maps of mine water geothermal potential, which tend to concentrate on coal mining areas. Cornwall is more prospective than coal mining areas because of its higher geothermal gradient.
- Although previous studies of mine water in the Camborne-Pool-Redruth area did not show the proposed schemes to be economic, the state-of-the-art has improved since then and it would be wise to visit a leading project such as Mijnwater, at Herleen in the Netherlands.

[6] European Technology and Innovation Platform on Deep Geothermal (ETIP-DG) (2019) 'Implementation Roadmap".

[7] https://www.mijnwater.com/?lang=en Accessed 3.9.19

[8] Who owns (geothermal) heat?, Policy Position Paper, British Geological Survey, November 2018 https://www.bgs.ac.uk/research/ScienceBriefingPapers/home.html Accessed 5.7.19

- Cornwall does not necessarily have the right businesses to take advantage of geothermal heat and cooling so it might be necessary to attract new businesses, such as horticulture or data centres, to the region to take full advantage of the opportunity.

Recommendations

3.1 - Continue to support the deep geothermal United Downs and Eden projects.

3.2 - Encourage participation in European initiatives on geothermal energy.

3.3 - Support further geophysical research to understand the fault structure and heat gradients across the Cornwall region. This study can be combined with the pre-competitive geophysics and geochemical study needed for technology metal deposits.

3.4 - Set up a Cornwall Georesources data and information centre to help attract investment and interest in geothermal energy in the region, again this is the same recommendation as for technology metals.

3.5 - Create and use a UK mine water map with Cornwall on it.

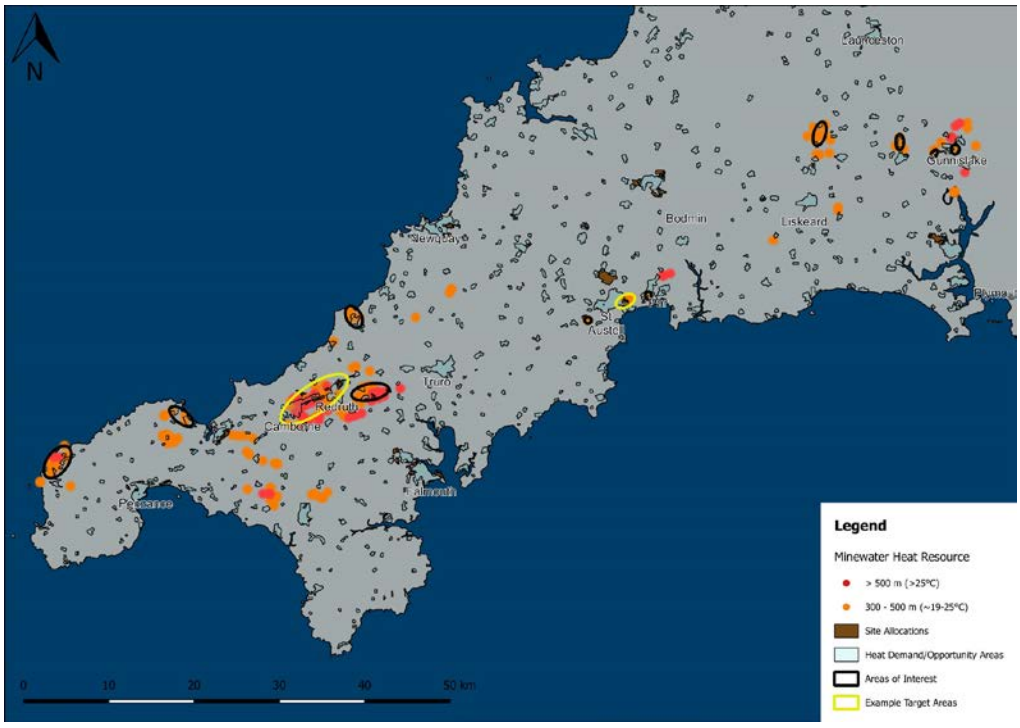


Figure 8: A new study of mine water potential done for the REMIX project has identified promising areas (see appendix for details).

3.6 - Support a new feasibility study/demonstrator site for mine water geothermal for heating houses or an industrial site.

3.7 - Visit Heerlen in the Netherlands to see state-of-the-art urban management of heat and cooling with a mine water base, and make contact with local authorities in County Durham, south Wales and Glasgow (via British Geological Survey) to exchange experience.

3.8 - Join with other authorities (Durham, South Wales, Glasgow) planning to use geothermal (heat), the British Geological Survey and Coal Authority to propose new legislation to protect heat, and clarify heat and metals in disused mine waters.

3.9 - Include deep and shallow geothermal, including ground source heat pump technologies, in climate change emergency actions, aiming to replace gas and oil central heating.

4. The Mining Life Cycle

Every mine goes through a life cycle from exploration through to construction, mining, closure and remediation. Even without major metalliferous mining today, experience of the full mining life cycle gives Cornwall expertise that can be applied worldwide. Regions and countries active today in mining, such those in Chile, Canada and Australia will all go through this cycle. Many coal mining regions in Europe are now in a closure phase. This experience also gives Cornwall the opportunity to ensure that sustainable economic development is delivered from future georesources industries, especially technology metals and minerals.

Opportunities

- Planning for environmental remediation is now done routinely during the mine planning stage before a mine opens but best practice now is to create additional economic activity during the life of the mine that will be sustainable after mine closure. There are some good practice examples as Imerys close parts of the St Austell china clay area. Alongside planning permission for any new mining activities, there needs to be a plan for generation of additional economic activity – into the georesources service sector, value chain or other services during the mine life.
- It should be possible to develop further export opportunities around expertise in the mining life cycle, especially post mining regeneration. Most mining regions develop a museum in a post mining landscape but Cornwall has a much wider range of initiatives.
    - Wheal Jane Earth Science Park – a range of businesses related to the mining sector, use and remediation of the tailings facility, renewable energy.
    - Eden Project – major visitor attraction.
    - Imerys – Eco-Bos West Carclaze Garden Village with associated businesses, and renewable energy, including wind energy and potential hydro-energy.
    - Cornwall Mining Alliance business cluster.
    - Camborne School of Mines, University of Exeter.
    - Cornwall and West Devon Mining Landscape UNESCO World Heritage Site.

Figure 9: Wheal Jane is an example of good practice in post mining regeneration (Photo courtesy of Bernard Ballard, Wheal Jane Group).

Barriers

- Unlike in many other countries, minerals are mostly owned privately (by the mineral rights owners) and so there are no resource rents/taxes flowing back to the state to invest.
- Lack of planning expertise in the sector except for planning considerations in relation to quarrying
- Too few learning opportunities to transfer best practice from larger organisations to local microbusinesses and SMEs.

Recommendations

4.1 - Cornwall Council can learn about international best practice in 'syn-mining' economic inputs from mining projects and apply this during the planning application stages.

4.2 - Encourage more opportunities, e.g. through the Mining Alliance for learning and sharing best practice and especially transfer from larger to smaller businesses.

5. Mines wastes: old problems, future opportunities

Centuries of mining in Cornwall have left a legacy of mine wastes. Some, such as arsenic–bearing wastes and acid mine drainage are hazardous but they also contain material of economic value. There are future opportunities in remediation and in finding novel uses of mine wastes.

Some of the most seriously contaminated sites, such as the arsenic labyrinth at Botallack, have been remediated. However, other iconic landscapes such as the tailing lagoons at Wheal Maid in Gwenap Parish are still contaminated[9]. Sediments in estuaries also contain potentially hazardous waste washed down the river from former mining operations. Acid mine water pumped from the Wheal Jane workings is treated to neutralise it and remove potentially toxic metals and metalloids before release to the Carnon river.

Working mines often produce large amounts of waste and are keen to find alternative uses for the material. Imerys china clay mines have engaged in good practice in working with other local companies who put waste rock to a range of uses, from aggregates to more unusual products such as bee bricks.

Figure 10 Arsenic-contaminated tin and copper mining waste, Wheal Maid tailings lagoon (Photo courtesy of Karen Hudson-Edwards

Opportunities

- The two known largest potential opportunities for re-use of mine waste are the lithium in mica in china clay waste and tin in mine waste deposited at sea near St Ives. Neither of these wastes are currently viewed as environmental hazards. They are best considered with the other minerals opportunities in Cornwall.
- The Wheal Maid site is contaminated with arsenic-contaminated areas in Cornwall and yet are also important amenity and cycle trail area, and a popular site for student fieldtrips to study contaminated land. There is an opportunity for a rehabilitation of

[9] Carrick District Council Environmental Protection Act 1990, Part2A – Section 78B Record of Determination of Wheal Maid Tailings Lagoons, Gwennap, Cornwall as Contaminated Land https://www.cornwall.gov.uk/media/3625647/2008-09-16-Record-of-Determination.pdf Accessed 3.7.19

this site to improve the amenity for local people and tourists, and create a field laboratory research and training site for use by local organisations and businesses.

- There are business opportunities in linking recycling to the primary supply of raw materials. There is already an aluminium smelter in Cornwall near Liskeard, recycling car engine parts and it is possible that other high tech solutions to reuse and recycling can also be developed building on the expertise in minerals processing in Cornwall. Expertise in circular economy, by-products, co-products is exportable and linking CMA cluster to R&I in this area will help to expand the business sector. The ERDF-funded Tevi project (promoting environmental growth for business) is running an Environmental Challenge Network to produce a road map for research and innovation and growth of this sector. It links to Cornwall Council's Environmental Growth Strategy 2015-2065.
- There is potential to recover useful metal products from mine waters rather than sending them to waste. The UK Coal Authority is carrying out research in this subject at several sites in the UK.
- The nature of soils is controlled by the geology, so soil may also be considered as a georesource. Better knowledge of soil geochemistry and links between geochemists and agricultural scientists may help the agri-food industry.

Barriers

- We have become used to contaminated sites in Cornwall and this probably creates some inertia about updating to best practice in remediation.
- R&I investment is required to start new projects.
- There is a lack of a circular economy sector for minerals in Cornwall
- Many former mine sites are now conservation areas and sites of special scientific interest[10]. These sites may benefit from remediation and may have minerals of economic interest, but any disturbance would need to be balanced against their biodiversity, geoconservation, heritage and amenity value.

Recommendations

5.1 - Consider outcomes of Tevi project Environmental Challenge Network on mine waste.

5.2 - Include reworking of mine waste and links to other circular economy opportunities in an overall strategy for Georesources in Cornwall and link to Mining Alliance businesses

5.3 - Include mine wastes in any new geophysical/geochemical study to de-risk exploration in Cornwall.

[10] Crane RA, Sinnett DE, Cleall PJ, Sapsford DJ. (2017) Physicochemical composition of wastes and co-located environmental designations at legacy mine sites in the south west of England and Wales: Implications for their resource potential, Resources Conservation and Recycling, 123, 117-134, DOI:10.1016/j.resconrec.2016.08.009

6 Cornwall Mining Alliance – Business Cluster

Figure 11 Cornwall Mining Alliance logo

Cornwall has the only cluster of mining-related businesses in the UK. The Cornwall Mining Alliance has 106 businesses and organisations related to mining and the wider georesources sector. It is recognised by the Department for International Trade as a high potential opportunity for the UK (www.cornwallminingalliance.org).

Figure 12: Sectors in the Cornwall Mining Alliance. Most of the businesses are microbusinesses or SMEs. Graphs are from a survey of the Mining Alliance done for the REMIX project, see appendix for further details.

The Cornwall Mining Alliance was launched in October 2016, by the Cornish Chamber of Mines and Minerals, together with the University of Exeter (Camborne School of Mines), with support from the Department from International Trade. It covers a wide range of georesources activities, and consists mainly micro businesses, SMEs and local branches of larger companies. Fifty eight per cent of companies export goods or services, with connections to 155 countries.

Opportunities

The opportunity is to be a world-leading cluster in this high value export sector. The supply chain companies complement the producers in that their activities are lower risk. Someone will need to mine, even if all the projects in Cornwall do not come to fruition and this business cluster sells good and services worldwide.

The World will need to mine more and a wider range of raw materials in order to combat climate change[11].
Four times as much copper in an electric car as a petrol car (World Bank)
As much copper needed in the next 25 years as in the last 5000 (World Bank)

[11] www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action

A wide range of elements needed - 44 elements even to manufacture one computer chip[12]

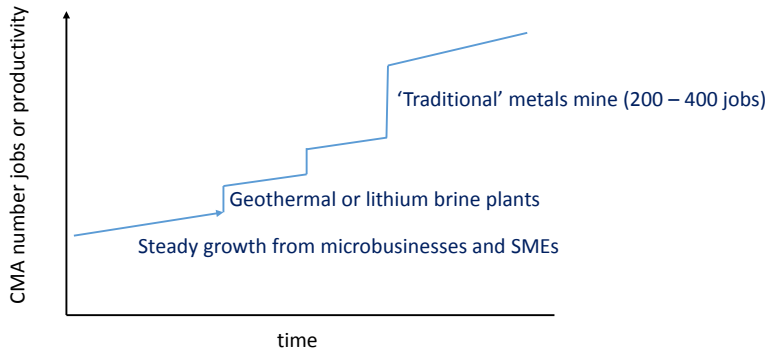


Figure 13 Continued growth of the service and equipment sector will be punctuated by larger increments of growth as geothermal and minerals extraction operations open up.

Jobs and productivity are likely to grow together, with steady growth of supply chain companies and exploration companies punctuated by opening of new operations

The sector is already highly collaborative, expanding and keen to innovate. Eighty percent of Alliance businesses already collaborate, and practically all would like to. One third are engaged in experimentation with new digital technologies. Two thirds have increased revenue or employees in the last five years.

The mining industry is moving quickly to embrace digital technologies, including use of 'big data, automation, remote control, robotics, remote sensing and artificial intelligence.

Primary production of raw materials, geothermal energy, oil and gas extraction and recycling all require many similar skills and are serviced by companies in the Alliance.

There is good potential to bring highly qualified professionals, such as graduates of Camborne School of Mines with international experience to Cornwall to set up new businesses as well as join existing organisations.

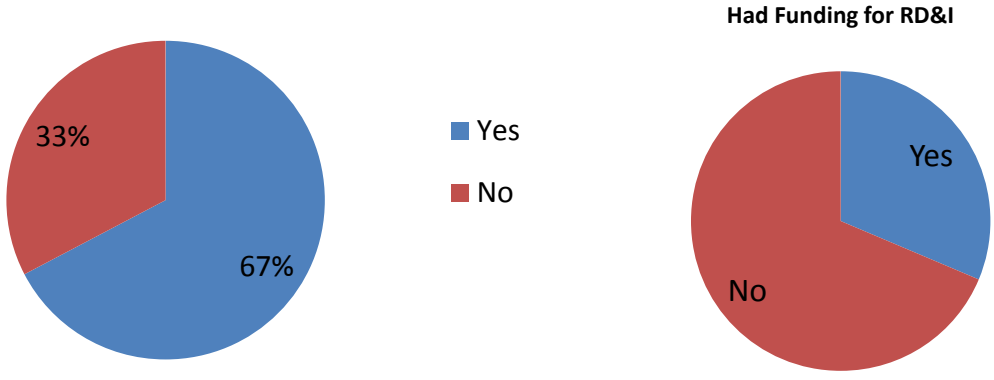


Figure 14 Two thirds of CMA businesses have increased revenue or employees in the last five years. A minority have received funding for RD&I. Further details are given in the appendix.

[12] Graedel TE, Harper EM, Nassar NT, Nuss P, Reck BK (2015) Criticality of metals and metalloids. Proceedings of the National Academy of Sciences of the United States of America 112: 4257-4262

A study bringing together the proposed investments and jobs in the current georesources exploration projects (deep geothermal, tin and tungsten, hard rock lithium and lithium brines (Appendix 6.3) shows that the sector has the potential for substantial growth that can contribute between £500 million and £1 billion additional GVA over the next 20 years.

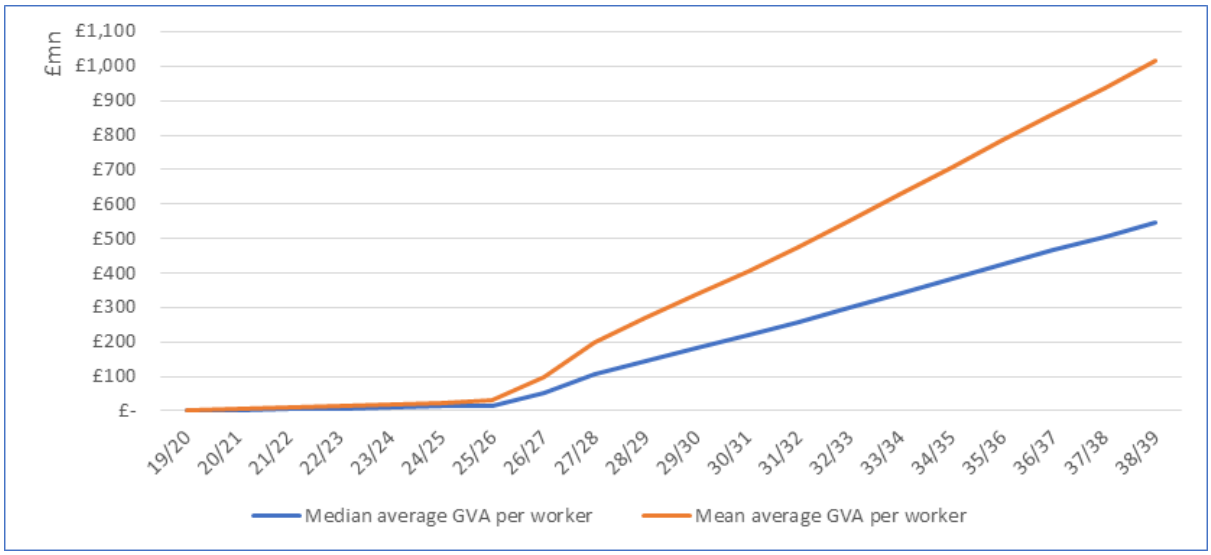


Figure 15 Cumulative direct economic benefits (Gross Value Added) based on average (median & mean) GVA per worker for the proposed new lithium brine, deep geothermal and hard rock tin, tungsten and lithium mines (Study by Moor Economics for the REMIX project, see Appendix 6.3)

Barriers

- The sector is largely composed of small companies who do not have the time and money to invest in experimental collaborative working and exploring new export markets.
- Evidence from other European clusters is that all have received substantial public funds in order to establish and grow. The Cornwall Mining Alliance has received no public funding yet (Appendix 6.2).
- Only 30% of companies have received funding for research and innovation, whereas 78% would like to innovate.
- There are few digital technology companies in the Alliance, although many are experimenting with digital technologies. Software companies in Cornwall have not engaged with the mining sector.
- Most investment for R&I between university and industry partners has been European-funded in programmes direct from the Commission rather than regional development. There is a need to maintain the applied research and continue to improve university links with local businesses.

Recommendations

6.1 - Public investment is needed from Cornwall Council/ Local Enterprise Partnership to support the cluster to grow, through seeking and setting up collaborative business opportunities so that micro businesses can operate as virtual larger companies working on higher productivity, larger contracts.

6.2 - Invest/ facilitate research and innovation funding, especially in digital areas such as 'big data', artificial intelligence, remote sensing in order to expand the sector and move the cluster to a world-leading position in this topic.

6.3 - Create incentives for new small business start ups and business expansion. A Digital Mining Hub / enterprise zone zone similar to that created for the space port can be set up. There are potential venues at Wheal Jane Earth Science Park and at the Heartlands and South Crofty site.

7. Universities: Research, Innovation and Education

There is already a strong and world-class research and innovation sector that is well-connected to many of the local businesses.

Highlights include:

- Camborne School of Mines, University of Exeter – multidisciplinary research and education across full mining life cycle, including engineering, physical and social science.
- University of Exeter Renewable Energy, Business School, Environment and Sustainability Institute (an interdisciplinary centre researching solutions to environmental change).
- Sustainable Earth Institute at University of Plymouth - public perception of the underground, geothermal and extractive industries
- Digital and creative innovation at Falmouth University e.g. gaming, virtual and augmented reality, Launchpad MA Entrepreneurship

Degrees in regional universities directly relevant to Georesources

	Undergraduate	Postgraduate taught	Research (MSc by Research and PhD
University of Exeter (including Camborne School of Mines)	Mining Engineering Geology degrees Renewable Energy	Suite of 12 MSc extractive industry degrees MSc Renewable Energy Engineering	Geology Mining and Minerals Engineering Renewable Energy
University of Plymouth	Geology degrees	-	Geology

There have been considerable grants from the European Union research and innovation programmes, such as Horizons 2020, European Fund for Coal and Steel and Interreg. The projects have not been particularly focussed on local businesses (except for one led by Imerys) but they bring European, World and wider national connections.

UK is second only to Germany in terms of the share of H2020 funding it has received.

Opportunities

There is relevant and world class expertise, including experience of coordinating large projects, in the local universities so that they can take part and lead research projects to help regional development with a variety of funding sources: UKRI (research councils and Innovate), European including H2020, Horizons Europe, Strength in Places Fund, and new regional development opportunities such as may come through the shared prosperity fund.

Barriers

- It is unclear if the UK will be able to participate in future EU R&I funding.

- Raw materials not high priority in any UK R&I strategy (unlike European Commission).
- There is no longer a university research and teaching mine in Cornwall.
- There are no technical (i.e. non-university) training courses in mining or geothermal energy running in the region.
- There is a gap in academic expertise to research the next stages in the value chain after mining and processing the ore, to turn into a product useful to manufacturers, such as smelting, solvent extraction, carbonate manufacture. Technical side of circular economy such as design for re-use and recycling.

Recommendations

7.1 – Cornwall Council and the LEP can promote R&I regional funding and other UKRI opportunities for this sector, including the Strength in Places Fund and Shared Prosperity fund.

7.2 – Lobby to ensure that the Department of Business, Energy and Industrial Strategy (BEIS) and research programmes such as the Faraday Challenge, realise that the georesources sector is important.

8. Industrial strategy – Natural Capital for Clean Growth

This section discusses the information in this paper in terms of key words for the local industry strategy, and includes in this mention of the sustainable development goals and Climate Change Emergency.

The Local Industrial Strategy needs to focus on locally specific challenges and opportunities. The Georesources in Cornwall are a unique feature of the region, and distinguish this local area from all others in the UK.

- World class tin, tungsten, lithium and kaolin deposits.
- The highest geothermal gradient in the UK, enabling geothermal electricity generation as well as heat from deep geothermal wells, mine water and ground source technologies.
- A business cluster of over 100 companies.
- A heritage and culture that welcomes the use of georesources.

Georesources contribute to the Foundation Industries keyword of the industrial strategy in that they provide the first stage raw materials for manufacturing – of batteries for electric vehicles, components of all electronic goods and manufacturing equipment. Supply chains are mainly international (mostly through China) but may be established in the UK for some specialist materials applications, such as lithium, tin.

In terms of the general evidence base, the sector is difficult to map using ONS data and SIC codes and for the REMIX project, we compared a top down approach using SIC codes with a bottom-up approach of mapping the Cornwall Mining Alliance sector (Appendices 6.1 and 6.3). Geothermal especially is a new sector that may expand rapidly in the region. Our new economic study estimates 2,750 jobs associated with georesources activity (ca. 1% of jobs in Cornwall). Mean average earnings in the mining and quarrying sector in the South West are £38 223, higher than the Cornwall mean of £28 500 for full time workers. In the UK mining and quarrying sector, there is a large step up in gross value added (GVA) from businesses of 1-9 people to larger microbusinesses and SMEs (£25 700 to £81 590). This may suggest that the sector has potential to increase its GVA in Cornwall if the businesses expand or collaborate more closely together. Using labour productivity estimates, the Georesources sector has an annual GVA in the range of £118.8mn-£219.7mn and has a turnover estimated at £365mn-£674mn. Imerys accounts for a large proportion of these figures with about 1000 employees and a turnover of £193mn in 2019[13].

Georesources in the Local Industrial Strategy

The georesources natural capital of Cornwall can contribute to Clean Growth in the UK, and the wider global community - by geothermal electricity generation, geothermal heat from deep geothermal, mine water geothermal and ground source heat pumps creating a leading

[13] https://www.pkf-francisclark.co.uk/wp-content/uploads/2019/08/WMN-Annual-Business-Guide-merged-PDF.pdf accessed 15.8.19

energy management system for heating and cooling using the subsurface, new world class technology metals mines and borehole metals extraction that will provide essential raw materials for clean growth. These activities and an associated business cluster of service and equipment companies are all closely connected to University R&I so that industry-leading expertise from Cornwall can generate export income worldwide.

Georesources links to the Industrial Strategy Grand Challenges

Industrial Strategy Grand Challenge	Cornwall Georesources
Clean Growth	Minerals and rocks are natural capital, just as much as the surface environment and ecosystems that are more usually associated with the term. Decarbonisation of industry and low carbon energy generation requires technology raw materials such as lithium and tin, tungsten and kaolin, all found in Cornwall, giving a unique place-based advantage. The Cornwall Mining Alliance cluster works worldwide to help produce the raw materials needed for decarbonisation responsibly. Foundation industries is a keyword with a corresponding funding call in the ISFF, but this seems mainly for steel and chemicals, not the 'real' foundation industry of raw materials production. Materials stewardship, efficient production and manufacturing, re-use and recycling are all components of the circular economy approach.
AI and Data Economy	A Digital Mining EDRF R&I investment to accelerate development in AI and Data Economy is at the contracting stage. There are already companies using AI and expertise in the data economy in regional universities.
Future of Mobility	Lithium = battery raw material. The other technology metals that Cornwall can produce are also important in manufacture of vehicles, and the Cornwall Mining Alliance works worldwide to help international industry secure the raw materials needed for future mobility responsibly.

Ageing Society	-

Cross-cutting links to the 10 Opportunities

There are cross-cutting links between georesources and the Cornwall and Isles Scilly Ten Opportunities identified as potential topics for inclusion in the local industrial strategy.

Links between Georesources and '10 Opportunities. Towards a Local Industrial Strategy'

10 Opportunities		
1	Creative	• Links to creative and cultural sector are essential to involve, interest and educate the public about georesources, e.g. Royal Cornwall Museum Rashleigh Gallery, Man Engine project, various Cornubian Arts and Science Trust activities, 'Time and Tide' history and creative initiative. • Gaming and augmented and virtual reality is used in mine site training worldwide.
2	Space	• Satellite monitoring – exploration, mine site development, environmental performance. • Raw materials on the Moon, Mars, asteroids for future space expeditions.
3	Energy	• Geothermal power and heat and cooling. • Moving to more renewable energy generation requires more raw materials to build wind turbines, solar panels etc – more than every mined before - Low carbon is the 'age of materials'. • Potential to obtain metals from geothermal waters.
4	Agri-Food	• Soil quality, variability and contaminated land controlled by natural geology and by past-mining. • Geothermal heat for new agriculture businesses.
5	Tourism	• New mines and geothermal plants need to attract tourists, not put them off. E.g. visitor centre at United Downs Deep Geothermal Project, Geevor, Poldark tourist mines, South Crofty is very close to Heartlands. • Potential for natural spa from geothermal energy.
6	Marine	• Shallow marine deposits of tin around coast of Cornwall. • Deep sea marine mining needs much R&D, engineering, earth science and environment, ecology.
7	Mining	• Links to geothermal energy, energy storage, tourism, space, marine, agri-food.
8	Aerospace	• Good global connections are essential for Cornwall Mining Alliance export cluster who work worldwide.
9	eHealth	• Mine site health and safety opportunities for wearable technologies .
10	Location	• Cornwall is one of World's most famous mining regions. Graduates from Camborne School of Mines and engineering at University of Exeter choose to stay in Cornwall or return for the high quality of life in the region. Lifestyle can attract other businesses to relocate/ start up in Cornwall.

Georesources and the Cornwall Climate Emergency

All of the suggested actions are relevant to the climate change emergency because of the importance of low carbon energy sources and the need for raw materials to build equipment for low carbon energy

generation and storage, and low carbon vehicles, such as electric cars. Three actions are highlighted as potentially particularly important to include in immediate climate emergency plans.

Recommendations from the Summary that are priorities for including in Cornwall's immediate climate change emergency actions.

Summary action from page 3	Recommendation	Comment
3	Join/form national working group to create national legislation regarding protection of deep and shallow geothermal energy and extraction of metals from deep and surface mine waters.	If a consensus can be reached across the UK, a local MP has volunteered to take legislation forward
5a	Accelerate understanding of regional sub-surface geology using state of art geophysics techniques and geological concepts.	There are various UKRI initiatives and other regional development funds
6	Continue support for deep geothermal electricity and heat projects but also invest in mine water geothermal energy domestic and commercial groundscource heating. The use of underground heat has become more sophisticated in the last five years and is an important opportunity as an alternative to gas central heating.	Visit best practice example of underground energy management in Herleen, the Netherlands, and visit South Wales mine water project.

Georesources and the Sustainable Development Goals

There are several studies of the impact of mining on the sustainable development goals (SDGs). All show that the industry has positive and potential negative impacts across most of the goals rather than a specific match to one SDG. In contrast, geothermal energy would usually be mapped straight to SDG 7 Affordable and Clean Energy. Geothermal is also relevant to climate change action, SDG 11.

Participants at the Georesources Cornwall workshop at Heartlands on 4 April 2019 carried out an exercise to write the positive and negative impacts of Georesources for all 17 SDGs. Worldles produced from the answers are reproduced below. Both 'Mining' and 'Energy' featured frequently as positive keywords, along with local and industry. Mining was more frequently mentioned in negative impacts than geothermal, but the word 'may' was the most used word, showing the importance of making sure that negative impacts are assessed and mitigated.

Positive for SDGs

Negative for SDGs

SDG12 Responsible Consumption and Production is one of the less well known and developed goals. Cornwall is very well placed to help tackle this goal, which brings together circular economy and mining. Many studies of mining development are thinking mainly about mining in developing countries and it is important for regions such as Cornwall, and other European mining regions, to find their own path. The following is a useful quote[14]

> **'SDG9 – Infrastructure, Innovation and Industrialization and SDG12 – Responsible Consumption and Production**: Mining can help drive economic development and diversification through direct and indirect economic benefits and by spurring the construction of new infrastructure for transport, communications, water and energy. Mining also provides materials critical for renewable technologies and the opportunity for companies to collaborate across the supply chain to minimize waste, and to reuse and recycle.'

[14] Mapping Mining to the Sustainable Development Goals: An Atlas (2016) White Paper by the Columbia Center on Sustainable Investment, UNDP, UN Sustainable Development Solutions Network, World Economic Forum. World Economic Forum, 75 pp. http://unsdsn.org/wp-content/uploads/2016/11/Mapping_Mining_SDGs_An_Atlas.pdf, Accessed 12.8.19

World Bank – Climate smart mining

Recognising the need for raw materials in order to be able to decarbonise energy generation and manufacturing industry, the World Bank has launched a 'Climate smart mining' initiative. The aim is help, particularly developing, countries take advantage of the expansion of mining that comes with the need to decarbonise. The same principles apply to regions in richer countries, such as Cornwall.

Figure 16: Extract from the Climate Smart Mining infographic.
https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action
Accessed 3.9.19