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Exploring alternative energy options for mine sites

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Abstract

Mine sites can be ideal locations for developing alternative energy facilities which, by re-considering many of the site properties which make them problematic in the first place, are a way of converting the potential negative legacy of mine sites into a positive inheritance for the wider environment and local communities.

The various properties of mine sites offer a comprehensive range of alternative energy generation possibilities including: wind, solar, geothermal heating, energy crops, mine methane, bioreactor landfills, hydropower and test-beds for a variety of more experimental power generation technologies.

Mine site conversion to alternative energy generation, as with any development, must take due account of impacts on the local environment and communities. Done well such activities are favourable as they can provide extra economic value from the site during the mining operational phase, or ongoing value after operations have ceased. Other benefits can include the mitigation of clean-up costs; enabling re-employment of a skilled mining workforce and/ or new local employment opportunities; and a clean and usually quiet after-use for a mine site (and more).

Despite this promising re-use option there remains widespread ignorance as to its potential. This review paper was inspired, initially, by several alternative energy projects – old and new – on mine sites in Cornwall, UK, and aims to encourage this approach to post-mining regeneration in an economic climate that remains favourable for alternative energy investment. It introduces the various site properties that make them amenable for this end-use; issues that need to be considered when contemplating this option on mine sites and how the potential of alternative energy after-use options can be combined with other modes of post-mining regeneration; and the creative thinking employed behind some of these examples. The paper illustrates the key points by introducing examples and discussing case studies from around the world.

Finally, the paper considers/ offers generic recommendations to encourage greater consideration of this re-use option as a means to successful post-mining regeneration.

1 Introduction

From a natural resource use perspective, the debate over whether mining operations can ever be regarded as sustainable is well-known; strictly speaking, to extract a non-renewable resource below an economically viable cut-off point means, by definition, that the process is not sustainable. However, confusion often reigns over the exploitation of renewable and non-renewable resources; in fact, very few ‘renewable’ natural resources are exploited on a large scale in a sustainable manner – witness what is happening to forests, water supplies, fisheries, soils, etc., which puts the lack of sustainability reference to mining and minerals exploitation in good company.

A more useful and rational discussion on resource exploitation in general can be framed around whether a resource is well- or poorly-managed. In which case, many examples of the well-managed exploitation of natural resources can be considered as ultimately sustainable including, possibly, mining. As well as exploiting mineral resources, the mining industry is also an exploiter of land and by definition the tenure of a piece of land by a mining activity is temporary. The key issue over the sustainability of mining is how the mineral values derived from exploitation are converted into enduring benefits for future generations, particularly in the locality and region surrounding the mining operation in question, i.e. those who have been impacted the most by the operations. This includes the beneficial future use of the land after mining itself has ceased, and applies to both abandoned mines and mines undergoing a planned closure and rehabilitation.

There are many examples, often over-looked, in the other well-worn arguments around mine closure, of the re-use of closed mine sites for new beneficial use of the land. A few of the best examples have been captured excellently by the Eden Project's Post-Mining Alliance team in their book, "101 Things to Do With a Hole in the Ground" (Pearman, 2009).

This paper focuses on a particular thematic after-use for former mine sites, namely the production of alternative energy. The term 'alternative energy' is used in preference to 'renewable energy' to reflect the fact that some of the technologies involved employ non-renewable energy sources.

1.1 Properties of mine sites favourable for alternative energy generation

Mine sites can be ideal locations for the generation of alternative energy owing to many of the site properties which make them problematic in the first place. Such sites are useful for this activity for several reasons:

- They may cover extensive areas (up to thousands of hectares or more) in areas where wind and solar power structures have less environmental impact and are thus less likely to meet opposition.
- They often already possess the necessary electricity transmission lines and transport infrastructure, thus avoiding extra capital costs.
- Land transaction costs are generally lower and the process simpler as brownfield areas tend to be owned by fewer landowners than a similar area of greenfield.
- Brownfield redevelopment for green energy can reduce development pressure on greenfield sites, therefore maintaining the carbon sink benefits of the latter.
- Other forms of re-development may not be an option due to the remoteness of the site, or the prevailing environmental conditions on such sites may preclude residential or commercial use without entailing significant extra development cost.
- The development, operation and maintenance of renewable energy plants on former mine sites may introduce new or replacement employment opportunities to surrounding communities.

Other properties of such sites include:

- Denuded and exposed – high incidence of solar radiation therefore solar power potential.
- Waste tips offer potential elevation for wind turbines.
- Open pits, underground workings, etc., can offer specific opportunities due to their location (e.g. relative to groundwater) or configuration (such as their shape or aspect).

2 Examples of alternative energy generation on mine sites

Alternative energy options for former mine sites include: wind, solar photovoltaics, geothermal (power or heating)¸ energy crops, coal mine methane, bioreactor landfills, hydropower and various experimental power generation options.

These options are introduced below with illustrative examples combined in Table 1. Such alternative energy activities have the potential to convert a problem site into an asset, in effect converting negative legacy to positive inheritance and providing finance that would otherwise be unavailable to ameliorate some of the negative properties of such sites during the construction/ development process. Of course, there may be several clean/renewable energy options for any one site as exemplified by the renewable energy demonstration project at the closed Bullfrog Mine at Beatty, Nevada, USA (USEPA, 2011), and at the closed Wheal Jane tin mine in Cornwall, UK, where plans include solar photovoltaics, hydro, wind, biomass and geothermal (Wheal Jane Group, 2011).

2.1 Wind

Large-scale wind energy projects are an increasingly common alternative energy use on former mine sites, particularly in Europe and the USA (USEPA, 2003). The visual impact of wind turbines may be less controversial in areas blighted by mining landscapes and, often, mineral waste dumps give increased elevation and exposure for the siting of wind turbines to enable increased output. Unlike some other alternative energy technologies, the use of wind turbines does not exclude the underlying land from being used for other purposes. However, there may be technical challenges to overcome due to the nature and stability of the dump material and constructing adequate foundations for turbines.

2.2 Solar

Former mine sites can be ideal locations for solar energy generation owing to their often expansive and exposed natures, especially in areas with an aspect facing the sun (south facing in the northern hemisphere, north facing in the southern hemisphere). Germany is the world leader in solar energy technology and production and is utilising its old mine sites in this regard though other countries, including the UK, are following suit.

2.3 Geothermal heating

The ambient temperature of the Earth increases with depth (as any underground mine visit will prove). Underground mine workings provide a convenient collection point for groundwater that may be sufficiently warm to enable its exploitation for raising the starting temperature of the water used in buildings and horticulture for heating and hot water, often involving ground-source or water-source heat pumps.

Mine and quarry sites can also offer opportunities for access to deep geothermal resources, involving hotter water or super-heated steam power generation via a turbine.

2.4 Energy crops

Post-mining land, such as from large scale strip mining, can offer a more sustainable model for growing energy crops than using existing agricultural land or clearing natural vegetation cover and this is a major area of research in many mining areas. Biomass crops (grown specifically to be burnt for fuel) typically include fast-growing trees planted at high densities and perennial tall grasses, while biofuel crops are subsequently processed to derive fuels.

There are also potential additional or combination benefits with less intensive energy crops, such as for biodiversity, and/ or providing a carbon sink or offset as forest biomass or soil improvement with ‘biochar’, which could qualify for carbon credits under schemes such as the Clean Development Mechanism.

2.5 Coal mine methane

Atmospheric methane is a greenhouse gas 25 times more potent than CO_2 – a sound reason for capturing methane from underground coal mines and using it to produce energy while simultaneously converting it to CO_2. Global anthropogenic methane emissions for 2010 were estimated at 6,875 million metric tonnes of CO_2 equivalent) and are expected to rise by 15% by 2020. The coal mining industry produces approximately 6% of this total (Global Methane Initiative, 2011).

Coal Mine Methane (CMM) technology captures methane from an operating mine and burns it to produce energy and CO_2. The technology is tried and tested in many developed country coal mining areas for working coal mines, but in the case of Abandoned Mine Methane, the production of methane declines – initially rapidly – and then over an extended period. Gas may be produced for only a few years if flooding is significant. That said, abandoned coal mines offer huge potential as a source of power in many coal mining regions.

Leading countries in this technology include Australia, Germany, the UK and the USA. Organisations such as the multi-stakeholder Global Methane Initiative work internationally to increase the use of methane for energy generation and have a large interest in promoting CMM energy technology.

2.6 Bioreactor landfills

Open pits and quarries have often been used for the landfill disposal of municipal and other biodegradable wastes. Today, such sites produce methane from anaerobic decay of the waste, which can be captured and burned to produce heat or electrical energy while being converted to carbon dioxide. If properly engineered for optimum gas production and recovery, such sites can be very efficient bioreactors with sustainable supply for many years.

2.7 Hydropower

Known as pumped storage hydroelectricity, off-peak electricity is used to pump water to a higher elevation where it is used as store of potential energy, which is released as kinetic energy during high demand periods as it falls under gravity through turbines. There are several examples around the world using closed/abandoned mine workings as pumped storage schemes.

Pumped water storage for power generation in the underground workings of closed/abandoned mines or surface open pits is an emerging option for the generation of hydroelectricity. Currently, this technology is not yet operational, but projects are being planned or are in development. This technology generally involves high capital expense, but avoids the potential environmental impacts of storing water at the surface.

2.8 Experimental power generation

Closed mine sites provide ideal opportunities for research in alternative energy uses simply based on the properties of such land. Such properties include the presence of vertical shafts, large volume underground workings – ideal for storing air or water and saline waters, which can be used as chemical batteries. Examples of such experimental approaches are outlined in Table 1.

Table 1 Examples of alternative energy generation on mine sites

General

- The United States Environmental Protection Agency (USEPA) programme 'Re-powering America's Land: Renewable Energy on Contaminated Lands and Mining Sites' aims to meet a significant proportion of the USA's 31% growth in renewable energy demand over the next 25 years by encouraging the development of renewable energy generation on former mine sites and other brownfield land, included contaminated land. The EPA has identified 480,000 such sites covering six million hectares across the USA, of which 345,000 ha have been cleaned up or protected long-term and are available for renewable energy development. The EPA and the US National Renewable Energy Laboratory have produced a series of on-line maps showing the potential of nationwide contaminated and mined lands evaluations for producing renewable energy across the USA (USEPA, 2010a).

Wind energy

- Buffalo Mountain, Knoxville, Tennessee, USA. Three 60 m turbines erected on a former mine generate 4,000 megawatt-hours of electricity – enough for 400 homes.
- Somerset County, Pennsylvania, USA. Six 1.5 megawatt turbines on a former mine site adjacent to Pennsylvania Turnpike. Generates 25,000 megawatt-hours annually – enough for 2,500 homes.
- Planned: West Virginia - largest wind farm in eastern USA. 166 turbines sited on over 4,000 hectares of land disturbed by coal and hard rock mining activities. Will be able to supply 65,000 homes and 99% of the land would remain usable for other activities, including farming.
- Klettwitz wind farm, eastern Germany – the largest wind farm in Europe. Started June 2000. 38 turbines built on coal mine waste dumps at the 275-hectare site. Generates 100,000 megawatt-hours annually – enough for 16,400 homes.
- Black Law Wind Farm near Forth, Scotland, UK, covers 1,850 hectares of abandoned coal mine land, grazing land and commercial forestry. 42 wind turbines generate 97 megawatts – enough electricity for 70,000 homes. Plans for an expansion will increase the total generating capacity to 193 megawatts.
- Kilronan, Ireland. Former coal mine. Generates 14,000 megawatt-hours annually – enough for 2,300 homes.

- Planned: Imerys, china clay area near St Austell, UK. The china clay mining area of mid Cornwall is in an area of high wind speed, being close to the Atlantic Ocean, and the characteristic sand waste tips have high elevation and exposure. This area has been researched for potential wind development and a number of commercially viable prospects identified. Technical problems, such as the cost of foundations on waste dumps, have been overcome, but do affect the economics of such schemes.

Solar electricity

- The closed Wheal Jane tin mine in Cornwall, UK, is becoming a focus for a range of alternative energy activities. At the time of writing, the UK's first large-scale solar photovoltaic farm is being constructed on-site (Wheal Jane Group, 2011).
- Geosol Solar Plant, Espenhain, Leipzig, eastern Germany. The world's largest photovoltaic power plant (or 'solar park') when it opened in 2004. Generates five megawatts – enough for 1,800 households, saving approximately 3,700 tonnes of CO_2 every year. The plant was constructed on a former lignite mine ash site in what was once one of the dirtiest regions in Europe.
- Göttelborn coal mine, Saarland, south-west Germany. The mine site has been converted into a solar energy park – again the largest of its type when opened. It generates eight megawatts from 50,000 photovoltaic panels covering 165,000 square metres.

Geothermal heating

- Rosemannowes Quarry in Cornwall, UK, was an ideal location (geologically, visually and environmentally) for the hot dry rocks deep geothermal energy research project undertaken by the UK Government during the 1980s. This project investigated the potential for deep geothermal energy being used to heat water to a sufficient temperature to power a steam turbine.
- Shettleston Housing Association, Glasgow, Scotland, UK. Flooded coal mine workings beneath the Glenalmond Street housing estate creates a geothermal heating system for residents, reducing their energy bills by 60% (Sust, 2006). 100 metres below ground, the mine water is a constant 12ºC – an ideal source of heat energy for the development. The water is passed through a heat-pump to boost the water temperature to 55ºC. The water is stored in an insulated 10,000-litre tank and benefits from an afternoon 'boost' provided by solar panels installed on the roof above. Although the water temperature is relatively low compared to most conventional boiler powered domestic heating systems, the properties above are very well-insulated, and heat pump heating systems using under-floor heating, warm air and conventional radiator systems are becoming common.
- Cape Breton, Canada, sits atop 3,200 km of flooded former underground coal mine workings, which once supplied half of Canada's coal requirements. The average water temperature is 12ºC. Investigations are underway into how best to capture the heat stored in the mine water using a loop system and use it in the former coal mining communities of the area. The first geothermal heat is expected to come on-stream in the very near future.
- The Con gold Mine in Yellowknife, Northwest Territories, Canada, has been the subject of a recent feasibility study to determine the viability of using its warm groundwater for a 10 megawatt district heating system in the city (CBC, 2010).
- The EU-Minewater-Project aims to research and promote the use of mine waters for district heating as a means of encouraging the sustainable re-development of mining communities. The world's first mine water power station opened at Heerlen, the Netherlands in 2008. It uses water at 32ºC extracted from underground coal mine workings through boreholes in what was once the Netherlands' coal mining heartland. It heats 350 homes and businesses and is estimated to reduce CO_2 emissions by 55% compared to conventional water heating systems (EU, 2009).

Energy crops

- In 2008, the USEPA funded West Virginia University to research the feasibility of growing switch grass as an energy crop on Appalachia's coal mine lands (USEPA, 2010b).
- In 2005, the USA's National Renewable Energy Laboratory published a detailed assessment of the potential biomass resource availability, including detail on the abandoned mine potential for this usage nationally (Milbrandt, 2005).
- Treepower's pilot Energy Crop Plantation in Florida, USA, growing eucalyptus and cottonwood trees for biomass on a closed phosphate mine in Florida. Approximately 250,000 trees cover 52 ha (Planet Power, 2010).
- As part of the Emscher Park's master plan, Dinslaken in the Ruhr area of western Germany is planning to convert up to 10,000 ha of former coal-mined land to willow and poplar to provide biomass for heating (Worldwatch Institute, 2009).
- Jatropha produces inedible oil that can be used to produce biodiesel and is the subject of much interest for growing on mined lands in China, the Philippines and elsewhere (TheBioenergySite, 2010).

Abandoned mine methane

- The USA is the world's second biggest coal mine methane emitter. Approximately 8% of its coal mine methane emissions emanate from abandoned coal mines – equivalent to approximately 275,000 tonnes. The USEPA has investigated abandoned coal mines in the USA for methane recovery and exploitation. It noted that presently 44 abandoned coal mines are used for this purpose in the country's coal mining regions (USEPA, 2008).
- Grayson Hill Energy Project, Illinois, USA, originally used abandoned coal mine methane from several mines to run four 705 kilowatt generators. The waste heat was used in greenhouses to produce tomatoes for sale. The project now collects methane and pumps it directly into a nearby gas pipeline. The gas processing plant utilises electricity produced from two 750 kilowatt methane-powered generators (USEPA, 2008).
- King's Station Mine Project, Illinois, USA, possesses two abandoned coal mine methane processing plants and sells the gas to an adjacent Toyota Truck Plant (USEPA, 2008).
- DTE Methane Resources Project, Illinois, USA, runs a gas processing plant which utilises methane from ten abandoned mines. The gas is then sold to a gas company (USEPA, 2008).
- An estimated 300,000 tonnes of methane seeps into the atmosphere every year from approximately 900 former underground coal mines in the UK alone, of which an estimated 52,000 tonnes are emitted from abandoned mine sites that have potential to be controlled. The UK government has codified tax incentives to encourage the use of CMM for energy. Several small-/ pilot-scale CMM plants have been built at some of the UK's 900 former underground coal mines, providing methane direct to the gas grid or converting it into electricity (The Coal Authority, 2011). The export of such technology to other countries has been encouraged by the UK government in bilateral technology transfer projects to Russia, China and India.
- China is the world's largest emitter of coal mine methane. In 2005, it produced an estimated 5.8 million tonnes of methane (135 million tonnes of CO_2 equivalent) – over 40% of the world's total coal mine methane emissions. It already captures methane and produces energy from it in working mines, but the potential for further development of this asset is enormous (IEA, 2009). The Clean Development Mechanism is being used to introduce CMM in some cases.

Bioreactor landfills

- The Woodlawn Bioreactor, at Tarago in New South Wales, Australia, is located in the 25 million cubic metre Woodlawn open cut base metal mine. It has received over 600,000 tonnes of putrescible waste by train from Sydney (250 km distant) since 2005. Methane is now being harvested to produce electricity. It is also intended to construct 25 wind turbines on the site to generate enough electricity to power 17,000 homes (The Tarago Times, 2008).
- The Ti Tree Bioenergy Facility is located in a former open cut coal mine near Ipswich, Queensland, Australia. It receives municipal waste from the expanding population of southeast Queensland. The methane is collected and burned to generate power. Over the next 10 years, power generation is expected to increase to 10 megawatt-hours (equivalent to that used by 12,000 homes) (TiTree Bioenergy, 2009).

Hydropower

- Located partly in the abandoned Dinorwic slate quarry – once the world's second largest slate quarry – on the Elidir Fawr mountain/ Electric Mountain of Snowdonia National Park, north Wales, UK, Dinorwig hydroelectric power station generates a peak capacity of 288 megawatts. During off-peak periods, turbines pump water to the top of the mountain where it is stored in the Marchlyn Mawr reservoir, being released to generate electricity on demand. Beginning in the mid 1970s, construction took 10 years and cost £450 million (US$744 million). The Electric Mountain Visitor Centre attracts about 250,000 visitors per year, with another 70,000 touring the Dinorwig power station itself (Wikipedia, 2011a).
- Underground pumped water storage: two that have been proposed in recent years include the Summit Pumped Storage Project in an underground limestone mine in Ohio, USA and the Mount Hope Pumped Storage Project in New Jersey, USA, using the underground workings of an abandoned iron mine (Wikipedia, 2011b).

Experimental power generation

- **Wave Shaft** – the use of coastal abandoned mines with shafts exposed at sea level to utilise oscillating water column devices and air compressed by wave action expelled under pressure to generate electricity through a turbine system, Cornwall, UK (DTI, 2004).
- **Compressed Air Energy Storage (CAES)** – CAES systems use cheaper off-peak energy to inject air underground where it is stored under pressure as potential energy. When electricity is required at peak periods the air is withdrawn under pressure and together with fuel to operate turbines. The world's first CAES plant was commissioned in 1978 at Huntorf, Germany, where compressed air is stored in underground salt caverns created by the solution-mining of salt. A broadly similar system exists at McIntosh, Alabama, USA, commissioned in 1991. At Norton, Ohio, a proposed CAES plant will use a worked-out limestone cavern (which produced limestone for the glass-making industry) to store the compressed air. Ultimately the system will generate 2,700 megawatts – enough for about one million homes through gas-operated turbines, yet with the emissions equivalent to a conventional gas turbine power plant of 600 megawatts capacity (Wikipedia, 2011c).
- **Acid Mine Drainage (AMD) battery** – Acid drainage emanating from mines is one of global mining's major environmental impacts. Current laboratory research is investigating the generation of electrical energy from the chemical energy inherent in AMD. The process also removes iron and other environmentally-problematic metals from solution, raising the possibility of economically-viable metals recovery (Cheng et al., 2007).
- **Osmotic power/ salinity gradient power** – a novel alternative energy that relies on the osmotic pressure difference between saline and fresh waters to drive turbines to generate electricity. A version of this technology is being used at the Eddy Potash Mine in New Mexico, USA (Wikipedia, 2011d).

3 Benefits accruing from re-using mine sites in this way

The benefits derived from the re-use of mine sites in this way include:

- Providing an alternative income stream over the long term.
- Helping to offset the cost of closure.
- Creating an opportunity to re-use existing infrastructure thus reducing the cost of decommissioning.
- Reducing the mine's carbon footprint.
- Providing clean energy for society and helps towards climate change objectives.
- Creating a potential source of carbon credits with tradable value.
- Re-deployment of mining-related skilled labour.

The last point can be particularly significant as illustrated briefly in Table 2.

Table 2 Examples of the re-deployment of mining-related skilled labour in the alternative energy sector

Manufacturing alternative energy equipment, Germany. The re-application of mining-related engineering skills after large-scale closure of coal mines in the Ruhr has created a new manufacturing industry from supplying the mining industry to supplying the alternative energy sector. Examples of companies which have taken this path include (Worldwatch Institute, 2009): • Voith Turbo BHS Getriebe GmbH and IBC Wälzlager GmbH once produced coal mining machinery; now they are world leaders in manufacturing parts for wind turbines. • Siemens once made conventional coal-fired power plants for the Ruhr area, now the company is building biomass generators. • Teramex used to provide mining equipment for coal mines, now it provides drilling equipment for exploiting geothermal energy.
Hard rock mining to geothermal energy, Cornwall, UK. The UK's historic Cornish metal mining industry spawned the world-renowned Camborne School of Mines (CSM) (established in 1888). After the industry's demise much of the mining knowledge and skills remained locally with CSM acting as a focal point (University of Exeter, 2011). The institution provided the academic backbone for the £40 million (US$66 million) government-funded Hot Dry Rocks project in the 1980s to explore the possibility of exploiting the high heat gradients in the local granite to produce super-heated steam to generate electricity. This research ended in the late 1980s, but some of the original personnel involved, who either stayed in the county or who have recently returned, are re-applying this technology on a commercial scale in two deep geothermal projects locally (Poluck, 2011).

4 Conclusions

Although the benefits are obvious and interest is on the increase, the re-use of mine sites for alternative energy generation remains at a small scale. In many cases the reason is likely to be a combination of: (a) the early stage of development of many alternative energy technologies at a commercially viable scale, and (b) unfamiliarity with the technologies and their potential. Therefore, there is a need to raise the profile of what is possible and the options available. This could be done through several routes, including through the mining industry itself, but other stakeholders, including government organisations, academia and civil society groups also have a key role to play.

The alternative energy sector also has a key role in developing a fuller and more dynamic interaction with the mining sector as both an energy option for the operating mine itself and as a beneficial use for former mine sites as part of planned closure.

Many alternative energy technologies are relatively new and are emerging and developing fast in response to the international climate change agenda and commitments being given by many states. As these become commercially viable, often with assistance from government incentive or green energy subsidy schemes, the opportunities will also increase.

Stringent planning or permitting conditions can affect many alternative energy developments, such as those relating to the visual impacts of solar and wind installations. A more sensitive land and development planning and permitting regime, particularly relating to the re-use of brownfield sites and the re-deployment of labour, could be given a higher priority in such decisions.

Funding availability is a key factor affecting such developments. As mentioned above much of the recent alternative energy development is being supported in the short term by subsidy and incentive schemes and various tax and economic instruments, such as the renewable obligations, Feed-in Tariffs and Renewable Heat Incentives of many EU countries. These are designed to encourage the development and implementation of commercial scale energy generation from low-carbon sources during the early years, when research, development and capital costs are not covered by free market energy prices. Similarly, carbon trading schemes are an incentive to, *inter-alia*, encourage renewable energy generation through economic instruments.

This could be encouraged by governments offering preferential or enhanced incentives or reliefs for alternative energy development on brownfield land such as former mine sites, an option that is currently being considered in the UK and already exists in some other countries.

As alternative energy becomes more commercially viable, financial institutions are more amenable to providing debt and equity finance for such schemes. Again, governments could do much to encourage this by providing tax incentives or guarantees in certain circumstances.

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