Role of V.V.Mineral in reducing global warming through green mining technology of Garnet

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Abstract

According to EPA, 21% of global green house gas emission is from industry sector and mining sector is one of the major emitters of green house gases. Scientists are certain that climate change effects are expected to increase in the coming decades and urge nations to implement mitigation measures. Implementation of Green technology at industrial level aid in reduction of global warming, green house effect, pollution and climate change. Present study aims to explore the importance of green mining of garnet and garnet based abrasive water jet cutting in reducing green house gas emission and climate change effects. M/s V.V.Mineral impelmented two common sense steps manual mining and solar drying to address the challenge of climate change in mining and beneficiation of garnet. The case study finding shows manual mining operation adopted by M/s V.V.Mineral for garnet sand mining is green and completely reduced the emission of 0.893 -1.19 kg CO_2/ton sand, normally emitted through mechanised mining process practiced in the area. Implementation of solar drying in the beneficiation process results in elimination of 29.67 -32.36 Kg CO_2 emission by every ton of sand dried in fossil fuel based driers. Garnet is the commonly used abrasive around the world. Garnet based abrasive water jet cutting is an environment friendly green process. Since it is a cold process, all materials can cut without fuel combustion and heat generation process. This paper highlights the advantages of replacing thermal cutting process by garnet based abrasive water jet cutting in mineral fabrication sector to reduce air pollution in the form of fumes and gases and reduces CO_2 emission and global warming.

Keywords : Garnet, green mining technology, solar drying, Abrasive water jet cutting, global warming, CO_2 emissions

1.0 Introduction

Global warming is responsible for climate change effects worldwide and is recognised as a significant man made global environmental challenge. This warming is cumulative and irreversible on a time scale of centuries (Susan Solomon et al., 2008). Intergovernmental Panel on Climate Change reported sustained and unequivocal rise in global temperatures are being caused by increasing concentrations of greenhouse gases produced by human activities (IPCC, 2013). To limit global warming to meet the internationally agreed 2°C target level would require major efforts to reduce greenhouse gas emissions. Think green act green is the potential option for reducing the effects of global warming. Green mining is implementation of technologies, best practices and mine process as a means to reduce the environmental impacts associated with the extraction and processing of metals and minerals (Kirkey, 2014). M/s V.V. Mineral, a pioneer in Garnet mining in Southern India contributing 60% of India's Garnet production took pivotal steps to reduce carbon foot prints in garnet mining and mineral processing through replacing conventional mechanized mining method and fossil fuel based dryers by manual mining and solar drying techniques. Beach Placer deposits are the major source of world's garnet production where garnet occurs as sand or gravel either alone or along with other minerals such as ilmenite, rutile and zircon (VV Mineral, 2014) with a concentration of approximately 30% and can be easily mined (Olson, 2000, NSW Department of Primary Industries, 2007). Worldwide mining of mineral sand deposits is generally undertaken by using heavy earth moving machineries (Force,1991) and the principal sources of emissions are from consumption of energy such as diesel fuel in mining equipment results in direct emissions of greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). To combat the environment impacts of mechanized mining, VV Mineral implemented scraping and scooping method of manual mining for collection of garnet sand. The associated minerals in the garnet sand are separated and 99% pure garnet is produced by physical methods in the Mineral Separation Plant. To increase the mineral response to the magnetic and electromagnetic separators elimination of moisture content in the mined placer garnet sand is prerequisite and it is normally done by the use of dryers. Operation of dryers require diesel fuel consumption and ultimately combustion of carbon bearing diesel fuel results in the emission of greenhouse gases viz., carbondioxide (CO_2), methane (CH_4) and Nitrous oxide (N_2O). V.V.Mineral utilized the environment friendly renewable energy source solar energy for drying mineral sand to limit the environmental problem and GHG emissions associated with fossil fuel based dryers. Renewable energy is central to climate change mitigation effects. India is endowed with rich solar energy resource and the average intensity of solar radiation received on India is 200 MW/km square (megawatt per kilometer square) with 250–300 sunny days in a year. The intensity of solar radiation received in the coastal districts of Tamil Nadu varies between 5.6 – 6.0 KW/m square (Garud and Purohit, 2009) which is utilized by VV Mineral in the drying process to eliminate moisture content of the mineral sand. In the present investigation carbon foot print or CO_2 equivalent emission from the mechanized mining events using Front end loader and dryer operations in the Mineral Separation Plant is studied based on fuel consumption estimates and applying default emission factors (EPA, 2016). The greenhouse gas (GHG) value is expressed in emissions per ton of garnet sand and simple calculation method is used to estimate the percentage saving of GHG emissions by green technology implemented by VV Mineral compared to the fossil fuel based operations.

Strength and chemical inertness of garnet made it the preferred abrasive in water jet cutting industry. In fabrication sector metal working by thermal cutting process generate fumes and gases that can impact on the environment can contribute to climate change. Abrasive water jet (AWJ) cutting is a climate friendly metal cutting process which is a cold process uses environmentally benign water and abrasive as the cutting tool can cut through almost every material, including those that are too hard to brittle or too soft to be effectively cut with other technologies (Khan and Yeakub, 2011) without any negative impact on the environment. Garnet is the most acceptable abrasive worldwide. Garnet can be re-used after recycling. Recycling is simple and does not alter the chemical composition of abrasives and reduce costs by an estimated 1/3 of the total cost (Bajor et al., 2012, Sobotova et at., 2014 and Melekhin, 2016). This paper focus on the the importance of garnet based AWJ cutting process over other non contact thermal methods in reducing heat and smoke emission and products on the environment and climate change.

2.0 V.V.Mineral

V.V.Mineral is a twenty five year old company dealing with Mining, Manufacturer and Exporter of Garnet, Ilmenite and associated heavy minerals have achieved significant market share all over the world.V.V. Mineral (VVM) is the only company in India with a 40 km stretch of beach area under an exclusive mining lease for 30 years in Tirunelveli, Tuticorin and Kanyakumari Districts, Tamilnadu, India (Fig.1). The annual production of VV Mineral is 7,00,000 metric tonnes of heavy minerals which include Garnet Abrasive, Ilmenite, Zircon, Rutile, Sillimanite and Leucoxene. V.V.Mineral's product fetch huge overseas market due to its quality and high class management system implemented during every step of manufacturing process which was acknowledged by the ISO 9001 : 2008, ISO 14001, OHSAS 18001 certificates issued by TUV Germany.

Fig 1. Beach stretch under exclusive mining lease for VVM in Tamilnadu, India

3. Material and Methods

For cost and practicality reasons IPCC (2000), World Resources Institute WRI/WBCSD (World Business Council for Sustainable Development) GHG Protocol 2005, recommends the use of calculation based method of estimating direct Carbondioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O) emissions from mobile and stationary sources. In the present study mining equipment front end loader GHG emissions are estimated based on EPA Greenhouse Gas Inventory Guidance for Direct Emissions from Mobile Combustion Sources (EPA, 2016). Mining equipment is categorised under non road vehicles. Based on the fuel consumption records and actual fuel heat content (Table.1) CO_2 emission is calculated based on the follwing equation (Equation 2)

$$\text{Emissions} = \text{Fuel} \times \text{HHV} \times EF_2$$

Where Emissions is the Mass of CO_2 emitted; Fuel represent Mass or volume of fuel combusted, HHV is Fuel heat content, in units energy per mass or volume of fuel; EF_2 is CO_2 emission factor per energy unit.

CH_4 and N_2O emissions is calculated based on the equation (Equation 5)

$$\text{Emissions} = \text{Fuel} \times EF_5$$

Where Emissions represent Mass of CH_4 or N_2O emitted, Fuel denotes Volume of fuel combusted And EF_5 is CH_4 or N_2O emission factor per volume unit.

Table 1. Diesel oil characteristics based on fuel purchase records

Characteristics	**Specification**
Density (Approx.g/cc at 15ºC) max	0.822
Sediment, % wt. max	0.05
Sulphur Total % wt.max	0.25
Water content, % vol.max	0.05
Ash %wt.max	0.01
GCV (KJ/kg)	44,800
HHV (mmBtu/gallon)	0.132

CO2 – equivalent emission calculation

Carbon foot print "the total set of greenhouse gas (GHG) emissions caused by an event (Thurwachter et al., 1998) is often expressed in terms of the amount of carbon dioxide, or its equivalent of other emitted GHGs, calculated as carbon dioxide equivalent (CO2e) using the relevant 100-year global warming potential (GWP100) (IPCC, 2014). CH_4 and N_2O emissions are multiplyed by the respective global warming potential (GWP) to calculate CO_2 – equivalent emissions. The GWP are 28 for CH_4 and 265 for N_2O from the Intergovernmental Panel on Climate Change, Fifth Assessment Report (AR5), 2014. Sum the CO_2 equivalent emissions from CH_4 and N_2O with the emissions of CO_2 to calculate the total CO_2 equivalent (CO_2 e) emissions.

GHG emissions from Dryer is calculated based on EPA Greenhouse Gas Inventory Guidance for Direct Emissions from Stationary Combustion Sources (EPA, 2016). CO_2, CH_4 and N_2O emissions from dryer is estimated using fuel analysis approach. The following equation is used to calculate CO_2, CH_4 and N_2O using appropriate emission factors.

$$\text{Emission} = \text{Fuel} \times \text{HHV} \times EF_2$$

Where Emissions is Mass of CO_2, CH_4 or N_2O emitted; Fuel is Mass or volume of fuel combusted; HHV represents Fuel heat content in units of energy per mass or volume of fuel; and EF2 is CO_2, CH_4 or N_2O emission factor per energy unit

GHG saving potential of the green technique adopted by VVMineral is calculated by the equation

$$\text{GHG saving potential (\%)} = \frac{\text{GHG emissions from fossil fuel based operation} - \text{GHG emission from green technique}}{\text{GHG emissions from fossil fuel based operation}} \times 100$$

In the present study importance of garnet based abrasive water jet cutting in reducing green house gas emission and climate change effects in metal fabrication sector over the non traditional thermal cutting process is presented based on open literature published reports and scientific findings.

Results and Discussion

Analysis of energy savings in green mining Technology

In order to explain the importance of green mining technology of garnet in saving fossil fuel based energy in mining operation, analysis on energy profile of mechanized and manual mining process were undertaken. Table.2 compares the amount of energy interms of diesel oil input and their energy equivalent for one hour mechanized mining and manual mining event for garnet sand. It was observed that front end loader based mechanical garnet sand mining activity (Fig.2) utilized nine litres diesel oil to expend 331.430 MJ/hr energy required to produce 25 ton garnet sand per hour. On the other hand VVMineral achieved the same task by manual mining through field works of 100 man –hr. From the study it is evident that VV Mineral intelligently replaced this fuel based operation which is the greatest part of total energy input of the mining operation by manual mining. Since garnet sand is present on the surface requires less effort to acces. VVMineral collect the garnet sand using hand showls and bucket (Fig.3) results in a human power usage of 87.864 MJ/hr. From table 2 it is clear that in manual mining process to achieve the same tonnage garnet sand production per hour as mechanized mining event a total of 87.864 MJ manual energy is expended which is 3.77 times lesser than the energy utilized in mechanized mining. This makes an overwhelming choice for manual mining by VVM to replace the diesel fuel based mechanized operation and made the garnet mining operation green.

Table. 2 Input Energy profile of Mechanized mining and manual mining operations

Specification	Mechanized mining	Manual mining
Mining capacity	25 tons/hr	25 tons/hr
No.of Unit	1 Front end loader	10 groups of workers (1 group = 10 persons)
Fuel used	Diesel	Nil
Fuel consumption rate liter/hr	9 liters/hr	Nil
Equivalent Energy (Kcal/hr)	79158.837	21,000
Energy MJ/hr	331.430	87.864
Energy MJ/ton	13.257	3.515
Impact on environment	Combustion of diesel releases CO_2 , CH_4, N_2O and particulate matter	No GHG emissions

Fig. 2 Mechanized mining of Garnet sand

Fig.3 Manual mining of Garnet Sand

Similar studies for bauxite mining reported after topsoil and overburden removal the loosened bauxite ore excavation process using surface mining equiment requires 54.34 MJ energy / ton bauxite excavation (Griffing and Overcash, 2010) which is 4.1% higher than garnet sand mechanized mining process suggest that garnet sand mining is very simple process and requires less energy when compared to other surface mining activities and pave way for manual mining idea of VVMineral.

Analysis of greenhouse gas emissions mitigation potential of green mining technology

Based on the energy input data of mechanized and manual mining events (Table.2) the corresponding GHG emissions was estimated and presented as Table.3. Results showed every ton garnet sand produced in the diesel fuel based mining equipment resulted in 0.9293 Kg CO_2, 0.0542 g CH_4 and

0.0247 g N_2O emissions whereas no such emissions are accounted in manual mining operations.

Table. 3 Green house gas emission profile of mechanized and manual mining operation

Specification	Mechanized mining	Manual mining
CO_2 emission, Kg CO_2/ton	0.9293	Nil
CH_4 emission, g CH_4/ton	0.0542	Nil
N_2O emission, g N_2O/ton	0.0247	Nil
Equivalent CO_2 emission for calculated CH_4 emission, based on GWP (g CH_4/ton)	1.5178	Nil
Equivalent CO_2 emission for calculated N_2O emission, based on GWP (g N_2O /ton)	6.5525	Nil
Carbon foot print of the event, Kg CO_2 e /ton	0.93737	Nil
GHG savings GHG savings	Nil	100%

It is estimated Carbon foot print of mechanized mining event is 0.93737 Kg CO_2 e /ton garnet sand. Manual mining operation is having 100% GHG saving potential and significantly contribute to mitigate the carbon foot print of mechanized mining operations.

Analysis of energy savings in garnet sand green drying process

The energy profile study of rotary dryer and solar drying process illustrate the importance of solar drying technique adopted by VV Mineral in saving fossil fuel based energy. The results of the present study showed (Table.3) 1841.2345 KW.h energy is required for uninterrupted operation of dryer to eliminate moisture content and to produce 15 ton of dry garnet sand /hr, which is derived by combustion of 180 litres diesel oil/hr ultimately resulted in environmnetal pollution and GHG emissions. The inexpensive method of solar energy utilization - natural open air solar drying method adopted by VV Mineral has the potential to replace the fossil fuel based dryer operation. Natural solar energy of 5.8 KW/sq.m available in the rainshadow region 300 days in a year is brilliantly utilized by VVM and produced the same tonnage output as dryer without any environmental impact. The present study exhibit that VVM drying yard represents ambient air drying technique using atmospheric heat. The natural daily average solar radiation of 20.88 MJ/m^2 available in the drying yards is utilized to remove moisture from garnet sand. The ambient air temperature in the drying yards ranged between 26 – 45°C and the mean daily maximum temperature recorded is 37.1°C. For even drying in the yards wet surface of garnet sand is exposed to the drying medium (sun) by mixing up together every now and then using hand scooper. VVM achieved 100% moisture removal in every 2.54 cm height layer of sand in the yard within 5 hours.

Table.4 Input Energy profile of Rotary dryer and Natural Solar dring operations in 15 ton/hr capacity plant

Specification	Rotary Dryer	Natural Solar drying
Capacity	15 tons/hr	15 tons/hr
No.of Unit	1 Rotary dryer	13 drying yards Size 30 m L x 8 m B x 2.54 cm height
Fuel used	Diesel	Nil (Natural solar energy 5.8 KW/sq.m)
Fuel consumption rate liter/hr	180 liters/hr	Nil
Temperature	Upto 120 ºC	26 – 45 ºC Average 37.1 ºC
Heat transfer rate (KW)	1841.2345 KW.h	1392 KW/yard
Energy (MJ/hr)	6628.444	5011.2 MJ/yard or 20.88 MJ/m^2
Impact on Environment	Combustion of diesel releases CO_2 , CH_4, N_2O and particulate matter	No GHG emissions
Impact on garnet sand	Increase the surface coating on minerals results in 5 - 10% reduction in mineral response during garnet separation process Average recovery % of Garnet = 58%	Mininize the surface coating on minerals results in good mineral response during garnet separation process Average recovery % of Garnet = 66%

Present study inferred that VVM drying yards performance is similar to fixed type bed drying process. Bengtsson, 2008 reported experimental fixed bed drying tests of biomass layer with a depth of 0.4 to 0.6 m requires a drying time of 5 hours for saw dust and ten hours for wood chips at an operating temperature 80 -110°C suggest performance of VVM drying yard of garnet sand layer is superior than fixed bed drying process because in fixed bed drying the operating temperature is high and derived from fossil fuels combustion process which ultimately results in greenhouse gas emissions but VVM achieved moisture removal within 5 hours with green renewable solar thermal energy due to the unique characteristics of garnet sand. Since garnet sand is inert and non porous material moisture is not drawn inside the sand hence it is very easy to remove the moisture adhere on the surface of garnet sand using natural solar radiation at a maximum avarage daily temperature 37.1°C. VVM replace the fossil fuel based dryer operation with solar drying and achieved 100% moisture removal without any environmental impacts. Another advantage of solar drying process is it minimizes the surface coating on minerals therby increase the mineral response efficiency by 5 - 10% compared to dryer produced garnet sand in the Mineral Separation Process.

Analysis of greenhouse gas emissions mitigation from green solar drying technology

The study illustrated dryer operation is extremely energy intensive and contributes to the emission of green house gases. Based on the input energy data of rotary dryer events (Table.4) the corresponding GHG emissions was calculated. The emissions from diesel combustion from the dryer equipment is calculated to be 30.6797 Kg CO_2, 1.2565 g CH_4 and 0.2513 g N_2O/ ton garnet sand (Table. 5) whereas no such emissions are accounted in natural solar drying operations.

Table.5 Green house gas emission details from Rotary dryer and Natural solar drying operation for producing one ton dry garnet sand

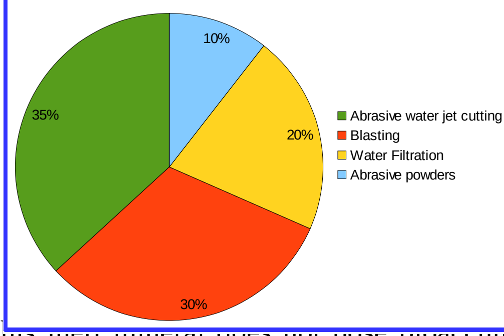
Specification	Rotary Dryer - Diesel fuel	Natural solar drying
CO_2 emission, Kg CO_2/ton	30.6797	Nil
CH_4 emission, g CH_4/ton	1.2565	Nil
N_2O emission, g N_2O/ton	0.2513	Nil
Equivalent CO_2 emission for calculated CH_4 emission, based on GWP (g CH_4/ton)	35.1822	Nil
Equivalent CO_2 emission for calculated N_2O emission, based on GWP (g N_2O /ton)	66.5949	Nil
Carbon foot print of the event, Kg CO_2 e /ton	30.7815	Nil
GHG savings GHG savings	Nil	100%

The carbon foot print from fossil fuel diesel based drying process is 30.7815 Kg CO_2 e /ton. Solar drying operation is having 100% GHG saving potential and it is inferred from the present study that solar drying technique make significant contribution in the mitigation of CO_2 emissions as a result of fuel switching.

Garnet – Climate friendly Green Mineral

Garnet is a climate friendly mineral that donot harm environment during its usage and disposal in industrial process. Climate-friendly goods refer to those the utilization of which reduce climate risks to a greater extent than alternative products that serve the same purpose (Zhang, 2011). Globally 35% of refined almandine garnet is used by Abrasive Water Jet Cutting (AWJC) industry (Fig.4) and blasting, water filtration and abrasive powders are the other end uses of garnet (Olson, 2014). In all such industries garned based operations are found to be green and climate friendly due to its natural inertness and perfect hardness provides excellent process efficiency without any environmental emissions. Another green property of garnet is the spent garnet can be

Figure 4. Different End uses of Garnet (Olson,2014)

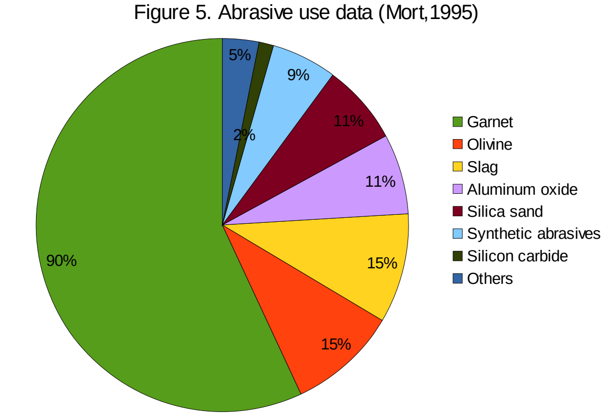


disposed as land fill and this inert mineral does not pose bioaccumulation or waterway and food chain contamination problems. Natural inertness of garnet provide the advantage of reuse of garnet 5 to 8 times in industrial process and reduces resource usage. Hence usage of garnet in industrial process is green which is cost effective, curb environment impacts and reduces the impact on climate change.

Importance of Garnet in Abrasive Water Jet Cutting (AWJC)

Garnet is the extensively used abrasive in all renowned water jet cutting machines around the world. Almandine garnet, a naturally inert mineral, with hardness between 6.5 and 7.5 on the Mohs scale and a density of 3.9 to 4.1 g/cm^3 is the single specific abrasive dominate the abrasive market (Mort,1995).

Figure 5. Abrasive use data (Mort,1995)



Performance of AWJC operations are influenced by the abrasive characteristics such as hardness, density, particle form, degree of purity and size distribution (Ohman 1993, WATERJETS.ORG, 2014). Even though a large number of materials represent all the aforementioned characteristics (Figure 6), the abrasive market seems to be dominated by a single, specific abrasive: Almandine Garnet. The right combination of hardness, density, toughness and particle size in the garnet maximizes water jet cutting performances and its preference around the world (Figure.7).

Figure 6. Different types of abrasive used In Abrasive water jet cutting (Alsoufi,2017)

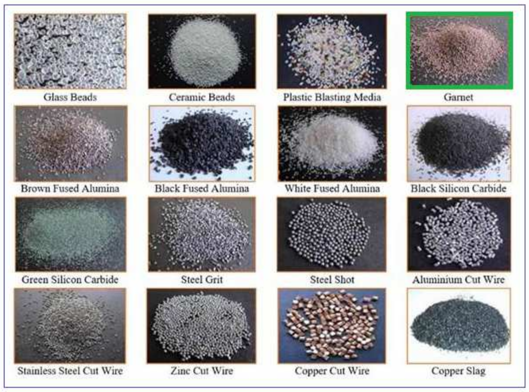
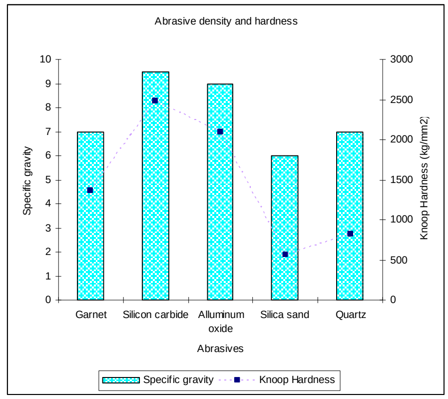


Figure 7. Hardness and density comparison of garnet and other commonly used abrasives



Profitability of AWJC relies on selecting the best abrasives which impart good cutting speed, edge quality and component life. Soft abrasives silica sand, quartz etc provide better component life but poor cutting speed and hard abrasives aluminum oxide and silicon carbide offers fast cutting but cause an increased wear of the nozzle and mixing chamber leads to poor accuracy and frequent nozzle replacement (Kulecki, 2002). Almandine garnet falls between 6.5 and 7.5 on the Mohs scale, which effectively balances the need to cut quickly and provide reasonable cutting tool life. Millions of years of weathering, the hard and tough sub-angular garnet grains provide the perfect balance between cutting speed and edge quality in water jet cutting process and made garnet as a very good and popular abrasive. Garnet – a hard brittle crystalline mineral is recognized as the world standard abrasive for water jet cutting (Carborundum Abrasives – Div. Saint – Gobain Abrasives).

Merits of replacing thermal cutting methods by Garnet based abrasive water jet Technology

All over the world manufacturing industries demand metal cutting technology for faster and precise cutting to withstand business competition. Garnet based abrasive water jet cutting came at first to fulfill the demand. Extensive studies were carried out regarding performance comparison of Garnet based abrasive water jet cutting with other cutting methods (Zeng et al, 1991, Ohlsson et al., 1994, Powell et al., 1995 and Akkurt, 2002, Akkurt, 2009, Mert, 2012 and Akkurt, 2015) and all the research approved garnet based abrasive water jet cutting system to be the most efficient method when compared to Oxy fuel cutting, Plasma arc cutting and laser cutting (Jain, 2009) which are said to be competitors and the merits are presented hereunder.

a. ***Garnet based abrasive water jet cutting – A Versatile technology***

Garnet based abrasive water jet cutting is a versatile process than the other thermal cutting methods because it has no restriction on cutting material and shapes. This method can cut any type of material thin or thick, soft or hard viz., steel, aluminum, glass, wool, plastics, laminates, ceramics, composites, metals, stones, marbles etc. with good accuracy. But thermal cutting process has restrictions on type of material and material thickness as provided in table 6. From the comparison table it is obvious that Garnet based abrasive Water jet cutting is the most positive method which cut any type of material upto 350 mm thickness with good accuracy and can effectively replace other thermal cutting process.

Table .6 Cutting characteristics of garnet based abrasive water jet cutting compared with thermal cutting methods

Technology	**Type of material**	**Material Thickness**	**Multilayer cutting**	**Accuracy of cutting**
Garnet based abrasive water jet	Any type of material Both metals and nonmetals.	Upto 12 inches (350 mm)	Possible	Upto 0.001inch
Laser	Only homogenous material which do not reflect light	<98 inches (25 mm)	Impossible	Upto 0.001inch
Plasma arc	Only conductive material	<3.5 inches (80 mm)	Impossible	0.01 inch
Oxy fuel	Only metals low carbon steel and low alloy steel	Upto 9 inches (250 mm)	Impossible	0.03 inch

b. ***Garnet based abrasive water jet cutting – Environment friendly cold process***

Thermal cutting processes release intense heat and substantial quantity of fumes and smoke due to vaporizing metals in the kerfs which has direct environment concern (Table 7). Effects of these chemical pollutants can be completely reduced by replacing thermal cutting processes with garnet based abrasive water jet cutting technique. It is an alternate continuous cold cutting process where abrasive garnet particles are dragged into the water stream and impelled at high speed against the target to get desired shapes. As the process is provided by water, heat and smoke emission is completely reduced and it does not create any grinding dust or chemical pollutants (Hascalik et al., 2007) and it can be stated that abrasive water jet cutting is the only non polluting method available for machining materials to precision details.

Table .7 Environment friendly characteristics of garnet based abrasive water jet cutting compared with thermal cutting methods

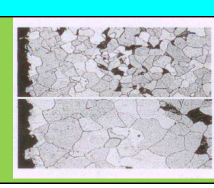
Technology	**Nature of process**	**Environmental hazard**
Garnet based abrasive water jet	COLD Erosion -Using high speed liquid and garnet (4000 – 6000 bars)	NO
Laser	THERMAL Melting using a concentrated laser light beam (10^5	YES Fumes and smokes.

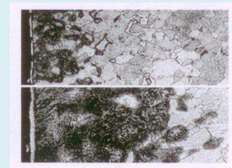
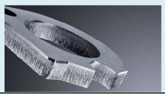
	W/mm^3)	Pollutants in the smoke is characterized by the cut material assist gas and laser power
Plasma arc	THERMAL Burning/melting Using high temperature ionized gas arc (10,000 – 14,000 ºC	YES Fumes and Smoke Smoke include oxides of hexavalent chromium, iron, copper, zinc, nickel, manganese, aluminum, tin, beryllium, cadmium, lead, and titanium.
Oxy fuel	THERMAL Chemical reaction /melting 13,000 ºF to 14,000 ºF (704 ºC to 760 ºC) Using exothermic reaction of oxygen with base metal	YES Greenhouse gas emissions Fumes, smokes and infrared radiation Fumes include oxides of Iron, cadmium, zinc, hexavalent chromium

c. ***Garnet based abrasive water jet cutting – provides perfect surface quality***

In metal cutting sector the effectiveness of different cutting process is evaluated by measuring the surface roughness of cutting section. Thermal cutting process affects the surface quality of the cut material where edges exhibit a rough surface caused by the action of cutting jets. All thermal cutting process showed heated affected zone (HAZ). Structural deformation is obvious in thermal cutting process and the changes in microstructure and hardness can be attributed to heat input during cutting process (Akkurt,2009). On the other hand garnet based abrasive water jet cutting is a unique process that has no adverse effect on the microstructure of the cut material. As the process location in the water which accelerates the removal of heat from the treatment zone (Borkowski and Borkowski, 2008), this cutting technology release no heat effect and structural deformation problem on the cut material and generates satin smooth surface (Ojmertz, 1994, Hlavacek et al., 2012). In garnet based abrasive water jet cutting process the original structure of cut material is preserved (Akkurt, 2009). Thermal cutting methods generate melted edges and require secondary process (Table 8) to get clean surface which increases the production cost suggesting abrasive water jet cutting is superior in industrial application for producing perfect quality cutting than other thermal cutting process.

Table .8 Surface quality comparison of garnet based abrasive water jet cutting compared with other cutting methods

Technology	**Surface quality**	**Secondary Process**	
Garnet based abrasive water jet	Perfect. Satin smooth edge 	Not required. No structural deformation	

Laser	Good 	Apparent structural deformation Required to remove HAZ (Heat Affected Zone)	
Plasma arc	Acceptable 	Excessive structural deformation Required to remove HAZ (Heat Affected Zone)	
Oxy fuel	Serrated 	Most excessive structural deformation Required to remove HAZ (Heat Affected Zone)	

Garnet based abrasive water jet cutting – An ecological process

Different cutting process requires specific tools to perform effective cutting. In thermal cutting process cutting tools are constricted by utilizing either electric or fuel gas energy sourced from non renewable sources. Hence all thermal cutting process utilizes dwindling fossil fuel resources for generating the cutting tools (Table. 9) which is ecologically unsafe and huge quantity of fossil fuel usage in thermal cutting process will end up in resource depletion. But in garnet based abrasive water jet cutting the cutting "tools," are water and garnet abrasive which are the resources abundantly available in Earth hence Garnet based abrasive water jet cutting process is ecologically safe never results in resource depletion.

Table .9 Comparison of garnet based abrasive water jet cutting compared with other cutting methods based on ecological effects

Technology	**Cutting tool**	**Cutting gas**	**Ecological effect**
Garnet based abrasive water jet	Water and garnet	No	Tools can be recycled and reused Available abundantly in earth
Laser	Monochromatic light beam and assist gas	Nitrogen, oxygen	Consume large amount of electricity to constrict monochromatic light beam which is sourced from dwindling fossil fuel resources. Tools disappear in the environment as heat, aerosols, NOx and Ozone Tools can not be re cycled or reused.
Plasma arc	Plasma arc	Nitrogen, argon, oxygen, mixture of nitrogen/hydrogen, argon/hydrogen	Requires high electric energy to constrict arc which is sourced from dwindling fossil fuel resources Tools disappear in the environment as heat, UV radiation, metal oxides, Nitrogen di oxide and Ozone Tools can not be re cycled or reused.
Oxy fuel	Fuel gas and oxygen	Acetylene, Propane, Propylene, natural gas	Tools disappear in the environment as heat, IR radiation, particulates and green house gases Tools can not be re cycled or reused.

Garnet based abrasive water jet cutting – A climate friendly process

Among the different cutting methods garnet based abrasive water jet cutting is climate friendly technology does not release harmful gases, UV radiation other hazardous substances harmful to environment and machine operators. Mixing of water and garnet abrasive do not emit any toxic vapor or unpleasant odor. The abrasive waste generally is inert garnet with a small fraction of particles from the material being cut. Unless the material being cut is a highly hazardous material, such as lead, the waste abrasive can be disposed of safely at a dry landfill, with no processing and no environmental risk (Arleo, 2010).The classification of the spent abrasive as inert waste makes its land filling an economically attractive option. Hence garnet based abrasive water jet cutting is the best method for processing engineering materials.

Garnet based abrasive water jet cutting curbs GHG emissions

Among the thermal cutting processes oxy fuel cutting is more hazardous and impacts the environment by emissions of green house gases during fuel combustion process. In this process a mixture of oxygen and the fuel gas is used to preheat the metal to its 'ignition' temperature which, for steel, is 700°C - 900°C (bright red heat) but well below its melting point. A jet of pure oxygen is then directed into the preheated area instigating a vigorous exothermic chemical reaction between the oxygen and the metal to form iron oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce through the material and continue to cut through the material (DeGarmo et al., 1999). The common fuel gases used for preheating the metal in oxy fuel cutting process are Acetylene, Propane, Propylene, natural gas which are hydrocarbons, and their combustion in oxy fuel cutting process leads to CO_2 emissions. Incomplete combustion of this fuel gas leads to other green house gases methane and nitrous oxide emissions.

In order to explain the role of garnet based abrasive water jet cutting process in reducing green house emissions comparison of GHG emissions from oxy fuel cutting and garnet based abrasive water jet cutting process in cutting per foot of length steel pieces were undertaken based on the Fuel gas characteristics and the GHG emission factors of different gases (Table.10) and the results are presented as Table 11.

TABLE. 10 Fuel gas charcterisitcs and combustion emission factors

Fuel gas	Maximum flame temperature °C	Oxygen to fuel gas ratio (vol)	Heat distribution KJ/m^3		Kg CO_2 emission/ scf	gCH_4 emission/ scf	gN_2O emission/scf
			Primary	Secondary			

Acetylene	3,160	1.2:1	18,890	35,882	0.1053	-	-
Propane	2,828	4.3:1	10,433	85,325	0.15463	0.000055	0.000252
Propylene	2,896	3.7:1	16,000	72,000	0.15379	0.006996	0.001399
Natural gas	2,770	1.8:1	1,490	35,770	0.05444	0.00103	0.00010

TABLE .11 Comparison of GHGs emissions from steel cutting by garnet based abrasive water jet cutting and oxyfuel cutting with different gases.

	Consumption (scf/hr)	Kg CO_2 emission/hr	gCH_4 emission/hr	gN_2O emission/hr	CO2 e Kg/hr
			Acetylene		
Garnet based Abrasive water jet cutting	Not required	Nil	Nil	Nil	Nil
Oxy fuel cutting	18.0	1.8954	-	-	1.8954
			Propane		
Garnet based Abrasive water jet cutting	Not required	Nil	Nil	Nil	Nil
Oxy fuel cutting	64.5	9.9736	0.0035475	0.01625	9.978
			Propylene		
Garnet based Abrasive water jet cutting	Not required	Nil	Nil	Nil	Nil
Oxy fuel cutting	55.5	8.5354	0.388278	0.0776445	8.56685
			Natural gas		
Garnet based Abrasive water jet cutting	Not required	Nil	Nil	Nil	Nil
Oxy fuel cutting	27.0	1.46988	0.02781	0.0027	1.47037

***Thickness of steel one inches**

From the table.11 it is evident that fuel gas is not a cutting tool in garnet based abrasive water jet cutting process but in oxyfuel cutting fuel gas play a vital role in cutting process and the result showed all the fuel gas used for oxy fuel cutting operation results in GHG emissions and the CO_2 equivalent emission of propane gas is the highest (9.978 Kg CO2 e/hr). The environmental effects of oxy fuel cutting can be mitigated using abrasive water jet cutting. From an environmental perspective, Abrasive water jet cutting is a cold process, uses environmentally benign water and abrasive as the cutting tool shall not impose any negative impact on the environment. Hence AWJ can be an ideal climate friendly alternative to oxy fuel cutting operations in metal cutting industry.

Garnet based abrasive water jet cutting curbs Environment Pollution

Thermal cutting processes separate materials by applying heat, with or without a stream of cutting oxygen. All cutting operations releases intense heat, fumes, smoke and atmosphere contaminants. The most common gases emitted during thermal cutting process are ozone, nitrous gases and carbon monoxide. According to the Fifth Assessment Report of the IPCC 'nearly all the non - CO_2 climate - altering pollutants are health damaging, either directly or by contributing to secondary pollutants in the atmosphere'. The hazards associated with different cutting process are presented as Table 12.

Table 12 Hazards associated with different cutting process

Hazard	**CUTTING METHODS**			
	Plasma arc	**Laser beam**	**Oxy fuel**	**Garnet based abrasive water jet**
Bright light	Hazard present	Hazard present	Hazard present	NO hazard
UV Radiation	Hazard- affect the eye	No	No	NO hazard
IR Radiation	No	No	Hazard – skin burn	NO hazard
Toxic fumes and gases	Hazard to environment and machine operators	Hazard to environment and machine operators	Hazard to environment and machine operators	NO hazard
Heat, fire and burns	Hazardous to environment and machine operators	Hazardous to environment and machine operators	Hazardous to environment and machine operators	NO hazard

Table 12 illustrated garnet based abrasive water jet cutting is a reliable process due to the cold nature of the process does not vaporize the cut section and avoid fumes and smoke emission and associated hazards. Due to high temperature during the thermal cutting process, different substances in the cut material are vaporized. Then, the vapor condenses and oxidizes in contact with the air, leading to the formation of fumes. Fumes and gases generated during cutting materials consist primarily of metal oxides from cut material and other contaminations present in the cutting consumables, surface coatings and within the atmosphere. Cutting of stainless steel is potentially the most hazardous as the fumes will contain chromium and nickel. Copper and its alloys are also commonly cut and can also produce a significant fume hazard. Oxides of nitrogen are formed during thermal cutting and could accumulate in areas of poor ventilation. These are likely to be most significant during plasma cutting where air or nitrogen is used as the plasma gas. Ozone is most likely to be formed during cutting of aluminium or stainless steel. Where inert gases are used they may accumulate in confined spaces causing an asphyxiation risk. This is most likely to occur when the gas is significantly heavier than air, eg argon/nitrogen mixtures.The metal fume emitted from plasma cutting consist of carcinogen hexavalent chromium (Cr6+), and other toxic heavy metals (Table.13). Overexposure to thermal cutting fume may cause pulmonary toxicity and other health effects (Wang,2017). Metal oxides and gas contaminants released by different thermal cutting process is illustrated in Table 13.

TABLE 13. Potential air emissions from different cutting process

Process	**Potential emissions**
Garnet based abrasive water jet cutting	**NO Air emissions**
Plasma arc cutting	Particulates : Compounds of Antimony, Beryllium, Boron, Cadmium, Carbon monoxide, Chromium, Hexavalent chromium, Cobalt, Copper, Lead, Magnesium oxide, Manganese, Mercury, Selenium, Zinc, Nickel, lead, zinc, iron oxide, copper, cadmium, fluorides, manganese, and chromium

	Gas : Oxides of nitrogen, PM_{10}, Sulfur dioxide, Ozone
Laser cutting	Particulates : Respirable dust, Cresol, 1,3-Butadiene, Iron oxide, compounds pf Nickel, Chromium, Cobalt, Chromium, Nickel Gases : Ozone, NOx, NO, NO_2, CO
Oxy fuel cutting	Particulates : Compounds of Lead, Nickel, Zinc, iron oxide, Copper, Cadmium, Fluorides, Manganese, and Chromium Gases : carbon monoxide, oxides of nitrogen, and ozone

Many of these contaminants fall within the scope of the Control of Substances Hazardous to Health Regulations (COSHH) 2002 (Amendment) 2004, and have permissible exposure limits (PEL) set by the Occupational Safety & Health Administration (OSHA) Table 14).

TABLE. 14 Common Thermal cutting contaminants with associated Permissible Exposure Limit set by Occupational Safety and Health Administration OSHA.

Common contaminants	**OSHA PEL Time Weighted Average (mg/m^3)**
Metal Contaminants	
Aluminum Oxide	10
Iron Oxide	5
Chromium (III)	0.1
Copper fume	0.2
Magnesium oxide fume	10
Manganese	0.2
Nickel (elemental)	1.5
Silica (fume)	2
Gas contaminant	
Ozone	0.1 ppm
Nitrogen di oxide	5 ppm

Air pollution is considered as a threat to human health as well as to the Earth's ecosystems. Based on WHO report, around 7 million people worldwide died due to the air pollution in 2012 (WHO,2014). Replacing thermal cutting with garnet based abrasive water jet cutting totally curbs the problem of hazardous fumes and air pollution. Climate-friendly aspects of water jet cutting process is illustrated in table 13 which highlighted no direct air emissions from Abrasive water jet machining operations. The advantage of this method is that it is a cold process. All materials can cut without any heat generation. Hence, unwanted poisonous gas formations are avoided. Having no negative effect on environment, Abrasive water jet cutting can be used as alternate to thermal cutting process in metal and other industries to avoid global warming.

Conclusion

From the present study it is concluded that green mining of garnet undertaken by V.V.Mineral in the coastal districts of Tamil Nadu, India through offering employment to local community has great potential to mitigate greenhouse gas emissions from mechanized mining process. Manual mining carried out by scrapping and scooping method using hand showls and bucket is efficient in garnet sand collection and save 13.257 MJ fossil fuel energy and mitigate 0.9293 Kg CO_2, 0.0542 g CH_4 and 0.0247 g N_2O emissions per ton garnet sand . The calculated global warming potential of mechnized mining operation expressed in CO_2 equivalent unit is 0.93737 Kg /ton of garnet sand using diesel as fuel for a front end loader equipment which is completely mitigated by green mining technology. Solar drying yards of VVMineral is a brilliant idea which effectively utilize the atmospheric heat for moistue removal from garnet sand. The beach area registered a mean daily maximum temperature of 37.1 ºC for 300 days and this heat energy is effectively utilized to replace dryer based moisture removal process and save 30.6797 Kg CO_2, 1.2565 g CH_4 and 0.2513 g N_2O emissions/ ton garnet sand. The calculated global warming potential expressed in CO_2 equivalent unit is 30.7815 Kg /ton of garnet sand using diesel fuel for rotary dryer equipment which is potentially mitigated by solar drying technique. Garnet is the world standard abrasive. Unique hardness and chemical inertness of garnet provides perfect balance between cutting speed and edge quality in abrasive water jet cuting process hence among the various natural and synthetic abrasvies garnet is the most preferred abrasive in Abrasive water jet cutting process. Information on climate friendly aspects of garnet based abrasive water jet cutting process over the other non conventional metal cutting process is presented based on literature review from which it is understood oxy fuel cutting is more hazardous and release GHGs during fuel combustion process. Among all common fuel gases, CO_2 equivalent emission of propane gas based cutting is the highest which is 9.978 Kg CO_2 e/hr. The environmental effects of oxy fuel cutting can be mitigated by replacing this thermal process with garnet based abrasive water jet cutting. More over all thermal cutting operations releases intense heat, fumes, smoke and atmosphere contaminants leads to air pollution. Gases emitted during thermal cutting process are ozone, nitrous gases and carbon monoxide which has intense health effects apart from contributing to secondary pollutants in the atmosphere'. The metal fume emitted from plasma cutting consist of carcinogen hexavalent chromium (Cr6+), and other toxic heavy metals. Overexposure to thermal cutting fume may cause pulmonary toxicity and other health effects. Environment pollution and work place contamination hazards related to thermal cutting process will be curtailed by replacing the thermal cutting process with garnet based abrasive water jet cutting which is an climate friendly green process. The advantage of this method is that it is a cold process, produce most accurate, fast and superior surface quality without any environmental hazards. As the process is provided by water heat and smoke emission is completely reduced and it does not create any grinding dust or chemical pollutants and it can be stated that replacing thermal cutting process by garnet based abrasive water jet cutting will reduce air pollution in the form of fumes and gases and reduces CO_2 emission and global warming.
