The main challenge that prompted the author to present in this paper was the difficulty of recycling GaN waste.Etching of GaN material is a challenge; hence, the chemical leaching of GaN is an essential and primary stage for recycling or treatment of waste.The Table 1 shows that any form of action by any acid renders ineffective. Even at high temperatures, the etching process doesn’t get initiated at all .

Pretreatment is done to make the GaN reactive for leaching . This is a well-known process that is administered even for complex ores. Oxidative roasting is a fairly common process that is used for processing complex sulfide ores and concentrates,refractory slag,and low-grade ore. In the oxidative roasting, Na2CO3 is used for processing the refractory ores or sulfides ores.Through this pretreatment they are converted into the gallium oxides. It has been found out from energy calculations that the oxides are generally the most reactive ,hence making it ready for leaching for recycling . It has been elaborated by reactions (1)-(4).

Now, the major question comes as to whether the oxidation is feasible or not . For that we use Ellingham diagram of all the species that are there in the above mentioned reactions.

The main thermodynamic concept we must concern ourselves with when it comes to metallurgy is Gibbs Free Energy. In thermodynamics, whether a process will happen spontaneously or not will be determined by Gibbs Free Energy. The symbol ΔG. If this value of ΔG is negative then the reaction will occur spontaneously. We will now look at two equations to arrive at ΔG.

ΔG = ΔH – TΔS

ΔH is the change in enthalpy. Here a positive value will depict an endothermic reaction, while a negative value will be an exothermic reaction. So when the reaction is exothermic, it makes ΔG negative. ΔS is the Entropy or the randomness of molecules. This changes very sharply when the state of the matter changes. Another equation which relates the Gibbs Free Energy to the equilibrium constant is

ΔG° = RTlnKeq

Keq is the equilibrium constant. It is calculated by dividing the active mass of products by the active mass of reactants. R is the universal gas component. Now to attain a negative value of ΔG (which is desirable) the value of the equilibrium must be kept positive.

An Ellingham diagram shows the relation between temperature and the stability of a compound. It is basically a graphical representation of Gibbs Energy Flow.

In metallurgy, we make use of the Ellingham diagram to plot the reduction process equations. This helps us to find the most suitable reducing agent when we reduce oxides to give us pure metals.

Important features of the Elingham diagram are :

* Here ΔG is plotted in relation to the temperature. The slope of the curve is the entropy and the intercept represents the enthalpy.
* As you know the ΔH (enthalpy) is not affected by the temperature
* Even ΔS that is the entropy is unaffected by the temperature. However, there is a condition here, that a phase change should not occur.
* We will plot the temperature on the Y-axis and the ΔG on the X axis
* Metals that have curves at the bottom of the diagram reduce the metals found more towards the top

The reaction of metal with air can be generally represented as

M (s) + O2 (g) → MO (s)

Now when reducing metal oxides the ΔH is almost always negative (exothermic) reaction. Also since in the reaction (as seen above), we are going from the gaseous state to the solid state ΔS is also negative. Hence as the temperature increases, the value of TΔS will also increase, and the slope of the reaction goes upwards.

So, over here also we are trying to find the most suitable reducing agent for GaN.

The negative change of G makes the reaction (1) makes us understand it is spontaneous and can be a potential pretreatment method for treatment and recycling of waste GaN.This individual treatment was done for all the four reactions using the Ellingham Diagram.To summarize, what was found out denoting each reaction as spontaneous or not . The chemical oxidation of GaN to GaNaO2 follows a two-step process. First of all, the Na2CO3 decomposes as Na2O and CO2, and then, GaN and Na2O react at high temperature to form GaNaO2. Using the Na2CO3, through oxidative roasting, GaN can be oxidized to GaNaO2. It subsequently adds the advantages of easier leaching out or treat these GaN bearing waste.

So, with the help of Ellingham Diagram, we established that Na2CO3 is the appropriate reducing agent .

The validity of the results found from Ellingham diagram and the phase-change behavior , TGA was done which proved GaN converted completely to Ga2O3 which is also verified through XRD. The high-temperature oxidative roasting of the GaN can form Ga2O and Ga2O3, subsequently, which would be easy to leach in the metal recovery process of waste treatment.The Ga-N-O phase stability diagram proves the stability of GaN ,Ga2O and Ga2O3.

From reactions (5)-(7) , since the change in G is negative ,it means those conversions are spontaneous and hence favoured.

Next thing that we need to concentrate is how the leaching is done and it can be found out from Pourbaix Diagrams . **Pourbaix Diagrams** plot electrochemical stability for different redox states of an element as a function of pH. As noted above, these diagrams are essentially phase diagrams that plot the map the conditions of potential and pH (most typically in aqueous solutions) where different redox species are stable. The lines in Pourbaix diagrams represent redox and acid-base reactions, and are the parts of the diagram where two species can exist in equilibrium.

* **Areas** in the Pourbaix diagram mark regions where a single species (Fe2+(aq), Fe3O4(s), etc.) is stable. More stable species tend to occupy larger areas.
* **Lines** mark places where two species exist in equilibrium.
  + **Pure redox** reactions are **horizontal** lines - these reactions are not pH-dependent
  + **Pure acid-base** reactions are **vertical** lines - these do not depend on potential
  + Reactions that are **both** acid-base and redox have a slope of -0.0592 V/pH x # H+⁄# e-)

Pourbaix diagrams were constructed using common leaching agents like HCl, HNO3,H2SO4.

Then it is tested on different pH ranges . The Pourbaix diagram shows that gallium can be leached both by acidic leaching and/or by alkali leaching though different species of gallium ion. Hence, reasonably it can be concluded that gallium can be leached either from Ga2O3 or from NaGaO2 using higher concentration of mineral acids or NaOH. The leaching of gallium can be enhanced with higher temperature. Through oxidative leaching, the gallium-leaching goal also can be achieved with moderate range of acidity and higher temperature. The values of standard free energy of formation in the Eqs. 8–11 are negative, indicates that, both acid and base leaching of the NaGaO2 are spontaneously feasible.

So , through this article we found out how to recycle GaN material-through oxidative roasting and leaching . We found out the validity and feasibility of both these processes.Further tests that can be carried out are maybe the calcination aspect may be explored and more refined search for the correct leaching agent to increase effectiveness.Experiments regarding leaching time using acidic and basic conditions need to be carried out to find out the best possible method to make the process more targeted .