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# Feasibility of Direct-Utilization Geothermal Applied Towards Recycling Plastic in the Reno-Tahoe Region

**C.L. Martin**

**Martin Geothermal LLC**

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## ABSTRACT

Direct-utilization of geothermal energy from geothermal reservoirs along the eastern base of the Sierra Nevada in the Reno-Tahoe region of the western United States (USA) can potentially be economically viable in assisting the recycling process of certain plastics, thus reducing $CO_2$ emissions that would have otherwise been generated from conventional energy production. Temperatures exceed 120 °C (248 °F) at commonly drilled depths up to 3 km (10000 ft) below most of the region; local areas are much hotter as shallow as 200 m (700 ft) where fault zones host a buoyant convective flow of hot water. For example, at the southern edge of Reno, the Steamboat Power Project generates 84 MW of electricity using hot water produced from a 140 to 180 °C (285 to 360 °F) reservoir at depths of 200 to 600 m (700 to 2000 ft) and from a 204 °C (400 °F) reservoir below 900 m (3000 ft) depth, heated by a much deeper magmatic source. Experience with geothermal-supported plastic recycling in Iceland supports the use of geothermal resources near the Reno urban area to recycle commonly used plastics such as HDPE and LDPE that soften-melt at ~130 °C (266 °F) and ~120 °C (248 °F), respectively. Plastics requiring higher temperatures can be recycled by using low emissions geothermal energy to supplement other energy sources. Direct-utilization of geothermal energy to recycle plastics reduces hydrocarbon consumption with respect to both the constituents of the plastic and the energy required in the recycling process. Developing this concept at scale in the Reno urban area will support its application to other areas where geothermal energy can be economically utilized to increase the world plastic recycle rate from its current 9%.

## 1. Introduction

A plastic recycle plant in Iceland successfully utilizes direct-use geothermal energy for assisting in the process for reintroduction of recycled plastic as raw material into the plastic industry (Richter, 2020). These processes include cleaning, melting, and preparing plastic for shipment to facilities such as bottling plants. Table 1 shows a list of plastic materials with their respective approximate softening to melting point ranges (in °C) required for recycling. It is possible to use this same technique in geothermal areas of the Reno-Tahoe region, USA, a region comprised of urban and suburban areas where lots of plastic waste is generated and collected from an even broader area. The plastic materials highlighted in green in Figure 1 are those which can be melted down solely with direct-use geothermal energy; no additional heat generated from conventional power sources is required.

| Plastic | Softening-Melt Range (°C) | Resin Code |
|---|---|---|
| ABS | 88-125 | |
| Acrylics | 91-125 | |
| Cellulosics | 49-121 | |
| LDPE | 107-124 | 4 |
| HDPE | 122-137 | 2 |
| Nylons | 160-275 | |
| PET | 225-255 | 1 |
| Polycarbonate | 140-150 | 7 |
| Polyesters | 220-268 | |
| PP | 158-168 | 5 |
| PS | 100-120 | 6 |
| Polyurethanes | 85-121 | |
| PTFE | 327 | |
| P.vinylideneclor | 212 | |
| PVC | 75-110 | 3 |

**Table 1: Melting point temperature ranges of plastic materials in °C (Modified from various sources). The materials highlighted in green are recyclable in certain areas of Reno, NV where the geothermal temperatures are high enough to bring the plastics up to the softening-melt range to be recycled.**

Earlier regional surveys of the Truckee Meadows basin, in which the city of Reno, Nevada is located, have identified several areas likely to host geothermal resources at the temperature required for recycling some types of plastics, shown in Figure 2 (Martin, 2021). The Truckee Meadows Basin is part of the N-S-trending Walker Lane zone at the western edge of the Great Basin, USA, an extensional geologic environment known for its prevalent geothermal potential (Busby et al., 2016, Coolbaugh et al., 2005; Faulds and Hinz, 2015, Siler et al., 2019). This region is classified by the International Geothermal Association (IGA) as a Convection Type 2 (CV2 ) geothermal play type (Moeck and Beardsmore, 2014; Hervey et al., 2014). Thermal waters, some like in the case of Steamboat heated from deep magmatic sources, upflow along fault-fractured zones typical of extensional geologic settings. These fracture zones and adjacent subsidiary fault zones generally trend north-south mostly along the base of the mountain ranges and are primary targets for geothermal energy production wells, typically up to 3 km depth locally (Faulds and Hinz, 2015). In outflow areas, thermal waters have been observed to flow in lateral aquifers with no visible surface indicators, flowing buoyantly up dip along the base of a clay cap (a.k.a. “blind” geothermal systems) (Cumming, 2009; Faulds and Hinz, 2015; Siler et al., 2019).

The following sections provide additional details on the feasibility of establishing a plastic recycle plant in the Truckee Meadows Basin utilizing geothermal energy with temperatures up to 130°C, focusing on initial research and surveying, the current status of recycling plastic in the region, and a discussion of resources saved and current market status. For purposes of this report, the geothermal reservoirs discussed would simply provide a means to recycle plastic as a component of the mechanical process of bringing the plastic material to its respective soften-melt phase via direct-use heating, not to generate the power required for the electrical needs. The principles described in this report are meant to act as the first step in initializing this project as well as be applied to other areas in the world where direct-use geothermal energy is economically available for this type of project.

## 2. Initial Research and Surveying

To establish a plastic recycle plant in the Reno-Tahoe region which directly utilizes geothermal energy requires a geothermal well dedicated to the plant. An order of operations must be followed in order to properly select the wellsite, starting with creating a conceptual model of upflows and outflows which is based on an initial literary review of published data and reports to select and area, followed by subsequent geophysical surveys in order to delineate a target drill site. Due to the urban development of most of the areas highlighted in Figures 1 and 2, most of the literature available is primarily structural geologic reports focused on the surrounding areas as well as historical well core logs from within the urban areas. The reports and logs currently available seem to suggest an extensive outflow in the region, sourced either solely from the Steamboat upflow system and/or possibly in combination from elsewhere, e.g. to the northwest of Reno (Cashman et al., 2012; Cumming, 2009; NBMG, 2022; Spampanato, 2014; Wallis et al., 2017). In many areas there exist prior wells which could be reworked for higher temperatures or help provide further constraints on isotherm cross sections (Cashman et al., 2012; Flynn, 2002). Next, commercial properties zoned for industry with the capability of obtaining drilling permits as well as geothermal and water leases would be considered. If possible, additional geophysical surveys would be conducted prior to land purchase, depending on urban conditions. Target areas for constructing the plastic recycle plant would be based on outflow areas that are economically viable to drill in that would be close in proximity to available land, since drilling and piping costs are one of the most expensive components of the budget. Once a target site is selected, the geothermal well would be established, and subsequent construction of the plant would take place.

### *2.1 Geothermal Areas Of the Reno-Tahoe Region*

Several areas in the region have been documented to have direct-use geothermal potential which can be economically harnessed for industrial purposes. However, each of these areas require further research before a drill site can be targeted, even if the area has been well-documented and its geothermal resources previously exploited.

#### 2.1.1 Documented Geothermal Areas In The Region

Geothermal temperatures recorded in the area range from <50°C (122°F) in areas such as near Lawton hot springs in northwest Reno and Minden, NV in the Carson Valley at a depth of <1 km

(NBMG, 2021) to >160°C (320°F) at Steamboat Power Plant in south Reno at a depths approaching 1 km, with increasing temperatures deeper towards the upflow source, the highest measured at 260°C (500°F) (Bjornsson et al., 2014; Ormat, 2018 and 2020). Figure 1 shows the recent Nevada Bureau of Mines and Geology (NBMG) map with geothermal data overlaid, with the darker colored areas representing higher measured temperatures (NBMG, 2022). Possible outflow areas include Moana (Flynn, 2002) and the nearby Peppermill resort (Spampanato, 2010).

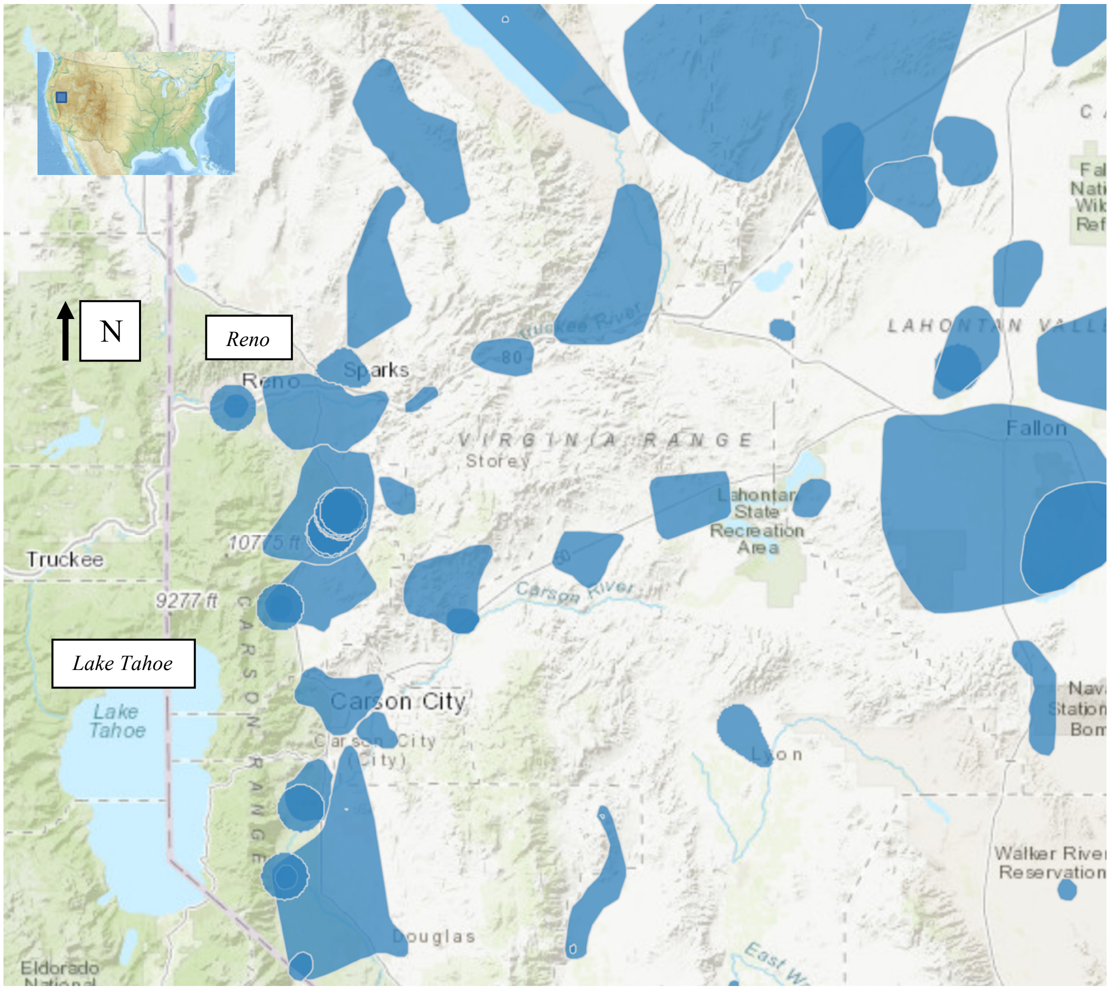


**Figure 1. Map of the Reno-Tahoe region, USA showing geothermal cluster data, with the darker colored areas representing higher measured geothermal well temperatures (average range 45°C to 120°C) (Nevada Bureau of Mines and Geology, 2022).**

2.1.2 Potential Areas

As stated, areas in the Reno-Tahoe region considered for drilling direct-utilization geothermal wells for industrial purposes such as assisting in recycling plastics require initial research and possibly surveys to target drill sites. Figure 2 shows some specific areas ideal for these targets (Martin, 2021). Geothermal waters in the Reno-Tahoe region typically upflow along fault fractured zones and outflow laterally in permeable stratigraphy along the base of a conductive clay cap which sharply contrast the surrounding rock. A conceptual cross section must be created based on structural data, historic well logs, and geophysical surveys, primarily broadband Magnetotelluric (MT) soundings. MT surveys can reveal clay cap alteration zones which typically overlay outflows and thus provide information to assist in delineating geothermal well targets (Cumming, 2009; Muñoz, 2013; Siler et al., 2019). There has been some gravity survey work in the area that would potentially be vital to the geothermal assessment that reveals depth to the basement rock; such data can potentially help to reveal upflow areas along fault planes(Abbott and Louie, 2000; Cashman et al., 2012).

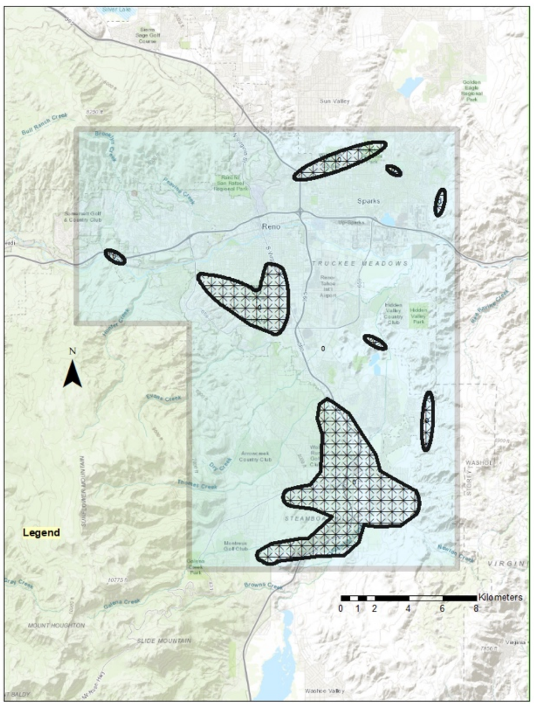


**Figure 2: Map showing the two main areas of known thermal groundwater occurrence in the Truckee meadows: Moana (north) and Steamboat (south), modified from Bateman and Scheibach, 1975) Additionally there are areas with geothermal potential to the south near Carson City (Martin, 2021).**

## *2.2 Known Examples of Direct-Utilization Of Geothermal Energy Applied Towards Plastic Recycling*

Several areas in the world have directly utilized geothermal energy for industrial purposes, but none have been documented to recycle plastic using geothermal energy (Lund and Toth, 2020), the exception being a plastic recycling plant in Iceland to an up-and-coming yet minor extent (Richter, 2020). Iceland remains in high ranking in geothermal categories for installed capacity (MWt/population), for annual energy use (TJ/yr/population), in terms of land area for installed capacity (MWt/area), largest percentage increase in geothermal installed capacity (MWt) over the past five years, and lead in several direct-use geothermal industrial categories from agricultural crop drying to snow melting (Lund and Toth, 2021). Thus, Iceland has much potential for expanding their plastic recycling operations with geothermal energy. Even though most of the plastic waste in Iceland is shipped offshore for recycling due to the carbon combustion, a total of about 2,000 tonnes of plastic rolls per year is produced from recycling (Richter, 2020). Pure North, the company which runs the recycling plant, is looking to have the recycled material produced into new containers in Iceland in the near future, but currently it is shipped offshore as raw material for production (Richter, 2020).

## 3. Constructing a Plastic Recycle Plant in the Reno Tahoe Region Which Directly Utilizes Geothermal Energy

Plastics recycling generally falls under four categories: primary (mechanical reprocessing into a product with equivalent properties), secondary (mechanical reprocessing into products requiring lower properties), tertiary (recovery of chemical constituents) and quaternary (recovery of energy) (Hopewell et al., 2009). Techniques of primary recycling generally include heating the waste then cooling it into the raw material, with some techniques assisting polymer isolation using heat along with solvents (Achilias, 2008; Hopewell et al. 2019). With advances in technologies and systems for reprocessing of recyclable plastics, it may be possible to utilize geothermal energy directly, thus reducing energy costs and helping to alleviate landfills. This section describes how geothermal energy can be directly utilized for recycling plastic with the temperatures available in the Reno-Tahoe region.

As discussed above in Section 1, the maximum temperatures available in geothermal areas of the Reno-Tahoe region are sufficient for providing the heat required to bring some types of commonly used plastics to the softening-melt phase for recycling. Furthermore, these same geothermal sources can be used to assist the process of recycling the remainder of the plastics that require additional heat, shown on Table 2. Direct-utilization of the geothermal heat energy via a closed-loop circuit that transfers energy to a plate-heat exchanger within the processing facility requires the construction of supplementary equipment to be housed in an entirely new facility in a geothermal area with an urban center nearby, such as the Reno-Tahoe region.

There is currently a plastic recycling collection center in Reno, NV run by Waste Management, Inc. which uses a single-stream system of recycling, allowing multiple types of material to be collected in a single receptacle at the collection point (home or business, etc.) (WM, 2022). This facility is where the majority of plastic waste from the Reno-Tahoe region is taken for the initial operations of sorting and filtering out non-plastic material. The plastic waste is not processed any further there but instead is shipped out to a facility in Sacramento (also run by Waste Management) where it is mechanically sorted and filtered to a higher degree, then subsequently distributed to various processing plants domestically (Eckman, 2022).

For geothermal energy to assist in the plastic recycling process, a plastic recycling facility in the Reno-Tahoe region would need to be constructed in a geothermal area economical for direct-utilization of geothermal energy (initially selected from an area in Figures 1 and 2). The cost to drill a geothermal well in the Reno-Tahoe region and construct a plate heat exchanger equipped to handle assisting in the plastic recycling process would cost at least 2-3 million dollars depending on the geothermal well target (Martin, 2021). There will be additional costs for other mechanical components that are required to apply the extracted geothermal heat from the plate heat exchanger to the plastics. Ultimately since the geothermal wells would be approaching 1 km deep and minimal equipment would be required for direct utilization of geothermal energy, the well would be relatively economical (ultimately depending on commodity prices, see Section 4.1). If the geothermal well were to be a considerable distance from the plant, heat would be lost in the transport circuit and additional energy costs required for plastic processing would accrue.

Table 2 shows most plastics currently being recycled with approximate energy values required from solely geothermal energy to assist in bringing some of the plastic to its softening-melt phase in °C, as well as additional power required per weight in Gigajoules per Megagrams (GJ/Mg) for the remainder of the plastics. Since there exists some discrepancies in the literature of the various physical constants of materials (Cafe, 2017), the values listed in Table 2 should be treated as approximates. Since 1 MWh = 3.6 GJ/Mg, we can approximate additional power requirements to process plastics with a higher melting point.

| Plastic | Softening-Melt Range (°C) | Resin Code | Energy Required To Soften-Melt (GJ/Mg) | Additional Energy Required To Soften-Melt w/Geothermal (GJ/Mg) | Additional Energy Required To Soften-Melt w/Geothermal (MWh) |
|---|---|---|---|---|---|
| ABS | 88-125 | | | 0 | |
| Acrylics | 91-125 | | | 0 | |
| Cellulosics | 49-121 | | | 0 | |
| LDPE | 107-124 | 4 | 78.1 | 0 | |
| HDPE | 122-137 | 2 | 76.7 | 0 | |
| Nylons | 160-275 | | 83 | 10 | 2.8 |
| PET | 225-255 | 1 | 82.7 | 9 | 2.5 |
| Polycarbonate | 140-150 | 7 | 79 | 3 | 0.8 |
| Polyesters | 220-268 | | 85 | 8 | 2.2 |
| PP | 158-168 | 5 | 73.4 | 2 | 0.6 |
| PS | 100-120 | 6 | 87.4 | 0 | |
| Polyurethanes | 85-121 | | | 0 | |
| PTFE | 327 | | | 13 | 3.6 |
| P.vinylideneclor | 212 | | | 10 | 2.8 |
| PVC | 75-110 | 3 | 56.7 | 0 | |

**Table 2: An extension of Table 1 showing melting point temperature ranges of plastic materials in °C along with energy required to melt the plastic and energy required (GJ/Mg) in addition to conventional power in MWh (Modified from Café, 2017 and Geyer, 2017). The materials highlighted in green are recyclable in certain areas of the Reno-Tahoe region where the geothermal temperatures are high enough to melt them. Energy values in the two right columns are based on averages spanning varied conditions and are thus approximate.**

## 4. Industrial and Environmental Benefits With Direct-Utilization of Geothermal Energy Applied Towards Recycling Plastic

Disposing of plastic wastes to landfill and incineration is undesirable for many reasons and thus recycling seems to be the only route of plastic wastes management towards sustainability (Achilias et al. 2008). Out of the over 8300 million metric tons (Mt) of plastic that has been produced in the world so far, 6300 Mt of plastic waste had been generated, around 9% of which had been recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment (Geyer et al., 2017). Since direct-utilization of geothermal energy would assist in the plastic recycling process, it undoubtedly has a positive impact on the environment.

### *4.1. Conserved Resources as a Result of a Plastic Recycle Plant with Direct-Utilization Geothermal*

There are two primary resources which are saved by recycling plastic: oil and energy; additionally it reduces $CO_2$ emissions. Direct-utilization of geothermal energy applied towards the plastic recycling process has the potential of reducing processing costs, thus promoting plastic recycling industry by rendering it more economically feasible.

#### 4.1.1 Oil and Power

It has been calculated that for every ton of plastic that is recycled, 1.8 tons of oil is saved (Richter, 2020) and ~1.4 Mt $CO_2$ emissions; emissions per ton of virgin plastic produced are estimated to be 3.6 times higher compared to recycling, and that value will increase significantly in the coming years with recycling processes improving (Moon and Morris, 2019). Up to 7-8% of oil and gas produced each year is used for plastic production for both raw material and energy required to manufacture, and a major portion of the plastic produced is for disposable recyclable containers (Hopewell et al., 2009), predicted to rise to 20% by 2050 (Rhodes, 2018). This breaks down to around 4 per cent of world oil and gas production being used as feedstock for plastics and a further 3–4% is expended to provide energy for their manufacture. Advances in technologies and systems for reprocessing of recyclable plastics (e.g. the inclusion of direct-utilization geothermal energy), it may be possible to divert the majority of plastic waste from landfills to recycling over the next decades. A 0.70 efficiency factor is estimated if geothermal energy is used directly to produce heat (Lund and Toth, 2021). In terms of energy use, recycling has been shown to save more energy than that produced by energy recovery (quaternary plastic recycling) even when including the energy used to collect, transport and re-process the plastic (Morris 1996). The nearby Steamboat geothermal power plant produces 84 MW of power which at least in part provides power to the recycling plant in Reno and can provide power to a newly constructed plastic recycling plant (Ormat, 2020).

4.1.2 Cost Effect on Plastic Market

There is an estimated $8.3 billion of plastic waste in U.S. landfills that can be recycled and used as feedstock (Rhodes, 2018). Since the plastic import restrictions implemented by China in the 2010s, including the 2018 China ban on imports of 24 types of solid waste, including post-consumer plastic, there has been an urgent need to reshape local recycling systems and global policies on plastic production and disposal (Moon and Morris, 2019). These restrictions were apparently created mostly due to the low quality of the recycled plastic, which mostly stemmed from mixing of non-recyclable constituents. With the new single-stream recycling system in place via Waste Management (WM), the quality of recycled plastic has improved in the Reno-Tahoe region (Waste Management, 2022).

Consequently, the plastic market has been forced to shift towards domestic markets (Waste Management, 2022). Recyclable plastics price index are currently on the rise (FRED, 2022), thus making geothermal use in recycling plastics even more economically feasible.

Since the plastic in the Reno-Tahoe region is exported to various processing plants domestically (Eckman, 2022), the cost of transportation will be reduced if plastic recycling is processed in this region.

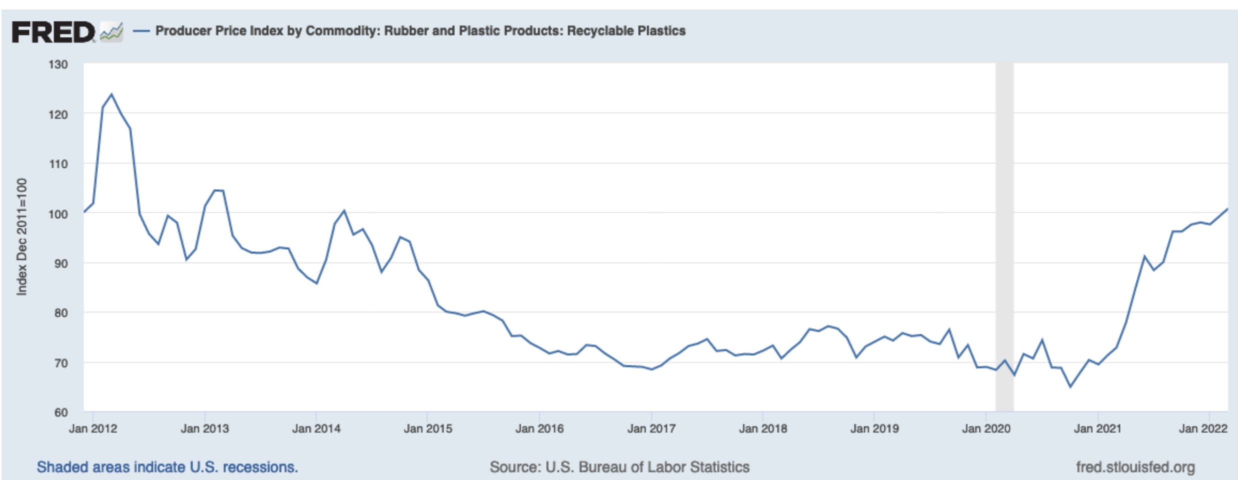


**Figure 2: A plot showing price index of recyclable plastics over the last decade. Recycled plastics are defined as those listed on Tables 1 and 2. Notice there is a sharp rise in price index over the last couple years. This suggests that recycling plastic, especially with directly-utilized geothermal energy assisting in the recycling process, is economically feasible (FRED Economic Data via U.S. Bureau of Labor Statistics, 2022).**

## 5. Conclusions

The Reno-Tahoe region has the capability of potentially directly utilizing geothermal energy to assist in the primary and secondary plastic recycle processes since geothermal energy temperature ranges in the region match ranges required to recycle certain plastics. Construction of a new plastic recycling facility in the Reno-Tahoe region is required for directly utilizing geothermal energy in the region to assist in the plastic recycling process. Further research is required to delineate a location for this facility, primarily depending on the geometry of the upflow and outflow paths as well as available land. This venture would not only be economically feasible, saving oil (the source material) and energy, but also greatly help alleviate carbon footprint via $CO_2$ emissions. In addition, these practices can be applied anywhere in the world where geothermal energy in the aforementioned temperature ranges can economically be directly utilized towards recycling plastics, thus helping to increase the current 9% plastic recycling rate.

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