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"Industrial Use of Steam in Sustainable Oil Recovery"

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Abstract

The enhanced oil recovery operation refers to an industrial process within the oil sector for producing crude oil from reservoirs that have been exploited to the point that ordinary lifting technologies prove to be inadequate. This enhanced oil recovery operation aims to change the characteristics of the crude oil such that it becomes more flowable. The present study considers solar-based thermal enhanced oil recovery systems in Oman at the oil field “Amal” that is located in Dhofar, which is the country’s largest governorate (state). In these systems, reflective trough concentrator surfaces are utilized for producing hot water vapor in a steam generator for the thermal recovery of crude oil. Three systems were established, which are “Amal I”, “Amal II”, and “Miraah”. If these systems are combined together, they can provide approximately two trillion British thermal units of heat annually while producing a peak of 2.1 kilotonnes of steam daily and avoiding the annual release of carbon dioxide, preventing annual emissions that exceed 100 kilotonnes. The three unconventional systems of oil recovery are briefly discussed here as examples of sustainability transformation practices in business and engineering under the oil sector.

Keywords: Crude Oil, Oil Recovery, Steam Generator, Sustainability

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Nomenclature

API	American Petroleum Institute gravity
Btu	British thermal unit
GWh	gigawatt-hour
HEOR	hybrid enhanced oil recovery
MMBtu	million Btu
NG	natural gas
PDO	Petroleum Development Oman

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1. Introduction

Recent research work shows that there is a statistically significant pattern of global warming. This is reflected in the trend of a continuous increase in the global mean temperature (Diffenbaugh and Barnes 2023). In accordance with the psychrometric and thermodynamic principles, this thermal phenomenon may be linked with unusual patterns of precipitation (Huang et al. 2013).

To control deviations in the global climate demands controlling the global warming potential caused by greenhouse gases, especially CO_2 (Bruhwiler et al. 2021). This can be attained by a number of pathways. One of them involves the shift in engineering and business operations, moving from casual practices to alternative ones that are sustainable (Bruhwiler et al. 2021). Such sustainable transformation includes the phasing out of systems that depend on the combustion of fossil-type fuels (Shindell and Smith 2019). Another example is electrification (Nadimuthu and Victor 2025). A third example is net-positive buildings (Vavouris et al. 2024). A fourth example is investment in low-emission vehicles (Marzouk 2022b). A fifth example is deploying low-carbon power systems (Zhu 2015).

Among the processes that require transformative alignment with sustainability is EOR or enhanced oil recovery. This process is particularly important in Oman and similar producers of crude oil (Sayyouh and Al-Blehed 1990). In the present work, a case study is presented for providing a top-level description of the partially-sustainable alternative of EOR or enhanced oil recovery (thermal type) in an Omani oil field called Amal. This partially sustainable process helps in reducing greenhouse gas emissions. Formerly, the EOR process at the Amal oil field was based on burning natural gas (NG) as the sole heating source. This heat is then used to boil water for generating hot gaseous water that is injected underground for heating the reservoir zone (Chaar et al. 2014). The partially sustainable alternative enhanced oil recovery depends on collecting solar irradiance for generating steam without emissions. Natural gas remains in use during the low-irradiance intervals as well as during the night. The present work provides a limited description of this hybrid enhanced oil recovery (HEOR) process. The hybrid enhanced oil recovery at the Amal field was implemented by the GlassPoint company. This hybrid enhanced oil recovery service is provided to the field owner, which is the PDO company (Petroleum Development Oman). Other enhanced oil recovery methods include the foam-assisted water alternating gas, the miscible gas injection, and the microbial enhanced oil recovery (Gbadamosi et al. 2018). However, these techniques are irrelevant here.

The HEOR technique of the Amal field adopts parabolic mirrors used to concentrate and irradiance for the purpose of industrial process heating (Ahmad et al. 2024). Liquid water is partly converted to vapor, leading to a two-phase medium with a quality of 80% (Al Shaibi and Al Abri 2018), at a subcritical pressure with the saturation temperature (Hong 1994). The obtained heat transfer fluid is utilized for EOR. The mirrors are rotatable to maximize the collection of incoming irradiance (Elshafey et al. 2018). Furthermore, the mirrors are housed inside an enclosure, which provides protection from harsh outside desert conditions, flow-induced vibrations, and erosive factors due to air-laden particles (Marzouk and Huckaby 2010). This protective enclosure also eases automated cleaning.

The present work is considered useful for an audience with an interest in EOR as well as solar thermal applications, and also sustainability transitions. The present work aims to briefly demonstrate an example of sustainability transitioning in the oil sector with innovative alternatives for engineering design and operation while taking advantage of the usable properties of locally available resources, such as the enthalpic content of water (Marzouk 2018). The present work has the advantage of being concise and easy to read without detailed technical information. Also, the economic aspects are not covered as they are outside the scope.

2. Literature Review

In the process of EOR, the amount of underground oil that remains unexploited in its wells is pumped up to the surface through artificial methods that aim to decrease the mobility resistance of the crude oil. This allows for further extraction of the oil from its reservoir (Donaldson, Chilingarian, and Yen 1985).

The oil recovery stages that precede enhanced oil recovery are called primary recovery and secondary recovery. In the primary oil recovery stage, the reservoir's pressure is high enough such that the oil flows under the natural pressure of the well. In the secondary oil recovery stage, the well is flooded with water or a gas. This action causes pressurization, and the well pressure is raised artificially (Mokheimer et al. 2018). The quantity of crude oil that can be produced in each of the three recovery phases is not fixed, but varies from one location to another based on the characteristics of the oil available.

Although there is no single universal rule to define heavy oils, they are roughly the oil grades that have an API (American Petroleum Institute gravity) less than 22.3 (Tirado et al. 2023). For such heavy crude oils, EOR is crucial, as it contributes largely to the overall amount of crude oil that is produced from the field. On the other hand, only a small portion is typically extracted in the two prior phases (Martines et al. 2022).

Aside from the relatively higher density of heavy oils compared to other types of crude oil, they tend to be relatively more viscous and harder to flow. Light oils are commercially desirable due to being easier to refine and easier to produce (Correa Pabón and Souza Filho 2019).

3. Research Methodology

The present work adopts a case study format, with analysis of secondary data. Third-party data are curated, processed, and presented in a way that serves the purpose of the current work. The main purpose here is to provide a simple case study demonstrating a sustainability shift in the industrial oil sector. This shift permits the reduction of greenhouse gases, which is an important target for slowing the climate change (Marzouk 2022a).

Most of the data accessed here were made publicly available at the GlassPoint website or in published research work by GlassPoint staff. Several figures shown here are owned by the GlassPoint company. However, gracious permission was obtained from the company to reuse these visual components here.

4. Results and Discussions

In the present section, a summary is provided for the operational and geometric conditions that correspond to the three Omani systems of ESEOR or enclosed solar enhanced oil recovery by the GlassPoint company. The location of the three systems is the offshore oil field "Amal". The position of this field is in the south of the Sultanate of Oman, in the northern part of the Dhofar governorate, near the northern border with the neighboring governorate of "Al Wusta".

The systems of hybrid-steam-generator enhanced oil recovery summarized here are:

- The small-scale Amal I system
- The small-scale Amal II system

- The large-scale Miraah system

The present Results section is structured into three parts. In the first part, the three GlassPoint systems are compared in a tabular form. In the second part, hybrid-steam-generator enhanced oil recovery concept of the GlassPoint company is illustrated graphically. In the third part, some photographs are presented, which assist in manifesting the actual view of the GlassPoint systems in the real oil field.

4.1 Comparative Summary of the Omani GlassPoint Systems

Eight characteristics of the three GlassPoint systems for thermal enhanced oil recovery by GlassPoint are compared in Table 1. The table also lists external references that can be consulted for further information.

It is noticeable that the Miraah system (the large scale system) was constructed (construction began in 2015, steam generation began in 2017) as more similar to the previous small scale system "Amal I" (construction began in 2011, steam generation began in 2012) than the later small scale system "Amal II" (construction began in 2018, steam generation began in 2020). As an example, both the "Amal I" system and the "Miraah" system have a similar roof design of gable, which is favored in terms of reduced complexity and cost (Kosić and Svetel 2022).

Table 1. Summary of the Omani ESEOR systems.

Characteristic	Amal I	Amal II	Miraah
1. Size	Pilot	Pilot	Commercial
2. Capacity - thermal (in MW)	8	8	330
3. Heat output - annual (in GWh)	12	12	445
4. Steam output - daily average (in tonnes)	50	50	2,000
5. Is the receiver evacuated?	No	Yes	No
6. Mirrors count	12	16	432
7. Savings in natural gas - annual (in MMBtu)	47,437	47,437	1,897,461
8. Avoided CO_2 emissions - annual (in tonne)	2,514	2,514	100,565
Reference	(Bierman et al. 2014)	(GlassPoint 2025b)	(Bierman et al. 2018)

4.2 Visual Illustrations

The geographic position of the Omani Amal oil field and the hybrid enhanced oil recovery systems covered is shown in the map represented by Fig. 1 (OSMF 2025b). As shown in the figures, the Amal field is found in the governorate of "Dhofar". Its location is approximately 50 kilometers away from the shore of the nearest water body, which is the Arabian Sea. The latitude, longitude coordinates of the Amal field are approximately 18.33° (north) and 55.67° (east).

Fig. 2 shows the configuration of the mirror troughs as housed inside the protective glasshouse enclosure (GlassPoint 2025f). The curvature of the roof in the figure pertains to the Amal II system, which was the latest one in terms of construction time. The recirculation of the received tube is easy to observe in the figure. This means that the heating process is carried out as a series of passes, where the water is heated sequentially by multiple concentrator mirrors.

In terms of the structural strength, the gain implied by the enclosing glasshouse (GlassPoint 2025e) is reflected through preventing airborne dust (Jing et al. 2014), as well as wind loads and wake vortices from affecting the reflector mirrors (Marzouk and Nayfeh 2009).

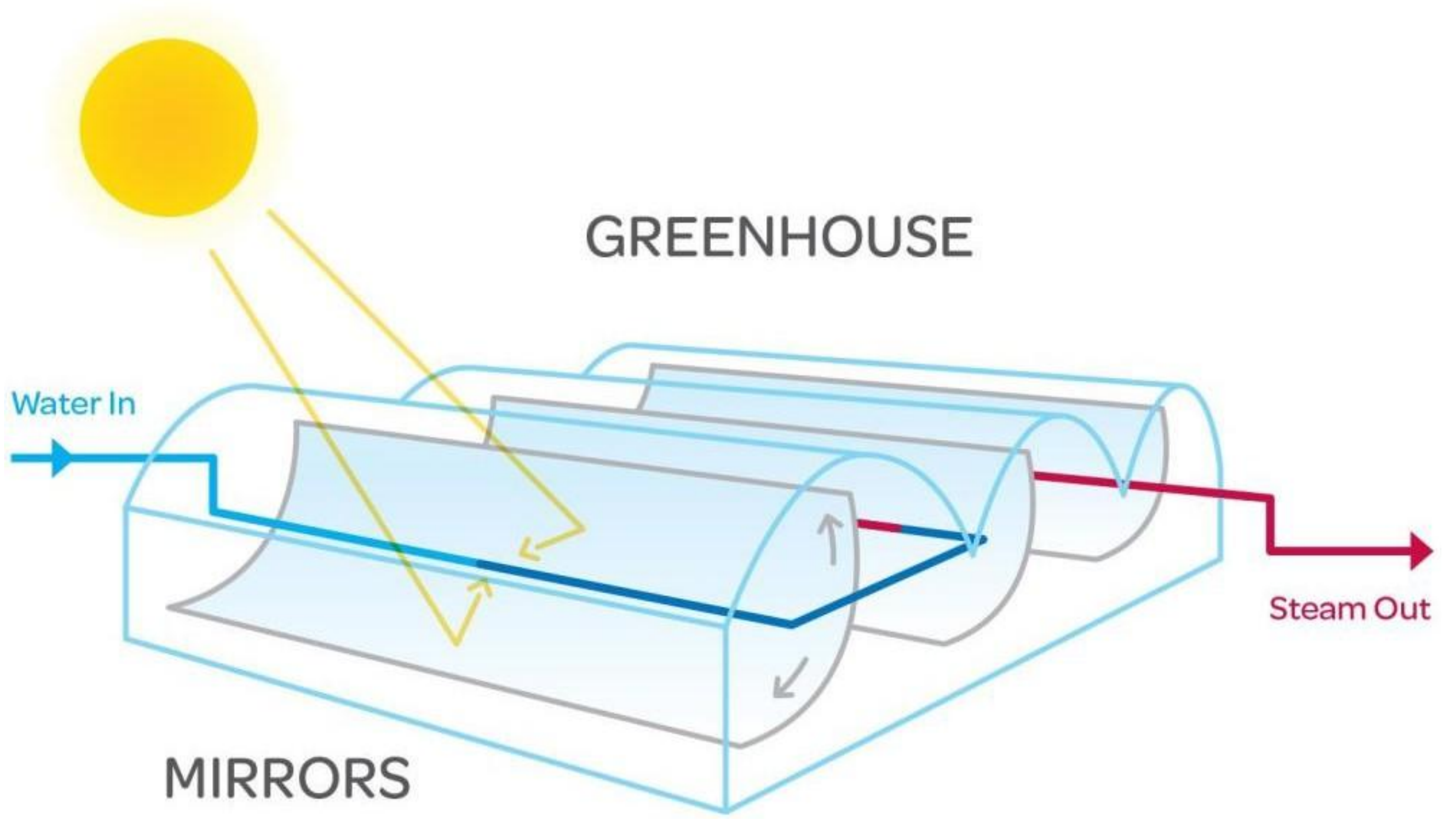

Fig. 2. illustration of the enclosed parabolic trough system (© GlassPoint, reproduced with permission)

4.3 Selected Photographs

In the current part, selected photographs are displayed to depict the actual appearance of the Omani hybrid enhanced oil recovery systems, as well as their size scale.

The photograph in Fig. 3 corresponds to the Amal I system (GlassPoint 2025c).

The photograph in Fig. 4 corresponds to the Amal II system (GlassPoint 2025d).

The photograph in Fig. 5 corresponds to the Miraah system (GlassPoint 2025a).

Fig. 3. photograph for the HEOR system "Amal I" (© GlassPoint, reproduced with permission)

Fig. 4. photograph for the HEOR system “Amal II” (© GlassPoint, reproduced with permission)

Fig. 5. photograph for the HEOR system “Miraah” (© GlassPoint, reproduced with permission)

5 Conclusion and Future Research

In the current work, a brief overview of the sustainable hybrid (natural gas and solar) enhanced oil recovery Omani systems was provided. In these sustainable enhanced oil recovery systems, clean solar radiation is blended with natural gas combustion as a hybrid heat source for steam generation in the Amal oil field. The introduced solar heating reduced the demand for natural gas by about 25%. The consumption of natural gas was not eliminated because of the need to burn natural gas during night operations. This reduction in natural gas consumption can be improved through altering the enhanced oil recovery process to better align with the variability of the natural heating source. However, such alteration is subject to the ability to retrofit existing systems.

Future work may include exploring the utilization of a partial vacuum to facilitate the phase change of water (Marzouk et al. 2018).

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The help of the company "GlassPoint" is highly acknowledged. The company (through Dr.-Ing. Gerhard Weinrebe) granted permission to display here the selected figures owned by the company. This permission was granted by an email message that is illustrated in Fig. 6.

RE: Seeking Permission to republish public photos for GlassPoint projects in Oman

From Gerhard Weinrebe <gerhard.weinrebe@glasspoint.com>
Date Mon 28-Apr-25 2:13 PM
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Cc Markus Balz <markus.balz@glasspoint.com>; Rod MacGregor <Rod@glasspoint.com>; Mohamed Mahmoud <mohamed.mahmoud@glasspoint.com>

Dear Prof Marzouk,

Thank you for your request! On behalf of the GlassPoint management (cc'ed) you are granted permission to use the photos from our website. Please mention '© GlassPoint' .
You may want to contact Mohamed Mahmoud (also cc'ed), my colleague in Oman, if you have further questions regarding the GlassPoint installations there.

Best regards,

Gerhard Weinrebe

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Fig. 6. email message showing the permission of the GlassPoint company to reproduce their images here

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