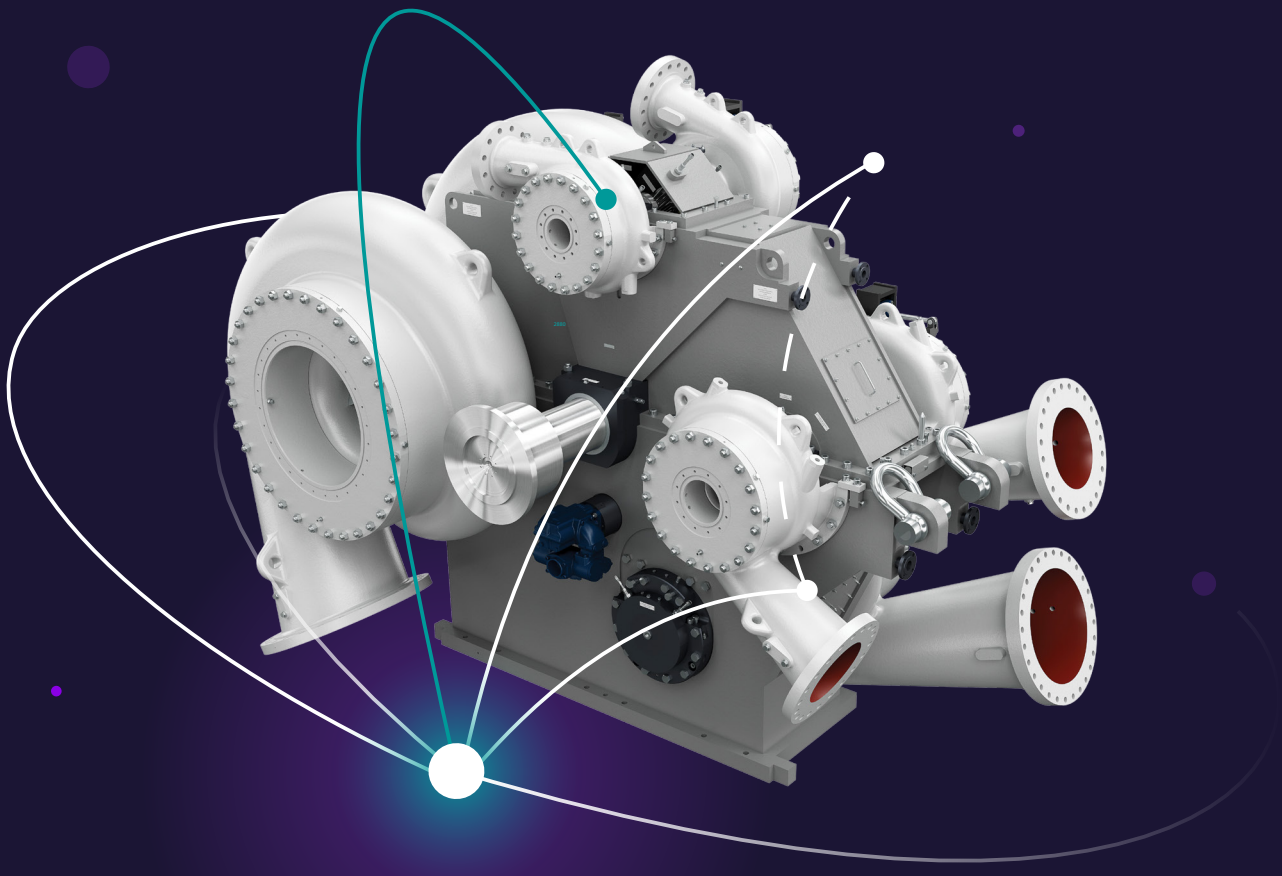
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Electrifying process steam production in LNG plants: A techno-economic approach to leveraging waste heat recovery and mechanical vapor recompression



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Executive summary

This paper evaluates Mechanical Vapor Recompression (MVR) as a means of recovering low-grade waste heat within LNG facilities and upgrading it into usable process steam, thereby improving overall energy utilization and reducing fuel-related emissions.

The analysis shows that MVR is particularly attractive where sizeable waste heat streams coexist with low- to medium-temperature steam users. In LNG plants, the most relevant heat sources include mixed-refrigerant cooling duties, fractionation condenser duties, and heat from CO_2 export compression. The most relevant heat-consuming processes include acid gas removal, condensate stabilization, hydrocarbon fractionation, and, in future low-carbon configurations, post-combustion carbon capture solvent regeneration. By using electricity to compress water vapor instead of generating steam directly from fuel or electric resistance heating, MVR can deliver a coefficient of performance (CoP) >1 and materially reduce primary energy demand when temperature lift is moderate.

A representative mixed-refrigerant LNG facility case study is presented, highlighting the importance of thermal life considerations and process integration. In a brownfield-oriented configuration, steam was raised to approximately 28 bara to serve high-temperature users up to 230°C. Although technically feasible, this option required approximately 27 megawatts (MW) of compressor power. It achieved a CoP of ~2.5, which is below the minimum value needed to create a net energy benefit in the evaluated power island. As a result, LNG production would slightly decrease. In contrast, a greenfield-oriented configuration serving lower-temperature users at approximately 130°C required only about 9.3 MW of compressor power for the same useful heat output of roughly 68.2 MWth. This increased the CoP to approximately 7.35 and improved LNG production by around 2,100 kg/h, corresponding to an estimated additional revenue of approximately 11.4 million USD per year at an LNG price of 680 USD/t.

The key conclusion is that MVR should not be viewed as a generic add-on technology but as a site-specific integration lever. Its value depends on matching available waste heat sources with suitable heat users, minimizing temperature lift, and ensuring access to low-carbon, reliable electricity. The strongest near-term opportunities are expected in greenfield LNG designs, or major revamps where process heat users can be configured around lower temperature levels. Additional use cases may emerge in carbon capture systems, where MVR can reduce steam extraction from the power island and recover compression heat that would otherwise be rejected.

For LNG operators and project developers, the recommended next step is to screen individual plant configurations for recoverable waste heat, steam demand profiles, achievable temperature lifts, power-system impacts, and carbon-intensity assumptions. Where conditions are favorable, MVR can support decarbonization while also improving plant efficiency and production economics. Siemens Energy is well positioned to support such assessments and deliver integrated solutions through its expertise in LNG process engineering, electrical infrastructure, and high-efficiency, integrally-geared compressor technology.

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Abbreviations

AGRU	Acid Gas Removal Unit
aMDEA	Activated Methyldiethanolamine
BFW	Boiler Feedwater
BOG	Boil-off Gas
C3/C4	Propane and Butane
C3/MR	Propane Mixed Refrigerant
CCPP	Combined Cycle Power Plant
CCUS	Carbon Capture Utilization & Storage
CoP	Coefficient of Performance
CO_2	Carbon Dioxide
e-LNG	Electrified Liquefied Natural Gas
GHG	Greenhouse Gas Emissions
GWP	Global Warming Potential
H_2S	Hydrogen Sulfide
HP	High Pressure
HRSG	Heat Recovery Steam Generator
IGC	Integrally-geared Compressor
LNG	Liquefied Natural Gas
LP	Low Pressure
LPG	Liquefied Petroleum Gas
MCHE	Main Cryogenic Heat Exchanger
MDEA	Methyldiethanolamine
MRC	Main Refrigeration Compressors
MVR	Mechanical Vapor Recompression
MW	Megawatt
MWth	Megawatt Thermal
NGL	Natural Gas Liquids
OEM	Original Equipment Manufacturer
VFD	Variable Frequency Drive

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1. Introduction

The global LNG industry is under intense pressure to decarbonize as climate policies tighten and stakeholders demand measurable reductions in GHG emissions across the natural gas value chain. To date, most LNG decarbonization efforts have focused on reducing direct CO_2 emissions from the liquefaction process by electrifying main refrigeration compression (MRC) trains (i.e., e-LNG). In comparison, far less attention has been given to reducing emissions from process heat production. Valuable opportunities exist to achieve incremental emissions reductions in this area, as virtually all heat in LNG plants today is supplied via gas-fired boilers.

Electrification is a viable pathway to address emissions from process heat and steam generation. Direct electrification methods, including electric boilers and resistive or inductive heating systems, are steadily advancing and being deployed in various industrial sectors. However, these technologies consume significant amounts of electricity and are therefore not the best choice to LNG plants, where substantial quantities of waste heat are inherently available. Heat pumps and the MVR system offer an alternative and often more economical strategy by upgrading low-grade thermal energy into usable heat and/or pressurized steam. Among those technologies, MVR systems stand out for their high coefficient of performance (CoP), which is the ratio of useful thermal energy output to the energy input required to drive the process.

The remainder of this paper discusses the technical potential of MVR systems to support process heat decarbonization in LNG plants. It explores integration opportunities, evaluates performance characteristics, and considers MVR's role within broader electrification strategies aimed at reducing the carbon intensity of LNG production.

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2. LNG liquefaction process overview

A large-scale LNG plant takes raw pipeline/field gas and turns it into a cryogenic liquid at roughly –160 to –162 °C, shrinking its volume by about 600x so it can be transported economically. The plant is built as one or more parallel "trains," each typically 4–8 MTPA, and every train follows the same logical sequence regardless of which licensor's liquefaction cycle is used. Because of the substantial power requirements, electrically driven LNG plants often operate a dedicated combined-cycle power plant. The power plant not only supplies electricity but also a share of the required steam.

2.1 Liquefaction process steps

Feed gas arrives and is metered for pressure, temperature, and flow. A slug catcher and inlet separators knock out free liquids like water, hydrocarbon condensate, etc., and solids before treatment.

Gas pre-treatment

Gas pretreatment removes contaminants from the feed gas before liquefaction. This protects downstream equipment, prevents freezing and plugging at cryogenic temperatures, and ensures the gas meets the composition and purity requirements for efficient LNG production. Specific steps include:

- **Mercury removal** - Mercury is removed using fixed adsorbent beds, typically sulfur-impregnated activated carbon or molecular sieves. This step is critical because mercury can amalgamate with aluminum components in brazed aluminum heat exchangers, potentially causing severe equipment damage or failure.
- **Acid gas removal (AGRU)** - CO_2 and H_2S are removed in an amine absorption and regeneration system, typically using MDEA or activated MDEA. CO_2 must generally be reduced to below ~50 ppm to prevent it from freezing as dry ice and plugging cryogenic equipment, while H_2S is removed because of its toxicity and corrosivity. The amine regenerator reboiler is also typically one of the largest steam consumers in the LNG plant.
- **Dehydration** - Molecular-sieve adsorbers reduce water content to below ~0.1 ppm, preventing ice and hydrate formation that could restrict or block cryogenic equipment.
- **Heavy hydrocarbon removal / NGL extraction** - Scrub columns and/or turbo-expanders remove heavy hydrocarbons, including C_5+ components and aromatics that could freeze at LNG temperatures. The process can also recover valuable natural gas liquids (NGLs), including ethane, LPG, and condensate.

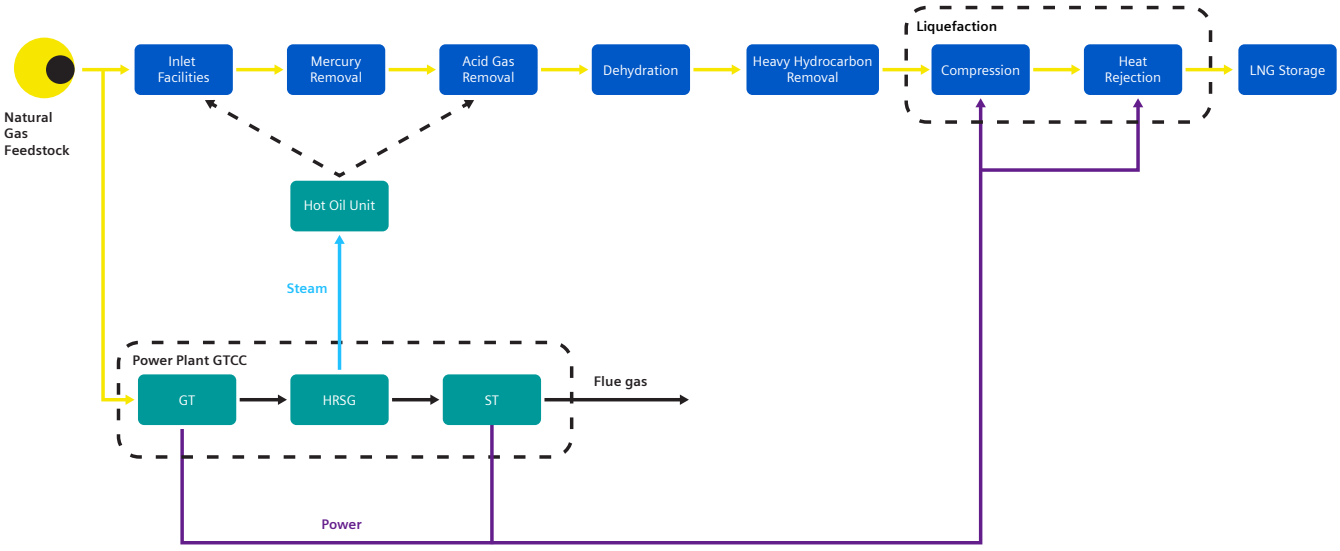


Figure 1: Process overview of the LNG liquefaction process

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Liquefaction (i.e., the cold box)

The clean, dry "lean gas" is cooled, liquefied, and subcooled in the main cryogenic heat exchanger (MCHE), typically a coil-wound or brazed-aluminum plate-fin exchanger. Large gas turbine- or motor-driven compressors supply refrigeration across the pre-cooling, liquefaction, and subcooling stages. Although the specific refrigeration cycle varies by licensor – such as single or dual mixed refrigerant, C3/MR, or mixed-fluid cascade –the fundamental function of this section is the same across LNG plants.

End flash (i.e., nitrogen rejection)

High-pressure LNG is reduced to near-atmospheric pressure, causing lighter components to flash off. The resulting end-flash gas, including excess nitrogen, is separated to meet LNG product specifications and reduce the risk of stratification and rollover in storage tanks. This gas is typically recovered for use as plant fuel.

Storage & loading

LNG is stored in insulated tanks at approximately atmospheric pressure and –162 °C before being transferred to LNG carriers. Heat ingress into the tanks continuously generates boil-off gas (BOG), which is captured and either used as fuel or returned to the LNG system through re-liquefaction.

Product & byproduct handling

Recovered NGLs can be fractionated into ethane, LPG components such as propane and butane, and stabilized condensate using de-ethanizer, de-propanizer, and de-butanizer columns. Acid gas removed during pretreatment may be routed to vent or flare systems, a sulfur recovery unit, or, increasingly, to carbon capture and storage systems.

2.2 Utilities & power island

The utilities and power island provide the supporting systems required for continuous LNG production, including power and heat generation, steam, fuel gas, cooling, flare systems, nitrogen, instrument air, and, where applicable, post-combustion carbon capture. Because LNG production is highly energy intensive, electrically driven plants may incorporate a dedicated combined-cycle power plant (CCPP). The CCPP supplies electricity to the liquefaction trains and auxiliary systems while recovering exhaust heat through heat recovery steam generators (HRSGs) to generate steam for process duties such as acid gas removal, fractionation, and/or carbon capture. This integration makes the power island an important contributor to overall plant efficiency, availability, and emissions.

2.3 Energy demand in LNG facilities

Power demand to drive compressors and other equipment

The refrigerant compression trains dominate electrical consumption in an e-LNG plant, typically drawing 70–85% of total site power. The remaining demand is spread across feed-gas and boil-off/end-flash compression, the large air-cooler (fin-fan) fans and process pumps, the gas-treatment and fractionation auxiliaries, and, in fully electrified concepts, electric heaters and e-boilers that replace fired duties. Electrification concentrates essentially all the site's energy into a single electrical network. This has several important consequences for plant design and operation.

- **Grid capacity and reliability** - With a large train demanding anywhere from several hundred MW to more than 1 GW, the plant behaves like a small industrial city. A single grid disturbance can trip the main compressors. Ultimately, power availability directly governs LNG production and uptime.
- **Motor start-up and dynamic stability** - Energizing compressor motors creates large inrush and reactive-power swings, managed through VFDs, soft starters, and synchronous condensers to protect grid voltage and frequency.
- **Efficiency shifts from thermal to electrical** - Overall plant efficiency now depends on motor, VFD, transformer, and conversion losses rather than gas turbine heat rate, which changes how energy performance is optimized and monitored.
- **Decarbonization hinges on the power source** - The plant's carbon footprint is only as clean as its electricity supply. Pairing the facility with renewable generation, a low-carbon grid, or a hybrid supply turns electrification into an actual emissions-reduction measure rather than merely relocating emissions to the power plant.
- **Operational flexibility improves, but exposure to power markets grows** - Electric drives allow finer speed control and faster response, yet they also tie production economics to electricity price and availability, making power purchase strategy a core commercial consideration.

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Steam demand for process services

Several processes within LNG facilities have thermal demand and thus consume steam. These include:

- **Amine regeneration in the AGRU** - The regenerator reboiler is typically the single largest steam consumer in an LNG plant. Low- to medium-pressure steam provides the stripping duty needed to remove CO_2 and H_2S from the amine solvent.
- **NGL fractionation (column reboilers)** - Distillation columns such as de-ethanizers, de-propanizers, and de-butanizers often use steam-driven reboilers to supply the latent heat required for hydrocarbon separation.
- **Condensate stabilization units** - Stabilizer columns rely on steam in the reboiler to remove light ends from condensate, ensuring it meets vapor pressure specifications for storage and export.
- **Solvent regeneration in post-combustion carbon capture systems** - If carbon capture is applied to CCPPs or boiler flue gas, the amine-based capture unit introduces a large additional steam load. The regenerator reboiler requires low-pressure steam to strip CO_2 from the solvent, often comparable to or exceeding the AGRU duty, depending on capture rate and flue gas volume.
- **Boiler feedwater deaeration** - Steam is injected into deaerators to strip dissolved oxygen and CO_2 from boiler feedwater, preventing corrosion and maintaining system integrity.
- **Tank and line steam tracing** - Steam tracing systems use low-pressure steam distributed through tracing lines to maintain temperature in piping, valves, and equipment, preventing condensation, hydrate formation, or wax buildup.
- **Fuel gas heating (steam heaters)** - In some designs, steam is used in heat exchangers to preheat or superheat fuel gas streams before combustion, ensuring stable operation of turbines and fired equipment.

Steam generation for these processes collectively represents a large portion of utility demand in LNG plants, making them a logical target for decarbonization efforts. When the CCPP provides steam for these processes, it is taken out upstream of the low-pressure turbine, reducing the power plant's electrical output and efficiency.

Cooling duties

As previously discussed, cooling is required for various process steps, such as fractionation and natural gas cooling to force condensation. The latter step is by far the largest duty and can easily be in the range of 50-150 MWth for large LNG plants. Typically, some de-superheating occurs before condensation, at temperatures ranging from ~40-50°C. Today, this heat is often rejected into the environment and goes unused.

Contrary to the LNG process, waste heat from the power plant is typically harnessed. The coexistence of high heat demand and substantial waste heat availability creates a strong opportunity for energy recovery and reuse. A meaningful fraction of the thermal energy currently lost could be captured and upgraded into usable steam, thereby reducing the duty on gas-fired boilers.

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3. Mechanical vapor recompression concept overview

MVR describes the process of upgrading low-temperature energy into high-temperature energy that can be reused in industrial applications. These systems consume mechanical or electrical work to drive a compressor that increases the temperature and pressure of a gaseous working fluid. Compared to direct electrification, which converts electricity into heat in a single step, MVRs can achieve CoPs >1 by incorporating waste heat streams into the energy balance.

$$COP = \frac{Usable\ Heat}{Electric\ Power}$$

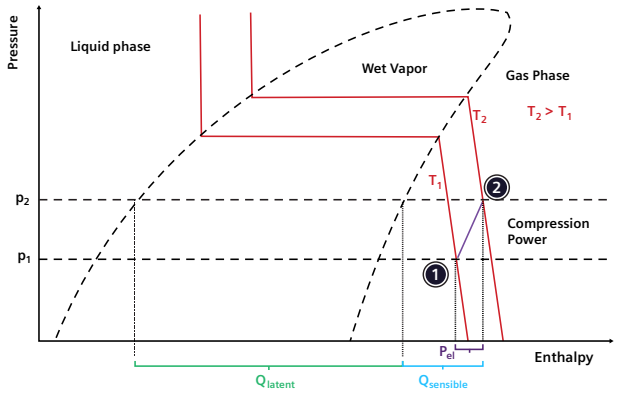


Figure 2: Compression process in the pressure-enthalpy-diagram

MVR is an established process applied extensively in process technology where vapor streams are available, and latent heat can be recovered. By recycling this latent heat, MVR systems minimize the need for external energy inputs while delivering steam at conditions suitable for many processes.

Within MVR systems, thermal energy from a mid- or low-temperature (> 60°C) waste stream is used to directly or indirectly evaporate feedwater into steam. The low-pressure steam is then compressed to the required process pressure. The waste heat provides the entire latent heat for evaporation, normally rejected into the atmosphere via air coolers or cooling-water loops; only the sensible heat, which is significantly lower than the latent/ evaporation heat, is provided through compression.

In nearly all cases, the waste heat source has a temperature below 100°C, which means that the water needs to be evaporated at sub-atmospheric pressure. While this requires consideration in equipment design (e.g., around the sealing system so no ambient air is sucked in), these challenges can be solved with existing technology.

3.1 Water as a working fluid

This paper considers only water vapor as the working fluid. As implied earlier, water allows heat to be recovered from waste streams with temperatures as low as ~50°C. At this low temperature, the water cycle operates at ~100 mbara. Other refrigerants allow for lower temperatures. However, they also typically require higher investments due to flammability, permitting, toxicity, GWP, etc. Overall, compressing water vapor is a well-known and mature process. During compression, the vapor temperature rises quickly. To avoid material issues, the temperature can be controlled via attemperation.

3.2 MVR processes for waste heat recovery

MVR systems used for steam generation and heat recovery can generally be categorized into closed-loop and once-through configurations. Each configuration has distinct thermodynamic characteristics and integration considerations. In both cases, the fundamental principle is the same: low-pressure vapor is compressed to a higher pressure and temperature, allowing its latent heat to be reused for process heating. However, how the working fluid is circulated and managed within the system has important implications for efficiency, operability, and application suitability.

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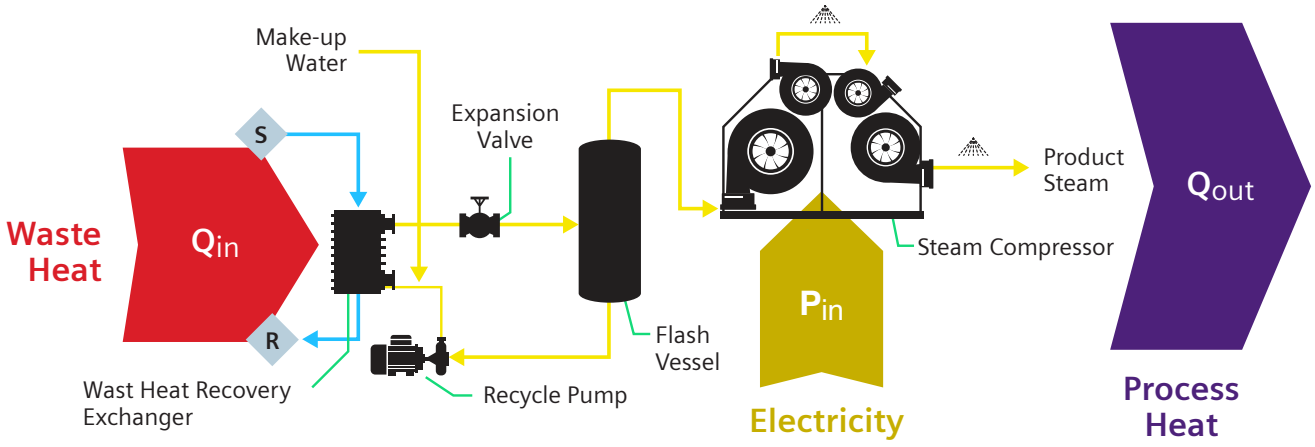


Figure 3: Once-through water-steam MVR system

Once-through water steam MVR

Once-through MVR systems are designed for direct steam consumption, as would be typical in a chemical synthesis process. The schematic shown in Figure 3 above is specific to a once-through MVR system with steam suction conditions below atmospheric pressure.

For this system, heat is recovered via a pressurized recycled-water loop to reduce the amount of equipment operating in vacuum conditions, which limits the potential for air contamination. The warm water is then expanded to vacuum conditions. The two-phase stream is separated in the vacuum flash drum, which acts as the steam compressor 1st-stage knockout drum. The liquid portion is pumped back, mixed with make-up water, and the entire liquid stream is recycled to the waste heat exchanger, which completes the loop. The vapor portion from the flash drum is routed to the steam compressor, compressed to the required conditions, and sent outside the battery limits. Depending on the boundary conditions (i.e., the required temperature lift), the CoP for this system ranges from 1 to 6.

Step 1

In the waste heat recovery exchanger, pressurized water is warmed with low grade heat

Step 2

Warm water is let down in pressure via an expansion valve generating a two-phase stream of low pressure steam and water

Step 3a

Low pressure steam is routed to the steam compressor to augment to the required pressure and temperature

Step 3b

Low pressure water is routed to a recycle pump to return it to the waste heat recovery exchanger where low grade heat is absorbed again

Step 4

Make-up water is added to the loop to replace the amount of generated steam

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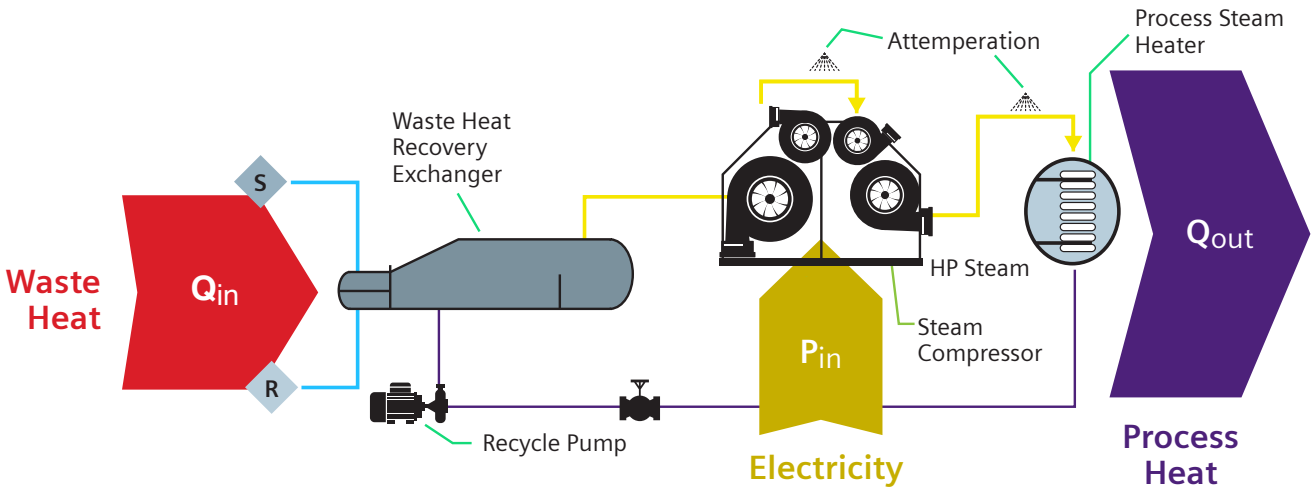


Figure 4: Closed-loop water-steam MVR system

Closed-loop water-steam MVR

In closed-loop configurations, steam is generated for process heating, and the steam condensate is returned. Figure 4 shows a closed-loop MVR system with steam suction conditions above atmospheric pressure. With this design, steam is generated directly from the waste heat recovery exchangers. The water from the exchanger is vaporized, and the low-pressure steam is routed directly to the steam compressor and compressed to the required product conditions. The steam is then utilized for process heating via condensation, resulting in steam condensate that is recycled back to the waste heat recovery exchanger.

From an application perspective, the choice between closed-loop and once-through MVR systems depends on process integration opportunities, water management strategies, and operational priorities. Closed-loop systems are often favored in tightly integrated heat recovery applications where maximizing efficiency and minimizing water usage are critical. Once-through systems, on the other hand, may be advantageous in retrofit scenarios or where operational simplicity and flexibility are more important.

Step 1
In the waste heat recovery exchanger, low pressure steam is generated

Step 2
Low pressure steam is routed to the steam compressor to augment to the required pressure and temperature

Step 3
The generated steam is condensed to transfer the energy to the process

Step 4
The condensate returns to the waste heat recovery exchanger via an expansion valve

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3.3 Applying integrally geared compressors in MVR systems

Steam compressors are the core component of MVR systems and account for nearly all the system's energy consumption. Early MVR designs typically operated with low pressure ratios, making them suitable for single-stage compressors or blowers. In contrast, many modern industrial MVR processes demand multi-stage compression, where integrally geared compressor (IGC) technology is a more effective solution.

IGCs are centrifugal compressors built around a central bull gear that can drive up to four pinion shafts, each equipped with one or two impellers. This configuration allows every impeller to operate at its ideal speed and frequency, maximizing overall efficiency. Additionally, each impeller is housed within its own volute casing, enabling the process gas to exit between stages. This design supports attemperation after each compression step, which is essential for reducing power demand, improving the system's CoP, and keeping temperatures within allowable limits, thereby avoiding the need for costly high-temperature materials.

The injected water absorbs heat from the steam and evaporates, leveraging its high latent heat of vaporization to achieve significant cooling. This approach ensures that all compression heat, normally considered waste, is instead recovered and used to generate additional steam. The final steam temperature, or degree of superheat, can be precisely controlled by adjusting the volume of injected water. Greater injection results in greater cooling.

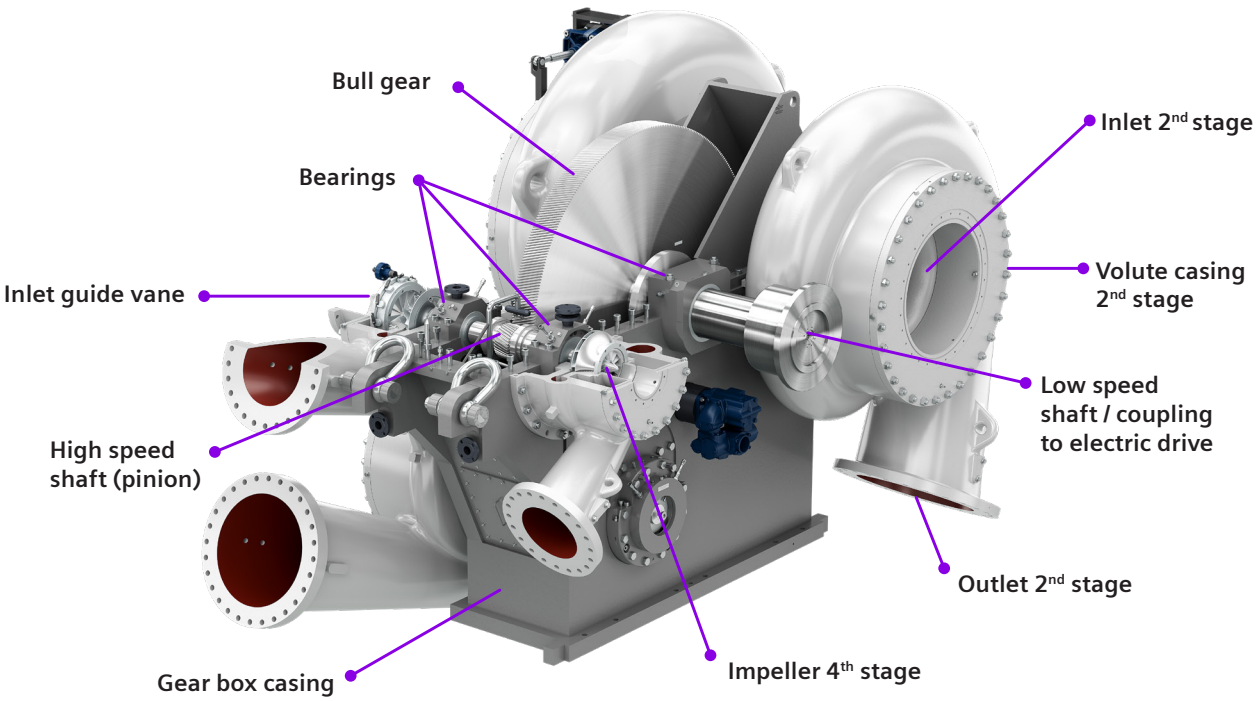


Figure 5: IGC with various components

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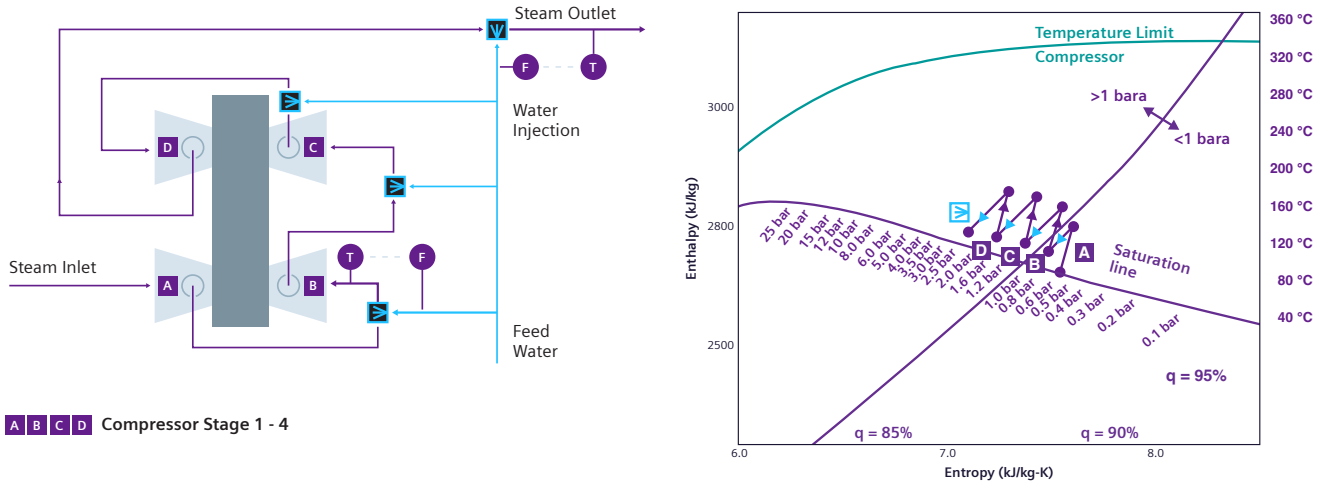


Figure 6: Steam compression with attemperation

Siemens Energy's IGC designs can process up to 1.2 million m^3/h in a single compression stage, with impeller diameters reaching up to 2 meters. In double-flow configurations, where inlet gas is split between two parallel impellers, flow rates can reach up to 2.4 million m^3/h. Because each impeller operates within its own casing, compression stages remain independent, allowing combined- or multi-fluid services within a single unit. For instance, in heat recovery applications involving CO_2 compressors, the same machine can compress both CO_2 for export and steam for process heating.

The number of steam compression stages can be tailored as needed. A typical setup might include four stages for CO_2 and four for steam, provided the total does not exceed eight stages. This flexibility allows a single compressor train to replace two separate systems, reducing capital expenditures for compression equipment by approximately 20–30%.

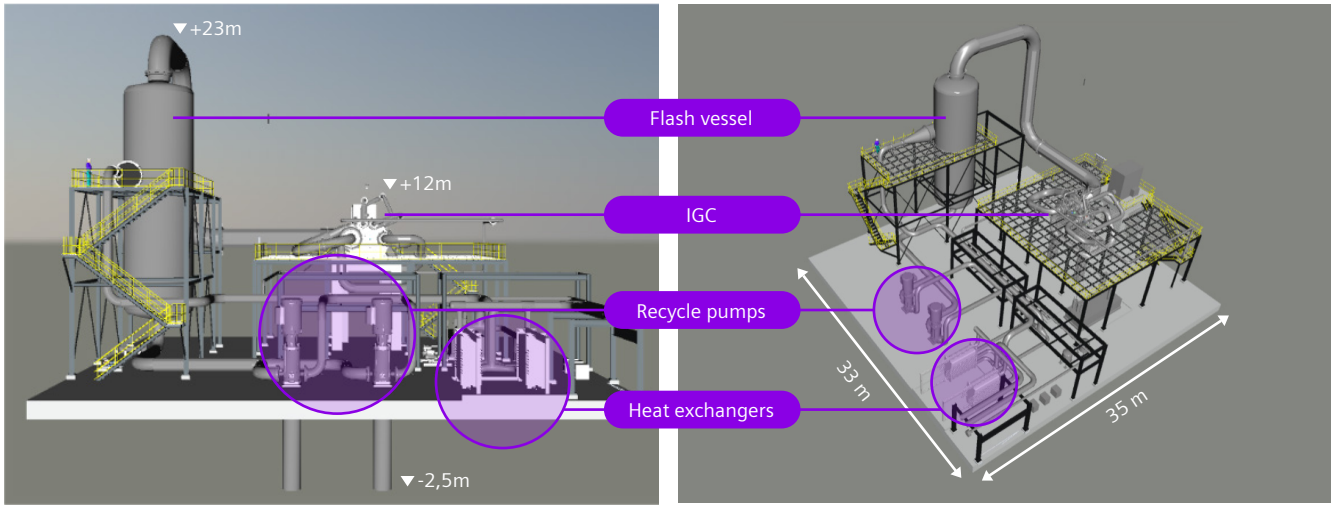


Figure 7: Rendering of MVR system producing 20MWth from a heat source. The arrangement is not optimized for occupied space.

Siemens Energy's IGC technology was developed in 1948 in Duisburg, Germany (the first IGC was formally named the VK). Today, more than 2,300 units are in operation worldwide, with a fleet reliability >99.9%. Apart from Duisburg, Siemens Energy can manufacture IGCs locally in Huludao, China, and Naroda, India. Our global packaging and service network provides support worldwide.

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4. Applying MVR technology in LNG plants

Within LNG facilities, MVR systems can generate steam from waste-heat streams and thus replace process steam, which is traditionally supplied through steam extraction from a CCPP or through dedicated fired heating systems. The following sections outline a case study based on a specific plant design.

4.1 Case study

A representative case was evaluated for a mixed refrigerant based LNG facility. In that process, heating duties for condensate recovery and AGRU services were supplied through an MVR system that recovered heat from the high-pressure mixed refrigerant (HP MR) cooler.

Solution description

The selected design is a closed-loop system in which the generated steam is used to heat a hot oil unit. The stream feeding the HP MR air cooler is available at 109°C. By reducing its temperature to 99°C, approximately 41.2 MWth can be recovered using a hot water stream that is subsequently flashed to generate low-pressure steam. The heat duties for condensate recovery and acid gas removal total 68.18 MW. Figure 8 shows an LNG plant process modified to accommodate the MVR system.

Importantly, an MVR system reduces steam extraction from the power plant, allowing more steam to expand through the turbine and increasing power output.

However, the MVR compressor introduces an additional electrical load. For the modification to provide a net benefit, the heat supplied by the MVR system must offset more steam than would otherwise have been extracted. The minimum thermodynamically required CoP of the MVR system can be determined by comparing its heat-to-power performance with the efficiency of the steam cycle Rankine process.

$$\eta_{Rankine} = \frac{P_{ST}}{Q_{extraction}}$$

$$COP = \frac{Q_{usable}}{P_{compressor}}$$

$$COP = \frac{Q_{usable}}{P_{compressor}} = \frac{Q_{extraction}}{P_{ST}} = \frac{1}{\eta_{Rankine}}$$

In this case, the steam tail efficiency is ~36%, corresponding to a minimum required MVR CoP of 2.78. At CoP >2.78, the MVR system provides a net energy benefit by recovering heat from a previously unused waste stream. This additional available energy can ultimately be used to increase LNG production. Operating concepts were evaluated for both a brownfield and greenfield scenario.

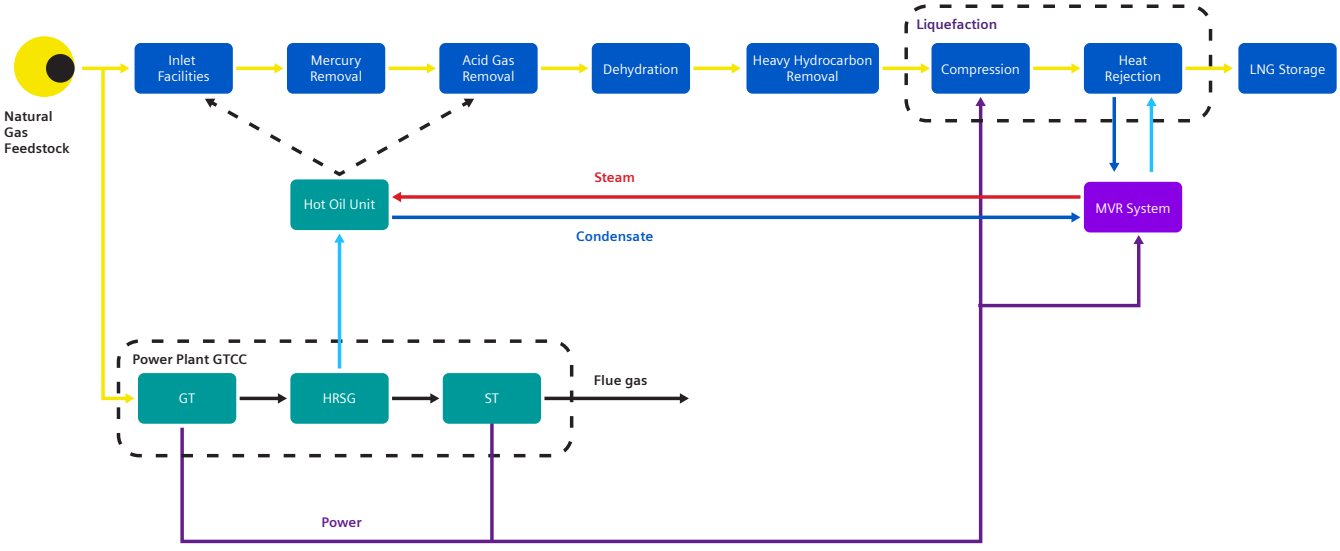


Figure 8: LNG process overview showing installation of MVR system

Brownfield

In the brownfield configuration, all conditions are unchanged, and the MVR system enables a portion of steam currently being supplied by the power plant to be replaced. However, the MVR system cannot meet all required steam duties of the plant.

The generated steam was compressed to ~28 bara and a temperature that allows heating the oil to 230°C. While technically feasible, the system required approximately 27 MW of compressor-drive power and achieved a CoP of approximately 2.5. The relatively large temperature lift between the waste heat source and the required process duty significantly increases power consumption. As a result, the LNG production is reduced by ~78 kg/h, which aligns with the earlier assessment that the CoP must be > 2.78 to create a net benefit.

Greenfield

A second configuration was evaluated using low-temperature heat users supplied at approximately 130°C. Under otherwise similar conditions, the MVR system required only approximately 9.3 MW of compressor drive power while maintaining the same useful heat output of roughly 68.2 MWth. The resulting CoP increased to approximately 7.35. This comparison demonstrates that MVR performance is highly sensitive to temperature lift and that low-temperature thermal users provide the strongest opportunity for efficient heat recovery and electrification within LNG facilities.

For the evaluated greenfield scenario, LNG production increased by approximately 2,100 kg/h while maintaining the same feed gas throughput. Assuming an LNG sales price of 680 USD/t, this corresponds to approximately 11.4 million USD per year in additional revenue before considering carbon pricing or other environmental incentives. These findings suggest that MVR can create value not only through emissions reduction but also through improved energy allocation and increased LNG production.

	Unit	Brownfield	Greenfield
Max. process temperature	[°C]	230	130
Max. steam pressure	[bara]	28	2.8
Generated heat output	[MW]	68.2	68.2
MVR power	[MW]	27	9.3
CoP	[-]	2.5	7.35
Change in LNG production	[kg/h]	-78	+2,100
Additional revenue, 680 US$/ton	[Mio. US$]	na	11.4

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4.2 Other potential applications of MVR systems

CO_2 capture systems

As LNG facilities increasingly incorporate carbon capture systems, steam demand associated with solvent regeneration becomes a significant additional energy consumer. In conventional configurations, this duty is typically supplied through steam extracted from the CCPP, reducing the amount of steam available for power production. MVR systems offer an alternative approach by upgrading low-temperature waste heat streams into usable process steam for solvent-regeneration duties. This allows a portion of the steam demand to be supplied without additional fuel combustion while simultaneously reducing steam extraction requirements from the power island.

- **Heat recovery from CO_2 export compression** - In addition to the previously discussed heat sources within the LNG plant, such as the LP and HP mixed refrigerant coolers, heat from the CO_2 export compressor can also be recovered. In some cases, operating the compressor at a higher discharge temperature can improve overall system performance by increasing the temperature and therefore the usefulness of the available waste heat. Although this increases compressor motor power consumption, the resulting improvement in MVR CoP can outweigh the additional power demand. The optimal operating point is plant-specific and must be evaluated for each configuration.

- **Lean vapor recompression** - In some solutions, the lean amine which flows from the bottom of the desorber column to the absorber head is routed through an expansion valve and a flash vessel. The generated vapor is compressed and returned to the desorber column to improve the system's energy efficiency. The required compression ratio is typically low so that one or two impeller(s) are sufficient. Instead of installing an additional compressor, it may be beneficial to combine this service with the CO_2 export compressor or another MVR. This assumes both compressors are IGCs, with at least one shaft unused.

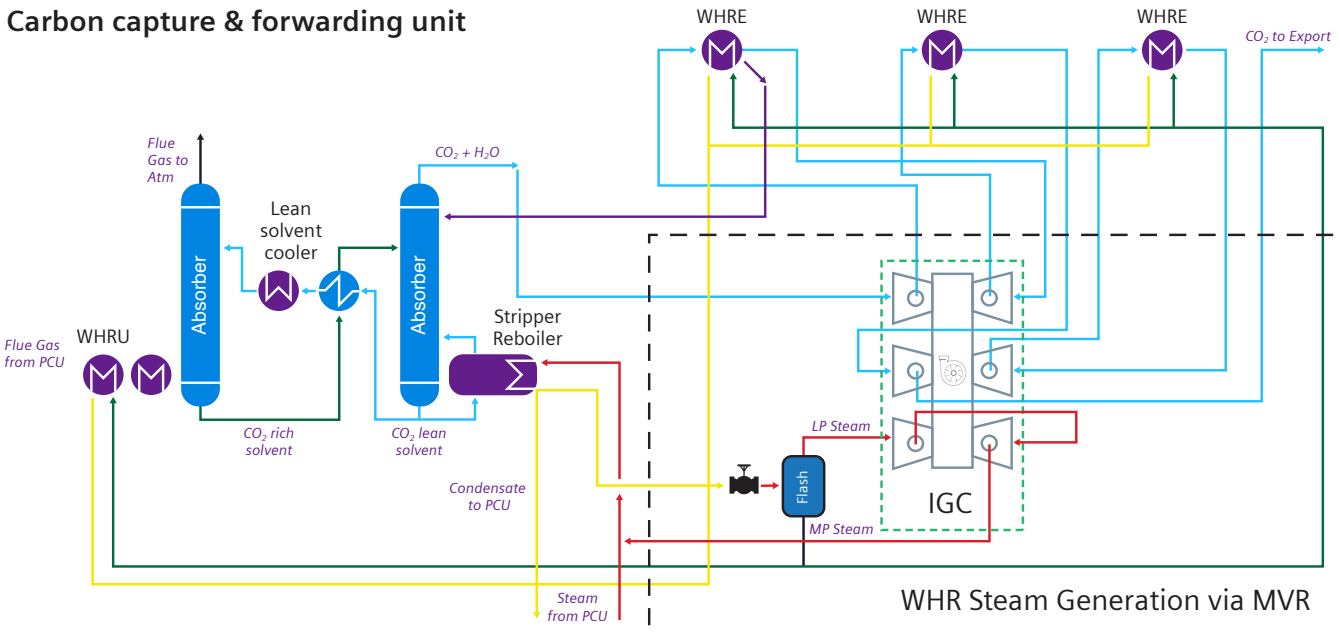


Figure 9: Schematic showing carbon capture and forwarding unit in an LNG plant

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Acid gas removal unit with lean vapor compressor

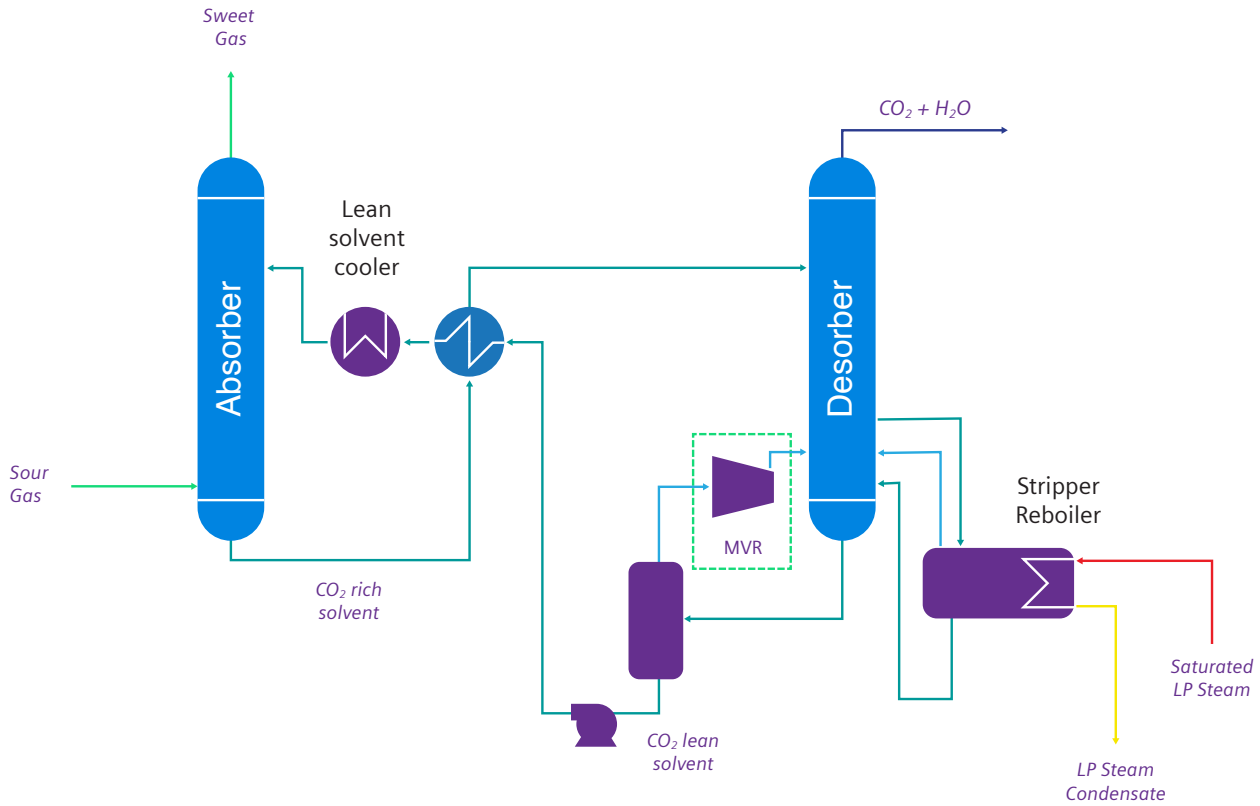


Figure 10: Lean vapor compression

Hydrocarbon fractionation systems

Additional opportunities for MVR integration exist within hydrocarbon fractionation systems, including condensate stabilizers, de-ethanizers, de-propanizers, and de-butanizers. These systems simultaneously reject heat in overhead condensers and consume heat within column reboilers, creating a natural opportunity for heat recovery and upgrading.

Simulation data indicate that condenser waste heat may potentially satisfy a significant portion of corresponding reboiler duties. However, these applications are usually characterized by relatively small thermal loads and, in some cases, substantial temperature lift requirements. As a result, the economic attractiveness of standalone water-steam MVR systems must be evaluated on a case-by-case basis.

Despite these limitations, fractionation systems remain an attractive area for future development because they often provide localized heat sources and sinks, simplifying integration compared with plant-wide steam systems.

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5. Conclusion

The application of MVR systems in LNG facilities presents an opportunity to improve energy efficiency and achieve incremental GHG reductions by recovering and upgrading waste heat that would otherwise be lost. However, successfully integrating these systems into LNG plant architectures, while maintaining the high levels of reliability and uptime required for continuous operation, is technically challenging.

LNG facilities are complex, tightly coupled systems where even minor disruptions can have major operational and economic consequences, making robust design, control, and system integration essential. Effective deployment of MVR requires original equipment manufacturers (OEMs) with deep, cross-disciplinary expertise in both advanced compression technology and LNG process engineering, as well as the capability to conduct rigorous, site-specific techno-economic analyses to determine where MVR integration is genuinely viable and value-accretive.

Furthermore, the economic and environmental performance of MVR systems depends on electricity availability and carbon intensity. Access to low-cost, low-carbon power is essential to maximizing decarbonization potential. Variability in waste heat availability, driven by changes in operating conditions, can also affect system performance and must be carefully managed through design and control strategies.

As a global leader in compression technology, including IGCs, Siemens Energy is uniquely positioned to deliver MVR solutions in LNG applications. Our expertise across LNG and broader industrial sectors enables us to design and supply high-efficiency systems specifically optimized for demanding multi-stage MVR duty cycles. Beyond compression, we bring extensive capabilities in electrical distribution and power infrastructure design, enabling fully integrated project execution from the electrical substation through to compressor trains. This end-to-end engineering approach supports truly holistic system optimization, ensuring that electrical supply, drive systems, and compression equipment are designed as a coordinated package rather than as standalone components.

For more information, please visit our website:

https://www.siemens-energy.com/global/en/home/products-services/product/integrally-geared-centrifugal-compressors.html#mvr

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