Challenging the status quo

Energy efficient design in brewing and distilling

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In 2020, brewers and distillers are acutely aware of the importance of energy and water efficiency and carbon emissions. There is broad consensus that carbon emissions are harmful to the environment and high energy and water bills are bad for business so there is a strong incentive to reduce energy and water consumption.


A sunny, small CSP (Fresnel collector) array (Photo: Solatom)

It is against the backdrop of increasing costs of carbon emissions that this article was written, and it places a focus on what innovations may become commonplace in the coming years to reduce energy and water use in brewing and distilling processes specifically.

There are substantial opportunities for savings elsewhere in the value chain (e.g. malting, distribution, innovation in packaging materials) but they are not discussed in detail here. Before looking forward, it is perhaps worthwhile looking back to see how far the industry has travelled in the latter half of the 20th century, to the present day.

While energy is a key focus for any brewer or distiller nowadays, in the 1950s and 1960s energy was proportionally a small part of the cost of production. As automation increased (reducing labour costs), and energy costs increased, energy became a more significant factor in the economics of production. This led to improvements in processing, such as energy recovery systems in brewhouses, regeneration in pasteurisation systems and improvements in reducing product waste in both breweries and distilleries.

Over the past 20 years, the implementation of energy management systems (e.g. ISO 50001) has made a substantial difference to energy use and ensured that gains made from continuous improvement campaigns are held through the principle of plan/do/check/act.

As part of this review, Energy Efficient Design will be explained and used to pose questions such as what is normal operation now and what can be challenged?

This article reviews where breweries and distilleries are in 2020, discusses some of the significant energy users, and looks to the future to consider what potential alternative technologies could be employed over the coming decades to help brewers and distillers reach net zero carbon emissions.

What is Energy Efficient Design?

Energy Efficient Design (EED) is a design review process that consists of a critical assessment of what needs to be achieved in a process and how energy is used to reach this goal. The philosophy at the core is to benchmark the operation/project from an energy standpoint, focus on the largest energy users and reduce consumption in a practical and affordable way.

The Challenge and Analyse sessions which form part of an EED study are analogous to a HAZOP study i.e. a methodical, logical process with clearly defined steps and outcomes. The output of the Challenge and Analyse stage is the Energy Savings Register. The energy saving opportunities are then assessed and accepted or rejected by the stakeholders.

Each of the steps described as part of the EED process are common sense and part of good design practice but unless a formal process is in place it is difficult to ensure that each will be completed for a project.

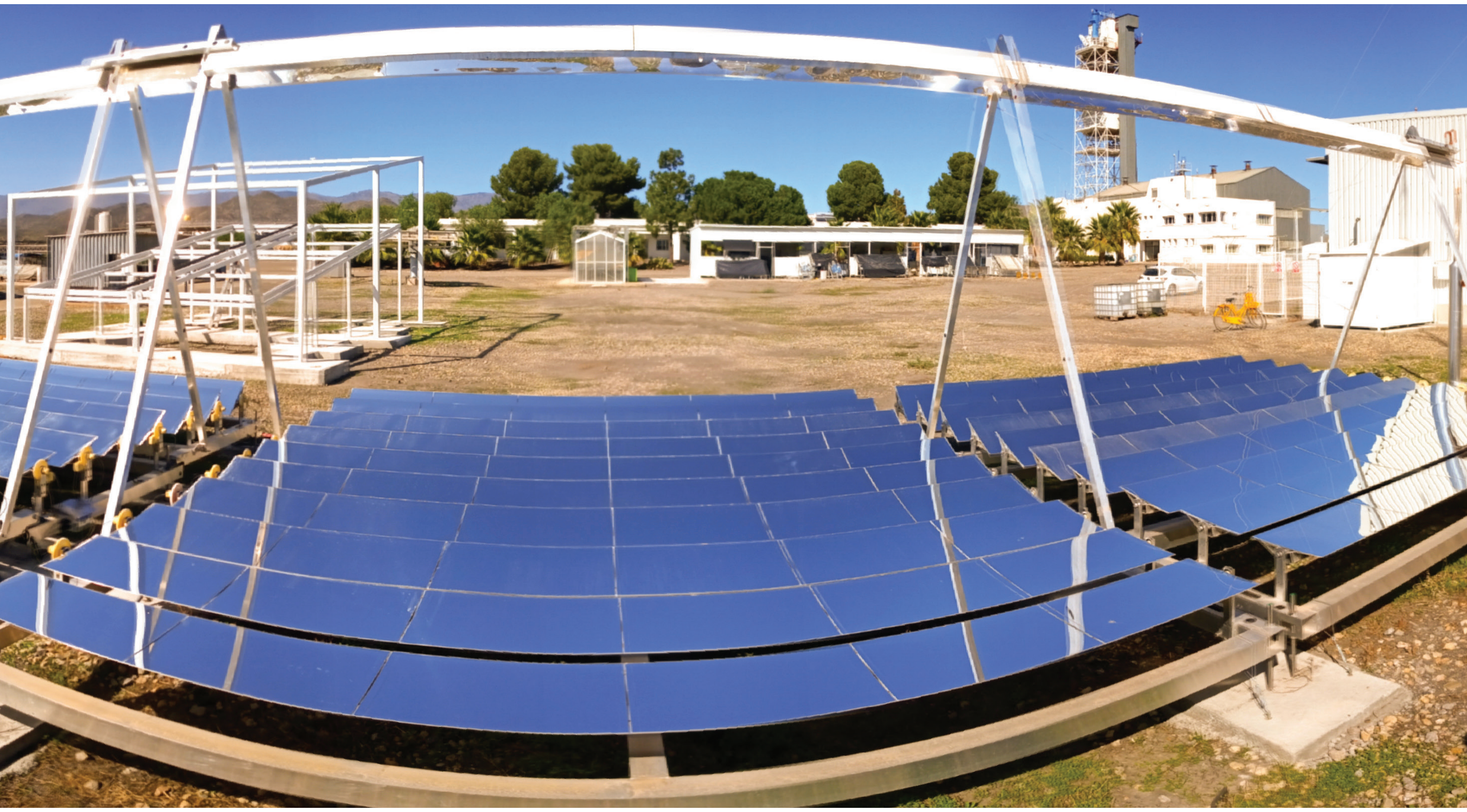
EED encourages the project team to look at the cost of the asset over its life rather than a short-term project delivery goal. Every project team will naturally focus on the KPIs they have signed up to deliver.

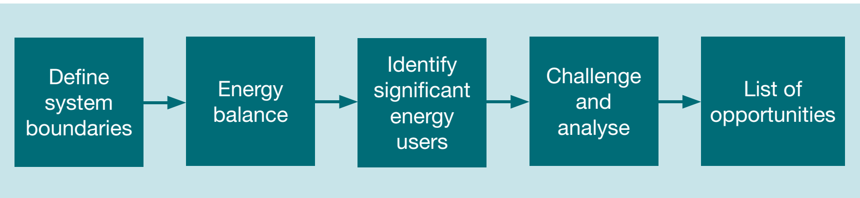
For example, it may be cheaper from a supplier perspective to provide design redundancy in cooling by designing to operate at a lower temperature. From a long-term operating cost perspective however, it could be much more economical to install additional heat transfer area to cover peak demand and operate at a higher temperature. EED provides a framework for the client and supplier to analyse these options and make the right decision for the site.

In Ireland, where FDT Consulting Engineers and Project Managers are based, the EED process is described in the Energy Efficient Design Management Standard I.S. 399. The standard is used as part of the Sustainable Energy Authority of Ireland's EXEED programme that provides significant funding of energy saving measures in large capital projects.

Significant energy users in brewing and distilling

In EED, it is important to understand the required end result and how energy is used to deliver it; this allows alternatives to be explored. Heating in brewing and distilling for example is necessary for





Key steps in the Energy Efficient Design process

many reasons, including for example, starch conversion and enzyme activation. The typical approach to deliver this heat is to produce steam through combustion of fossil fuels. Some of the largest energy and water users in brewing and distilling are discussed below.

Boiling in brewing: Boiling is an important part of the brewing process. It halts malt enzyme activity, sterilises and concentrates the wort, affects colour and flavour, evaporates unwanted volatile flavour compounds, isomerises bitter substances and precipitates protein-polyphenol complexes.

The kettle in a typical brewery could account for up to 35% of the peak steam load and would traditionally have driven the sizing of the steam system.

Some challenges to the boiling process include:
- Can volatile compounds be removed by gas stripping?
- Can the percentage boil off be reduced? (It should be noted that below approximately 4%, the available heat which can be recovered in the vapour condenser is no longer enough for the brewhouse, this can limit the extent of savings available from reducing boil off rate.)
- Is the kettle operating as efficiently as possible with respect to heat recovery? Most modern systems should have wort pre-heating from an energy recovery system as standard.

Some breweries favour low-pressure wort boiling or vacuum boiling and these technologies are efficient, provided there are no flavour stability risks (for low-pressure boiling) and that the process can guarantee that sterilisation can be achieved (for vacuum boiling).

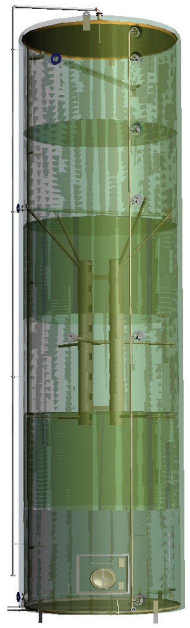
Some recent innovations in the area of boiling technology include:
- Krones Equitherm system allows the use of hot water at high pressures instead of steam while offering better opportunities for reusing that energy
- Meura's Meurastream low evaporation stripping system
- AB InBev's 'simmer and strip' technology

The most challenging question a brewer must ask themselves when building a new brewhouse is whether steam is required. Designing steam out of the brewhouse unlocks huge opportunities in heating system design, as combustion to generate steam is no longer necessary.

Cooling in brewing: Cooling is vital in every brewery to ensure low temperature processing of the product. Cooling is the largest electricity user in every brewery, so it is worth analysing if it is as efficient as possible.

One of the biggest energy-saving opportunities in breweries operating single temperature cooling systems is to introduce a second cooling system for de-aerated and ice water cooling. This can result in substantial operating savings but with additional capital cost.

While the requirements of the brewer and the product recipes ultimately dictate the amount of heat which is removed from the beer, the following are some sample observations which can be implemented in most breweries without significant investment to deliver energy savings:



Equitherm Energy Storage Vessel (Image: Krones)

1. The secondary refrigerant circuit is usually the largest pumping load in a brewery; the secondary refrigerant is pumped in a closed loop 24 hours a day, 365 days a year. In volumetric terms, this is typically more than three times the amount of water pumped through the plant in the same period. As a result, improvements in secondary refrigerant pumping (reducing system pressures, ensuring return temperature are maximised to minimise flowrates and eliminating unnecessary pumping baseloads) yield significant energy saving opportunities.
2. Ice water is nearly always overcooled in order to make hot water production management easier. This results in unnecessary cooling and production of less water at a less useful temperature. There should be a relationship between the ice water temperature and the initial fermenter temperature e.g. if the target temperature for wort is 14°C, ice water could be used at 10°C (increased heat transfer area may be required). Savings will be realised from increased chiller efficiency and reduced heat input to bring the hot water to the required temperature.
3. When transferring beer to bright beer tank (BBT), if gas correction is carried out post BBT, then higher BBT storage temperatures are possible (with the target BBT temperature equal to the maximum packaging temperature). This presents an opportunity to use the beer leaving the filter at below 0°C to pre-cool another stream by up to 4°C.

Distillation: The energy service in distillation is the separation of volatile components over several stages, the end result being a product which contains the correct concentration of ethanol and the correct combination of congeners for the product.

There are two main forms of technology in the industry, each with variations – pot distillation and column distillation. Column distillation is by its nature much more efficient than pot distillation but is associated with a different product group. The energy in nearly all distillation plants is provided in the form of steam (usually produced by combustion of fossil fuels).

Options to reduce energy use in distillation include:
1. Operation under vacuum reduces the energy input to evaporate volatile compounds.
2. Mechanical or thermal vapour recompression.
3. Reduce steam distribution pressure to as low as is feasible. This will result in lower flash losses (a reduction of 0.5bar for a 1MLA distillery would result in approximate savings of €3,500 per annum) and lower radiant losses.

Options to improve efficiency specifically in continuous column distillation include:
1. Longer campaign runs (reduces water and chemical usage during cleaning and avoid heat loss associated with stopping and starting).
2. Use indirect steam rather than direct steam injection so that condensate can be recovered. This results in a heat saving, a water saving, and a reduction in the volume of spent wash sent to effluent or co-product route.
3. Identify an alternative use of heat recovered from distillation (i.e. displace heat which is removed using cooling towers).

Evaporation of pot ale: The most common treatment method for pot ale and thin stillage is evaporation, producing concentrated pot ale syrup and sending condensate to effluent. This reduces transport costs and increases shelf life of the co-product.

Evaporation is an energy intensive process, accounting for a large portion of site electrical and thermal energy usage. In a 2015 FDT study on treatment of distillery co-products it was concluded that for a large distillery an MVR evaporator was the most economic treatment route, but it was noted that this conclusion was highly sensitive to energy prices and carbon costs.

Carbon costs have doubled in the intervening period so distilleries should review the economics of their co-product operations and consider if anaerobic digestion for example is now a cost-effective option.

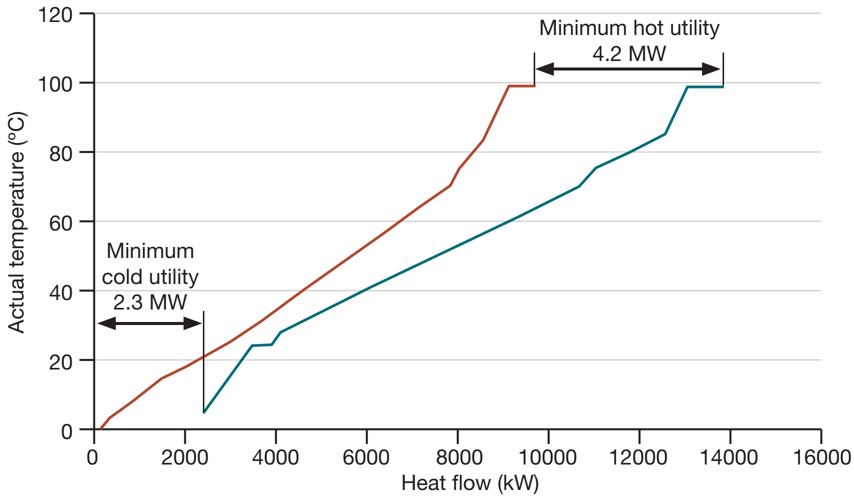
Options to increase efficiency of an evaporator system include:
1. Track the specific energy consumption for the evaporator (electrical and thermal energy per tonne of evaporation).
2. Operate at as low a temperature as possible.
3. Add enzymes to pot ale/thin stillage to reduce viscosity and fouling.
4. Reduce the evaporation set point.
5. Maximise heat recovery where possible from condensate, syrup and vapour exhaust streams. (Do not recover heat from liquid en-route to the evaporator).
6. Increase evaporator area.

Cleaning in Place (CIP): The aim of CIP is to ensure that products are free from risk of contamination (physical, microbiological and chemical) and meet the specific quality and regulatory requirements of the markets they serve.

CIP is usually a significant user of thermal energy and water. Most sites use a CIP programme comprising a pre-rinse, chemical rinse steps and a final rinse. The purpose and end point of each step should be clearly defined and understood. For instance, the pre-rinse step has normally only two basic purposes; to prove the route prior to the introduction of cleaning media with chemicals (safety) and to ensure that most contaminants are flushed directly to drain to prevent return to dilute chemical tanks.

Because CIP is such a frequent operation, tuning of CIP systems can result in substantial savings. When considering the savings associated with CIP it is important to remember the additional savings that apply such as effluent treatment, pumping and effluent charges.

Some challenges to be considered in order to achieve CIP savings:
• Do CIPs need to be completed at the current frequency? Could a vessel be cleaned every two or three uses? Would a cold water rinse suffice?
• Can caustic be re-used? Is the caustic volume correct or is a smaller



Pinch analysis (analysis by FDT for 1 mhL brewery)

volume appropriate? (If the volume is too large, caustic is being heated unnecessarily and the heat is then lost to atmosphere).

- Can the final hot rinse be recovered to be used as pre-rinse?
- Is a sterilant rinse required? Has its effect been measured?
- Can recovered heat from elsewhere in the process be used instead of steam for heating?

Cleaning can directly impact product quality so any changes need to be fully validated to ensure the benefits can be delivered without any negative impact.

Packaging: Packaging consumes a significant portion of energy in breweries, particularly in the form of steam used in the pasteurisation process. Filling with only flash pasteurisation of the liquid is a less energy intensive process but most brewers opt for tunnel pasteurisation for cans and bottles on the basis of risk management.

Modern tunnel pasteurisers have become much more efficient, make greater use of heat recovery and have evolved to no longer require any other cooling medium besides an ambient cooling tower. Some employ blowers and air knives on the outlet to reduce as much as possible water loss from the system to improve their water consumption ratio.

Other options to increase packaging efficiency include using the pasteurisation system as a heat sink (recovering heat from elsewhere in the plant) and using hot water generated from high temperature heat pumps and/or other renewable heat sources.

Heat recovery

As can be seen from some of the examples discussed in previous sections, there are a myriad of opportunities within breweries and distilleries to recover heat between process streams.

The pinch analysis example above illustrates what could be theoretically possible for a brewery of 1 mhL output.

To understand the graph, the red line illustrates the 'process heat sources', i.e. the liquid within the process which has to be cooled down (hot wort to the wort cooler, green beer, beer to the filler etc.), while the red line illustrates the 'process heat sinks', i.e. the liquid within the process which has to be heated up (wort, CIP fluids etc.).

The reason heat recovery cannot be 'perfect' for a brewery is due to two considerations; firstly, there is usually a difference between the starting temperature of the water used in the brewhouse and final temperature of the beer in packaging and secondly, boiling of the wort usually requires an external heat source at a higher temperature than can be achieved with simple heat exchange technology (assuming atmospheric boiling).

The same limitations exist in distilling but with distillation rather than boiling which drives the requirement for high grade heat.

The analysis shows that if heat recovery were possible between all the various processes in a brewery, a heating utility of 4.2 MW and a cooling utility of 2.3 MW would still be required. In reality, the requirements for these utilities is higher, as buffering of heat sources and sinks has an economic breakpoint and factors such as production patterns can also impact opportunities for energy recovery.

Later in the article when looking to the future, we consider how developing technologies can deliver these hot and cold services as efficiently as possible.

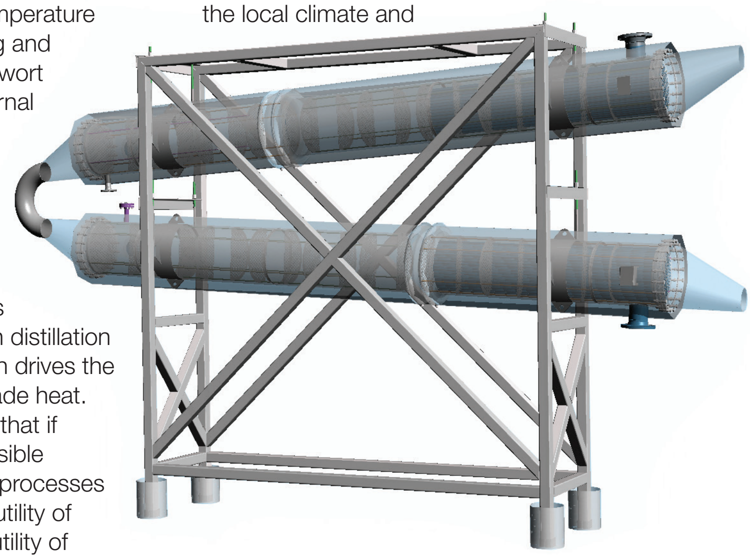
Benchmarking

When benchmarking breweries and distilleries, much focus is placed on MJ/hL and kWh/la metrics and inter-site comparisons. Whilst this benchmarking is useful and fosters a competitive environment which in turn can drive further reductions in energy consumption, there is no substitute for internally benchmarking your facility against mass and energy models and historical energy performance.

For example, whether you brew lager or stout, or whether you produce double or triple distil malt whiskey will result in differing specific energy consumption metrics.

To assist in this approach, metering and measurement is key, as are the correct reports. Every brewery and distillery should measure and track key parameters. If you don't measure it, you can't control it.

With the advent of Science Based Targets (a set of goals developed by a business to provide it with a clear route to reduce greenhouse gas emissions), a good understanding of the way all variables impact energy and water consumption is of key importance; recipes, product mix , shift patterns, packaging format, site output volumes, age of plant, plant layout, and the local climate and



External calandria that can be run on steam or pressurised hot water (Image: Krones)

Skid mounted heat pump (Photo: GEA)

environmental conditions all play a part in how efficient a facility is.

What does the future look like? Recent innovations and the next steps in energy efficiency

Brewing and distilling without steam

Recent innovations in brewing technology are calandrias that can use pressurised hot water at 115°C instead of steam for boiling. While pumping the hot water consumes electricity, the thermal savings are substantial (flash steam losses, condensate traps losses and blown losses). This can result in a thermal saving of 20% depending on how well a brewery and its utilities are maintained. High pressure hot water could similarly be used for distilling.

While greater heat-exchanger surface area is required (accompanied with increased capital costs), technologies like this offer the potential for integration with renewable energy including heat pumps, and solar concentrating technologies.

Moving away from fossil fuels

Heat pumps. Heat pumps can recover up to 85% of low temperature waste heat and elevate it to higher temperatures, using the Carnot cycle, in which heat is transferred from a cold reservoir into a warm one with the help of an external force.

There are four main sources of heat in these technologies; air, water, process streams and ground source. In industrial applications, the waste heat from processes tends to be more constant, making the whole process more efficient.

Ammonia heat pumps can generate hot water using skid mounted screw compressor-based heat pumps that are integrated into refrigeration plants and processes, with outlet temperatures of up to 90°C, heating capacities vary from 300 kW to 10,000 MW and COPs up to 3.95.

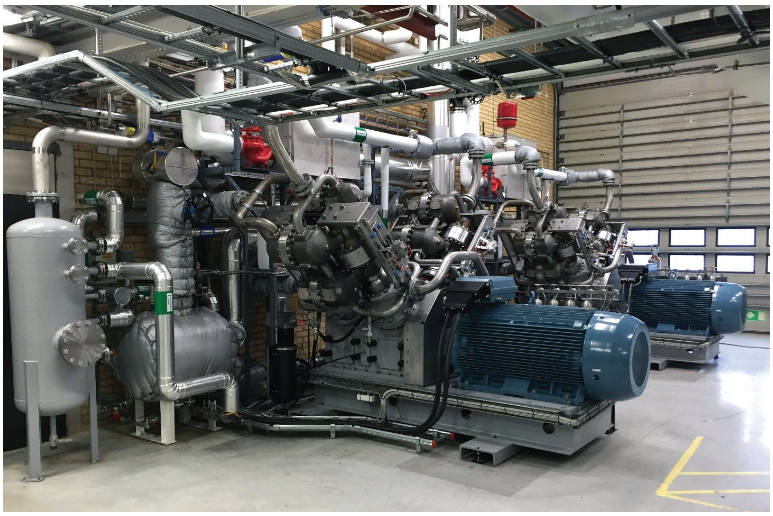
Heat pumps are being developed which can be used for steam generation, supplying heat at temperatures greater than 100°C. These technologies are in the early stages of development but could offer significant opportunities for breweries and distilleries to generate high temperature hot utilities without the requirement to burn fuels in boilers.

One example is Norwegian company Olvondo Technology which has developed a 'VHTHP' very high temperature heat pump based on a reverse Stirling engine cycle with helium as a working medium. This delivers up to 700kW of heat at 100-200°C and 350kW cooling with an electricity power input of 350kW (dependent on heat source).

Renewables: Many breweries and distilleries utilise on-site renewable electricity generation including photovoltaic panels and wind turbines. These devices are used mainly to generate electricity which is used to supplement the grid or generator electricity that most rely on.

There are other integration possibilities in renewable thermal energy which are becoming commercially available. For example, industrial scale concentrators (linear Fresnel collectors) are available that can be packaged into standard shipping containers for easy deployment and integration into a system. Units rated at 15 kW each can supply temperatures up to 300°C. They can be joined together to provide large arrays and have been designed to be light enough to be installed on rooftops.

Biofuels from co-products: Biofuels from brewing and distilling co-products



HighLift heat pump from Olvondo Technology

CSP (concentrating solar power) technology; a large array of linear Fresnel collectors (Photo: Solatom)

include spent grains/draff, bagasse, biomethane and bioethanol. The economics and environmental impacts vary according to the material type, the water content, the processing and energy input required and what other processing and disposal options are available.

Anaerobic digestion can be used to produce biogas, which can then be used to produce electricity, steam or hot water (or a combination thereof) depending on site requirements or can in some cases be fed directly to the grid.

The advantage of anaerobic digestion is that it is suitable for wet biomass i.e. there is no efficiency loss associated with drying or otherwise removing water from co-products. It is possible to anaerobically digest both liquid and solid co-products and produce biogas, but the residence times required for spent grains/draff/bagasse are extremely long (60 days relative to three days for liquids). This increases the volume required (and thus capital expenditure) significantly.

Combustion of co-products creates a reliable disposal route and a low carbon energy source for the site. The downside is that if the co-product has a high water content (e.g. spent grains), a lot of energy is required to dry the biomass ahead of combustion, affecting the efficiency and economics of the operation.

Renegade Rum in Grenada is an example of where recovering energy from co-products is the most sustainable option for the site. The sugar cane used to produce rum is grown on fallow land, the biomass plant eliminates bagasse disposal issues and displaces heavy fuel oil consumption for both electricity and steam production. The photos illustrate the scale of the bagasse boiler and furnace compared to the backup conventional fuel oil boiler.

Production of bioethanol from lignocellulosic co-products is known as 2nd generation bioethanol. The feedstock is first broken down to constituent sugars by hydrolysis with the use of heat, acid, or enzymes. This process requires significant energy input however, so this is not yet an attractive route from an efficiency or environmental perspective.

The 'food for fuel' debate is a factor when considering using biofuels from co-products i.e. is it ethical and/or sustainable to incinerate substances rich in protein and other potentially valuable by-products which could feasibly be returned to the food chain? The answer to this usually depends on what other options are available to the site in question.

Renegade Rum 4T/h bagasse fired boiler with steam drum and water-cooled furnace (pre-insulation and cladding)

Hydrogen is a carbon-free fuel when produced using renewable electricity. There is much development in this area, with the possibility that in some countries, the existing natural gas network infrastructure can be used for hydrogen rather than natural gas in the long term.

Brewers and distillers will likely first see hydrogen in the form of blends with natural gas. Additionally, hydrogen can be used as a transport fuel (e.g. for heavy goods transport), as seen when Anheuser-Busch procured a fleet of hydrogen powered trucks in 2019.

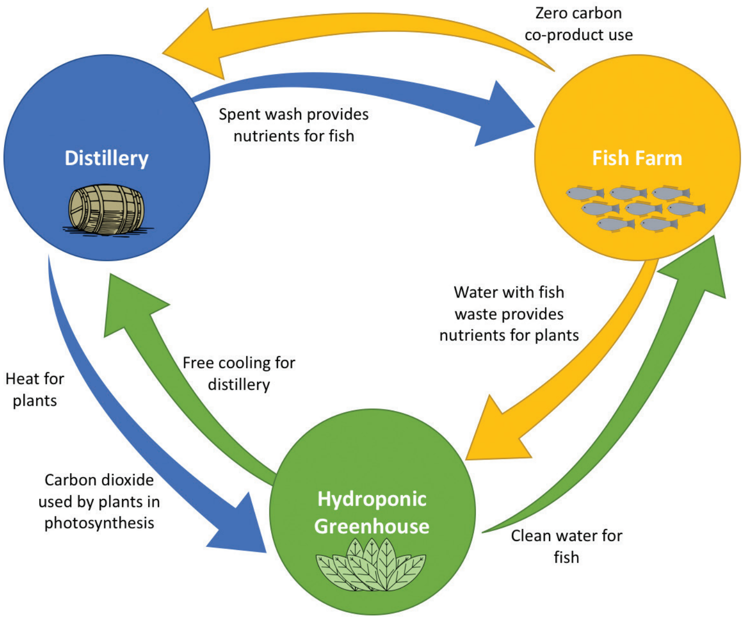
Electrolysers partnered with renewable generation with could give plants in remote locations the opportunity to reduce their reliance on fossil fuels by producing their own heating fuel on site.

Energy storage: There are many types of energy storage systems both on the market and in development such as lithium-ion batteries, compressed air and pumped hydro. Electrothermal Energy Storage (ETES) stores energy thermally and incorporates both a hot store and cold store in the design. This makes it a particularly useful design for industrial use, including in breweries and distilleries and can facilitate greater use of renewable energy.

Co-operative energy use

Breweries and distilleries tend to be stand-alone entities from the perspective of importing energy and using this energy within the operation, whether that be in the form of heating, cooling

Renegade Rum 4T/h bagasse fired boiler and 3T/h back up HFO boiler



Schematic showing a symbiotic relationship between a distillery, greenhouse and fish farm

or motive power.

With the evolution of the circular economy and energy hubs, there are a growing number of examples where the waste energy, water and by-products of one operation can be utilised by another operation.

The brewing and distilling industries are ideally placed to be a key part of the development of symbiosis in the coming years, as they are consumers of heating and cooling energy, but also can provide valuable streams from waste heat, free cooling, good quality waste water, high-quality carbon dioxide as well as potentially useful by-products from the production processes. Possible partner types include:

• District heating – domestic and commercial (to use low grade heat).
• Fish farms (to use pot ale from distilleries for nutrition and low grade heat).
• Pig and cattle farms (to use pot ale and spent grains).
• Anaerobic digestion plants (using waste water, pot ale and spent lees to produce heat and/or electricity) – economies of scale from shared system.
• Greenhouses (to use pot ale for fertiliser, low grade heat, carbon dioxide from fermentation).
• Swimming pools (to use low grade heat).

Discussion

Many breweries and distilleries are pursuing aggressive energy, water and environmental targets as part of their Energy Management Systems (e.g. ISO 50001) and while these efforts are admirable, it is important to challenge the status quo, starting at the core energy (or water) service and from that point working outwards to the process, plant and management of the operation. This Energy Efficient Design approach, if implemented correctly can lead to innovation and large savings.

Whether a facility is a green-field build, or an existing plant undergoing refurbishment, this type of approach and mindset invariably yields benefits to the business, ranging from large capital, energy and carbon savings on the project itself to potentially significant opportunities outside of the core project scope. When the project team adheres to the principle early in the project timeline it often leads to significant capital savings.

For brewing and distilling projects, challenging set-points and maximising heat recovery within the process reduces peak heating duties, while sensible electrical design (including setback modes and sensible use of variable speed drives) means peak electrical demands are minimised.

These approaches at the process plant level, cascade outwards to the utility plant and can mean smaller utilities are needed to run the brewery or distillery. Energy storage also plays an important part in this type of system, whether that be hot or cold energy storage.

While nobody knows what the future holds, innovation in renewable technologies suggests that combustion of fuels in the service of brewing or distilling may not be required, should the burgeoning developments in heat pump technology and energy storage become economically feasible. With increases in carbon taxation becoming likely in the coming years, this could become the case, or more likely a mixture of technologies could become commonplace.

Considering these factors, it is not implausible to imagine the scenario where a brewery or distillery runs on clean electrical energy, has minimal water consumption and is able to provide waste heat to other users.

Additionally, process co-products could generate green gas for other consumers to use or supply the feedstock for developing high-value products as part of the nascent circular economy. In this type of future, breweries and distilleries could become anchors around which energy and bio-economy hubs and communities could develop.

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