THE POWER OF MUSHROOM WASTE

By Dr Jenny Ekman

Growing mushrooms inevitably generates waste. There is spent compost, cut stems, unsaleable mushrooms and drain water all to dispose of. Finding ways to turn so-called waste into an income generating resource has been a puzzle, but one where there may now be solutions.

What is biogas?

Biogas is produced by the anaerobic digestion of organic matter. It is typically 50-70% methane and 25-45% CO_2, with small volumes of other gases.

Biomethane is identical to natural gas, both being created by degradation of organic materials under anaerobic conditions. Compressed natural gas can readily be used to power vehicles. In the UK, some trucks are now running on compressed natural gas, with five refuelling stations already open and plans for another 14 at least in the next two years.

Simpler systems can use the methane component of biogas directly. However, if hydrogen can be added, then CO_2 within the mixture can also be converted to biomethane, greatly increasing the amount of gas produced.

Anaerobic digestion also produces nutrient rich digestate. This is a mixture of dead bacteria, minerals, and incompletely degraded plant matter (mainly lignin and cellulose). The anaerobic digestion process has been shown to achieve a one-log reduction in any human pathogens present within 2.5 days at 35°C, and

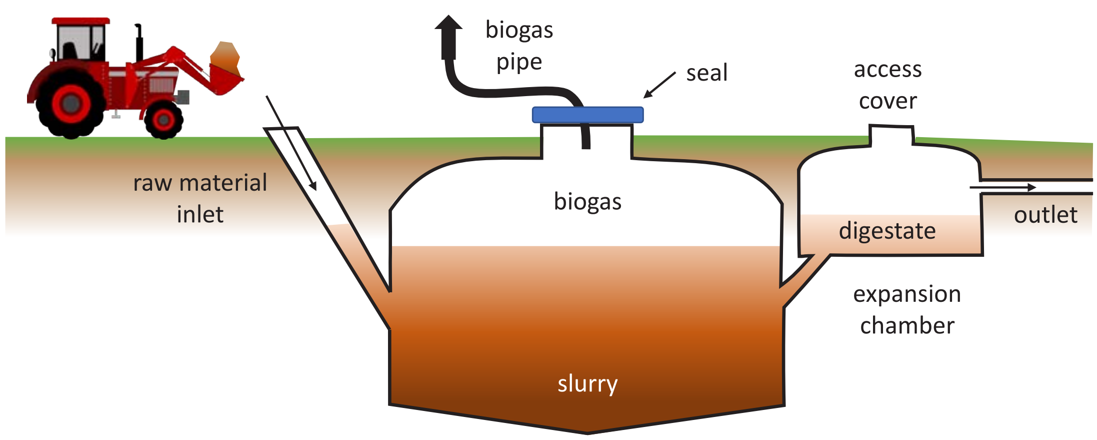

Figure 1. Biogas plant

less than one day at 53°C. Both plant pathogens and weed seeds are also destroyed during the digestion process[1]. As a result, the digestate can safely be used as a fertiliser[2], especially if it is dried and pelletised.

There are already at least 132,000 small, medium, and large digesters around the world. However, there is huge capacity to expand this technology; it is estimated that only 2% of organic wastes (e.g. food wastes, sewage, manure) that could be used to generate biogas are currently used for this purpose. According to the World Biogas Association, this technology could cut global emissions by up to 4 billion tonnes of CO_2 equivalent annually (CO_2e), reducing global emissions by up to 12% by 2030[3].

In 2019 the Australian Renewable Energy Agency[4] (ARENA) commissioned an extensive review of biogas opportunities for Australia[5]. They estimated that biogas could provide almost 9% of Australia's total energy costs as well as preventing up to 9 million tonnes of CO_2e emissions.

According to the report, key advantages of biogas are:

- Energy can readily be stored for later use
- Biogas can be transported through existing gas pipeline infrastructure
- Biogas production diverts waste from landfill
- Potentially a local industry supporting regional economies and communities and offering additional income for farmers

However, there are also barriers, including:

- High level of investment required
- Accessing funding may be problematic
- Government and local policies can create obstacles to development
- Plant operation is complex, and there is little local experience

Can mushroom wastes be used to generate biogas?

There are a number of key factors affecting the feasibility of biogas for mushroom farms:

1. The suitability of spent mushroom compost and mushroom waste as a substrate
2. The quantity of spent mushroom compost and mushroom waste available

Figure 2. Waitrose truck powered by biomethane. Photo by Scania Waitrose.

3. Availability of high calorie amendments (such as glycerin) to help break down the compost
4. The cost of natural gas and electricity
5. Capital investment required and the payback period

There has been considerable work on generating biogas from mushroom farm wastes, particularly trimmed stalks and spent mushroom substrate (SMS). The process may be even more attractive as biogas digestors produce CO_2, which can be used in mushroom growing rooms to manage pinning.

A recent review of biogas production notes that fungi are effective at breaking down lignocelluloses in different types of organic wastes. This reduces the need for pre-treatment with physical or chemical processes[9]. The authors suggest that waste products from mushroom production are therefore very suitable for biogas production.

However, according to Feng et al[6], the production of methane from SMS used to grow *Agaricus bisporus* is generally lower than other substrates. A mixture of SMS and casing material produced only 67m^3 methane/tonne solids. This compares to 155m^3 methane/tonne sewage sludge and 531m^3 methane/tonne food waste[7].

Unfortunately, it is not clear from this work whether the casing layer was removed before digestion; it seems likely that peat is not very suitable for biogas production due to its low nutrient content. This suggests that separating compost from the casing layer is likely to make biogas production from SMS more efficient.

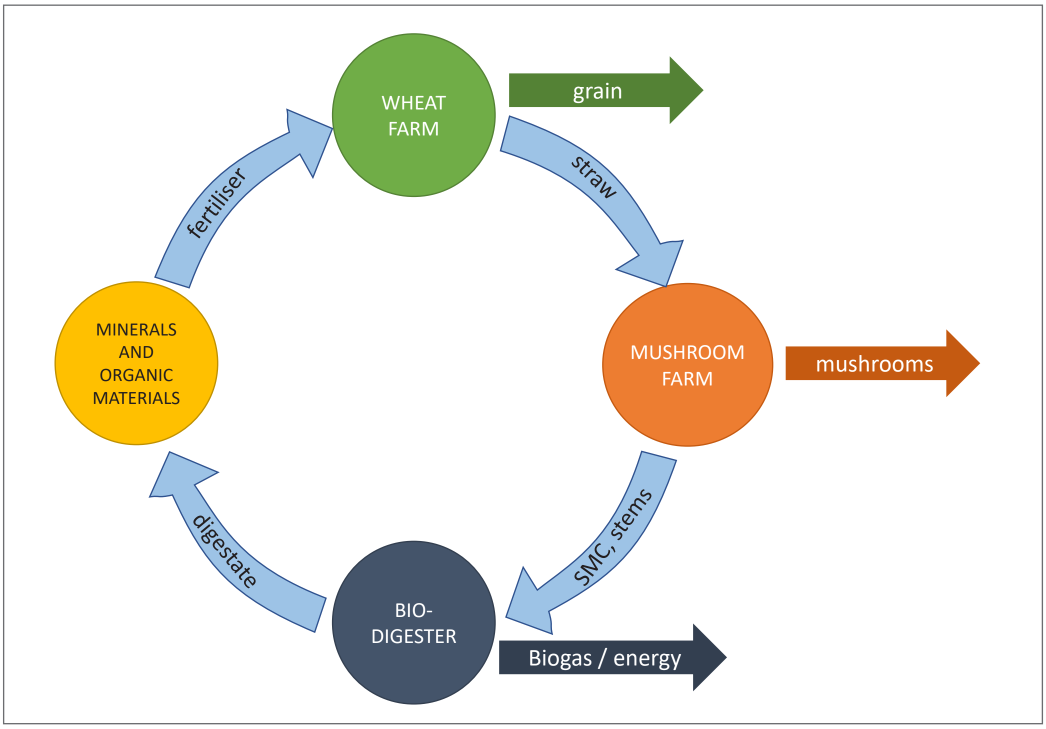

Figure 3. The "virtuous circle": sustainable production of biogas from mushroom wastes. From Perez-Chavez et al. 2019.

The "SmartMushroom" project

A recently completed project funded through the European Commission under GA 820352 and coordinated by the Mushroom Research Centre of La Rioja (CTICH; ctich.com) has developed a method to add value to SMS, using it to produce both biogas and pelletised fertiliser. The key aim was to develop a "virtuous circle" of production, as well as reduce disposal costs for the 3.65 MTonnes of SMS produced annually. This is a particular issue for farms in the Netherlands, as SMS cannot be used locally, but must be trucked to Germany for disposal.

Dr Thomas Helle, Managing Director of Novis GmbH in Tübingen, Germany, has suggested that SMS is difficult to ferment, being low in nutrients and high in insoluble fibre. However, adding certain fungal additives and enzymes can increase biogas production by 200-300%[8]. It is also possible to reduce salts in the digestate by increasing the digester temperature.

The project team has developed a pilot plant in La Rioja, Spain. According to project leader Pablo Martinez Martinez, "For our pilot plant we used glycerine and wastewater from a nearby jam factory as co-substrates. The jam water was very useful as it replaced half of the water needed for digestion and increases biogas yield. As a waste product, the only cost is for supply. Glycerin has very good properties for biogas production as it is 100% organic dry matter."

"We used a mix of 7 parts SMS to 2 parts jam water and 1 part glycerin. This achieved a yield of 120 m^3 biogas/ tonne wet material."

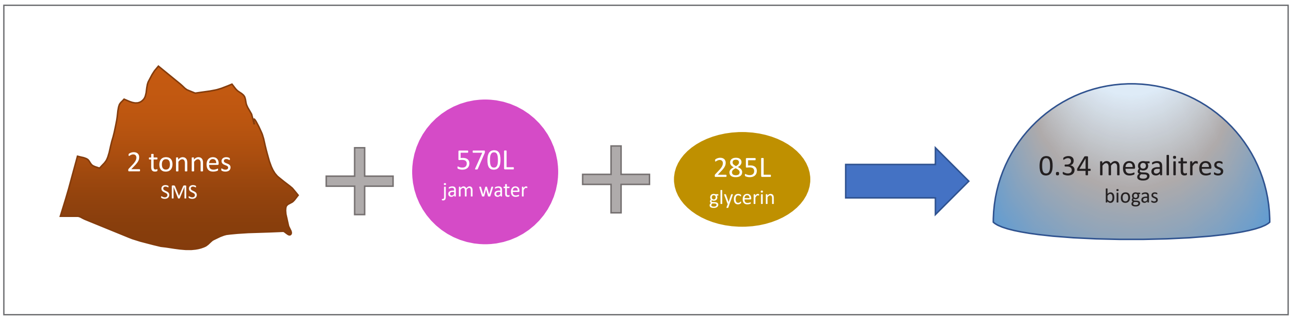

Figure 4. A 'recipe' for biogas from SMS

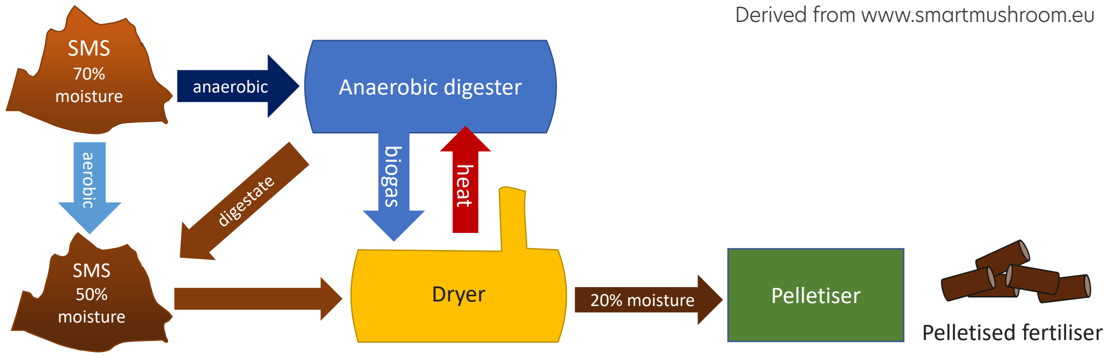

Figure 5. The SmartMushroom process. Derived from www.smartmushroom.eu

Only some of the SMS was used for anaerobic digestion. The remainder was combined with digestate and processed using a dryer fuelled directly by the biogas produced. Energy efficiency was further increased by extracting water from the saturated air with a condensation and absorption system, then reintroducing the hot air to the dryer. Drying at 65-80°C was most efficient and avoided loss of nutrients from the SMS.

The resulting fertiliser pellets are an excellent source of phosphorus, potassium, and nitrogen as well as trace elements. According to Pablo the material is readily transportable, adds organic matter to soil and is cheaper and more effective than conventional fertilisers. "We developed specific formulations for a range of vegetable crops. The preliminary results show that the fertiliser pellets improve rooting and vegetative growth as well as resulting in earlier flowering and fruiting compared to the controls".

The team also conducted an economic feasibility study for an industrial sized SmartMushroom plant. While this includes SMS disposal savings of €6/t, the results suggest a high rate of return, with the plant paying for itself in less than 4.5 years.

If excess biogas is produced, this could potentially be used to generate electricity and fed into the grid or used for other purposes on-site.

Summary of economic assessment:

Throughput/year	10,000 tonnes
Size	1.25 kWh
Plant cost	€2.2 million
Operating cost/year	€307,000
SMS disposal savings	€6/tonne
Pellet sales	€90/tonne
Payback time	4.4 years
Project IRR	21%

Figure 6. The SmartMushroom pilot plant

Other benefits of biogas

The digestate has other uses apart from fertiliser. The early stages of anaerobic digestion produce a digestate with a fine structure and high moisture retention properties. There is some interest in testing this material as a partial replacement for peat, although salt content may prove limiting.

The digestate also contains readily extractable fibres. German researchers are developing natural fibre-boards based on combining these fibres with bio-based resins. The boards have properties that may make them superior to wood-based boards and are readily composted at the end of their life cycle.

Even without these processes, biogas offers an opportunity for the sustainable use of resources[9]. With 350,000 tonnes of spent mushroom compost SMS produced each year in Australia this technology could provide an alternative source of clean energy, whether used alone or as a co-substrate in anaerobic digestion.

A new Australian project on recycling SMS into fertiliser

The recent outcomes from the SmartMushroom project are particularly interesting given the recent contracting of new project MU21006 *Recycling SMS for fertiliser in a circular economy*.

Led by Dr Kevin Wilkinson from Frontier Ag & Environment, the project will focus on developing a circular economy for SMS. There is no doubt that SMS is an undervalued resource with many useful properties. The aim is therefore to improve the value proposition of SMS for potential end-users, including grain growers.

With few practical alternatives, the industry is heavily reliant on wheat straw as a compost input. However, drought, floods, climate change, changed farming practices and increased competition from the feedstock industry all affect the cost of wheaten straw, potentially reducing availability to compost producers.

Developing a circular economy between mushroom and grains production can strengthen linkages between these industries. It could also provide a revenue raising value-add proposition for mushroom farms and improve the sustainability of grain production.

The project will examine the options available for turning SMS into fertiliser by:

1. Reviewing past research on value adding to SMS
2. Mapping supplies of SMS with potential end-users
3. Conducting intensive consultation and demonstration trials with mushroom growers and agricultural producers

The circular economy models for recycling SMS will be presented as practical case studies.

For more information, please contact Dr Kevin Wilkinson, Director Frontier Ag and Environment, kevin@frontieragenvironment.com.au

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