Report Work Package 4.1 "Testing of innovative housing and manure handling techniques on emissions" of project Climate Care Cattle farming[1]

# Dairy housing innovations

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*Results from several projects were used (see also literature), notably:*

- Private Public Cooperation (PPS) Manure Separation in Dairy Housing: Galama et al. (WLR)
- Private Public Cooperation (PPS) Better Barn, Better Manure, Better Harvest (BSMO): Emma van Boxmeer et al. (WLR)
- Experiment air circulation by Paul Robin and Nadege Edouart (INRAE, France)
- EU project Freewalk: Knut Anders Hovstad et al (NIBIO, Norway)

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## Summary

This report outlines a number of developments in cubicle and freewalk housing systems. Recently completed research or ongoing research has been used. From the CCC Farming project, support has been given mainly to the measurements at Experimental farm Dairy Campus on manure separation by means of Cowtoilet and a permeable synthetic floor in a cubicle barn. Systems from other research have been described such as LelySphere and manure fermentation. Developments in a freewalk barn involve a bedding with woodchipc, a permeable synthetic floor and a draining sand package. These systems produce different manure fractions and each has its own effect on emissions from the barn, when stored and when applied to the land.

The choice of a barn system has an effect on many aspects of farming operations, such as emissions throughout the entire chain of barn - storage and spreading, on fertilization on the dairy farm and fields, when sold to third parties on the fertilization of crops in arable farming or possibly horticulture, on integration into nature-inclusive agriculture, on milk quality and finally on animal welfare and animal health. For the Dutch situation, it is important for farms with a manure surplus (especially N surplus) whether the separated urine fraction can be considered as an artificial fertilizer replacement. The EU legislation on Renure (REcovered Nitrogen from manURE) has not yet been finalized.

These developments were also discussed with dairy farmers and consultants from different countries. These included advisers from Seges in Denmark, consultants from the Belgian Farmers' Union, researchers from Germany, students from Italy, dairy farmers from Slovenia, agricultural representatives from Austria and a seminar during an exhibition in Latvia. Some developments have already been adopted such as woodchip bedding in several countries, synthetic floor in Slovenia and sand bedding in Italy.

This report is an elaboration of work package 4.1 of project Climate Care Cattle farming and should be seen in conjunction with the detailed study described in Report 1, report of work package 2.1.1. "Manure separation in dairy cattle houses."

## Table of contents

# 1. Introduction

A barn system affects many aspects of farm management. The development of the cubicle barn in the 1960s and 1970s, as a successor to the tied barn, was a major breakthrough in improving labor efficiency and exercise space for cows. Since then, requirements to improve animal welfare and reduce ammonia and greenhouse gas emissions have become more important. The emergence of the cubicle barn also changed manure quality. In the tied barn, urine was separated from feces. The feces mixed with straw was stored as solid manure in a manure pile outside the barn. The new developments in the cubicle barn focus, among other liquidgs, on the separation of feces and urine. Starting in 2010, the Netherlands also saw the development of freewalk barns, a barn without cubicles where the walking and lying areas are combined. This is similar to a deep litter barn, however with more m2 per cow and bedding material other than straw. The bedding in a freewalk barn can consist of organic material which provides an organic-rich manure product or can consist of a separation floor made of synthetic or an (inorganic) sand bedding that separates feces and urine.

In this report, Chapter 2 lists the main requirements from the cow, the farmer and the environment, in Chapters 3, 4 and 5 successively the developments in cubicle barns, freewalk housing and what consequences this has for manure quality.  Chapter 6 presents the integrated farm assessment and finally in Chapter 7 the discussion and conclusions.

This report used knowledge developed in several research projects. This is referred to in the text. Knowledge and experience from these projects has been exchanged internationally in the CCC Farming project.

## 2. Housing requirements

A housing system must respond to the needs of the cow, the farmer and the environment (Galama et al, 2009). The focal points of interest for the innovations described in this report are:

Cow

- Ample space for natural behavior, lying down and standing up
- Good walkable floor
- Good air quality

Farmer

- Attractive living environment to work in
- Extend life of livestock through few health problems
- No risk to milk quality
- Low investment and annual costs

Surroundings

- Attractive in the landscape
- Low emissions of ammonia, greenhouse gases and odor
- Manure quality appropriate for precision fertilization and increase soil organic matter

The floor systems in a cubicle barn and a freewalk barn respond primarily to manure quality, walkability and reduction of emissions. The freewalk barn is characterized by lots of space and freedom of movement by omitting the cubicles. The essence of improving air quality is, on the one hand, to create a pleasant living environment for humans and animals and, on the other, to reduce emissions outside the barn. By capturing the ammonia and possibly also the methane from barn air and filtering or oxidizing it, the emissions are limited without adjusting the animal through feeding or breeding.

Figure 1 shows the different sustainability aspects. Figure 2 shows the emissions from the barn and at application of manure in the field and the availability of nitrogen and degradability of carbon of the manure products in the soil. These include slurry from a cubicle barn and organic rich "humest" from a freewalk barn with a woodchip bedding.

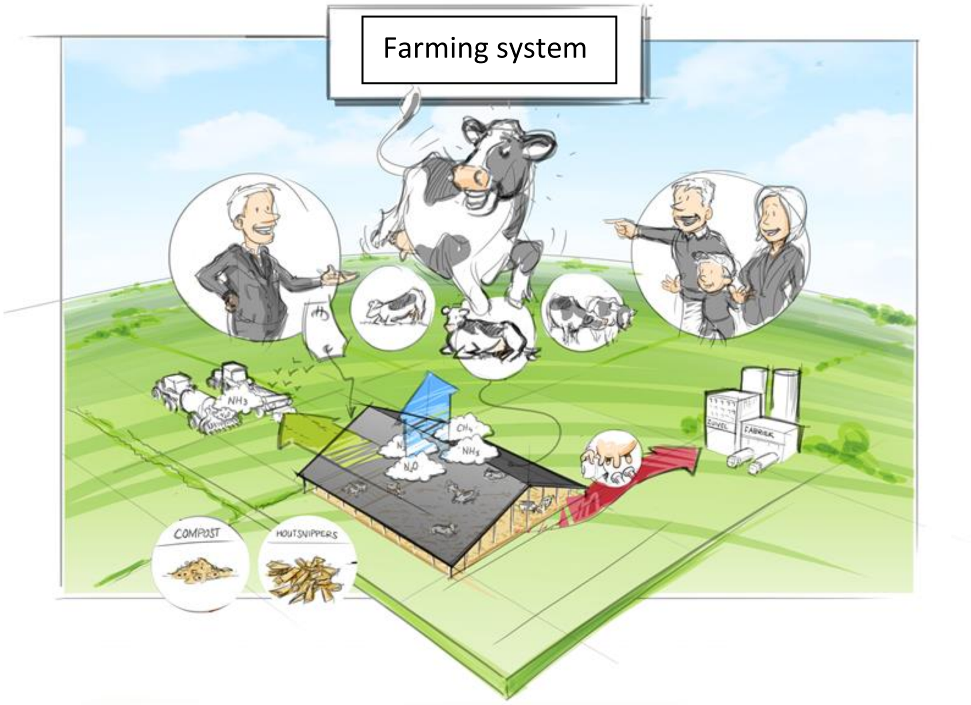



*Figure 1. Dairy housing sustainability aspects: animal welfare & animal health, economy & labor, hygiene & milk quality, emissions from the barn and manure quality.*

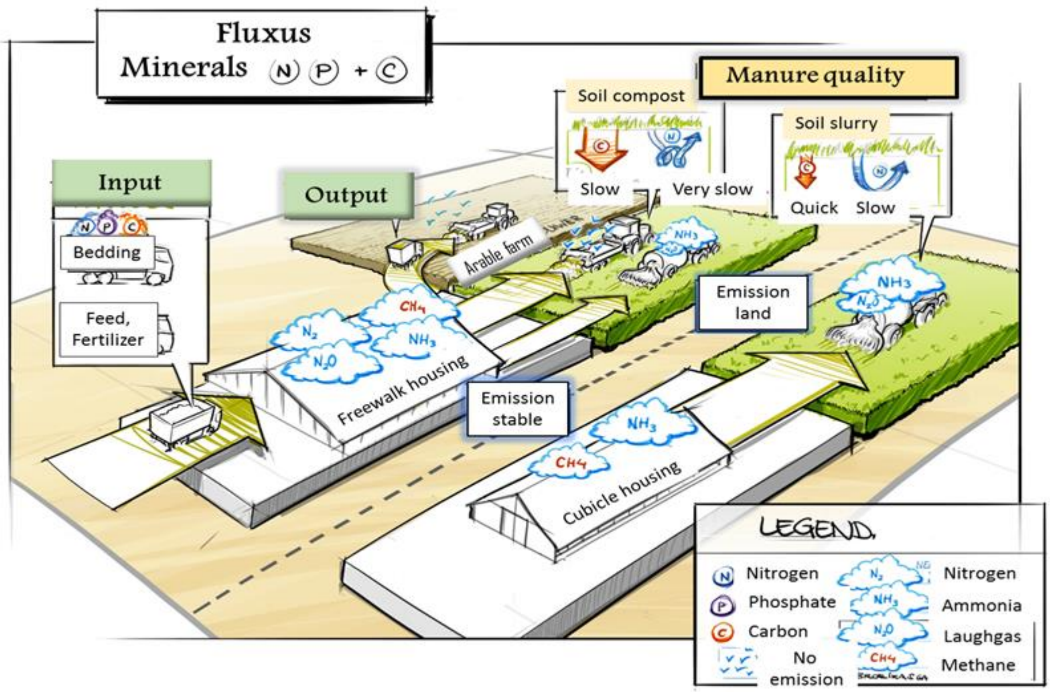



*Figure 2. On-farm comparison of emissions and manure quality between cubicle barn and freewalk barn (with woodchip bedding)*

## 3. Developments in cubicle housing system

### Emission factors of existing floor systems

For dairy farming in the Netherlands there is a list of different floor systems with an emission factor expressed in kg ammonia per animal place per year, the so-called RAV (Regeling Ammoniak Veehouderij) list. This list currently (2023) describes 39 systems. Figure 1 shows the emission factors. The reliability of these emission factors is currently under discussion in the Netherlands, because practical experience (exploratory measurements) shows that ammonia emissions are not as low as assumed based on this RAV list. This has implications for permit granting (RVO, 2023).

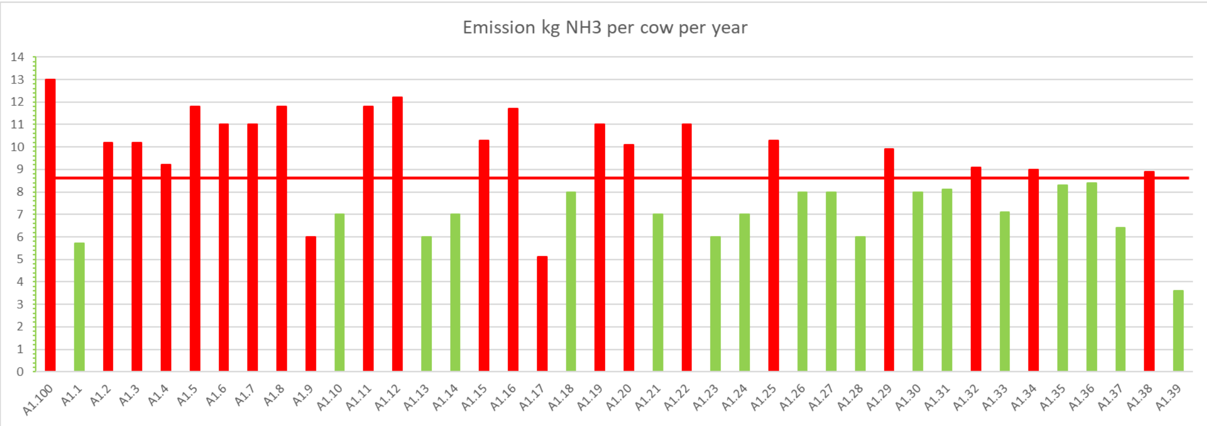
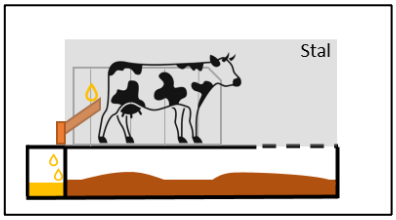


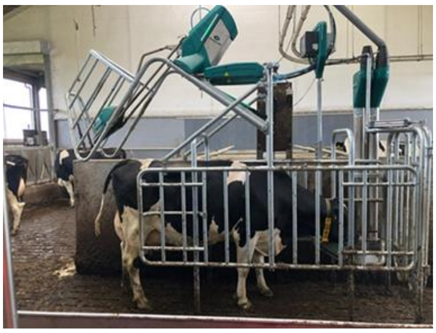

*Figure 3. Low emission systems on the RAV list. Green concerns systems that comply with less than 8.4 kg ammonia per animal place per year and red concerns systems with more than 8.4 or no reliable measurement report is present (source RVO of Ministry LNV).*

### Emission factors and manure products new developments

In the PPS project "Better Barn, Better Manure, Better Harvest (BSMO)", samples were taken of different manure fractions from the various separation systems and other new developments (Boxmeer van, et al. 2023). Of these barn systems, the following are described: the system, the manure products, the impact on emissions, and the assessment of the manure products.

<u>Cowtoilet</u>

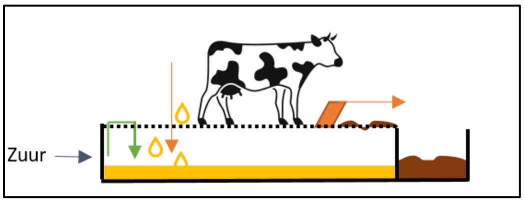


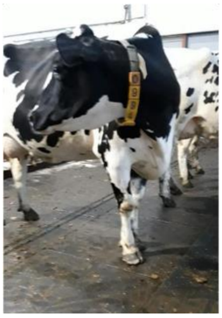



The Cowtoilet is an automatic urine collection system placed in a concentrate box. The natural nerve reflex between the tail and the rear udder is stimulated, which causes the cow to urinate. When the cow urinates, this urine is collected in a reservoir and extracted to a storage area. This prevents this urine from reaching the floor (and storage) and results in a clean urine fraction. When a cow urinates outside the Cowtoilet, this urine does end up on the floor and in the manure

storage. Therefore, the manure storage does contain slurry, but with less urine.
The indication is that ammonia emissions are reduced by 30 to 35%.

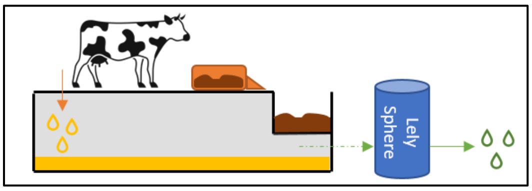
Permeable synthetic floor



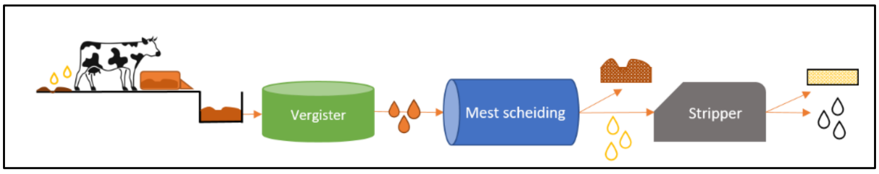
A permeable plate is put on the slatted floor in existing cubicle stalls. The urine sinks through the plate into the storage below, while the feces remains on the plate. The feces is then collected with a manure scraper and transported to a separate storage area through a gutter. This permeable plate floor is still under development and is also described in Report 1 CCC Farming. The measured ammonia concentration in the storage was very high due to the high pH of 8.5 to 9. Therefore, research was done to investigate the effect of acidifying the urine in the storage to a pH of 4.5 to 5 on ammonia and methane emissions. The plates have also been improved so that urine sinks well through the plates. This prevents the plates from remaining after-emitting urine for a long time. In addition, the possibility of flushing the plate floor with acidified urine from the storage has been explored, so that the urine in the plates passes more quickly. With acidifying the urine and flushing the plate with the acidified urine, a reduction in ammonia emissions of more than 60% was achieved. Another development was tested by spraying the plate with water and with additional addition of a urease inhibitor. This reduced ammonia emissions by almost 50%. It was less than 60%, probably because of less permeability of the plate or short measuring period of 5 days.

Lely Sphere




The LelySphere system is a combination of source separation and storag air extraction. Perforated metal strips are placed in the grate slits. The urine flows through these slits into the storage below and the feces remains on the floor. A manure robot picks up the feces and deposits it in a separate deposit. Next, the air from the cellar is extracted by the LelySphere N-Capture, in which nitrogen is filtered out of the air with an acidified solution (air scrubber). Due to the extraction of the air in the storage and the fact that the manure dump contains a siphon, a negative pressure is created in the storage. This leaves the holes in the floor open for urine passage, and the air just above the floor is also extracted. This system produces three manure products: feces rich in phosphate and organic matter, slurry rich in potassium and sluice water rich in nitrogen. Ammonia emissions from the barn are reduced by more than 70%.

Jumpstart manure fermentation and stripping



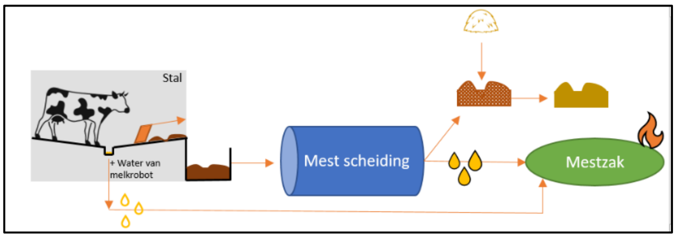

Feces and urine fall onto the solid floor and are picked up by a manure robot wiliquid an hour. The slurry is deposited and transported to the mono-digester. During the digestion process, a digestate is produced, which is then mechanically separated into a solid and liquid fraction. The solid fraction can be used as bedding material in the cubicles and solids are partially disposed of. The liquid fraction goes through a stripper and from this ammonium sulfate and effluent are produced. The effluent is then used as a potassium-rich fertilizer on the grassland.

Concrete slotted floor

These concrete floors contain slots with slurry holes. Urine flows through the holes in the slots into the storage or gutter below the solid floor, while feces remains on the floor and is collected by a manure scraper or robot.

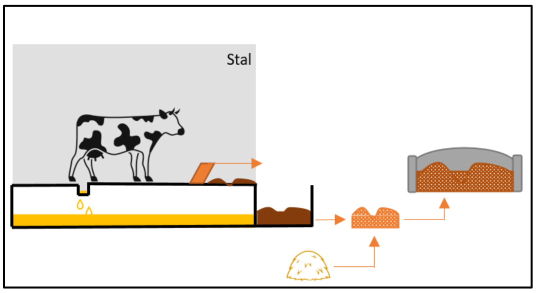
*Two variants have been applied in practice:*

*Variant 1*




Urine drains to the gutter and daily flushing of the gutter with water drains urine from the barn. The sheared feces is mechanically separated. The solid fraction after mechanical separation is mixed with natural hay and applied to the land. The urine and liquid fraction after mechanical separation are stored in a manure bag. When sufficient gases are formed, they are compressed with a mobile plant, cleaned and the methane is stored in gas cylinders; a low-cost system of passive manure digestion.

*Variant 2*



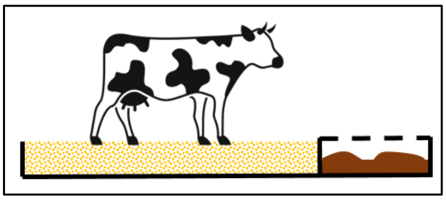

The urine is stored through a gutter with holes in the solid floor. The sheared feces are mixed with straw, shell lime, clay minerals and fermentation liquid with a special mixer and this mixture is fermented in a covered trench silo (bokashi).

## 4. Developments in freewalk housing system

The development of freewalk barns has been underway in the Netherlands since 2009 with inspiration from America where Compost Bedded Pack Barns were in development and from Israel where keeping cows on dried manure is the most common housing system. In the Netherlands, starting in 2010, different principles have been tested to keep the top layer dry, namely by evaporation of moisture through composting wood chips, by absorbing moisture using dried dredge from ditches mixed with reeds and by draining moisture through a sand pack. In 2010 and 2011, woodchip bedding proved the most promising. About 60 of these were built in the Netherlands. Due to the rising prices of wood chips, some switched to using straw. Later, new developments started with a draining synthetic floor and the further development of a sand bedding where the feces is collected with a so-called BeddingCleaner. The first synthetic floor in the Netherlands was constructed in combination with trees in the barn, the cow garden.

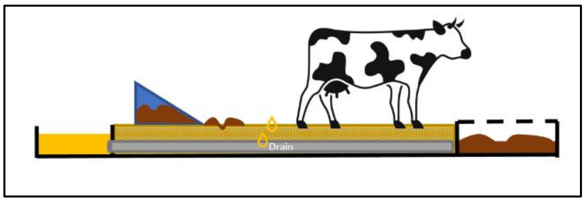
These developments are explained further.

<u>Woodchips bedding</u>



There are no cubicles and the lying and walking areas are combined. The barn has a composting bedding of wood chips and urine and feces both fall onto the bedding. Organic material is added regularly and the top layer is cultivated daily. Composting is slower and at lower temperatures than composting biomass in a composting plant, so it can be called semi-composting (Galama et al., 2011). Only near the feed fence is a slatted floor, where slurry is collected. If necessary, a low-emission floor can also be used at this location.

<u>Sand bedding</u>



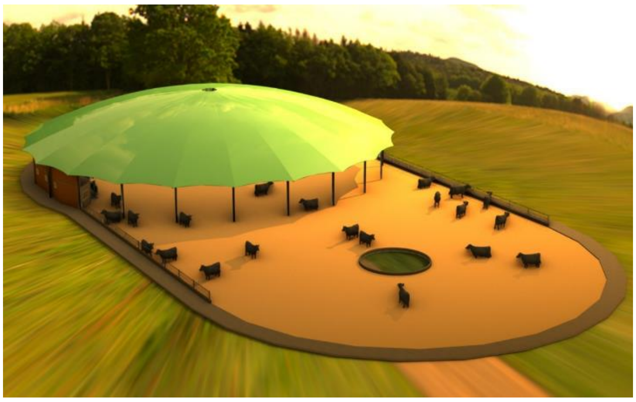

The sand floor in a freewalk barn is also called Free-Living Barn. Urine sinks through the sand to a drainage pipe, where it is drained and centrally stored. Feces remains on the sand and is picked up by a BeddingCleaner. Wet parts are panned by the BeddingCleaner and dry sand partly falls back onto the bedding. Only at the feed fence is a slatted floor, where slurry is collected. If necessary, a low-emission floor can also be used at this location.

<u>BeddingCleaner in combination with sandy or organic soil</u>

The development of the Free-living barn has two variants, namely an organic and an inorganic (sand) bedding in which the technical innovation of the BeddingCleaner (see photo) is an essential part. This idea was developed by Wageningen Livestock Research in conjunction with company Hanskamp AgroTech BV, which also developed the Cowtoilet. The BeddingCleaner picks up the manure slats with a specially developed machine behind the tractor. The collected manure slats together with some organic material can be used to increase the efficiency of manure fermentation. On a practical farm in the Netherlands the first experiences with this are being made. If there is a sand bedding, a choice will have to be made to separate the sand from the feces with a sand separator or to apply the feces mixed with sand to the land above ground. By separating the sand from the feces, it can be reused, saving acquisition costs. This savings will have to be weighed against the cost of a sand separator. One indication is that this may be an option for large farms with more than 250 - 300 cows. Without separation, it is important to further develop the BeddingCleaner in a way that little sand is collected to save costs of purchasing sand and costs of applying feces with sand to the land. On a few commercial farms, experience is being gained with a Free-Living Stall with a sand bedding. One involves a freewalk section with a feed alley along the feed fence (photo) and the other involves a round barn with the sand bedding up to the feed fence on the outside, with also an exit to the outside on a drained sand bedding (photo).

*BeddingCleaner that picks up feces from sand bedding*

*Freewalk barn with sand bedding (Free-Living Barn) with walkway along feed fence.*



*Freewalk stall with sand bedding (Free-living Stall) with round roof and exit on sand bedding. Feed fence on outside of round barn. Milking robot and urine storage underneath*

Important points of attention for the further development of the sand bedding concern the choice of sand type in relation to walkability and draining effect. Coarse sand grains are important for good drainage, but fine sand is more walkable. On the other hand, much is still unknown about the processes of nitrification and denitrification in a sand bedding in relation to nitrogen losses, including in the form of nitrous oxide ($N_2O$), ammonia ($NH_3$) and nitrogen ($N_2$).

Permeable synthetic floor

The floor consists of a soft liquid-permeable floor that quickly separates urine from feces. The feces is picked up by a manure robot. The first version was applied in 2010 in combination with a Cow Garden. The floor was supplied by company ID Agro and, together with a dairy farmer, also the inventor, was further developed as High Welfare Floor. In addition, several more cow gardens were developed and the floor was also installed on a farm in Slovenia (see photos). The floor was studied at Dairy Campus from 2016 to 2019 in terms of cow behavior and emissions (Galama et al, in prep. 2023). The study was stopped at the end of 2019 due to disappointing reductions in ammonia emissions. The reason was that the cleaning of the floor was insufficient and the interlayer acted too much as a sponge, causing urine to be discharged too slowly through the underlayer. In the latest version, the intermediate layer has been modified, but its effect on ammonia emission has not been measured. For the further development of the synthetic floor, rapid drainage of urine and a properly functioning robot that picks up all feces is essential.

*The first Cow Garden with permeable synthetic floor in the Netherlands*

*Synthetic floor at Dairy Campus*

*Synthetic flooring on practice farm Netherlands*

*Synthetic floor in Slovenia*

## 5. Relationship of housing system and manure quality

The urine/liquid fractions from the innovative barn systems were assessed for suitability as fertilizer substitutes (REcovered, Nitrogen from manURE (Renure)) and the feces for suitability as an organic fertilizer or if high organic matter in the manure product as a soil improver (Boxmeer et al., 2023).

### RENURE

To qualify for Renure as a nitrogen fertilizer, the product must have comparable nitrogen utilization to fertilizer and there should be no increased risk of nitrate leaching. The Joint Research Center's SAFEMANURE study established criteria that a fertilizer substitute should meet (Huygens et al., 2020). One of these criteria states that the fertilizer is at least 90% inorganic/mineral *or* the ratio of total carbon to total nitrogen is less than 3. This means that the ratio of N-mineral/N-total is greater than or equal to 0.9 *or the* ratio of C-total/N-total is less than or equal to 3. At the time of writing, nitrogen fertilizers from livestock manure are not yet allowed as fertilizer substitutes. The publication of SAFEMANURE provides the scientific and substantive justification to allow it, however, the Nitrates Directive indicates that products from livestock manure should be considered as livestock manure and RENURE would therefore deviate from that. In addition, political decision-making must take place in the European Commission.

### Organic fertilizer or soil improver

In the research conducted in the BSMO project, a fertilizer product is rated as a soil improver if the ratio of effective organic matter (EOS) to mineral nitrogen exceeds 150 kg/kg and the ratio of EOS to phosphate exceeds 35 kg/kg. If either or both ratios are less than these values, the fertilizer is rated as an organic fertilizer.

### Review

In the diagram below, the urine/liquid fractions from the barn systems were assessed for suitability as Renure and both the feces/solid fraction, possibly mixed with straw, as an organic fertilizer or soil improver. The "humest" from a freewalk barn in which wood chips are slowly composted over a year along with the manure and urine was assessed for soil improver.

| | **Urine /liquid** | **Feces / solid** | |
|---|---|---|---|
| **Stable system** | **Renure** | **Organic fertilizer** | **Soil improver** |
| Cowtoilet: urine/dung with less urine | ++ | + | |
| Permeable plate floor: urine / feces with straw | +0 | | + |
| Concrete floor: urine and feces | - | + | |
| Lelysphere: urine and feces | +0 | | |
| Freewalk stable with woodchip floor | | | ++ |
| Freewalk stable with sand floor: urine / feces with sand | ++ | + | |
| Jumpstart (mono fermentation: digestate) | -- | + | |

*Figure 4. Suitability of manure fractions from barn systems as Renure, organic fertilizer or soil improver. (++ = very suitable, +0 is fairly suitable, - = not suitable)*

The urine from the Cowtoilet gives the best separation and is therefore most suitable as a fertilizer substitute (Renure). Not all urine is collected so the feces is similar to slurry but with over 30% less urine. The solid manure is suitable as an organic fertilizer. The sandy bedding also provides good separation so the urine meets Renure criteria (if accepted by EU). The permeable plate floor also gives reasonable separation. Concrete floors with slots and holes do not provide adequate separation. For the liquid fraction to qualify as Renure, it will have to be filtered. The composted wood chips with manure contains a lot of organic matter and is suitable as a soil improver partly because of relatively little nitrogen and phosphate.

## 6. Assessment at farm level

### From barn system to farm system

Further development of cubicle barn

The cubicle barn has continued to evolve in recent decades through the application of low-emission floor systems. There is much debate about the extent to which these floors reduce ammonia emissions. That does not stop innovations from continuing. The Cowtoilet and the permeable plate floor have been studied. These are two promising developments that can reduce ammonia emissions in particular but also methane emissions. This development of manure separation at the source produces manure fractions that can be fertilized more precisely on the dairy farm or when sold on an arable farm. However, it is important that the manure fractions are treated in such a way that they fit into the total farming system. Acidifying urine can limit emissions on the farm because it limits the emission of both ammonia and methane in the barn and during application on the land.

Feces are not always pumpable or stackable when manure is separated. The dairy farmer will therefore have to make a choice of adding water to the feces to make it pumpable or, for example, adding straw to make it stackable. The feces can also be made stackable by mechanically separating it. This solution is becoming increasingly common. The liquid fraction from the separator can then be stored separately or added to the urine from the primary separation. To reduce emissions from feces mixed with straw, this fraction can be stored in a covered storage silo. A fermentation process then takes place in this storage.

Example ammonia emission in farm

Figure 8 shows the ammonia emissions throughout the manure chain from barn - storage - and application to grassland when the permeable plate floor is applied in combination with acidification of urine. The reference refers to slurry from a conventional cubicle barn and this was compared to the emission from the separated manure stream of feces made pumpable by adding water and applied above ground. The urine was acidified with sulfuric acid to a pH of about 4.5. This required 8.7 liters of sulfuric acid per ton of liquid fraction in the study. Acid consumption is thus about 40% lower than for acidifying slurry. The acidified urine is applied to the grassland with a slurry injector.

Ammonia emission is expressed as % of total N excretion in Figure 6. It shows that by acidifying the urine, the ammonia emission from the barn is approximately halved and the emission from the acidified urine on land is zero.  However, the emission from above ground application of the diluted feces is still a significant part. In a total farm context, about 7 kg N per cow per year can be saved in this way. If the diluted feces would be applied with a slurry injector, about 11 kg N per cow per year could be saved.

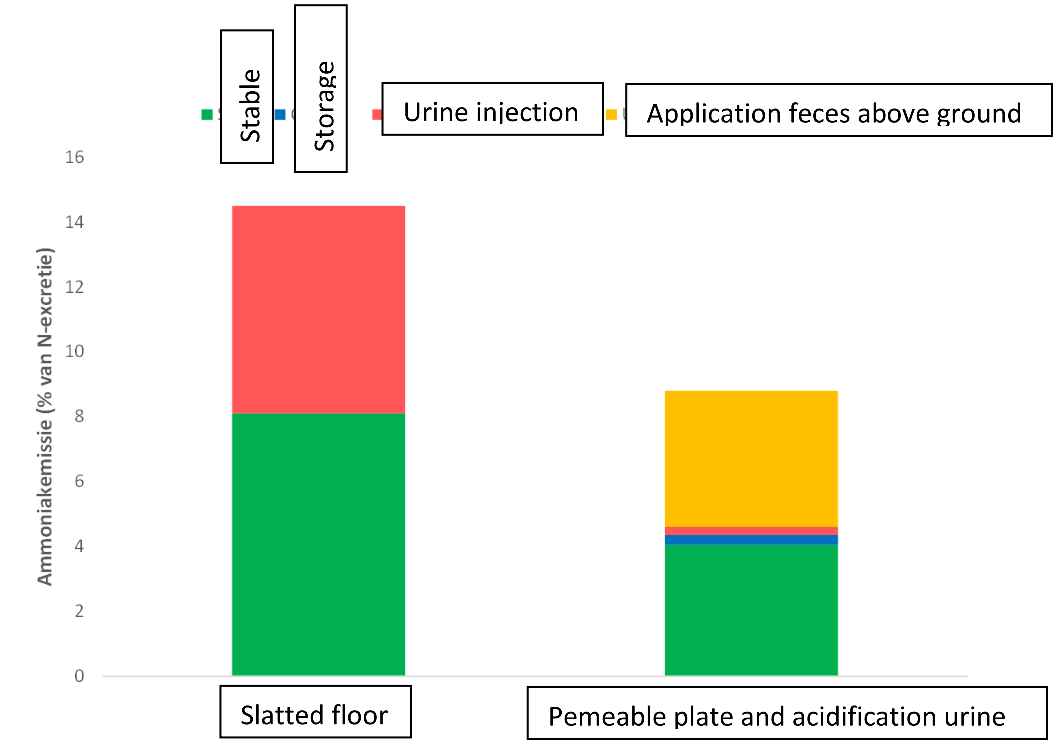



*Figure 8. Ammonia emissions (% of total N-excretion) in stable, storage and spreading of reference farm with a slatted floor compared to application of the permeable plate floor where urine in the storage is acidified and feces is diluted with water. Emissions in the barn were measured and estimated during spreading based on the composition of the manure product. Feces is applied above ground and urine with injector.*

<u>Continued development of freewalk stable</u>

The development of freewalk barns is aimed, on the one hand, at creating movement space for the animals and, on the other hand, at making manure fractions with high organic matter by composting organic material such as wood chips or by separating feces and urine on a permeable synthetic floor or a sand bedding.

The above indicates that the choice of desired manure product and desired space for the animals can be very influence the barn system that fits well in the overall farm system in terms of soil type, crops and life span of the livestock. Drought-sensitive sandy soils and arable land will require more manure with high organic matter. The freewalk barn can increase longevity through increased animal welfare and reduced claw problems. These stalls are still very much in development and require good workmanship to keep the top of the bedding dry and hygienic.

### Comparison of cubicle barn and freestall barn

In the European project Freewalk (www.freewalk.eu), 20 free stall barns were compared with 20 free stall barns in 8 countries. They were evaluated on different criteria. The criteria that could be economically valued are shown in Table 2.

*Table 2. Economic comparison between cubicle barn and freestall barn (Freewalk, Anders Hovstad et al, 2023, in prep.).*

| | Compost bedding | Cubicle |
|---|---|---|
| Building costs, annual, € | 63 396 | 47 132 |
| Bedding material costs annually, € | 15 323 | 4 586 |
| Energy costs, € | 1 406 | - |
| Labor costs, € | 1 842 | 4 170 |
| Manure application costs, € | 5 935 | 3 348 |
| Cattle replacement costs, € | 55 106 | 68 438 |
| Cattle replacement % | 0.248 | 0.308 |
| Health costs, € | 2816 | 2186 |
| Subclinical mastitis per 100 cows | 18.9 | 12.9 |
| Mastitis, €/case | 128 | 128 |
| Claw problems % per 100 cows | 9.69 | 13.05 |
| Claw problems, €/case | 41 | 41 |

The cost of a freestall barn is higher than a cubicle barn because of higher building costs and because of costs for bedding material (bedding in freestall area). There can be cost savings in a freewalk barn due to lower cattle replacement (longer life span) and fewer claw problems. The risks for mastitis seem somewhat higher in a freewalk barn, but are mainly related to management of the bedding material so that the top layer remains dry and hygienic throughout the year, even in the damp winter months. This (Freewalk) study also interviewed 3693 consumers in 8 countries. They gave the freewalk barn a significantly higher rating than the cubicle barn (score 7 vs. 4). It should be noted that grazing and organic is a more important issue for consumers than the housing system.

It should also be noted that freewalk barns are still very much under development, while the cubicle barn has already had over 60 years of development.

### Renure

Figure 9 explains the effect on farm level if the urine fraction from manure separation would be accepted by the EU as a fertilizer substitute. The total N-gift per ha consists of the permitted amount of nitrogen from manure and fertilizer. Manure separation creates two manure products in which the N-gift from feces is determined by the maximum N-gift from slurry. This will be reduced from 230-250 kg to 170 kg N per ha due to the reduction of derogation in the Netherlands. The N-gift from urine depends on whether or not it is accepted as Renure. In the case of no Renure, it falls below the maximum N-gift from manure of 170 kg N. If the urine is accepted as a fertilizer by the EU, then the N from the urine does not have to be disposed of, if there is a manure surplus, especially an N surplus. Savings can then be made on both manure disposal costs and purchase of fertilizer which also reduces the energy consumption for producing fertilizer.

It should be noted that the possible allocation of manure fractions as Renure should distinguish between urine/liquid fractions from primary manure separation and stripping nitrogen from liquid fractions. Stripping creates effluent that does not contain organic matter, and thus may be more easily accepted as Renure.

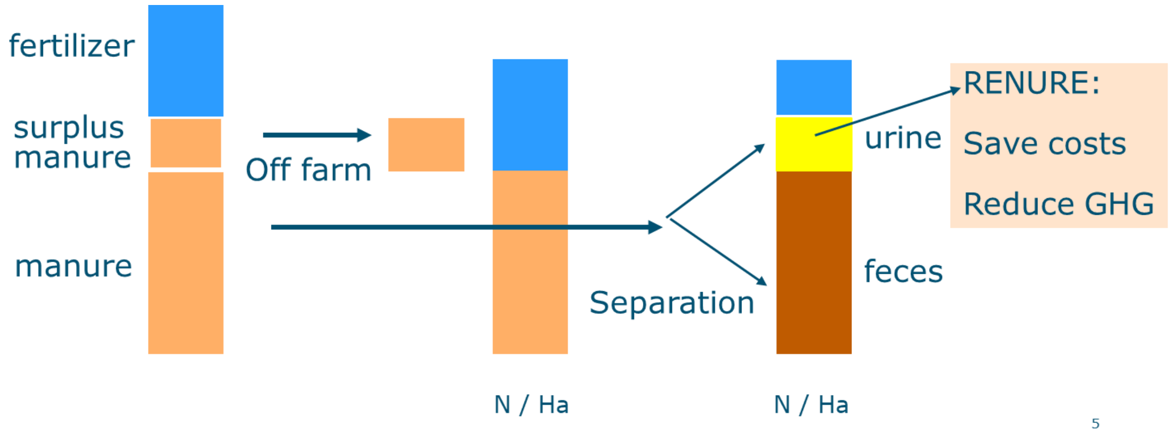



*Figure 9. Diagram effect Renure on fertilization.*

## 7. Discussion and conclusions

### Cubicle housing system

New developments in cubicle barns are aimed at reducing ammonia and methane emissions and providing separate manure flows. Reporting of measurements at Dairy Campus will be completed in 2023 (Galama et al, 2023, in prep.). The indicated reduction rates are therefore still indicative. The developments described are:

- Concrete floors
  There are various separation floors with gutters and holes that separate the manure, usually concrete but can be asphalt or rubber. The urine can be stored in the storage under the floor or removed from the barn through a gutter to a storage area outside the barn. The separation is insufficient for the urine to qualify as a fertilizer substitute. Additional filtration of urine will then be required.
- Cowtoilet
  About 35% of the urine is collected by the Cowtoilet and stored separately. Preliminary results of emission measurements at Dairy Campus indicate that approximately 30 tot 35% of ammonia emissions can be reduced (Dooren et al, in prep. 2023). Due to the high separation efficiency, the urine meets a high N-mineral content and low C: N ratio, making it potentially eligible as Renure.
- Permeable plate floor
  With the permeable plate floor, all urine is collected. By acidifying the urine to a pH of 4.5 to 5, storage emissions are greatly reduced. The preliminary indication is that the emission of the whole stable is 60% lower. If the plate is flushed with the acidified urine, the barn emission was reduced by almost 50%, less than expected maybe because of the short measuring period of 5 days or less permeability of the plate. The plate floor provides good separation of urine and feces.
  Another option is to spray the plate with water. Ammonia emissions are reduced by more than 24%. By applying a urease inhibitor once daily, an additional reduction of 18 % can be achieved (Prelimary results).
- Lelysphere
  The LelyShere system has a recognized RAV emission factor. Ammonia emissions from the barn are reduced by over 70%. It produces different manure flows, namely a potassium-rich product in the urine fraction stored in the cellar (storage), phosphate-rich feces sucked up by the manure robot and nitrogen-rich sluice water from the extracted cellar air. Urine and sluice water could potentially qualify as Renure.
- Manure Digestion (Jumpstart) Rapid removal of fresh manure from the barn can increase the efficiency of manure digestion. Fermentation reduces methane emissions. The digestate can be mechanically separated where the liquid fraction after stripping produces a potash-rich fertilizer.

### Freewalk housing systems

Freewalk barns focus on providing more space for the animals to move around compared to the cubicle barn and providing manure products as soil improvers or separated manure streams. Reducing emissions in the different types of freewalk barns requires further research.

- Freewalk barn with woodchip soil
  The woodchips are composted over a year into an organic-rich fertilizer product ("humest"). The nitrogen is organically bound and therefore has a slow action. The 'humest' is suitable as a soil improver. Ammonia emissions in the barn are 30% lower, however, methane emissions are 30% higher (Dooren et al, 2019).
- Freewalk barn with permeable synthetic floor
  With a permeable floor, urine is separated from feces. Ammonia emissions from the barn were disappointing because of the slow passage of urine through the floor. The intermediate layer retains too much moisture (sponge effect). Meanwhile, the floor has been further developed with a more permeable intermediate layer, but no emission measurements have been made.
- Free-Live Stable with Organic Soil
  This system in which feces is cleaned up with organic material by a BeddingCleaner is still under strong development. The cleaned up organic matter rich material is suitable for increasing the efficiency of fermentation.
- Free-Live stable with sand bedding
  In this system, urine is separated through a drainage system under the sand package and stored centrally. The feces with sand is collected by the BeddingCleaner. The sand could be reused by using a sand separator, but this large investment is only profitable on large farms with roughly more than 250 to 300 cows.

## Points of interest

For assessing the prospects of new housing systems in dairy farming, a number of attention points are important:

- Assessment in whole manure chain
  The choice of a particular floor system in a cubicle barn and the floor/bedding in a freewalk barn affects the manure product or manure fractions and the emissions of ammonia and greenhouse gases in the barn, during storage and when applied to the land. From the point of view of precision fertilization, separate manure flows offer advantages for more targeted application of nitrogen and phosphate to grassland or arable land and throughout the spring, summer and fall.
- Renure
  Especially for companies that have to dispose of manure because of a nitrogen surplus, it can be attractive to apply primary manure separation, provided the urine fraction is going to be accepted by the EU as a fertilizer substitute
- Nature-inclusive
  Stackable feces applied above ground fits well into a nature based farming system.
- Cooperation with arable or horticulture
  The various manure fractions from the barn systems fit or can be made fit for application with different crops in arable, arboriculture or horticulture.
- Animal health and welfare
  The freestall barn offers plenty of room to move for natural behavior, however, with poor management of the floor or bedding, the risk of mastitis can increase. Walkability of the floor is also an important aspect in both a cubicle barn and a freestall barn.
- Milk quality
  The type of cubicle bedding in a cubicle barn or soil material in a freestall barn affects the bacterial flora. One example is that use of compost (GFT: vegetable, fruit and garden waste) from a composting company can increase the proportion of spore-forming Extreme Thermophilic Aerobic bacteria (called XTAS bacteria). When these enter the milk via the teats, the shelf life of sterilized dairy products can be limited (Driehuis et al, 2012). Therefore, in the Netherlands from 1-1-2015 the use of GFT compost in cubicle and freewalk barns is prohibited.
- Valuation by consumers
  The freewalk barn has been valued more than a cubicle barn by consumers from different countries. However, it should be noted that grazing and organic is a more important issue for consumers than the housing system (study www.freewalk.eu).
- Further development
  A number of developments mentioned in this report are still at an early stage. In order to achieve broad implementation in practice, further development is particularly needed in low-emission manure separation techniques in cubicle barns, and different and cheaper floor / bedding material in freewalk barns.

## Literature


Anders Hovstad, K., V. Kvakkestad, G. Lien, I. Blanco Penedo, K. Brugemann, U. Emanuelsen, P. Galama, A. Kuipers, L. Leso. J. van Middelkoop, E. Ofner – Schrock, M. Klopcic. 2023 in prep. Farmer evaluation of housing systems for dairy cows – a multi-criteria analysis. Department of Food Production and Society, Norwegian Institute of Bioeconomy Research, Norway.

Boxmeer van, E, N. Verdoes, H. Schilder, P. Galama, G. Kupers. 2023. Samenstelling mestproducten uit innovatieve stalsystemen in de melkvee-, varkens- en kalverhouderij. Wageningen Livestock Research rapport in kader van project Beter Stal, betere Mest, betere Oogst (BSMO).

Dooren, H. J. C. van, J.M.G. Hol, K. Blanken, and P.J. Galama. 2019. Gasvormige emissies uit vrijloopstallen met houtsnipperbodems. Ammoniak-, lachgas en methaanemissie op stalniveau. Wageningen Livestock Research.

Dooren van, H. J., K. Blanken, P. H. R. van Valkengoed, H. R. Kamstra-Brouwer, P. J. Galama. 2023 in prep. Ammonia emissions of the Cowtoilet for use in dairy barns. Case control measurements at Dairy Campus

Driehuis, F., E. Lucas-van den Bos, and M.H.J. Wells-Bennik. 2012. Risico's van microbiële contaminanten van strooisels: compost, geschieden mest, paardenmest en vrijloopstallen. NIZO.

Galama P. J., W. Ouweltjes, M.I. Endres, J.R. Sprecher, L. Leso, A. Kuipers, M. Klopcic. Symposium review: Future of housing for dairy Cattle. 2020. Journal of Dairy Science. Volume 103, Issue 6, Pages 5759-5772

Galama, P. J., S. Bokma, H. J. van Dooren, W. Ouweltjes, M. Smits, and F. Driehuis. 2011. Prospects for bedded pack barns for dairy cattle. Wageningen UR Livestock Research, Lelystad, NL.

Galama, P.J., H. J. C. van Dooren en W. Ouweltjes. 2023 in prep. Mestscheiding met doorlaatbare kunststofvloer in vrijloopstal op Dairy Campus. Wageningen Livestock Research.

Galama, P.J., de Vries C., van Dooren H.J. Grensverleggend huisvesten van melkvee (2009). Een uitgave van Courage.

Galama, P.J., S. F. Spoelstra, A, Kuipers, R. Maasdam, K. Wiering, P. Groot Koerkamp. 2023 in prep. Removing methane and ammonia from ventilation air of dairy farms. A survey / a feasibility study. Wageningen University and Research.

Huygens, D., G. Orveillon, E. Lugato, S. Tavazzi, S. Comero, A. Jones, B. Gawlik, H.G.M. Saveyn (2020) Technical proposals for the safe use of processed manure above the threshold established for Nitrate Vulnerable Zones by the Nitrate Directive (91/676/EEC). JRC science for policy report 121636. Publication Office of the European Union, Luxemburg. http://dx.doi.org/10.2760/373351

RVO. 2023. Regeling Ammoniak Veehouderij (RAV). https://www.rvo.nl/onderwerpen/mest/innovatieve-veehouderij/rav

*Websites of relevant projects:*

EU project CCC Farming: www.cccfarming.eu

EU project Freewalk: www.freewalk.eu

PPS Betere stal, betere mest, betere oogst (BSMO): https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksprojecten-lnv/soorten-onderzoek/kennisonline/pps-betere-stal-betere-mest-betere-oogst-1.htm

PPS Mestscheiding: https://www.wur.nl/nl/project/mestscheiding-in-melkveestallen.htm