



Interim report from 18 July 2025

NOSES 5to6

Reattore non agitato e con biomasse adese –
dal livello di prontezza tecnologica 5 al livello 6
completato



Source: ©Laborex, 2025

**Publisher:**

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Berne
www.energy-research.ch

Co-financing:

VSG ASIG (Verband der Schweizerischen Gasindustrie)
CH-8027 Zürich
www.svgw.ch

Co-financing:

Swiss Climate Foundation
CH-8002 Zürich
www.klimastiftung.ch

Subsidy recipients:

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SFOE contract number: SI/502771-01

The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.



Summary

The low biogas producibility of manure and slurry, plus the considerable cost of transporting this water-rich biomass from the stables to the biogas plant convinced us that the most logical solution was to set up plants at the biomass production site or at most in close proximity.

Added to this it has to be observed that the majority of farms in Switzerland and also in Europe are very small compared to the minimum size of comparable plants proposed by the main market players.

As the plant size decreases, the supply of technology decreases more than proportionally, and practically becomes non-existent below a plant size of 100-70 kW (250-500 head of cattle).

Below this size, however, there are biogas plants, which are constructed in an artisanal and non-standardised way and whose motivations often disregard economic considerations, but are more related to the need to confine the biomass in order to avoid odour emissions.

On the basis of these considerations, we felt that it is necessary to design and engineer a new small-scale anaerobic digestion plant to recover the great untapped energy potential of livestock biomass produced by small, dispersed farms in hilly and mountainous areas.

With the NOSES 5to6 project, a new anaerobic digester concept is to be tested: suitable for medium-small farms, standardised to reduce implementation costs and easy to manage so as not to burden farmers.

The NOSES 5to6 digester is based on the joint use of bio-mass irrigation technology for handling the biomass and Fixed Film Reactor (FFR) to increase the efficiency of the transformation of volatile solids into biogas by bacterial colonies.

The realization of the NOSES prototype serves to demonstrate that the implementation of a plant with non-stirred reactors and FFR reactors (Fixed Film Reactor) with filling bodies induces an increase in gas production as highlighted in the literature in experimental studies (e.g. Krishania, Meena, Vijay, Virendra K. and Chandra, Ram. "Performance evaluation of various bioreactors for methane fermentation of pretreated wheat straw with cattle manure" Green Processing and Synthesis, vol. 5, no. 2, 2016, pp. 113-121. <https://doi.org/10.1515/gps-2015-0067>). The increase in biogas production demonstrated in various studies that can be obtained with this type of reactor is approximately 20-30% higher than in a conventional reactor, with a 5-10% higher methane concentration, and with a higher rate of gas production in the initial stages of the anaerobic digestion process. This prototype was studied with the aim of verifying whether the increase in production exists and whether a pre-treatment can improve its efficiency even more.

The cost-effectiveness of the prototype, in addition to the standardization of the system is linked to the reduction in consumption. In a normal CSTR, the active 24-hour agitation phase is characterized by an average energy consumption of about 4 kWh/MWh biomethane produced (evaluated on low-speed and low-consumption agitator models). In the NOSES project, the expected energy consumption for the production of 1 MWh is lower, as despite having the pumping system installed a higher power, to keep the biomass surface humidified is activated for a short period of the day (4-5 hours) with a consumption close to that of the agitators, but given that the expected production is increased by at least 20%, consumption is approximately 2,84 kWh/MWh biomethane produced, therefore considerable energy savings are expected.

In its preliminary activities, the best pre-treatment of the raw biomass was tested to make it homogenous enough to avoid clogging problems and increase its digestibility.

Subsequently, the new NOSES 5to6 digester was designed and a small-scale prototype built.

The 5to6 prototype was placed at the cantonal agricultural school in Mezzana in May 2025 and is now ready for the final project phase, which consists of monitoring biogas production in comparison with a reference line.



In particular, the NOSES 5TO6 concept envisages that the digestion process takes place by means of a pre-treatment and four vertically placed digesters (Vessels) working in sequence:

1. The biomass before being loaded into the first Vessel will be pre-treated through a cavitation process to make it homogeneous and micro-sized in order to avoid sedimentation effects or separation of the biomass because the whole digestion process is non-shaking;
2. The pre-treated biomass is loaded into Vessel 1 and in sequence from Vessel 1 to Vessel 2, from Vessel 2 to Vessel 3 and from Vessel 3 to Vessel 4. In each Vessel digestion takes place by stratification from top to bottom; the discharge of the more liquid digestate takes place from the bottom and is pumped into the next Vessel;
3. Vessels 3 and 4, where the digestate is more liquid and clogging effects are less likely to occur, will be filled with filler bodies (FFR) to increase the efficiency of the transformation of volatile solids into biogas by bacterial colonies

This will be followed by the experimental phase, which involves monitoring biogas production that will take place contemporaneously in a reference line (standard CSTR reactor) and the NOSES line loaded with the same biomass (feed).

The monitoring will cover:

- The characterisation of the input biomass and the output digestate every 15 days;
- The production of biogas every hour and the analysis of its components (CH₄, CO₂ and O₂) every two hours

The expected result is that the production of biogas produced by the NOSES line is higher than that produced by the reference line replicating a standard CSTR digester; furthermore, a lower energy consumption of the NOSES line is expected.

Zusammenfassung

Die geringe Biogasproduktivität von Mist und Gülle sowie die beträchtlichen Kosten für den Transport dieser wasserreichen Biomasse von den Ställen zur Biogasanlage haben uns davon überzeugt, dass die logischste Lösung darin besteht, Anlagen in den Ställen, in denen die Biomasse produziert wird, oder allenfalls in unmittelbarer Nähe zu errichten.

Hinzu kommt, dass die meisten Betriebe in der Schweiz und auch in Europa sehr klein sind im Vergleich zu den Mindestgrössen vergleichbarer Anlagen, die von den grossen Marktteilnehmern angeboten werden.

Mit abnehmender Anlagengröße nimmt das Technologieangebot überproportional ab und ist unterhalb einer Anlagengröße von 100-70 kW (250-500 Stück Vieh) praktisch nicht mehr vorhanden.

Unterhalb dieser Größe gibt es jedoch Biogasanlagen, die handwerklich und nicht standardisiert gebaut werden und deren Beweggründe oft nicht in wirtschaftlichen Erwägungen liegen, sondern eher in der Notwendigkeit, die Biomasse einzuschließen, um Geruchsemissionen zu vermeiden.

Auf der Grundlage dieser Überlegungen hielten wir es für notwendig, eine neue anaerobe Vergärungsanlage in kleinem Maßstab zu konzipieren und zu bauen, um das große ungenutzte Energiepotenzial der Biomasse aus der Viehhaltung zu nutzen, die von kleinen, verstreut liegenden Betrieben in Hügel- und Berggebieten erzeugt wird.

Das Projekt NOSES 5to6 zielt auf die Erprobung eines neuen anaeroben Fermenterkonzepts ab: Es ist für mittelgroße landwirtschaftliche Betriebe geeignet, standardisiert, um die Implementierungskosten zu senken, und einfach zu verwalten, um die Landwirte nicht zu belasten.



Der NOSES 5to6-Fermenter basiert auf der gemeinsamen Nutzung der Biomasse-Bewässerungstechnologie für die Handhabung und Befüllung von Behältern, um die Effizienz der Umwandlung von flüchtigen Feststoffen in Biogas durch Bakterienkolonien zu erhöhen.

Die Realisierung des NOSES-Prototyps dient dem Nachweis, dass die Implementierung einer Anlage mit ungerührten Reaktoren und FFR-Reaktoren (Fixed Film Reactor) mit Füllkörpern zu einer Steigerung der Gasproduktion führt, wie in der Literatur in experimentellen Studien hervorgehoben wird (z. B. Krishania, Meena, Vijay, Virendra K. und Chandra, Ram. „Performance evaluation of various bio-reactors for methane fermentation of pretreated wheat straw with cattle manure“ Green Processing and Synthesis, vol. 5, no. 2, 2016, pp. 113-121. <https://doi.org/10.1515/gps-2015-0067>). Die in verschiedenen Studien nachgewiesene Steigerung der Biogasproduktion, die mit diesem Reaktortyp erzielt werden kann, ist etwa 20-30 % höher als bei einem herkömmlichen Reaktor, mit einer 5-10 % höheren Methankonzentration und mit einer höheren Gasproduktionsrate in den ersten Phasen des anaeroben Vergärungsprozesses. Dieser Prototyp wurde mit dem Ziel untersucht, zu überprüfen, ob die Produktionssteigerung existiert und ob eine Vorbehandlung die Effizienz noch weiter verbessern kann.

Die Kosteneffizienz des Prototyps ist neben der Standardisierung des Verfahrens auch mit der Reduzierung des Verbrauchs verbunden. In einem normalen CSTR ist die aktive 24-stündige Rührphase durch einen durchschnittlichen Energieverbrauch von etwa 4 kWh/MWh erzeugtem Biomethan gekennzeichnet (bewertet an Rührwerksmodellen mit niedriger Drehzahl und geringem Verbrauch). Im Rahmen des NOSES-Projekts ist der erwartete Energieverbrauch für die Produktion von 1 MW niedriger, da trotz des Pumpensystems

Im Rahmen der Vorarbeiten wurde die beste Vorbehandlung der Rohbiomasse getestet, um sie so homogen zu machen, dass Verstopfungsprobleme vermieden und die Verdaulichkeit erhöht werden.

Anschließend wurde der neue NOSES 5to6-Fermenter entworfen und ein verkleinerter Prototyp gebaut.

Der 5to6-Prototyp wurde im Mai 2025 in der kantonalen Landwirtschaftsschule in Mezzana aufgestellt und ist nun bereit für die letzte Phase des Projekts, die darin besteht, die Biogasproduktion im Vergleich zu einer Basislinie zu überwachen.

Im Einzelnen sieht das Konzept von NOSES 5TO6 vor, dass der Vergärungsprozess über eine Vorbehandlung und vier vertikal angeordnete Fermenter (Vessels) erfolgt, die nacheinander arbeiten:

1. Die Biomasse wird vor dem Einfüllen in den ersten Vessel durch ein Kavitationsverfahren vorbehandelt, um sie homogen und mikroskopisch klein zu machen, um Sedimentationseffekte oder eine Trennung der Biomasse zu vermeiden, da der gesamte Vergärungsprozess nicht gerührt wird;
2. Die vorbehandelte Biomasse wird in Vessel 1 und nacheinander von Vessel 1 in Vessel 2, von Vessel 2 in Vessel 3 und von Vessel 3 in Vessel 4 gefüllt. In jedem Vessel findet der Aufschluss durch Schichtung von oben nach unten statt; der Abfluss des flüssigeren Gärrestes erfolgt von unten und wird in das nächste Gefäß gepumpt;
3. Die Vessel 3 und 4, in denen die Gärreste flüssiger sind und Verstopfungseffekte weniger wahrscheinlich sind, werden mit Füllkörpern (FFR) gefüllt, um die Effizienz der Umwandlung flüchtiger Feststoffe in Biogas durch Bakterienkolonien zu erhöhen.

Daran schließt sich die Versuchsphase an, in der die Biogasproduktion überwacht wird, die gleichzeitig in einer Referenzanlage (Standard-CSTR-Reaktor) und in der mit derselben Biomasse (Futtermittel) beladenen NOSES-Anlage stattfindet.

Die Überwachung wird Folgendes umfassen:

- Die Charakterisierung der Input-Biomasse und des Output-Gärrestes alle 15 Tage;
- die stündliche Produktion von Biogas und die Analyse seiner Bestandteile (CH₄, CO₂ und O₂) alle zwei Stunden



Das erwartete Ergebnis ist, dass die Biogasproduktion der NOSES-Anlage höher ist als die der Referenzanlage, die einen Standard-CSTR-Fermenter nachbildet; außerdem wird ein geringerer Energieverbrauch der NOSES-Anlage erwartet.

Résumé

La faible productibilité de biogaz du fumier et du lisier, ainsi que le coût considérable du transport de cette biomasse riche en eau depuis les étables jusqu'à l'usine de biogaz nous ont convaincus que la solution la plus logique était d'installer les usines dans les étables de production de biomasse ou tout au plus dans les environs immédiats.

De plus, il faut noter que la majorité des exploitations agricoles en Suisse et en Europe sont très petites par rapport à la taille minimale des installations comparables proposées par les principaux acteurs du marché.

Lorsque la taille de l'installation diminue, l'offre de technologie diminue plus que proportionnellement et devient pratiquement inexistante en dessous d'une taille d'installation de 100-70 kW (250-500 têtes de bétail).

En dessous de cette taille, cependant, il existe des installations de biogaz qui sont construites de manière artisanale et non standardisée et dont les motivations ne tiennent souvent pas compte des considérations économiques, mais sont plutôt liées à la nécessité de confiner la biomasse afin d'éviter les émissions d'odeurs.

Sur la base de ces considérations, nous avons estimé qu'il était nécessaire de concevoir et de réaliser une nouvelle installation de digestion anaérobie à petite échelle pour récupérer le grand potentiel énergétique inexploité de la biomasse animale produite par de petites exploitations dispersées dans des zones de collines et de montagnes.

Le projet NOSES 5to6 vise à tester un nouveau concept de digesteur anaérobie : adapté aux exploitations de taille moyenne à petite, standardisé pour réduire les coûts de mise en œuvre et facile à gérer pour ne pas peser sur les agriculteurs.

Le digesteur NOSES 5to6 est basé sur l'utilisation conjointe d'une technologie d'irrigation de la biomasse pour la manipulation et le remplissage des corps afin d'augmenter l'efficacité de la transformation des solides volatils en biogaz par les colonies bactériennes.

La réalisation du prototype NOSES sert à démontrer que la mise en œuvre d'une installation avec des réacteurs non agités et des réacteurs FFR (Fixed Film Reactor) avec des corps de remplissage induit une augmentation de la production de gaz comme le souligne la littérature dans les études expérimentales (par exemple Krishania, Meena, Vijay, Virendra K. et Chandra, Ram. « Performance evaluation of various bio-reactors for methane fermentation of pre-treated wheat straw with cattle manure » Green Processing and Synthesis, vol. 5, no. 2, 2016, pp. 113-121. <https://doi.org/10.1515/gps-2015-0067>). L'augmentation de la production de biogaz démontrée dans diverses études qui peut être obtenue avec ce type de réacteur est d'environ 20 à 30 % supérieure à celle d'un réacteur conventionnel, avec une concentration de méthane de 5 à 10 % plus élevée, et avec un taux de production de gaz plus élevé dans les phases initiales du processus de digestion anaérobie. Ce prototype a été étudié dans le but de vérifier si l'augmentation de la production existe et si un prétraitement peut améliorer encore son efficacité.

La rentabilité du prototype, outre la normalisation du procédé, est liée à la réduction de la consommation. Dans un CSTR normal, la phase d'agitation active de 24 heures se caractérise par une consommation d'énergie moyenne d'environ 4 kWh/MWh de biométhane produit (évaluée sur des modèles d'agitateurs à faible vitesse et à faible consommation). Dans le projet NOSES, la consommation d'énergie attendue pour la production de 1 MW est plus faible, car malgré le système de pompage



Dans le cadre de ses activités préliminaires, le meilleur prétraitement de la biomasse brute a été testé afin de la rendre suffisamment homogène pour éviter les problèmes de colmatage et augmenter sa digestibilité.

Par la suite, le nouveau digesteur NOSES 5to6 a été conçu et un prototype à petite échelle a été construit.

Le prototype 5to6 a été placé à l'école cantonale d'agriculture de Mezzana en mai 2025 et est maintenant prêt pour la phase finale du projet, qui consiste à contrôler la production de biogaz par rapport à une ligne de référence.

En particulier, le concept NOSES 5TO6 prévoit que le processus de digestion se déroule au moyen d'un prétraitement et de quatre digesteurs verticaux (Vessels) fonctionnant en séquence :

1. Avant d'être chargée dans la première cuve, la biomasse sera prétraitée par un processus de cavitation afin de la rendre homogène et de lui donner une taille microscopique, de manière à éviter les effets de sédimentation ou de séparation de la biomasse, l'ensemble du processus de digestion se déroulant sans secousses ;
2. La biomasse prétraitée est chargée dans Vessel 1 et, dans l'ordre, de Vessel 1 à Vessel 2, de Vessel 2 à Vessel 3 et de Vessel 3 à Vessel 4. Dans chaque Vessel, la digestion s'effectue par stratification du haut vers le bas ; l'évacuation du digestat le plus liquide s'effectue par le bas et est pompée dans la cuve suivante ;
3. Vessels 3 et 4, où le digestat est plus liquide et où les effets de colmatage sont moins susceptibles de se produire, seront remplis de corps de remplissage (FFR) afin d'augmenter l'efficacité de la transformation des solides volatils en biogaz par les colonies bactériennes

Cette phase sera suivie par la phase expérimentale, qui implique le contrôle de la production de biogaz qui aura lieu simultanément dans une ligne de référence (réacteur CSTR standard) et dans la ligne NOSES chargée de la même biomasse (alimentation).

Le suivi portera sur les points suivants

- La caractérisation de la biomasse d'entrée et du digestat de sortie tous les 15 jours ;
- La production de biogaz toutes les heures et l'analyse de ses composants (CH₄, CO₂ et O₂) toutes les deux heures

Le résultat attendu est que la production de biogaz produite par la ligne NOSES est supérieure à celle produite par la ligne de référence reproduisant un digesteur CSTR standard ; en outre, on s'attend à une consommation d'énergie plus faible de la ligne NOSES.



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List of abbreviations

SFOE	Swiss Federal Office of Energy
SUPSI	University of applied Sciences and Arts of Southern Switzerland – Dipartimento ambiente costruzioni e design – Istituto di Microbiologia.
UE	European Union
MOSTCH4	Research Project: Mini Onsite System To valorize manure in methane – Innosuisse grant contract n. 27685.1 PFIW-IW.
FAT	Factory acceptance Test
SFC	Swiss Climate Foundation
VSG-ASIG	Verband der Schweizerischen Gasindustrie
FFR	Fixed Film Reactor
CSTR	Continuous Flow Stirred Tank Reactor
BMP	Biochemical Methane Potential
FOS/TAC	Ratio between volatile organic acids (FOS) and total inorganic carbon (TAC)
C/N	Carbon to Nitrogen ratio
COD	chemical oxygen demand test measures the oxygen consumption resulting from the chemical oxidation of organic matter
TRL	Technology readiness level
Tq	Tel quelle
SAT	On Site Acceptance Test
KPI	Key Performance Indicators
pH	Scale used to specify the acidity or basicity of aqueous solutions



1 Introduction

1.1 Context and motivation

Biogas produced by anaerobic digestion of livestock substrates and agricultural waste is one of the most interesting renewable energy sources, because its use lends itself to being modulated according to need; a characteristic that other renewable sources such as wind and photovoltaics do not possess.

The delivery of biomass from stables to biogas production centres is a problem due to its energy and economic cost; livestock biomass, in fact, has a high moisture component. For this reason, it would be desirable for biogas production to be carried out in small plants located at stables and then fed directly or transported in cylinders to hubs for inlet the gas into the grid. In fact, it can be calculated that transporting biogas by road consumes 2.5 times less energy than transporting the amount of biomass needed to produce it.

Technologies for producing biogas fall into two broad categories: those that start from wet biomass with a dry matter content of less than 15% (pumpable biomass) and those that start from dry biomass with a dry matter content of more than 20-30% (palatable biomass).

For both of these technologies, the main focus so far has been on large-scale plants. However, some attempts have been made to build small-scale plants in industrial and non-industrial form.

There is a multitude of plants of more or less small dimensions. The table below shows a brief description of the differences between the indicated technologies and the current NOSES 5to6 project.

As shown in the table, there are many small plants on the market, most of the plants are represented by a CSTR, some by Horizontal plug flow digesters, one by FFR (Roering), one with biomass sedimentation (Bekon). The others, despite having different technology descriptions, are all attributable to a CSTR.

The difference of the CSTR will not be described, but those of the other implant models.

The plug flow reactor is similar to the continuous stirred tank bioreactor. Plug flow reactors have been reported to be efficient for dry anaerobic digestion processes, instead the NOSES 5to6 prototype il used to wet biomasses: e.g. manure.

As regards the BEKON percolation process (similar to garage type digester of Eggersmann) is different as it is based on a mixture between a CSTR reactor where gas production takes place and a static reactor where biomass hydrolysis takes place with extraction of organic components which will then be degraded in the CSTR. This trickling reactor works on solid biomass: generally solid waste is loaded and the digestate is continuously pumped from the CSTR reactor to enzymatically degrade the biomass. In the NOSES reactor the biomass stratifies in a liquid medium and not in a solid one.

The Roering technology is similar to that implemented in NOSES plant, but it is only a part of the technology implemented. In the prototype there is two technology: anaerobic digestion for sedimentation in liquid medium and fixed film reactor or bed reactor. So we expect greater gas production by combining the two technologies.



Table 1a: Selection of existing anaerobic digestion solutions

COMPANY	SYSTEM NAME	TECHNOLOGY	PLANT CAPACITY
Agrikomp	Güllewerk	Horizontal plug-flow fermenter	<105 kWel, 120m ³
Agrofutur SA		Anaerobic filter digester	60m ³ -140m ³
Bebra Biogas GmbH	Bebra Compact or Classic	Vertical plug flow digester	60, 75 or 100 kWel
BIO4GAS GmbH	Bert Güllerveredelungsanlage	Double chamber fermenter	30, 40, 50, 75 kWel
BioConstruct	BioCompact	CSTR	75 kWel
Biogas Hochreiter		CSTR	> 30 kWel
Biogas Weser ems		CSTR	70 kWel, 1300 m ³
Biogas-Ost	Clever-Ferm-System	CSTR	30, 50, 75, 100 kWel
Biogest Energie- und Wassertechnik GmbH	PowerCompact	Single processing digester	>64 kWel
Eggersmann	Smartferm	Garage-type digester	>75 kWel
Energie-Anlagen Röring	UDR-MonoTube	Fixed bed reactor	30-75 kWel
Energieraum	EVA 75	CSTR	75 kWel
Erigene	ERibox	Mobile unit (batch system)	50 to 150 LSU
fre-energy	Fre-Energy Digester	CSTR	> 80 kWel
HoST	Mircoferm	Vertical plug flow digester	62 kWel (150m ³)
KGBH	enbea Bots	Garage-type digester	40 -100 kWel
MT-Energie	MT-Farm	CSTR	75 kWel
NG Biogas	Archemax	two phase thermophilic	<100 kWel
Novatech	Kleinkraftwerk	CSTR	60-75 kWel
Ökobit	FarMethan	CSTR	75 kWel
Ökobit	FermPipe	Horizontal plug-flow fermenter	75 kWel
Sauter Biogas	Lea	CSTR	50, 60, 75 kWel
Schmack	EUColino	Horizontal plug flow digester	75, 100 kWel
SEaB Energy	MuckBuster® and FlexiBuster™	Horizontal plug flow digester	>10 kWel
SwissEcosystems	EcoGas	CSTR	50 or 60 kWel (500m ³)
UTS Biogastechnik GmbH	UTS Kairos®	CSTR	>50 kWel

The following table shows the list of producers of these mini-plants, which is deemed most similar to the project in question to us from attending trade fairs and market knowledge.

The table highlights the salient characteristics that a small biogas plant should possess in order to obtain a high level of approval from small livestock farms and therefore a large market success.

The table then compares the various systems proposed by the competitors, with the NOSES 5to6 solution.

These competitors have been in this market for years and others have been there; the fact that to date there has not been a convinced response from customers means that the proposed solutions have not yet achieved a sufficient degree of acceptance and therefore there is room for innovative solutions.

The characteristics that we consider essential and that require technological evolution are:

- **The reduced size of the plant:** it is necessary to start from the smallest possible number of cattle;
- **The plant must be able to use slurry and dung manure** with a high degree of inhomogeneity and the presence of impurities
- **A high degree of standardization** in all phases of: production, transport and installation; only in this way can the investment cost be reduced



- **A high efficiency** that allows a reduction in the volumes of the digesters and the energy cost of the plant
- **The sustainability**, which through the quality of the design and construction ensures compliance with the emission limits and the technical and economic durability of the plant.

The NOSES 5to6 project tries to maximize all these characteristics by innovating the treatment process of biomasses of livestock origin. In doing so, it does not intend to apply scientific innovations, but seeks to make the best technologies (such as adhered biomasses) applicable to these biomasses, which are used for other more homogeneous and pure biomasses.

Table 1b: comparison between existing anaerobic digestion solutions and the proposed NOSES concept

	DRY MATTER – BATCH REACTOR	WET MATTER – CSTR			NOSES
	GIS recycling Austria	Bioelectric Belgium	Roeringer Germany	Haral Switzerland	Biotrailer Switzerland
<u>Small size:</u>	from 40 head of cattle ++	from 30 head of cattle +++	from 100 head of cattle --	from 45 head of cattle ++	from 30 head of cattle +++
<u>Slurry and dung manure</u>	uses only manure. slurry is dispersed ---	uses liquid manure and dung +++	uses liquid manure and dung +++	uses liquid manure and dung +++	uses liquid manure and dung +++
<u>Standardisati on</u>	Production, transport and installation +++	Production and transport ++	Production and installation ++	Built on site ---	Production, transport and installation +++
<u>Efficiency</u>	Standard ++	Low -	Standard ++	Standard ++	Increased +++
<u>Sustainability</u>	High quality +++	Low quality -	High quality +++	Standard quality ++	High quality +++

The NOSES 5to6 prototype was studied as an evolution of the so-called CSTR reactor to improve the anaerobic digestion process and reduce self-consumption of classic biogas plants.

The classic biogas/biomethane plants built in Europe are 90% characterized by “wet” digestion technology. They consist of one or more reactors of the CSTR type with mechanical components inside, the agitators, which keep the biomass agitated. This plant model has two problems or limitations: a high self-consumption and the impossibility of introducing an excessive amount of solids (>15% dry matter) into the reactor to avoid stirring problems.

The NOSES prototype has been designed to overcome these problems, the prototype plans to reduce self-consumption, further increase the share of solids loaded into the reactor and increase the production



of biogas/biomethane. The achievement of the results should allow even small plants to improve economic results, and its implementation in containerized units to reduce the cost making them competitive on the market.

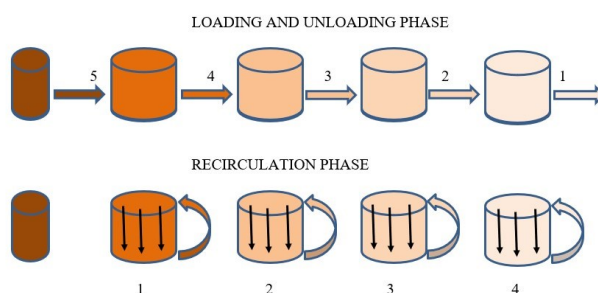
Flow description

The flow of the prototype is divided into two macro-phases, one of unloading/loading and one of recirculation.

The first phase will allow the loading of the plant with virgin biomass and the unloading of the exhausted one as digestate: this phase begins with the unloading of the last reactor and with its filling from the previous reactor, and will end with the loading of the fresh biomass from the feed tank in a single solution in the first digester

The biomass recirculation phase begins within the same digester. This phase is characterized by the suction of part of the contents of a reactor from the bottom of the same and by pumping it to the top of the reactor with an irrigation system consisting of a small hydrant. This cycle is repeated several times a day according to the degradation needs of the biomass.

Figure 1: NOSES operating diagram



The re-circulations are carried out on the same reactor to avoid mixing the different stages of degradation of the biomass which would reduce the expected gas production.

The loading of the biomass in single solution in the absence of agitation in normal CSTR plants produces the formation of a crust on the surface which prevents gaseous exchanges and in the long run blocks the fermentation reactions of the reactor. In the NOSES prototype, the development of a crust on the surface of the liquid is not a problem, since the crust slowly disintegrates thanks to the flow of recirculated digestate.

In particular, the absence of mechanical agitation presupposes the formation of various layers of biomass inside the digester and this prototype aims precisely to exploit this sedimentation process to improve gas production.

First of all, the recirculation of the biomass inside the digester itself due to the surface irrigation system allows in any case to produce a stirring effect with minimum energy expenditure of the digester, and to keep the crust constantly moist which will progressively deepen in the reactor by adding on the surface of new biomass and for the continuous wetting of the surface with the development of a degradation effect of the biomass by sedimentation.

The sedimentation process occurs as the fresh biomass has a different specific weight from the degraded one which is progressively heavier and precipitates to the bottom of the digester. The repechage



from the bottom of this degraded biomass with recirculation on the surface produces the effect of progressive sedimentation.

Sedimentation also has the advantage of creating different living environments for microorganisms within the same reactor with pH variations that allow the development of certain microorganisms. This produces an improvement in the growth of colonies that do not find themselves living in an "ideal" condition for their development and do not interfere with those of other consortia.

The prototype will therefore allow for a separation of the various phases of the process:

- Hydrolysis phase: dissolved complex organic molecules are broken into elementary or smaller molecules (sugars, amino acids, fatty acids): in this phase the degradation of particulate or soluble complex organic substrates takes place, such as proteins, fats and carbohydrates, with the formation of simple compounds, such as amino acids, fatty acids and sugars in soluble form. The progressive reduction of the dimensions of the substrate is also obtained
- Acidogenesis phase: the soluble compounds derived from hydrolysis are metabolized by the fermenting acidogenic microorganisms. The products of the reaction are: organic acids and alcohols.
- Acetogenesis phase: organic acids and dissolved alcohols are converted, through fermentation, into acetic acid (70% of organic matter), carbon dioxide and hydrogen.
- Methanogenesis phase: the production of methane represents the conclusion of the anaerobic trophic chain. Methane can be generated via two main metabolic pathways: the acetoclastic pathway and the hydrogenotrophic pathway. The Acetoclastic pathway involves a dismutation reaction of acetic acid, with the formation of methane and carbon dioxide.

The hydrogenotrophic pathway leads to the production of methane via anaerobic oxidation of hydrogen and reduction of CO₂.

The presence of two reactors without filling bodies serves to have a greater guarantee of the degradation of the coarser biomass, for example manure rich in straw, to avoid clogging processes in the digesters with filling bodies and to produce greater degradation of the solids suspended by reducing the dry matter value of the digestant. These digesters also allow the value of solids loaded into the digester to be raised, exceeding the limit value of dry substance loaded into the digester greater than 15% of dry substance.

The insertion of the filling bodies in the last two Reactors has the purpose of reducing losses due to wash out of the microorganisms during the discharge phases of the exhausted biomass, as so-called adherent colonies are formed which will detach only after the death of the microorganisms themselves. This considerably saves methanobacteria which have much slower development times than the other microorganisms involved in the fermentation process, and consequently increases the production of biogas.

The filling bodies are made of eco-plastic material. The presence of filling bodies also allows the rate of volatile solids loaded into the digester to be raised, which on average is between 2 and 4 kg/m³ reactor, up to values above 6 kg/m³ reactor without the development of phenomena of "indigestion", if you compare the plant to a ruminant digestive apparatus.

We estimate that there are at least 3,000 farms in Switzerland that can benefit from a small-scale biogas plant and about 100,000 in the European markets analysed.

At the current stage of our knowledge and experience, we consider this prototype essential to primarily realise a small-scale digestion system in order to test its efficiency and above all reliability in a pilot plant. This is why the current project shows the extension 5to6, which means a transition from TLR 5 to



the completion of TLR 6. Only after the positive results of this project will it be possible to move on to a further NOSES 7to9 project, which will concern the construction of the full-scale demonstrator digester.

Thus, the final goal of NOSES project is a system of anaerobic digestion, which we want to realise on an industrial scale, modular and built on the dimensions of a 20/40-foot ISO tank container for easy transport. A tank container has a usable volume of about 24 (20 feet) to 48 cubic metres (40 feet).

Given a biomass retention time of about 30 days and the slurry and dung production of an adult cattle, it can be estimated that two 20 feet ISO Tank Containers are sufficient for a herd of 10-15 cattle and four 40 feet ISO tank container for a herd of about 60-70 cattle.

The digesters should be made in the workshop with all the necessary mechanical components already installed and then transported to the site where they will be positioned vertically on reinforced concrete platforms and hydraulically connected, wired and connected to the other parts of the plant:

- loading tank for the livestock biomass to be digested
- digestate storage tank
- energy exploitation systems, which could be either a cogenerator or a biomethane purifier and compressor for feeding into the grid.

This standardisation of the digester is expected to reduce the cost of realising the AD by 30-35% compared to other solutions now on the market (-15% engineering costs and -20% reduction in costs for industrialisation of the product).

If the NOSES 5to6 technology is proved feasible, it will be possible to proceed with the construction of a full-scale demonstrator and its management to verify its operation and reliability in normal context conditions, thus passing - but it will be the subject of a further project - from TRL 7 to TRL 9.

Finally, once TRL 9 has been reached, it will be possible to engineer the demonstrator and produce it on a large scale, thus reducing the unit cost due to standardisation.

The plants derived from this project will be able to be produced directly for the Swiss market by a company that will be created by LABOREX.

For other national markets LABOREX will decide whether to produce the rigs directly or have them manufactured under license by third parties.

The table below estimates the economic advantage that a farm that builds a biogas plant in-house can realise. This advantage is added to the agricultural income of the families owning the livestock farm, giving them an incentive to continue in their activity, which involves the preservation of the land in mountainous regions and prevents their depopulation.

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Table 1c: Economic analysis of the NOSES concept

DESCRIPTION	UNIT OF MEASURE	FIGURES
REVENUES		
Primary Energy contained in biogas produced in a small farm	kWh/farm	531.440
Primary energy price	chf/kWh	0,22
Yearly revenues	chf/y	116.917
OPEX		
Self consumption - from the grid	kWh/farm	175.375
Price energy form the grid	chf/kWh	0,18
Yearly cost for energy	chf/y	31.568
Investment cost	Chf	600.000
Amortisation 20 years	chf/y	30.000
Maintenance 4%	chf/y	24.000
Personnel for operation	h/y	187
Personnel cost	chf/h	60
Personnel annual cost	chf/y	11.220
Opex and Amortisation cost	chf/y	96.788
PROFIT	chf/y	20.129

1.2 Project objectives

The NOSES project follows the MOSTCH4 project¹ with which, using the same approach and methodology, the best technology for the pre-treatment of zootechnical biomass to make it more homogenous and digestible by bacterial colony was already tested.

With MOSTCH4, the efficiency of two pre-treatments - Cavitation and Micro-aeration - of biomass was tested in terms of higher biogas yield compared to a reference line without pre-treatment application

The MOSTCH4 pilot was realised by placing two normal CSTR digesters downstream of the two identified pre-treatments. In addition, in the MOSTCH4 pilot there was a third reference line, also CSTR, without upstream pre-treatment. The three lines worked in parallel, using the same biomass in quality and weight and checking the same parameters.

All MOSTCH4 data from the three lines flowed into the same gas analyser, which thus provided perfectly comparable data.

The MOSTCH4 project showed with a prototype of the same NOSES scale that the best biomass pre-treatment technology is Cavitation. This technology enabled the pilot digester to operate at a scale of

¹ <https://www.aramis.admin.ch/Dokument.aspx?DocumentID=71676>



1/500 and a higher yield of biogas production of about 10% compared to the feed-back digester without pre-treatment.

In the execution of the NOSES project, therefore, biomass will be used that will be pre-treated with cavitation by the MOSTCH4 prototype

As mentioned, the MOSTCH4 pilot was designed and built to test the efficiency of the two pre-treatments, but based on digestion in normal CSTR digesters.

The NOSES 5to6 pilot is still a small-scale pilot (and therefore not a full-scale demonstrator) that intends to test the feasibility of a new digester concept (i.e. downstream of pre-treatment).

The NOSES digester is located downstream of the pre-treatment and reference line contained in MOSTCH4 prototype.

By using the MOSTCH4 pilot it will be possible to avoid the construction of a new reference line or even the data collection and transmission station; it will be sufficient to by-pass the two CSTR digesters downstream of the MOSTCH4 pre-treatments and connect them to the new NOSES 5to6 prototype digester(s).

The Experimental Programme of the Project NOSES 5to6 consists of three basic phases:

- 1) Detailed design of the plant component - prototype NOSES 5to6 - to be connected to the existing MOSTCH4 prototype.
- 2) Workshop realisation of the designed plant component and implementation of improvements on the existing prototype.
- 3) Execution of experimental tests.

The experimental phase will involve the acquisition of data on various parameters, which are listed below.

The data obtained will have to be represented in table format or by means of graphs so that they can be used to make comparisons between the two lines under study.

Statistical evaluations will have to be carried out to define production differences between the two lines under study: the "reference" line, the "cavitation" line plus the "NOSES" line.

With regard to **biogas**, quantitative and qualitative data will be obtained from the two lines under experimentation:

- Quantity of biogas/biomethane produced (hourly/daily; cumulative)
- Volumetric flow of the biogas
- Qualitative characteristics of the biogas:
 - a. CH₄ content
 - b. CO₂ content
 - c. H₂S content.

The biomasses fed into the prototype will be subjected to a preliminary characterisation analysis; the parameters analysed to characterise the biomasses loaded into the plant are listed below.



Table 1d: chemical-biological analyses conducted on biomass

Parameter	Frequency
pH	Approximately 15 days
Total Solids (%tq)	
Volatile Solids (%TS)	
Total Nitrogen (%TS)	
Ammoniacal Nitrogen (mg/lit)	
C/N ratio	
COD	
Total phosphorus	
Sulphates (mg/lit)	
Solphides (mg/lit)	
ABP Biogas Potential (Nlt/kg) Buswseil formula	

The experiment will also sample **the digestate** leaving the plant.

The sample taken will be analysed in the laboratory for a chemical-physical characterisation to obtain the data listed below:

Table 2: Chemical and biological analyses conducted on digestate

Parametro	Frequency
pH	Approximately 15 days
Total Solids (%tq)	
Volatile Solids (%TS)	
Total Nitrogen (%TS)	
Ammoniacal Nitrogen (mg/lit)	
C/N ratio	
COD	
Volatile fatty acids (mg acetic/lit)	
Alkalinity (mg CaCO ₃ /lit)	
Density	
Sulphates (mg/lit)	
Solphides (mg/lit)	

In addition, a FOS/TAC analysis will also be carried out on the digestate samples, which by means of a titration in the laboratory gives an approximate indication of the digester's state of operation

Key Performance Indicators (KPI)



Two methods will be used to assess the efficiency of the plant in terms of gross energy production capacity; one Indirect and the other Direct.

The **first method - Indirect** - is based on measuring and comparing the degradation of volatile solids in the three prototype lines. This method leads to percentage values of degradation of volatile solids, which are a precursor to the production of biogas and thus biomethane, but which may not accurately indicate the energy efficiency of the digester, as it is not certain that all the degraded volatile solids have turned into biogas and thus biomethane.

This data is however a useful reference because this methodology, also due to its practicality of application, is often used to verify the efficiency of plants in operation. There is therefore also a lot of literature data indicating average efficiency values of various types of plants measured with this method. Typically, a digestion plant is considered to be correctly sized and of normal efficiency when it reaches a volatile solids degradation level of 60-70%.

The **second method - Direct** - is based on the measurement and comparison of the energy produced (litres of methane) in the three prototype lines with the theoretical producible energy calculated on the basis of chemical parameters measured in the biomass entering the digesters; for the calculation of the theoretical producibility, reference will be made to Buswell's formula. The usefulness and interest in having this percentage ratio is to know the level of exploitation of the maximum theoretical energy potential contained in the biomass obtained from the digesters of the three prototype lines.

The NOSES 5to6 project aims to test on a prototype scale a new digester concept suitable for herd concentrations of 50 to 100 large livestock units (1 / 3 stalls of the size found in most cases in Switzerland), which has the characteristic of being standardised and reliable so as to reduce production costs and make it very easy for farmers to manage

The separation of the anaerobic digestion phases due to sedimentation and the implementation of FFR in the prototype aim to increase gas production by at least 25-30%, reducing management costs and improving the stability of the final product.

2 Approach, method, results and discussion

The approach taken is very practical and is based on a comparison of the biogas production measured in parallel over a period of approximately 6 months between a digester built with the usual biomass technology moved by agitators and the new NOSES concept which is based on biomasses that are not agitated, but moved by pumping between different stages of the process and FFR in the last stages.

The scale of the prototype is 1/7 the size of the full-scale plant. This small size at this stage of the project's development towards a future full-scale demonstrator is a further valuable element of the experiment.

One of the main problems in the production of biogas from raw bio-masses such as livestock is pipeline clogging.

While this is a problem at full scale, its solution at prototype scale will be a strength of the project for the design and realisation of the future full-scale demonstrator plant.

In terms of approach, the project was divided into 5 Work Packages (WPS) of which:

WPS 1 is the Project Management

WPS 2 is the Preliminary Activities.

In WPS 2 with the MOSTCH4 prototype, it was determined that the best pre-treatment of the biomass input is Cavitation, which improves biomass producibility by approximately 10% compared to the baseline.



Micro-aeration was also excluded at this stage, which produced about 50% less biogas than the reference line.

This phase was also useful to specify the methods of measuring the performance of the various lines monitored. In particular, it proved particularly useful to combine the direct method of measuring performance with the indirect method (see previous point). In fact, with the indirect method it was possible to explain that the lower biogas production in the CSTR digesters of the micro-aeration was due to an accelerated degradation of volatile substances in the aerobic reactor of the micro-aeration.

The proper NOSES 5to6 project is then divided into the following:

WPS 3 Design and realisation of the NOSES 5to6 prototype positioning and integration with the MOSTCH4 prototype.

WPS 4 Field Monitoring of the line Cavitation + NOSES 5to6 and comparison with the reference line.

WPS 5 Final report and Dissemination

WPS 3 is further divided into the following activities:

WPS 3.0 - Identification of the NOSES technology supplier and budget for machinery.

In this activity we selected three candidate subcontractors and through evaluation of the budget offers received and subsequent discussion with each of them, we chose the best one.

WPS 3.1 - NOSES line design.

With this activity we have drafted:

- The Technical specification of the NOSES prototype
- The Lay-out
- The Basket container for the Filling Bodies
- The Piping and Instrumentation Diagram
- The data tables
- The NOSES operating logic and alarms for PLC software compilation

WPS 3.2 - NOSES line realization

This activity was mainly conducted by the selected supplier under our continuous supervision. It started in December 2024 and ended in May 2025 with the on-site testing of the NOSES 5to6 prototype.

WPS 3.3 - Monitoring program and PLC implementation

This activity was conducted and concluded at the same time as the previous one.

WPS 3.4 - NOSES line installation and final test of functioning

The SAT - Site Acceptance Test was completed the 28 May 2025 with on-site function test with water

The minute was drafted and signed.

For the WPS 4 - NOSES project monitoring a Measurement Concept document has been drafted and a contract with SUPSI has been signed for the provision of start-up services for the MOSTCH4 prototype, chemical-physical analysis of biomass input and digestate - analysis of biogas production data.

The experimental setup consists of the MOSTCH4 prototype (reference and biomass pre-treatment) and the new NOSES digestion system prototype.

The two prototypes are housed in two different containers placed in close proximity to each other. The MOSTCH4 container is blue, while the NOSES container is yellow.



Figure 2: Exterior of NOSES (yellow) and MOSTCH4 (Blue) Prototypes

The two prototypes are hydraulically interconnected in terms of the biogas adduction pipeline produced by the reference digester contained in MOSTCH4, and the new digestion system contained in the NOSES prototype.

The two biogas pipes both flow into the analyser for the quality of the biogas produced in the two different lines. The analyser from the German Awite produces continuous data that are stored in its resident memory and periodically acquired by SUPSI for production statistics.

The amount of biogas produced and other operating parameters of the digesters will be measured by special sensors and fed respectively to the PLC of MOSTCH4 (reference line) and the PLC of NOSES (new digestion system), which in turn will send them by means of a data logger.



Figure 3: NOSES Prototype Interior



Figure 4: MOSTCH4 Prototype Interior

The two containers are positioned near the dairy cattle barn of the Azienda Agricola del Canton Ticino in Mezzana. In the cowshed, the liquid slurry is separated from the solid slurry, then to restore the conditions normally found on farms, the separated solid and liquid slurry are combined in a mixing tank. From this tank a part goes to the reference digester and a part to the cavitation. All the installations mentioned so far are contained in MOSTCH4. the part of the biomass that has been processed with cavitation is manually transferred with buckets into the first digester of NOSES.

The biomass loading operation will be carried out 3 times a week for a quantity of 30 litres of slurry per load.

Given the useful volume of 450 litres of both the reference line and NOSES, this periodicity and quantity of loading corresponds to a retention time of 35 days:

30 litres loaded 3 times a week for 5 weeks = 450 litres

The same amount of digestate is discharged at each load of biomass, which returns to the storage tanks of the Mezzana farm and is then spread on their land.

The experimental phase will last about 10 months and will be divided into:

- Reactors start-up phase
- Comparison phase 1 between reference line and NOSES line fed with cavitated biomasses

It should be mentioned that at the beginning of the NOSES project, a second comparative phase was also planned:

- Comparison phase 2 between reference line, cavitation line and NOSES line fed with non-cavitated biomasses



This last phase could tell whether the Noses digester can achieve the same production results even without going through cavitation.

The rising costs of the project together with the foreseeable reduction in federal funding force us to suspend this phase for the time being. It may possibly be resumed if federal funding for 2026 is restored.

Reactors start-up phase

The start-up phase will consist of transferring part of the contents of the digesters in the re-activated MOSTCH4 prototype in order to have a similar inoculum for all working digesters of the NOSES 5to6 prototype and to reduce the adaptation time of the microorganisms and the start-up time. Then, continuous feedings of the reactors will be carried out in order to stabilise the gas production in all two test lines, and the tests will then be started. It is estimated that the steady state of the reactors can be reached in about 3-4 months.

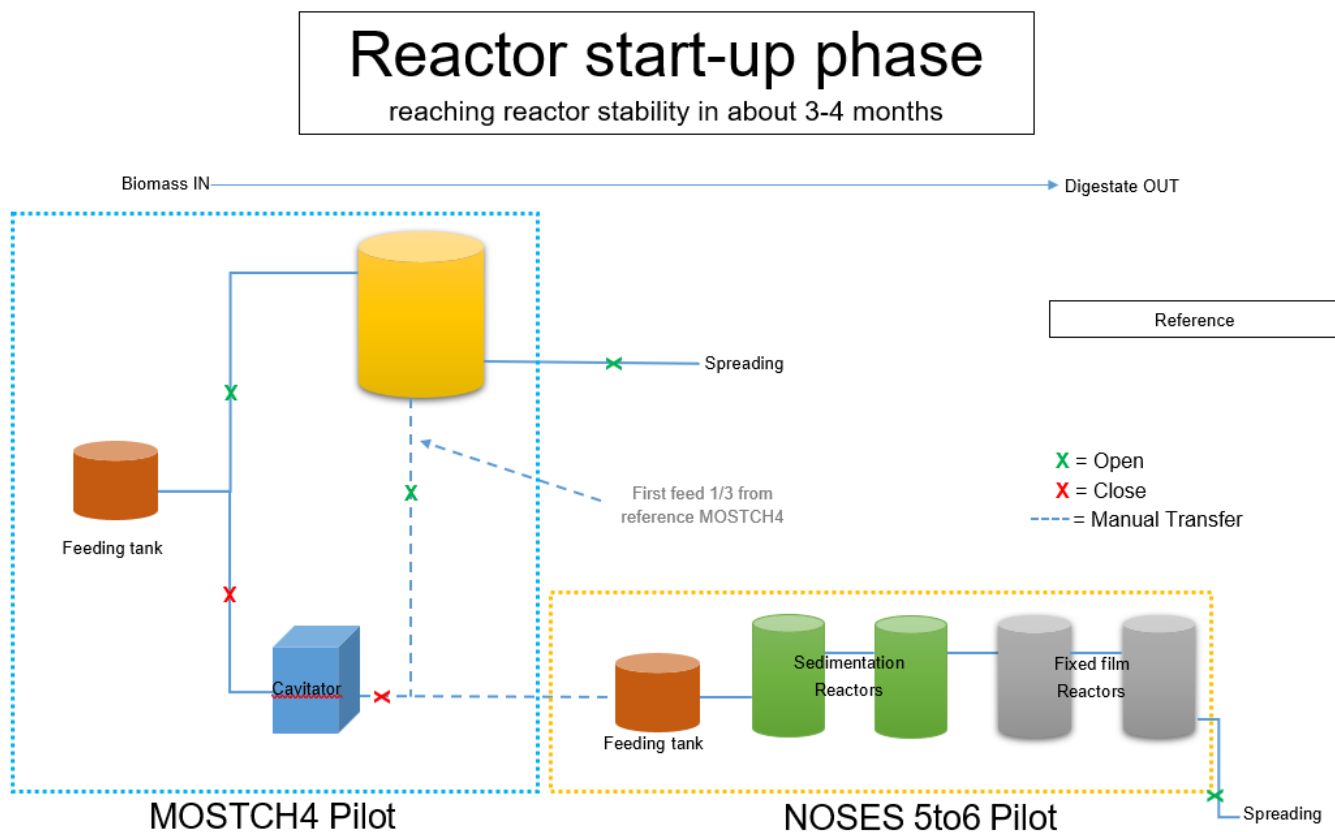


Figure 5: Reactor start-up phase diagram

Comparison phase 1

Once a certain stability of gas production between the two test lines has been reached, comparison phase 1 will begin, consisting of the semi-continuous feeding of the two test lines with untreated biomass the "reference" line and the "cavitation" line and the "NOSES" line, respectively. This phase will last approximately 6 months and the semi-continuous feeding will take place by loading the reactors 3 times a week with 30 kg of biomass each. Results between the two lines will be compared, including a third set of data from previous tests within the MOSTCH4 project using the "reference" line together with the cavitation pre-treatment.



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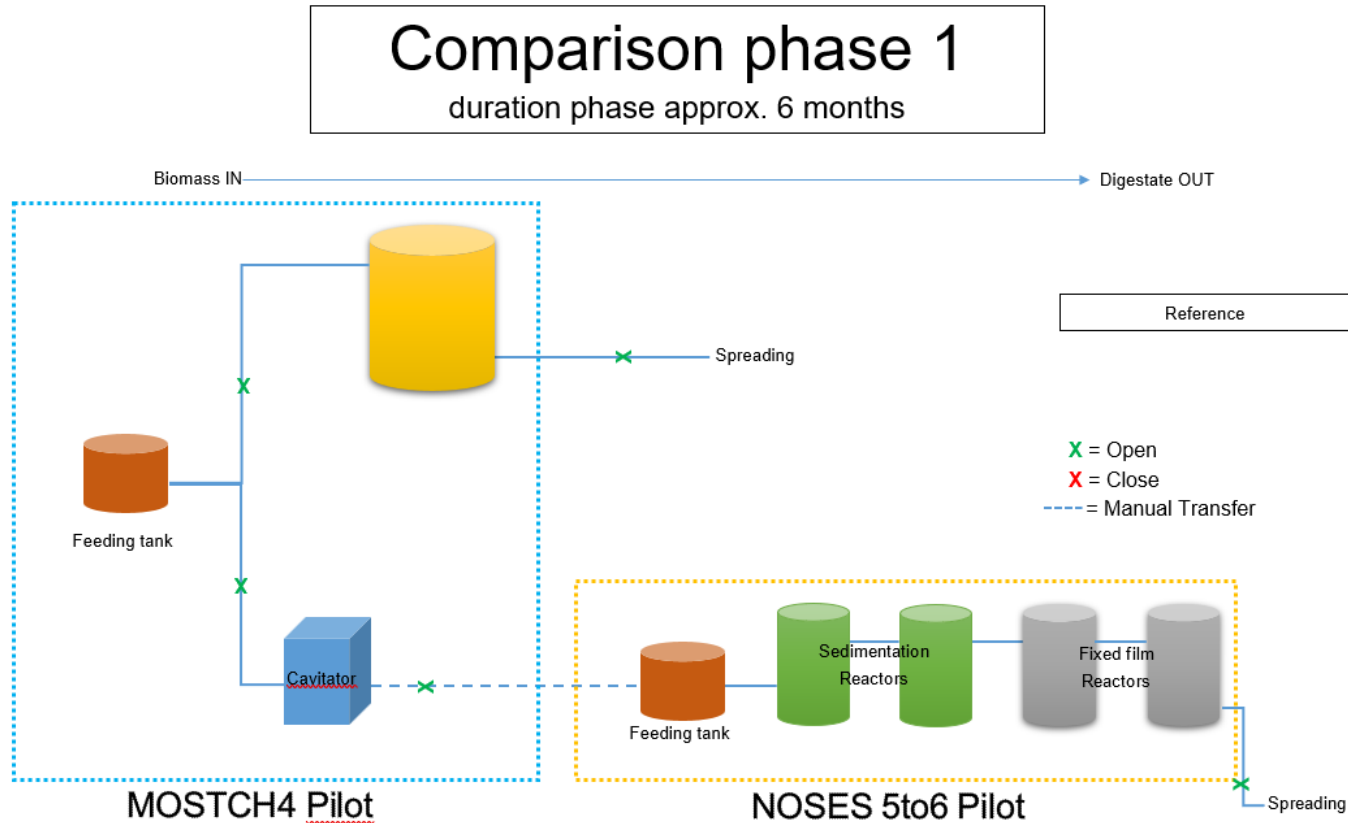


Figure 6: Comparison phase 1 diagram

3 Conclusions and outlook

Given the extremely practical approach of the experiment, the work carried out up to this interim report has been essentially engineering in nature, the activities of which were as follows:

February to May 2024: execution of the final design of the NOSES prototype and obtaining budget bids from two candidate suppliers.

From June 24 to December 24: fund-raising activities, which became necessary due to the higher-than-expected cost of the prototype and the concomitant reduction in UFE's contribution due to the Confederation's cost containment policy.

December 24: selection of the supplier of the prototype

January 25: executive design of the prototype

February 25 to April 25: construction of the prototype, acceptance at the factory, transfer to the Ticino cantonal farm in Mezzana

May 25: functioning tests and testing of the prototype with biomass

So far, the most experience has been gained with the monitoring of MOSTCH4.

This experience was used in the design phase of NOSES.



The method of calculating the BMP of the biomass used with laboratory batches based on a biological approach for our experience showed to be not adequate.

This laboratory method, in fact, does not take into account the fact that in continuous processes the biomass in the digesters, does not always remain the same, but is continuously replaced by new biomass.

A laboratory batch analysis, moreover, requires a rather long period (30-40 days) to be able to observe the exhaustion of the biogas production for that batch, while the continuous replacement of biomasses in a continuous process can also lead to a change in their methanogenic quality.

Therefore, a type of analysis is needed that can be performed more frequently and at reduced costs.

The producibility analysis that meets these requirements is of a chemical type based on the Buswell formula that defines the producibility of biogas based on the content of chemical elements of the biomass.

In addition, this formula can also provide the NH₃ and H₂S producibility data of the analysed biomass.

The **next steps in the monitoring phase** are the following.

Rump up phase from June to September/October 2025

First comparison phase from October/November to April/May 2026

If federal funding from the “Lighthouse, Pilot and Demonstrator Projects” Act is confirmed from June to December 2026, the second comparator phase can also be completed.

Otherwise, the project will be completed with the first phase that aims to demonstrate whether the system consisting of cavitation as biomass pre-treatment plus the new digester concept based on biomass irrigation technology and FFRs can lead to a net efficiency increase of 20/30% can be achieved. Furthermore, if this plant combination does not present any clogging and management problems that could hinder the normal operation of the entire plant system in a way that cannot be overcome.

If this is proven, a further full-scale NOSES 7to9 demonstrator project can proceed.

4 National and international cooperation

For the realisation of the project so far, essentially national resources and cooperation have been used.

The supplier identified and who realised the prototype is a Mendrisio-based mechanical engineering company specialising and with extensive experience in the construction of stand-alone plants for the production and treatment of technical and energy-related gases.

Only for some sub-supplies did the supplier use materials and components of EU origin.

SUPSI is supporting us from the moment the prototype is transferred to the Mezzana agricultural school for start-up. It will then collect and validate the data from the Prototype.

5 Publications and other communications

In December 24 we published the news of the grant received from the Swiss Climate Foundation for the NOSES project on our website and on social media.



In May 25 we published the news of the approval of the revision of the CO2 Ordinance on our website and social media. Laborex welcomes the implicit recognition of its work the decision to subsidise bio-methane production. In addition, Laborex participated in the consultation process by requesting a reduction of the minimum limit for access to incentives. This request was accepted.

Below is the link to the news section of our website where the two publications can be found.

<https://www.laborex.ch/home/news#h.5bmtauj3d2kk>

6 References

Not applicable