Can international non-sewered sanitation standards help solve the global sanitation crisis?

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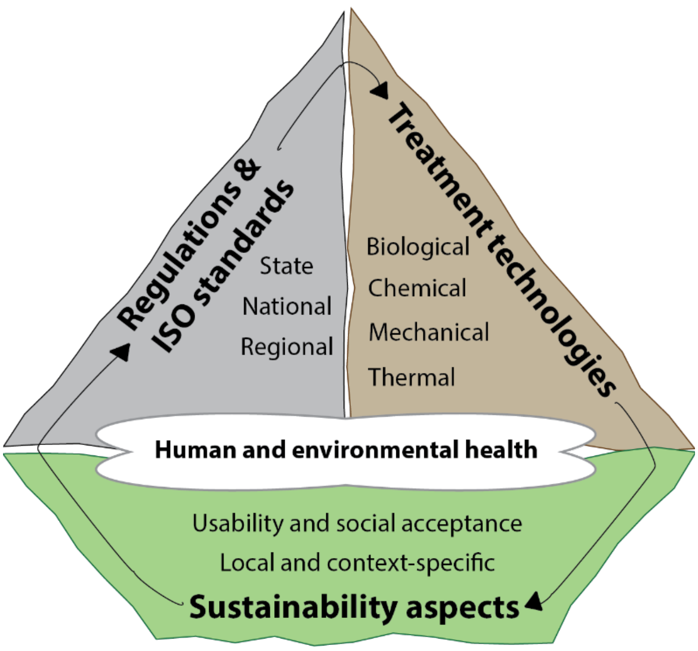
Graphical abstract



Keywords

Sustainability, standards, non-sewered sanitation, fecal sludge management

Synopsis

Regulatory, technical, and sustainability aspects of fecal sludge management can be addressed through international voluntary product standards.

Abstract

To address one of the most severe global challenges affecting human health and the environment, two new voluntary product standards (ISO 30500 and ISO 31800) for non-sewered sanitation systems (NSSS) and fecal sludge treatment units (FSTUs) have been developed and published. While providing stringent voluntary product requirements for the containment and the treatment of human excreta with safe outputs (air, liquids, and solids), ISO 30500 and ISO 31800 make the inextricable connections between environmental emission thresholds, technical innovations, and sustainability aspects of NSSS and FSTUs. The purpose of this feature is to discuss these connections.

1. Introduction

Despite tremendous efforts made by governments and non-governmental organizations in increasing the number of people who have access to safe sanitation, the current trend reveals that many countries have difficulties in coping with the global sanitation crises.[1] This will make it difficult for them to meet the target 6.2 of the Sustainability Development Goals set by the United Nations which is: "by 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations".[2]

Recent efforts in providing access to toilets have not necessarily resulted in providing people access to safe sanitation as human excreta remain untreated or partially treated, at best.[3] Moreover, following a general policy shift towards decentralization over the last decades[4], an abundance of smaller scale, decentralized, wastewater treatment plants exist today. Often these plants are infrequently monitored and maintenance is neglected due to a weak regulatory framework and/or lack of funds for operation, resulting in plants which often deteriorate soon after construction.[5, 6] Further, to provide sanitation to the highest number, a "good enough" and inexpensive sanitation solution (i.e., CATNAP – Cheapest Available Technology Narrowly Avoiding Prosecution) will often be preferred to a more advanced treatment technology.[7] In addition to the limited performance of such wastewater treatment technologies, many produce large quantities of fecal sludge (FS) that need to be safely managed.[8]

Recent initiatives supported by non-governmental organizations, such as the Bill & Melinda Gates Foundation, have tried to tackle this unsustainable situation and has led to the development of a variety of new and often complex technologies (see **Section 3**) to better treat wastewater and FS at the decentralized level without connection to a sewer system. These new technologies are named NSSS (Non-sewered Sanitation Systems) and FSTUs (Fecal Sludge Treatment Units).[9] With the maturing of NSSS and FSTUs, the need for international standards ensuring quality and performance became crucial.[10] Because emission requirements for sanitation systems are defined at the regional and country levels, they are very different from each other (see **Section 2**), thus making it difficult for manufacturers to enter multiple markets with the same product.

As a result, global efforts guided by the International Organization for Standardization (ISO) have led to the publication of two new product standards: ISO 31800[11] and ISO 30500[12]. ISO 31800 addresses the technical requirements of a FSTU that is designed for safely treating FS from a neighborhood in a city or an entire town. ISO 30500 addresses NSSS at the scale of a family or a small community (*e.g.*, an apartment building or a school). ISO 30500-compliant NSSS are not connected to a network sewer system, whereby they collect, convey, and fully treat human feces, urine, menstrual blood, bile, flushing water, anal cleansing water, toilet paper, and other bodily fluids/solids, to allow for safe reuse or disposal of the generated solid output and/or effluent.[12]

In this document we address the inextricable connection between regulatory, technical, and sustainability aspects of NSSS and FSTUs. First, we discuss the scope and background of the environmental thresholds for emissions. Second, we provide a brief overview of new technical developments of NSSS and FSTUs that can meet those thresholds. Third, we explain relevant sustainability aspects, and finally, we discuss the findings and draw conclusions.

2. Setting a global standard for emission thresholds related to NSSS

The need for quality guidelines for health and environment protection in handling human wastes is clearly identified by systematically recognizing standardization needs and features in many regions of the world.[13] Unfortunately, these needs are not fully addressed due to weak regulations in many countries, often resulting in lack of monitoring and enforcement of standards and leaving existing systems essentially unregulated (see **Section 1**). Product standards related to packaged/pre-manufactured wastewater/sludge treatment plants can therefore help to manufacture treatment systems that meet certain standards, independent of the final location of the product. The working group members (including the authors) involved in the development of ISO 30500 in Project Committee (PC) 305 and ISO 31800 in PC 318 proposed ambitious emission thresholds to encourage technological development. Traditionally, technological development comes first, and then environmental standards are updated to reflect the enhanced technical treatment capabilities (principle of Best Available Technologies or BATs)[14]; here the working group members went the opposite way.

The following text explains how a set of emission thresholds has been elaborated to be relevant at a global level. Reviewing requirements currently in place, the variety of wastewater reuse and discharge guidelines and standards leads to multiple reuse and discharge scenarios (**Tables 1 and 2**) that are often difficult to compare. Whereas there may be valid (scientific) reasons why parameters are different in various standards (e.g., different local conditions, different risk assessment parameters), these differences are often based on disparate environmental policies (and thus different perceptions of environmental risks).

Difficulties in establishing quality thresholds related to treated wastewater and FS were also experienced during some of the working group discussions of ISO PC 305 and PC 318. While the goal of human safety was unambiguously shared, leading to comprehensive microbial parameters requirements for the output solids and liquids that encompassed not only bacterial pathogens, but also human enteric viruses, helminths, and protozoa (which are not included in most of the surveyed standards and guidelines in **Table 1**), discussions were more disputed regarding environmental parameters. Basically, two approaches were in conflict: on the one side the wish to establish reliable minimum thresholds to globally ensure a high level of treatment, and on the other side the argument to consider specific local situation and technical limitations. For instance, discharge limits for organic nutrients as measured by chemical oxygen demand (COD) and 5-day biological oxygen demand (BOD_5) may greatly differ depending on the final use of the output (**Table 2**). Furthermore, existing standards and regulations cited in **Table 2** mainly refer to conventional sewage treatment plants (STPs) with highly diluted nutrients due to graywater and sometimes surface runoffs mixed with domestic waste (e.g., 266 L/person/day in the USA).[15] Comparatively, because NSSS and FSTUs treat excreta with limited amount of flushing water (*e.g.*, 0 L/person/day for a dry pit latrine and 30 L/person/day for a flush toilet connected to a cesspool), the inlet nutrients concentrations entering the NSSS are higher than that of conventional STPs. One could argue that a load reduction requirement for all major nutrients present in NSSS and FSTUs would be enough. Nevertheless, as a basic environmental principle, one should not throw even small amounts of highly polluted effluent in a river or lake. The working group considered a threshold value of 30 mg O_2/L of BOD_5 appropriate (as per EPA 2012, reuse scenario 1, see **Table 2**). Subsequently, in ISO 30500 a threshold of 150 mg O_2/L COD (assuming a 1:5 relationship between BOD_5 and COD for domestic wastewater)[16] was agreed for discharge into surface water.

It is even more difficult to find consensus among regional and national standards cited in **Table 2**, with regards to N and P nutrient discharge limits. N and P discharge in the environment due to domestic wastewater is a well-known problem. The US EPA has set rules for Total Maximum Daily Loads (TMDLs) for certain pollutants in environmentally sensitive locations such as the Chesapeake Bay to limit non-point source (*e.g.*, domestic) emissions through the use of best management practices. These practices are based on local pollution levels and dictate the needs for local technology upgrades to BATs. In order to allow for a technology-agnostic and universal minimum requirement for N and P removal, the working group committee members of PC 305 based the removal requirements on equivalent removal requirements used for the design of STPs in developed countries. Participants in these discussions were also aware that removal of N and P may not be beneficial for agricultural reuse scenarios, however, from a global product certification perspective, it is impossible to consider the final point of use. As a consensus, a precautionary measure of N and P reduction requirements was chosen, respectively to 70 % and to 80 %. However, if direct resource recovery of N and P is required, and higher concentrations of N and P should therefore be allowed in the effluent (e.g., use of treated wastewater for irrigation), then technologies certified under ISO 30500 or ISO 31800 may not be suitable (and other technologies should be selected).

Similarly to nutrient removal requirement, heavy metal emission thresholds have been discussed during the working group meetings of PC 305 and PC 318. When deciding on thresholds for heavy metals in solid outputs, the disposal routes must be considered. Christodoulou and Stamatelatou illustrated that the disposal routes of treated sewage sludge differ greatly between countries.[17] For instance, in the US, agricultural reuse and landfill disposal are the most used routes. In Japan, around 75 % of the sewage sludge is thermally disposed. In the UK, almost 80 % are used in agriculture. Further, varying assumptions in the underlying risk assessments have led to different requirements (**Table 3**). A pragmatic approach was chosen in the PC 318 working group discussions: US and EU regulations were compared, and for each heavy metal the strictest value related to land application has been selected due to lack of better alternatives. The intent of PC 318 was to avoid an absence of threshold limits in a particular country.

3. New technologies for non-sewered sanitation

The extremely high level of performance required by ISO 30500 and ISO 31800 is not achievable by traditional onsite sanitation systems (e.g., septic tanks, ventilated pit latrines, pour-flush latrines, dry toilets, or container-based sanitation systems)[18], and not even by conventional treatment technologies used in decentralized or centralized sanitation systems (see **Section 1**).

Driven by global initiatives such as the Reinvent the Toilet Challenge, started by the Bill & Melinda Gates Foundation in 2011, a variety of NSSS and FSTUs have been developed with the goal to meet the stringent environmental requirements set by ISO 30500 and ISO 31800. They are complex machines that have reached technology readiness levels (TRLs) ranging from TRL 6 (prototype demonstration in a simulated environment) to TRL 8 (actual technology completed and qualified through tests and demonstrations), as noted in **Table 4**.[19]

Some NSSS are based on a similar design strategy as large-scale STPs: one or multiple biological treatment steps (anaerobic, aerobic, or a combination), followed by one or more post-processing steps such as electro-oxidation, disinfectant dosing, distillation, *etc*. Other NSSS rely on the source- or process separation of urine and feces. These technologies often consist of a thermal drying or wet oxidation process to treat the feces and take advantage of the heat capacity of feces for energy recovery. The liquid (*i.e.*, potentially contaminated urine) processing part is often one or a combination of the post-processing steps described above. Whether solids and liquids are separated or treated together, challenges to reach ISO 30500 and ISO 31800 treatment and emission requirements are numerous, particularly with regards to N and P removal in NSSS.[20] Nonetheless, it is encouraging to note that the technology developers who were participating in the PC 305 and PC 318 working group discussions confirmed the technical feasibility of reaching the emission thresholds of ISO 31800 or ISO 30500.

The resulting complexity of NSSS makes it necessary to provide requirements that go beyond treatment quality and capacity of the machines. To this end, generic and specific risk assessment studies according to ISO 12100[21] were conducted when writing ISO 30500 and ISO 31800. Based on the identified risks, requirements for safety, process controls, and other relevant aspects were defined in those standards. For instance, NSSS using thermal treatment shall be safe for the user not to be burnt when using the "front-end" (*i.e.*, the toilet) of the system. Another example of requirement is to mitigate risks linked to the generation of explosive or corrosive gases (e.g., H_2 or NH_3) in the "back-end" (*i.e.*, the treatment system), so NSSS can be installed inside or near a house. In addition to high safety requirements, ISO 31800 certification requires high-throughput treatment and energy or resource recovery by the FSTU, making those machines at the same level of complexity as a chemical manufacturing plant. These requirements ensure safe and robust technologies meet the strict environmental thresholds of ISO 30500 and ISO 31800.

4. Sustainability

The local context in which the NSSS or the FSTUs will be placed has to be considered to achieve fully sustainable technologies. The variety of local contexts will lead to a variety of local and context-specific sustainability criteria. These specific sustainability challenges faced by the sanitation sector have been extensively discussed in this journal and elsewhere, emphasizing the importance of socio-economic and institutional aspects:

- Starkl *et al.* analyzed various context-specific factors leading to either success or failure of sanitation systems and discussed their policy implications, confirming the importance of well-known sustainability aspects such as acceptance, affordability, and complexity.[5]
- Hoffman *et al.* highlighted that strong lock-in effects also occur at the social level, in particular when moving towards non-grid and small grid systems, recommending that widely held cultural norms, regulations and beliefs need to be identified that influence the success of alternative systems.[22] They further reported that case studies examining the success or failure of systems in Beijing, Hamburg, and Zurich emphasized context-specific institutional barriers.
- Davis *et al.* analyzed several sanitation sustainability assessment frameworks covering over 100 indicators.[23] They highlighted that many sustainability definitions are incomplete and recommended that the sanitation sector seek consensus on a unified sanitation sustainability definition and a baseline set of universal indicators, allowing for context specific weightings.

In summary, previous research highlighted the importance of context-specific economic, social, and institutional sustainability aspects in the sanitation field. Although technical requirements can be agreed upon and formulated well in a technical standard, sustainability requirements are more challenging to standardize. ISO 31800 and ISO 30500 attempted to include various sustainability aspects by using verbs such as “shall” and “should” for environmental and technical aspects related to sustainability such as recovery of nutrients, water, and energy. To this end, ISO 30500 and ISO 31800 included an Informative Annex on sustainability as an attempt towards including socio-economic and institutional sustainability aspects in a technical product standard.

The Informative Annex on sustainability covered cost of use calculations, reasonable configuration, adjustment and maintenance activities, as well as financing aspects that can help making sanitation systems more sustainable, therefore avoiding project failures. For instance, as an input to life cycle cost calculations, both standards require the manufacturer not only to give detailed information on recurring operational requirements related to annual consumption of various resources (*e.g.*, water, electricity, fuel, chemicals) but also to provide a detailed breakdown of all activities required for regular configuration, adjustment, and maintenance of the system including their complexity, frequency, and expected duration. With this information on hand, the buyer of the NSSS or FSTU can assess the technical competency required to fulfil each activity (lack of skilled operation staff has been identified as a major cause of failing sanitation infrastructure in developing countries)[24] and in turn, to calculate the costs related to consumables and personnel required for these activities throughout the lifetime of the product. However, to acknowledge the importance of various socio-economic and institutional aspects, the Informative Annex on sustainability includes a section dedicated to financing and highlights the likelihood of limited willingness to pay at the household level for ISO 31800-compliant FSTU services. Therefore, significant factors such as the public sector's willingness to set relevant tariffs and taxes as well as organizational arrangements were included in the Informative Annex on sustainability. Further, a suitability analysis to assess whether the inherent complexity of a FSTU is reasonable for the intended setting has been suggested (this would check whether the locally available resources would be sufficient to operate the plant successfully). Moreover, in view of often fragmented planning of infrastructure projects, it is also suggested to apply a well-structured planning process to involve stakeholders and coordinate with other infrastructure projects in related sectors (water supply, solid waste, *etc.*). Finally, when addressing an institutional shortcoming in many developing countries, it is emphasized that a well-functioning process for environmental compliance monitoring and enforcement be in place before an ISO 31800-compliant FSTU is installed. Only then can the lifetime environmental performance of the FSTU be ensured.

However, because the application of the Informative Annexes is voluntary and their aspects are context-specific, they are not part of the standardization process. How could they be made a part of the standardization process? One way could be, as pointed out by Davis *et al.*, to seek consensus on a unified sanitation sustainability definition and a baseline set of universal indicators while allowing for context-specific weightings. This takes into account the observation that sanitation experts agree on the importance of considering sustainability aspects for sanitation project implementation, but may not find consensus about all individual principles and indicators.[25]

Hence, a standardized assessment of the sustainability of sanitation projects could be based on a framework that includes key sustainability principles, indicators, and a uniform evaluation procedure, while leaving some flexibility in each step to accommodate preferences of the stakeholders using that framework. A similar approach has for instance been adopted in ISO 13065[26] which is based on a detailed framework on principles, criteria, and indicators, but does not specify thresholds, thus leaving flexibility to consider the local context.

5. Discussion

Figure 1 summarizes the scope of this feature: starting from human and environmental health and usability concerns (as part of the sustainability dimension), better and stricter regulations (*i.e.*, emission thresholds) for human and environmental health protection, as well as better usability requirements (for ISO 30500 only), were considered as part of ISO 30500 and ISO 31800. To achieve those stricter regulations, new sanitation technologies are needed and are being developed. Subsequently, to implement those technologies in a sustainable manner, various sustainability aspects must be considered, many of them depending on the local context which cannot be mandated as part of a product standard. Although in some situations, location-specific requirements (*e.g.*, more or less strict emission thresholds) might be preferable to the general performance and product requirements of ISO 30500 and ISO 31800. The voluntary approach of ISO certification gives this flexibility to governments.

In our opinion, the ideal scenario is that no further regional, national, or local certifications and approvals are required to implement the technologies which have been certified according to one of these standards. Hence, to be fully effective, national authorities need to endorse and adopt these standards so these technologies, once certified, can easily and rapidly be implemented globally, avoiding the need to meet an abundance of varying local regulations. As of 2021, 5 countries have adopted ISO 31800 and more than 28 countries have adopted ISO 30500.[27] However, populous countries with limited safely managed sanitation services such as China, India, and Indonesia[1] have not adopted ISO 30500 or ISO 31800, yet. This highlights the need for ongoing awareness-raising activities such as the work currently undertaken by the American National Standards Institute (ANSI) and the Senegalese Standards Association (ASN). Funding and development organizations can also contribute to ISO 30500 and ISO 31800 adoption by requiring that NSSS and FSTUs in bids for projects involving sanitation technologies meet those standards. These measures would push the demand side. Looking at the supply side, as of 2021, there were no NSSS certified to ISO 30500 and no FSTU certified to ISO 31800, yet. There may be two reasons for this situation: first, as both standards were only published recently, technology developers may still need more time to develop sanitation technologies that can meet the requirements of these standards. Hence the two standards aim at enhancing current BATs, according to the slogan: today’s standards are tomorrow’s technologies. Second, many small technology developers may not be able to afford the certification process without external support. The latter challenge could be overcome if funding agencies and development organizations encourage and financially support technology developers to achieve certification of their sanitation products falling within the scope of these two standards.

6. Conclusion

ISO 31800 and ISO 30500 can help solve the global sanitation crises by providing a comprehensive set of requirements and recommendations for developing technologically-mature and safe sanitation systems that meet advanced environmental and human health requirements. Thereby, these standards guide technology developers on how to design tomorrow's sanitation technologies and can eventually help them market as certified products. Further, support from funding organizations in adopting those standards can greatly contribute to their success. However, we are aware that context-specific socio-economic and institutional aspects are often crucial for achieving sustainable sanitation solutions. For that reason, both ISO standards include an Informative Annex which can guide the purchaser of such systems on these aspects and their relevance for a specific implementation project. But these aspects cannot be considered for global product certification. We therefore suggest developing a standardized framework for sustainability assessment for sanitation technologies (and systems), which may be a separate ISO standard similar to ISO 13065 on sustainability criteria for bioenergy.

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Notes:

The authors declare no competing financial interests. M. S., F. A., and C. A. C. were working group members of PC 305 and PC 318.

Table 1: Pathogen and indicator microorganisms' requirements in different regional standards for wastewater reuse and discharge scenarios. Reuse scenario #1: restricted urban reuse (e.g., toilet flushing, washing machines, garden), #2: agricultural reuse in non-processed food crops, #3: agricultural reuse in processed food crops.

Reuse and discharge scenarios	**EPA 2012**[28]	**Australia 2006**[29]	**ISO 16075**[30]	**WHO 2006**[31]	**NGT 2019**[32]	**GBT 18921**[33]	**NWA 1998**[34]	**ASN 2001**[35]	**EU 1991**[16]	**ISO 30500**[12] **ISO 31800**[11]
	Fecal coliforms (per 100 mL)	*E. Coli.* (CFU per 100 mL)	Thermo-tolerant coliforms (per 100 mL)	*E. Coli* (numbers per 100 mL)	Fecal Coliform (MPN per 100 mL)	Fecal Coliform (numbers per 100 mL)	Fecal Coliforms (CFU per 100 mL)	See below	No guideline	See below
#1: restricted urban	≤ 200	< 1	-	-	100 (desirable) – 230 (permitted)	≤ 50	-	-	-	≤ 10 CFU per 100 mL (*E. Coli*) ≤ 1 PFU per 100 mL (MS2 Coliphage) < 0.1 per 100 mL (*Ascaris suum*) < 0.1 CFU per 100 mL (*Clostridium perfringens*)
#2: agricultural – non-processed food	n. d.	< 1	≤ 10 (95^{th} percentile) – 100 (max)	$\leq 10^1$ or 10^0	-	-	-	-	-	
#3: agricultural – processed food	≤ 200	< 100 - <1,000	≤ 200 (95^{th} percentile) – 1,000 (max)	-	-	-	-	-	-	
Discharge in non-urban environment	-	-	-	-	-	≤ 200 - ≤ 1,000	≤ 1,000	≤ 2,000 per 100 mL (Fecal Coliform) ≤ 1,000 per 100 mL (*Streptococcus*) Absence per 5,000 mL (*Salmonella*) Absence per 5,000 mL (*Vibrio Cholerae*)	-	

Table 2: Environmental parameter requirements in different regional standards for wastewater reuse and discharge scenarios identical to the ones described in Table 1.

Parameter	**Units**	**EPA 2012**[28]	**Australia 2006**[29]	**ISO 16075**[30]	**WHO 2006**[31]	**NGT 2019**[32]	**GBT 18921**[33]	**NWA 1998**[34]	**ASN 2001**[35]	**EU 1991**[16]	**ISO 30500**[12]	**ISO 31800**[11]
Reuse scenario #1: restricted urban reuse (e.g., toilet flushing, washing machines, garden)												
BOD_5 (or COD)	mg O_2/L	≤ 30	Case by case basis	-	-	≤ 10 (50)	≤ 6	-	-	-	≤ 50	-
SS	mg/L	≤ 30		-	-	≤ 20	-	-	-	-	≤ 10	-
Turbidity	NTU	-		-	-	-	≤ 5	-	-	-		-
pH	-	6.0 – 9.0		-	-	5.5-9.0	-	-	-	-	6-9	-
N and P	mg/L or % removal	-		-	-	≤ 10 (N, total)	-	-	-	-	TN: ≥ 70%, TP: ≥ 80%	-
Reuse scenario #2: agricultural reuse in non-processed food crops												
BOD_5	mg O_2/L	≤ 10	Case by case basis	≤ 5 (max 10)	-	-	-	-	-	-	-	-
TSS	mg/L	-		≤ 5 (max 10)	-	-	-	-	-	-	-	-
Turbidity	NTU	≤ 2		≤ 2 (max 5)	-	-	-	-	-	-	-	-
pH	-	6.0 – 9.0		-		-	-	-	-	-	-	-
Reuse scenario #3: agricultural reuse in processed food crops												
BOD_5	mg O_2/L	≤ 30	≤ 20	≤ 10 (max 20)	-	-	-	-	-	-	-	-
TSS	mg/L	≤ 30	≤ 30	≤ 10 (max 25)	-	-	-	-	-	-	-	-
pH		6.0 – 9.0	-	-	-	-	-	-	-	-	-	-
Discharge in non-urban environment												
BOD_5	mg O_2/L	-	-	-	-	≤ 10	6-10	-	40-80	≤ 25	-	≤ 25
COD	mg O_2/L	-	-	-	-	≤ 50	-	≤ 75	100-200	≤ 125	≤ 150	≤ 100
SS	mg/L	-	-	-	-	≤ 20	10-20	≤ 25	≤ 50	35-60	≤ 30	≤ 30
pH	-	-	-	-	-	5.5-9	-	5-9	5.5-9.5	-	6-9	6-9
N and P	mg/L or % removal	-	-	-	-	-	-	-	-	-	TN: ≥ 70%, TP: ≥ 80%	TN: ≤ 15 TP: ≤ 2

Table 3: Acceptable contamination levels for biosolids and sludge disposal in mg/kg of dried material.

Metal	**Ceiling concentration limits for all biosolids applied to land (EPA Part 503)[36]**	**EU "Sludge Directive" (86/278/EEC)[37]**	**ISO 31800[11]**
Arsenic	75	-	75
Cadmium	85	20-40	20
Chromium	3000	-	3000
Copper	4300	1000-1450	1000
Lead	840	750-1200	750
Mercury	57	16-25	16
Molybdenum	75	-	75
Nickel	420	300-400	300
Selenium	100	-	100
Zinc	7500	2500-4000	2500

Table 4: Some Reinvented Toilet technologies as NSSS with the general categories of treatment used and their technology readiness level (TRL).[19]

	Liquids treatment	**Solids treatment**	**NSSS Name**	**TRL[19]**	**Reference or Company name**
Separated solids liquids and treatment	Electro-oxidation	Thermal treatment	Duke Empower	7	[38]
	Catalytic oxidation	Smoldering	Toronto Toilet	6	[39]
	Multi-step liquid filtration	Pasteurization or micro-supercritical water oxidation	Generation 2 Reinvented Toilet	Data non available	[40]
Mixed solids and liquids treatment	**Biological treatment**	**Post-treatment (polishing)**	**NSSS Name**	**TRL[19]**	**Reference or Company name**
	SBR or A/O + Biosorption	Electro-oxidation	CLASS and Eco-san	8 (Eco-san)	[41]
	MBR	UV	Clear Recycling Toilet	8	CLEAR, China
	Multi-step bio	Electro-oxidation	Zyclone Cube	8	SCG, Thailand [42]
	AMBR + Biosoportion	Electro-oxidation	NEWgenerator	7	[43]
	Multi-stage effluent treatment system	Heated above 160°C, at a pressure up to 25 bar	HT Clean	6	Helbling, Switzerland

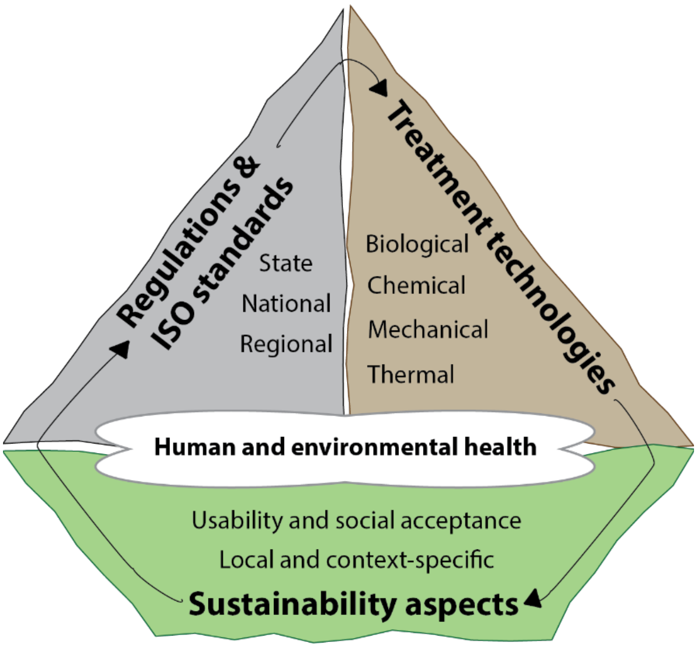

Figure 1: Interdependence between sustainability aspects, regulations & ISO standards, and treatment technologies.

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