FLORIDA DEPARTMENT OF HEALTH

Florida Onsite Sewage Nitrogen Reduction Strategies Study

Task A

Prioritization of Nitrogen Reduction Technologies

Draft Report

June 2009

44237-001

HAZEN AND SAWYER
Environmental Engineers & Scientists

In association with

Colorado School of Mines 1874

AET Applied Environmental Technology

OTIS ENVIRONMENTAL CONSULTANTS, LLC

Florida Onsite Sewage Nitrogen Reduction Strategies Study

TASK A
DRAFT REPORT

Prioritization of Nitrogen Reduction Technologies

Prepared for:

Florida Department of Health
Division of Environmental Health
Bureau of Onsite Sewage Programs
4042 Bald Cypress Way Bin #A-08
Tallahassee, FL 32399-1713

FDOH Contract CORCL

June 2009

Prepared by:

HAZEN AND SAWYER
Environmental Engineers & Scientists

In Association With:

AET
Applied Environmental Technology

Otis Environmental Consultants, LLC

Prioritization of Nitrogen Reduction Technologies

Prioritization of nitrogen reduction technologies was based on systematic application of the ranking criteria to the technologies identified in the literature review conducted in Task A.1. Technologies were grouped according to the classification scheme developed in Task A.3. Each technology classification received individual scores for the separate evaluation criterion, and the weighting criteria were used to generate the total score for the technology classification. The technologies within each classification were prioritized according to their total score.

List of Technologies

The literature review and survey of manufacturers indicated that many processes and commercial systems are available for onsite wastewater treatment. The technology database is comprised of available onsite nitrogen reduction technologies from manufacturers and the literature review. The identified technologies were sorted according to the major classifications developed in Task A.3: source separation, biological treatment, physical/chemical treatment and natural systems. The basis for assignment of classification was the principal nitrogen reduction process of the technology. The systems within the major groupings were then further grouped into the process variations within each major classification.

Technology Evaluation Criteria

The technology evaluation criteria were individually discussed and edited, and a final consensus list of criteria was agreed to and adopted during the Technology Classification, Ranking and Prioritization Workshop held with the Research Review and Advisory Committee on May 28, 2009. Also agreed to and adopted at that meeting were the weighting factors for each individual criterion. The finalized criteria and weighting factors are listed in Table 1.1.

Table 1.1
Technology Criteria and Weighting Factor

Criteria	Weighting Factor
Effluent Nitrogen Concentration	11
Performance Reliability	10
Performance Consistency	9
Construction Cost	7.5
Operation and Maintenance Cost	7
Energy Requirement	7
Construction Complexity	5
Operation Complexity	5
Land Area Required	4.5
BOD/TSS Effluent Concentration	3.5
Restoration of Performance	3.5
System Aesthetics	2
Stage of Technology Development	0.5

For each of the individual technologies identified within the literature review (Task A.1), data were acquired from a wide variety of sources focusing on the ranking criteria. Manufacturer's information and third party test results such as the NSF International (NSF) Standard 40 Protocol, EPA Environmental Technology Verification Program (ETV), or field and/or laboratory evaluations reported in the technical literature were utilized to develop the technology database. Some performance data were available only as manufacturer's claims, other data as a range of removal percentages from field installations, and some data included detailed analytical results with statistical ranges. Nitrogen effluent data were generally available while nitrogen influent data were not. The attributes of the performance consistency and performance reliability criteria were based on the type of treatment process used. Construction cost was estimated for a newly installed, complete treatment system for a three-bedroom home in Florida, and included primary treatment (i.e. septic tank) and a conventional drainfield. Performance reliability data were available for a few systems for which frequency of maintenance visits recorded were available, and estimated for the remainder. Energy use data (kW-h/day or kW-h/year) were available for a few systems that detailed a cost per month or cost per year, and estimated for the others. For energy use, a conversion to uniform data values was obtained by using an assumption of $0.10 per kW-h. Operation and maintenance cost estimates, land area required, constructional complexity, operational complexity, and system aesthetics data were very limited, so professional judgment were used to assign scores for individual criteria to the technology classifications.

o:\44237-001R006\Wpdocs\Report\Draft

Criteria Scores

For each of the thirteen criteria, scores were established based on cost and/or non-cost attributes. Table 1.2 presents a summary of score assignments for each criterion. The criterion assignments were the basis for scoring and ranking of the technology classifications.

Table 1.2
Criteria Scores

Criteria Number	Criteria	Score				
		1	2	3	4	5
1	Effluent Nitrogen Concentration (mg-N/L)	> 30	16 – 30	11 – 15	3 – 10	< 3
2	Performance Reliability	Monthly		Quarterly	Semi-Annually	Annually
3	Performance Consistency	Activated Sludge Nite/Denite	IFAS	MBR/IMB	Fixed Film	Physical /Chemical & Source Separation
4	Construction Cost[1] ($1,000's)	>20	15-20	10-15	5-10	<5
5	Operation and Maintenance Cost[2] ($/year)	>500	400-500	300-400	200-300	<200
6	Energy Requirement (kW-h/year)	>2500	1500-2500	1000-1500	500-1000	<500
7	Construction Complexity	Complex installation, specialized training, sophisticated electrical and controls knowledge req., master septic tank contractor		Some specialized knowledge and training required		Simple to install by any Contractor

Table 1.2
Criteria Scores

Criteria Number	Criteria	Score				
		1	2	3	4	5
8	Operation Complexity	Complex operation with operator training required; Scheduled visits by manufacturer's representative required > quarterly		Some specialized operator training required; Scheduled visits by manufacturer's representative required twice per year		Simple operation with limited operator requirements annual scheduled visit
9	Land Area Required[3] (ft^2)	>2000	1001-2000	501-1000	251-500	<250
10	BOD/TSS Effluent Concentration (mg/L)	>50	30/30		20/20	10/10
11	Restoration of Performance	Activated Sludge Nite/Denite	IFAS	MBR/IMB	Fixed Film	Physical /Chemical & Source Separation
12	System Aesthetics	Not Acceptable		Perceived Nuisance/ Displeasing		Acceptable
13	Stage of Technology Development	Conceptual	Experimental	Demonstration	State Use	National Use

1. *Construction cost assumes a standard septic tank cost of $2000 and drainfield cost of $4500 installed.*
2. *Operation and maintenance cost includes inspections, annual operating permit fee ($100), and maintenance entity, but it does not include power costs.*
3. *Land area is for a new entire system, and assumed standard septic tank 50 SF and drainfield 400 SF.*

The criteria were developed with the full knowledge that data for many of the criteria would be sparse and difficult to attain. Good engineering judgment and experience with various types of systems were used to develop technology ranking scores when data were not available. A summary of the individual criterion scores for technology classifications is presented in Table 1.3. While the table encompasses the full range of possible systems contained in our classification, types of systems lacking available data are left blank. Natural systems need to be considered separately and are therefore summarized in Table 1.5.

Table 1.3
Criteria Scores for Physical/Chemical and Biological Technology Classifications

Technology Classification	Criteria													Total Scores (Weighting Factor *Score)
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Effluent of TN Conc. (mg/L)	Performance Reliability	Performance Consistency	Construction Costs ($1000)	O&M Cost	Energy Req. (kW-h/yr)	Construction Complexity	Operation Complexity	Land Area Req. (ft^2)	BOD/TSS Effluent Conc (mg/L)	Restoration of Performance	System Aesthetics	Stage of Technology Development	
Weighting Factor	11.0	10.0	9.0	7.5	7.0	7.0	5.0	5.0	4.5	3.5	3.5	2.0	0.5	
Physical/Chemical														
Membrane Processes														
Ion Exchange														
Evapotranspiration														
Biological														
Mixed Biomass														
Suspended Growth: w/, w/out recycle	3	3	1	2	2	2	3	3	3	4	1	5	5	188.5
Fixed Film														
Fixed Film with recycle	2	4	4	2	3	4	3	3	3	5	4	5	5	235.5

Table 1.3
Criteria Scores for Physical/Chemical and Biological Technology Classifications

Technology Classification	Criteria													Total Scores (Weighting Factor *Score)
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Effluent of TN Conc. (mg/L)	Performance Reliability	Performance Consistency	Construction Costs ($1000)	O&M Cost	Energy Req. (kW-h/yr)	Construction Complexity	Operation Complexity	Land Area Req. (ft^2)	BOD/TSS Effluent Conc (mg/L)	Restoration of Performance	System Aesthetics	Stage of Technology Development	
Fixed Film without recycle	1	4	4	2	4	3	3	3	3	4	4	5	5	235
Integrated Fixed Film Activated Sludge	2	3	2	2	2	1	3	3	3	4	2	5	5	183
Two Stage (Segregated Biomass)														
Heterotrophic Denitrification	4	4	4	2	3	4	3	3	3	4	4	5	3	273
Autotrophic Denitrification	4	5	4	2	3	2	3	5	3	5	4	5	3	276.5

For each technology classification, the criterion scores (Table 1.3) were multiplied by the weighting factor (Table 1.1) and summed to generate a total score. The total score was used to rank technology classifications. Total scores for physical/chemical and biological technology classifications are listed in Table 1.4 and plotted in Figure 1-1.

Table 1.4
Physical/Chemical and Biological Technology Classification Overall Ranking

Technology Classification	Total Score	Overall Ranking
Two Stage (Segregated Biomass) – Autotrophic Denitrification	276.5	1
Two Stage (Segregated Biomass) – Heterotrophic Denitrification	273.0	2
Mixed Biomass – Fixed Film with Recycle	235.5	3
Mixed Biomass – Fixed Film without Recycle	235.0	4
Mixed Biomass – Suspended Growth	188.5	5
Mixed Biomass – Integrated Fixed Film Activated Sludge	183.0	6

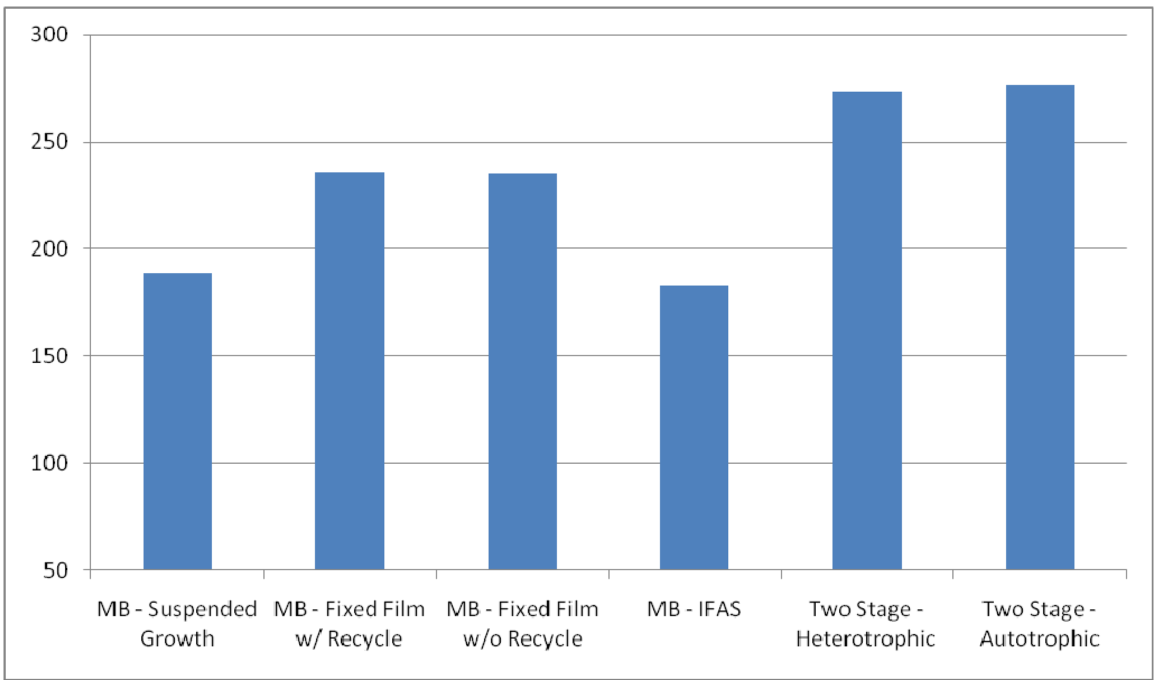

Figure 1-1: Overall Ranking of Physical/Chemical and Biological Technology Classifications

The top ranked technology classifications (1 & 2) were biological systems with two stage segregated biomass employing autotrophic and heterotrophic denitrification. These systems are passive, require little operator attention, and provide high reliability. The total scores for autotrophic and heterotrophic denitrification technologies in two stage segregated biomass systems were sufficiently close that they were considered essentially equal.

The third and fourth ranked technology classifications were mixed biomass fixed film biological systems with recycle and without recycle, respectively. The total scores for these systems were sufficiently close that they were considered essentially equal. These technology classifications have the stability advantages that are inherent in fixed film processes.

Mixed biomass suspended growth systems were the fifth ranked technology classification and mixed biomass integrated fixed film systems were the sixth. These systems employ suspended growth basins and exhibit higher effluent nitrogen concentrations and lower performance consistency and reliability.

Table 1.5
Criteria Scores for Natural System Technology Classifications

Technology Classification	Criteria													Total Scores (Weighting Factor *Score)
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Effluent of TN Conc. (mg/L)	Performance Reliability	Performance Consistency	Construction Costs ($1000)	O&M Cost	Energy Req. (kW-h/yr)	Construction Complexity	Operation Complexity	Land Area Req. (ft^2)	BOD/TSS Effluent Conc (mg/L)	Restoration of Performance	System Aesthetics	Stage of Technology Development	
Weighting Factor	11.0	10.0	9.0	7.5	7.0	7.0	5.0	5.0	4.5	3.5	3.5	2.0	0.5	
Natural														
Soil Infiltration														
With dosing	1	5	4	5	4	5	5	5	5	5	4	5	5	305
With reactive barriers	5	5	4	3	3	5	3	4	5	5	3	5	3	316.5

o:\44237-001R006\Wpdocs\Report\Draft

Table 1.5
Criteria Scores for Natural System Technology Classifications

Technology Classification	Criteria 1: Effluent of TN Conc. (mg/L)	2: Performance Reliability	3: Performance Consistency	4: Construction Costs ($1000)	5: O&M Cost	6: Energy Req. (kW-h/yr)	7: Construction Complexity	8: Operation Complexity	9: Land Area Req. (ft^2)	10: BOD/TSS Effluent Conc (mg/L)	11: Restoration of Performance	12: System Aesthetics	13: Stage of Technology Development	Total Scores (Weighting Factor *Score)
With drip dispersal	3	4	4	4	3	5	3	3	5	5	4	5	5	271.5
Heterotrophic Nitrification / Denitrification														
Annamox														
Constructed Wetlands														
Subsurface flow with pre-denitrification	3	5	4	3	4	5	3	3	4	3	3	5	5	281.5
Source Separation														
Urine Recovery														
Wastes Segregation														

Table 1.6
Natural System Technology Classification Overall Ranking

Technology Classification	Total Score	Overall Ranking
Soil Infiltration with reactive barriers	316.5	1
Soil Infiltration with dosing	305.0	2
Constructed Wetlands subsurface flow with pre-denitrification	281.5	3
Soil Infiltration with drip dispersal	271.5	4

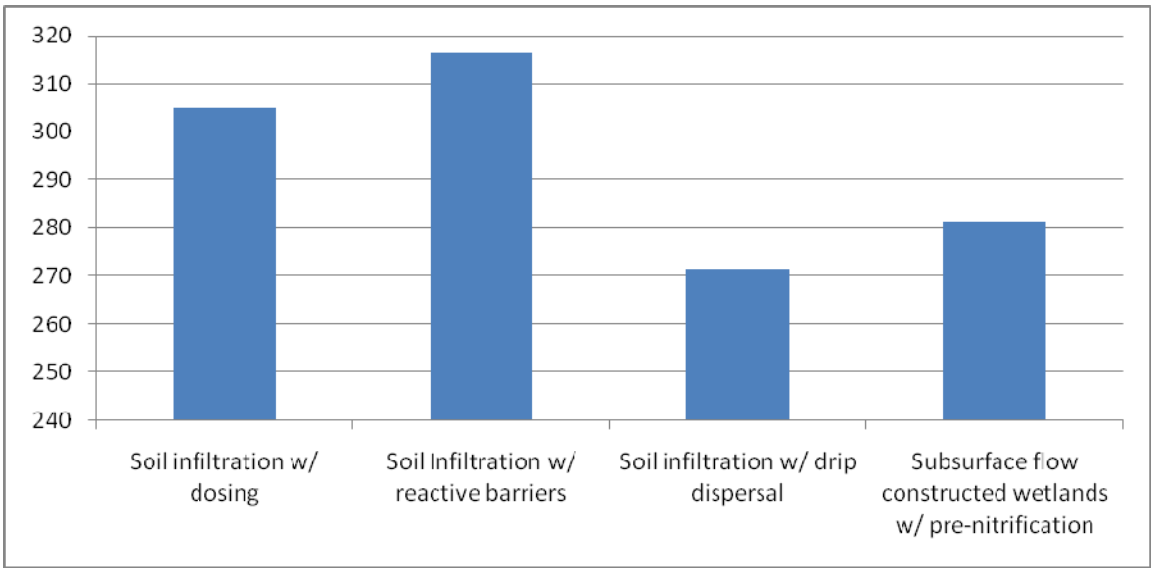

Figure 1-2: Overall Ranking of Natural System Technology Classifications

The top ranked natural system was soil infiltration with reactive barriers. The second ranked natural system is traditional trench drainfield with timed dosing of septic tank effluent. However, this system received the lowest treatment score. Application of our ranking system to certain kinds of natural systems can be misleading from a purely quantitative perspective: in this instance, the score is high because of its passive characteristics and low operating costs, but does not address the difficulty of performance monitoring and the costs associated with correcting poor performance.

Subsurface-flow constructed wetlands with pre-nitrification and drip dispersal of septic tank effluent to soil infiltration technologies ranked within 3.5% of each other. The constructed wetlands can achieve more complete nitrification and denitrification than soil infiltration with drip dispersal, but drip dispersal offers much greater control of performance and repairs of malfunctions are less costly and easier to perform. Aesthetically, the systems scored the same, but the acceptance could be quite different among property owners.

It is important to note that the natural systems should not be quantitatively compared, using these ranking criteria, to the groups of proprietary and non-proprietary biological systems detailed in Tables 1.3 and 1.4, and Figure 1-1. Primary among considerations supporting this division of technologies is the need to consider separately the elements of each system that performs treatment. The soil infiltration units utilize the soil's ecology and physical characteristics to perform treatment and all relevant data measures the treatment capacity within the soil pedon to reduce nitrogen. However, it must be kept in mind that the vast majority of proprietary systems also discharge to the soil. In order to be able to rank each technology fairly, only the nitrogen reduction components were considered. Moreover, management of non-soil based technologies, though more expensive, is simplified because the units can be operated effectively to adjust to varying conditions and serviced easily, which may not be the case with soil-based nitrogen reduction technologies. When malfunctions occur with soil-based technologies, repairs may be necessary and could lead to expensive reconstruction. When the latter is necessary, available land area can become a severe constraint. Finally, while soils provide good treatment over a broad range of conditions, variability of characteristics among soil units can be large creating significant uncertainty in predicting a soil's nitrogen reduction capacity.

Recommendations for Testing

The technology classification ranking provides the basis from which to formulate recommendations for the field testing to be conducted in Task B of the Florida Onsite Sewage Nitrogen Reduction Strategies Study. The criteria used to consider in establishing priorities for testing include representation of several technology classifications, nitrogen effluent performance data, similarity of technologies, and maturity level of technologies. The purpose of prioritization is to select the more promising technologies that may not have sufficient prior testing or may be differently configured to improve performance, and to avoid duplicate testing where substantial experience already exists. The priority list for Task B testing is listed in Table 1.7. The recommended technologies include mixed biomass, two stage segregated biomass biofiltration systems, natural systems with and without external sources of electron donors for denitrification, fixed film and integrated fixed film activated sludge processes, denitrification filters with reactive media as post-treatment to commercial aerobic treatment processes, onsite elimination of urine effluent, and urine separation and recovery.

Table 1.7
Technologies Recommended for Testing in Task B

System	Technology	Comment
1	Two stage (segregated biomass) system: Stage 1: Biofiltration with recycle (nitrification) Stage 2: Autotrophic denitrification with reactive media biofilter	• Top ranked system capable of meeting the lowest TN concentration standard • Suitable for new systems or retrofit
2	Two stage (segregated biomass) system: Stage 1: Biofiltration with recycle (nitrification) Stage 2: Heterotrophic denitrification with reactive media biofilter	• Top ranked system capable of meeting the lowest TN concentration standard • Suitable for new systems or retrofit
3	Natural system: Septic tank/Mound with in-situ reactive media layer	• Lower cost natural system that is untested but appears capable of achieving 75-78% TN removal before reaching groundwater • Suitable for new systems or replacing existing systems at end of useful life
4	Natural system: Settled or secondary effluent with drip dispersal	• Suitable for reducing TN impacts on groundwater through enhanced TN removal and reduced TN loading on soil • Suitable for new systems or retrofit
5	Two stage (segregated biomass) system: Stage 1: Mixed biomass fixed film with recycle Stage 2: Heterotrophic denitrification with reactive media biofilter	• High performance aerobic treatment with anoxia for enhanced TN removal followed by second stage heterotrophic denitrification for high nitrogen removal • Suitable for new systems or nitrogen reduction upgrades
6	Two stage (segregated biomass) system: Stage 1: Mixed biomass fixed film with recycle Stage 2: Autotrophic denitrification with reactive media biofilter	• High performance aerobic treatment with anoxia for enhanced TN removal followed by second stage autotrophic denitrification for meeting low TN concentration standard • Suitable for new systems or nitrogen reduction upgrades
7	Mixed biomass integrated fixed film activated sludge system: Suspended growth with recycle	• High performance aerobic treatment • Suitable for new systems or nitrogen reduction upgrades

Table 1.7
Technologies Recommended for Testing in Task B

System	Technology	Comment
8	Mixed biomass integrated fixed film activated sludge system: Moving bed bioreactor	• High performance aerobic treatment with simultaneous denitrification • Suitable for new systems or nitrogen reduction upgrades
9	Mixed biomass suspended growth system: Suspended growth sequencing batch reactor	• Aerobic treatment • Suitable for new systems or nitrogen reduction upgrades
10	Membrane process system: Membrane bioreactor (MBR)	• Suitable for new systems or nitrogen reduction upgrades
11	Source separation system: Dry toilet (evaporative or composting)	• Eliminates liquid disposal or wastes
12	Source separation system: Urine separating (recovery) toilet	• Innovative system that is capable of removing 70-80% of the household TN at little capital cost • Provides potential for sustainable recovery of nutrients

The first two technologies listed in Table 1.7 are two stage segregated biomass. The first stage of each is a recirculating biofilter through which nitrification occurs. Significant denitrification also occurs due to the recirculation. The biofilters can employ a variety of fixed film media, many of which are in current use and are described in the literature review in Task A.1. PNRS II testing will provide additional data for biofiltration with recycle using clinoptilolite, expanded clay, and polystyrene. The best performing media from PNRS II testing will be recommended for Task B testing. Stage 2 of these segregated biomass systems will employ autotrophic denitrification (System 1) and heterotrophic denitrification (System using reactive media biofilters). The hybrid Systems 1 & 2 can be employed for new installations or inserted between primary treatment (i.e. septic tank) and soil dispersal in existing systems.

System 3 is a natural system that uses drip dispersal into the soil of settled or secondary effluent. To enhance denitrification, an in-situ reactive media barrier will be constructed below the drip dispersal tubing. Effluent is dispersed within the root zone and percolates downward through the reactive media barrier containing high water retention materials such as expanded clay and lignocellulosic or elemental sulfur electron donors to support heterotrophic or autotrophic denitrification. This system would meet the FDOH definition of passive technology and has the potential to be a low cost in-situ system that can be applied for new installations or retrofits.

System 4 is a natural system using drip dispersal of settled or secondary effluent into the soil. By dosing septic tank effluent into the soil on timed cycles alternating aerobic and anoxic conditions are created in the soil near each emitter, which creates the necessary conditions for nitrification/denitrification to occur. This intermittent dosing of septic tank effluent has been shown by several studies to reduce the total nitrogen applied.

Systems 5 and 6 are similar to Systems 1 and 2, in that it is a mixed biomass fixed film system with recycle, followed by a heterotrophic or autotrophic denitrification filter. While Systems 1 and 2 utilize various widely available media, System 5 and 6 consist of a combination of different proprietary and non-proprietary media systems. As with most systems intended for nitrogen removal, recycling is used to treat effluent more than once before discharge.

Systems 7 and 8 are IFAS (Integrated Fixed-Film Activated Sludge) systems. They combine elements of both fixed film and suspended growth microbial communities, resulting in highly stable treatment processes that achieve more reliable and consistent performance than other mixed biomass processes.

System 9 is a suspended growth system, specifically Sequencing Batch Reactors (SBR). Theoretically, SBR's should be able to control the loss of carbon better than other mixed biomass systems.

System 10 is a membrane bioreactor (MBR) which combines suspended growth with a membrane filtration unit. MBR is an emerging treatment option for single family home systems.

Systems 11 and 12 are source separation systems. Source separation is an emerging option for treatment, likely to become increasingly prevalent in keeping with trends towards sustainability and resource recovery. With regard to nitrogen removal, source separation has the potential to be a particularly efficient option since 50 to 75% of household waste nitrogen is from urine. Accordingly, separating the waste streams allows for more efficient, dedicated treatment options.