Guide to Starting a Community-scale Urine Diversion Program

PUBLISHED BY

RICH EARTH INSTITUTE

Version 1

CREDITS

Lead Author
Jennifer Atlee

Contributing Authors
Abraham Noe-Hays
Kim Nace
Tatiana Schreiber
Arthur Davis
Conor Lally
Stephen Dotson

Reviewers
Nadav Malin
David Cedarholm
Nancy Love
Rebecca Reuter

Graphic Design and Illustration
Briony Morrow-Cribbs

Any opinions, findings,and conclusions or recommendations expressed are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

Published By:
Rich Earth Institute
44 Fuller Drive
Brattleboro, VT 05301

RichEarthInstitute.org

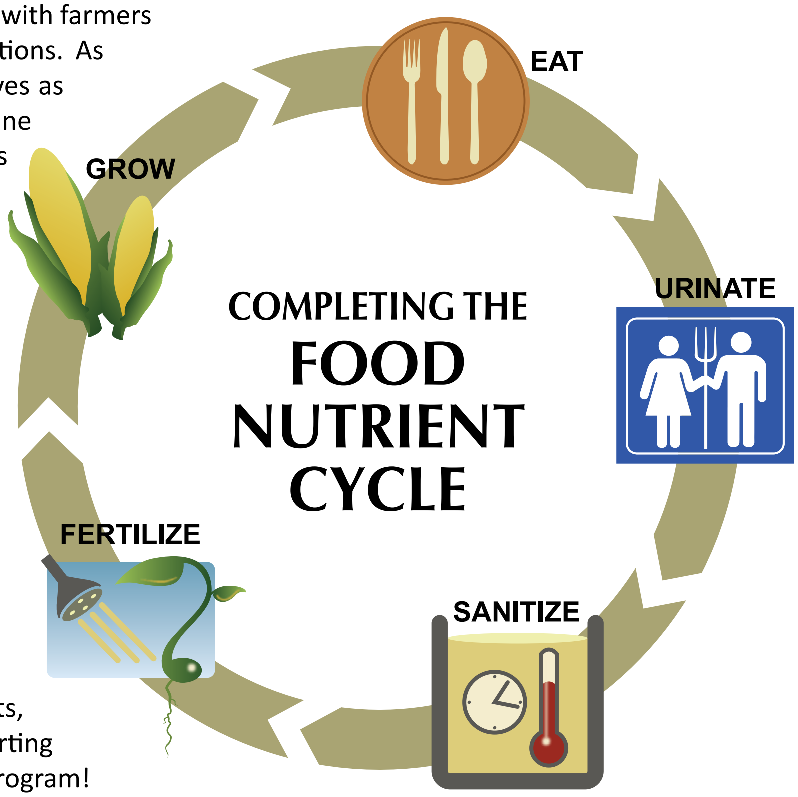
info@richearthinstitute.org

TABLE OF CONTENTS

OVERVIEW

The Rich Earth Institute's Urine Nutrient Reclamation Program (UNRP) is the first community-scale urine diversion program (UD program) in the United States. Initiated in 2012, we now divert thousands of gallons of urine from the wastewater stream annually. We recycle the urine into sanitized fertilizer and apply it to hay fields on participating farms in Windham County, Vermont. Demand for urine fertilizer among participating farmers is currently higher than the available supply.

This ongoing program prevents water pollution, conserves drinking water, and produces fertilizer for local farms. At the same time we are providing a research platform for academic partners across the country, developing tools and technologies for handling and processing urine, and working closely with farmers to integrate urine-derived fertilizers into their operations. As we continue to refine our approach, our program serves as an example for communities considering their own urine diversion program, and creates a precedent for others to replicate and expand on our work.



This document describes the work of the Rich Earth Institute (Rich Earth) in detail, primarily to support those seeking to move this work forward in their own regions. We cover the process of starting up a community-scale urine diversion program (UD program) and key elements of its operation. These include technical details for processes and equipment, regulatory and economic considerations, and the human factors that come into play—including effective education and community outreach and building relationships with farmers. Throughout the document we also reference the UD program Toolkit, where we have publicly made available a host of open source documents, presentations, and other materials to support those starting a UD program. Please do let us know if you start a UD program! We'd love to hear what happens, and assist if we can.

This document assumes familiarity with the rationale for urine diversion: that separation of nutrient-rich urine at the source keeps these nutrients from causing water pollution, allows them to be used as an agricultural resource, and conserves potable water. It also has the potential to be a highly cost-effective approach to meeting national requirements for reducing the nutrient load in water bodies across the U.S., alongside or as an alternative to conventional septic tanks and wastewater treatment methods. The subsections below cover some of the most important points to understand and share with others about urine diversion.

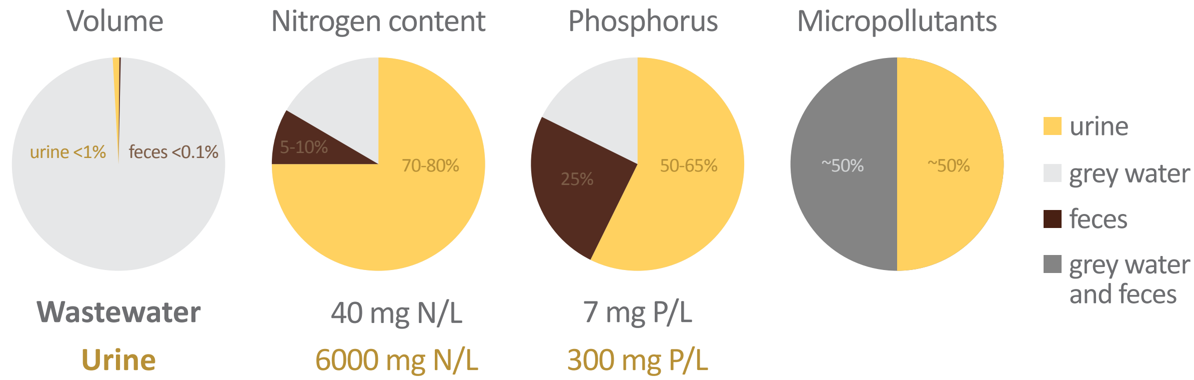
OUR VISION:

A world with clean water and fertile soil achieved by reclaiming the nutrients from our bodies as elements in a life sustaining cycle.

OUR MISSION:

The Rich Earth Institute engages in research, education, and technological innovation to advance the use of human waste as a resource.

Make-up of wastewater



Why divert urine?

Modern-day sanitation practices represent one of the primary sources of nutrient pollution, as urine constitutes approximately 80% of the nitrogen (N) and 55% of the phosphorus (P) found in wastewater[1]. These elements are also primary ingredients of synthetic fertilizer. Capturing these nutrients by diverting urine before it enters the wastewater stream prevents environmental degradation and conserves water used to flush toilets. Recycling these nutrients into fertilizer reduces the need for synthetic fertilizer. Since the production and distribution of synthetic fertilizer is a significant source of greenhouse gases [cite], urine diverting systems offer a long-term resilient model for human waste management and agricultural practices.

The science of urine

What happens when urine leaves your body

When urine leaves your body its chemistry changes rapidly. Most of the nitrogen is in the form of urea, which typically transforms into ammonia over a period of several days. This process is called urea hydrolysis, and is caused by the urease enzyme that is produced by bacteria from the environment. The urea in urine is broken down into ammonia and bicarbonate, which increases the pH of the urine to about 9. The ammonia that develops in stored urine is a natural sanitizing agent, which destroys pathogens over time. In this alkaline environment, minerals including struvite begin to precipitate out, creating deposits that can clog waterless urinals and urine-diverting piping systems that are not installed and maintained properly. In an open container, ammonia will volatilize, leading to odor as well as loss of nitrogen. In contrast, urine can be stored in a sealed container indefinitely without losing significant fertilizer value.

Acidifying urine to preserve urea

Adding acid (such as vinegar) to fresh urine prevents the urea from converting into ammonia by creating conditions too acidic for the urease enzyme to work. This prevents loss of N through ammonia volatilization and maintains lower (acidic) pH, which also means minerals are less likely to precipitate out. The urine must be acidified when it is fresh, typically by adding urine to a container already containing acid, because once the urea transforms into ammonia it cannot be turned back to urea. This also has implications for treatment processes. At Rich Earth we have experimented with instructing donors to add 2-4 cups of white vinegar to a 20-L collection container–before filling with urine–both for odor control and to keep the N in the urea form. (The phenomenon is called "urease inhibition," and can also be achieved by raising the pH with the addition of alkali.)

1 Larsen, T. A.; Gujer, W. Separate management of anthropogenic nutrient solutions (human urine). Water Sci. Technol. 1996, 34 (3-4 -4 pt 2), 87–94.

UD PROGRAM TOOLKIT:

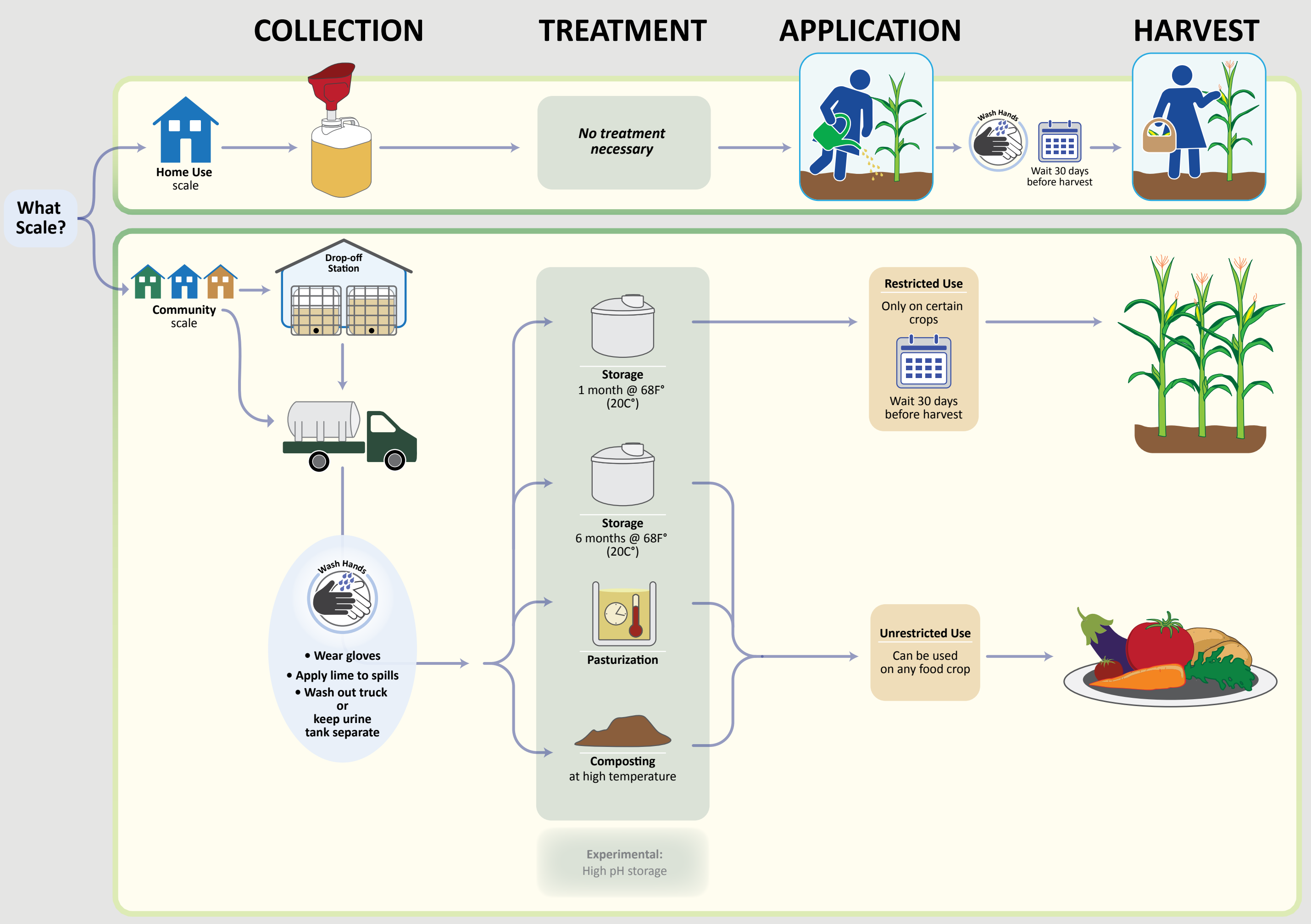
Rich Earth Introductory Powerpoint
This annotated powerpoint may be used as-is or adapted with attribution to introduce stakeholders to UD program.

Videos featuring Rich Earth
These videos are available from our website

- NSF "Science Nation" video
- Uri Nation animation

"Just the Facts" brochure

Safe Urine Reuse (AKA 'Pee-cycling')



What's required for safe urine reuse (aka 'pee-cycling')

Farmers and gardeners have harnessed the fertilizing power of urine for millennia, using it directly as fertilizer using only the most basic technology. Guidelines published by the World Health Organization in 2006 affirm this practice and specify how urine from a single household can safely be used on home gardens without any pre-treatment (see sidebar "Home-scale reuse" on page 4).

Beyond the scale of a single home, it is important to implement a pathogen management strategy. Urine is typically very low in pathogens (though not truly sterile), and the primary pathogen risk in working with diverted urine is from fecal contamination. Urine diverting toilets with divided bowls are effective at separating urine from feces, but there is always the potential for fecal pathogens being introduced into the urine they collect.

At Rich Earth we currently use pasteurization as our primary pathogen management strategy for the ongoing UD program. However a variety of treatment methods are available to manage pathogens (see "Pathogen reduction" on page 27). This diagram gives an overview of pathogen management options and process relevant for developing a US-based community UD program.

HOME-SCALE REUSE

People practicing home-scale reuse often do so without any pre-treatment. Home urine recyclers typically dilute urine with water and then apply it directly to the soil with a watering can, sometimes covering it with mulch or further watering it after application. Use of untreated urine at the household scale is recommended under guidelines issued by the World Health Organization (WHO) in 2006,[2] with the following stipulations:

- Wash hands after handling urine or wear gloves.
- Apply urine close to the ground, not as a spray.
- If the crop grows above ground and is eaten raw, incorporate the urine into the soil by tilling or additional watering.
- Wait at least one month after fertilization to harvest crops that are to be eaten raw.

"No storage is needed to fertilize crops within the same household collecting the urine, as long as crops are not harvested within a month of fertilization. In this case the risk of direct disease transmission within the household, via hand contact, etc. is far larger than via fertilization with urine."[3]

How much urine to apply, how much to dilute it, and when to apply it will depend on the needs of the plants (see "Calculating application rates" on page 42).

Applying diluted urine to a vegetable garden.

2 "Guidelines for the safe use of wastewater, excreta and greywater - Volume 4 Excreta and greywater use in agriculture" World Health Organization 2006 ISBN: 92 4 154685 9 https://www.who.int/water_sanitation_health/publications/gsuweg4/en/

3 "Urine diversion – hygienic risks and microbial guidelines for reuse" by Caroline Schönning (2003) https://www.who.int/water_sanitation_health/wastewater/urineguidelines.pdf

STARTING A COMMUNITY URINE DIVERSION PROGRAM

Launching a community-scale UD program is first and foremost a collaborative endeavor. From establishing close partnerships with farmers, haulers, and donors, to educating regulators, to engaging stakeholders across the community, the tone you set at the beginning will make or break the effort. We can't stress this enough.

A community-scale UD program also requires a clear plan for how the UD program will work, including both technical and financial aspects. It is essential to have at least one person or institution with a long-term commitment to seeing the initiative through the startup phase.

There are five key steps to getting a UD program started:

1. Educate your community and potential partners.
2. Establish your partners & work with your stakeholders.
3. Identify a central responsible party.
4. Understand your unique context.
5. Have a plan for collection, transport, treatment, application.

Educate your community and potential partners

The first step to launching a community-scale UD program is to talk with potential partners and begin educating the community. Approaching this initial phase of education and outreach with enthusiasm and confidence is key. It takes many conversations with people in every sector to get a program launched.

Assume people don't know anything about human urine and source separation. Assume they haven't thought about nutrient value or the link between urine and nutrient pollution in our waterways. Start with the science (see "The science of urine" on page 2) and help people understand the basic rationale for urine diversion (see "Why divert urine?" on page 2 and share toolkit resources).

2016 Urine Diversion Summit participants inspecting a composting toilet bin.

We have found that once potential partners understand how a UD program can simultaneously protect the environment and support local agriculture, it becomes possible to form relationships to advance the project. Regulators are motivated to help you along the permitting path; businesses and households become interested in installing urine diversion systems; farmers sign up to receive fertilizer; and the media promotes the work and reports on its successes.

Work with stakeholders and establish your partners

It is particularly important to find and cultivate your early adopters. People who are eager to support a new initiative are invaluable partners in a program's success, whatever part of the program they are involved in.

At Rich Earth our approach is always collaborative. We view every person as a potential partner. We are very careful to avoid saying "this is how it should be done." While there will be challenges in getting a UD program going, such as encountering people who do not support your efforts, it never helps to engage in a fight. We approach conversations positively with no attitude of blame about the current state of sanitation or water quality. We simply inform people about the benefits and potential of UD program.

Understand the unique perspective, needs, and concerns of those you are talking to. Below are some things to consider in working with stakeholders:

Farmers

- Farmers appreciate the nutrient value of urine, although small volumes of urine aren't necessarily of significant monetary value to them. However, they—and their customers— may appreciate urine recycling in terms of environmental stewardship.
- Farmers need to see an efficient process. Farmers are already overworked—if the process takes too much time or hassle they will reject it. Work with them to optimize the fertilizer application process.
- Farmers deal with manure and other forms of organic waste as fertilizer, but may still respond with skepticism—particularly regarding how farm customers will react to use of urine on crops.
- Farmers need and want accurate information on urine nutrient composition and any risk associated with microconstituents, so share data with them as it becomes available.
- (See "Working with farmers" on page 40)

Donors

- You may be surprised how many people don't think urine is gross, especially when they learn about its value. People often actually get excited about the chance to talk about pee. Do respect the ick/giggle factor when found, and help donors find a way to make UD work in their household.
- When donors understand the benefits, and begin to appreciate that they are contributing to closing the food-nutrient cycle, they can become avid champions.
- (See "Engaging donors" on page 11)

Haulers

- Work with your hauler partner to understand how hauling urine for farm application will differ from their typical septic collection and hauling process.
- (See "Hauler partners and permits" on page 20)

Regulatory and public health officials

- Regulators are understandably risk averse. Their goal is to protect human health and the environment, which they do by enforcing regulations. Make it clear that you share those goals, and want to work with them to find a place for your UD program within the regulatory framework.
- Educate your regulators about the basic science of urine diversion, and how it helps achieve the regulatory goals of reducing nutrient pollution and managing pathogens. Share with them the precedent established by Rich Earth and put them in touch with regulators who support urine diversion. Even if they do not fully buy into urine diversion, this can help allay their concerns and motivate them to help you navigate the regulations.
- (See "Permitting" on page 44)

Plumbers, architects, tradespeople

- Tradespeople may be concerned with ensuring that these systems will work, and not cause problems in the future that they will be responsible for. They may also want to know if there will be work available installing these systems.
- (See "Plumbing and installation" on page 16)

Town officials and building owners

- Understand how sewage is handled in your town, the relative use of centralized sewage treatment and/or decentralized septic systems, as well as state requirements and local codes.
- Seek to understand what challenges building owners and town officials may face that UD could address, such as high water and wastewater costs or development constraints due to nutrient pollution limits.
- (See "The business case for a community/municipal scale UD program" on page 46)

TIPS FOR STARTUP CONVERSATIONS:

- Enthusiasm and confidence matter.
- Don't fight—inform.
- Start with the basic science.
- Don't assume an ick/giggle response.
- Everyone is a partner.

Identify a central responsible party

Launching a community scale UD program is a long-term commitment (unless it is explicitly designed as a temporary demonstration project). A community-scale UD program should only be undertaken if there is at least one person who is the responsible point of contact acting as the caretaker of the project over the long term.

The commitment and care with which new projects are undertaken will greatly impact the ultimate success of urine diversion. Make sure you have—or acquire—the capacity to implement and manage all aspects of your operation competently (technical, outreach, financial management, regulatory, etc.) and for the long term. We are still at the early stages of infrastructure transformation in support of a paradigm shift from waste management to nutrient reclamation. It is very important to pay close attention to all the physical, regulatory, and social aspects of a project, because public opinion toward urine diversion will be shaped by the success or failure of the first community-scale urine diversion projects.

Rich Earth Institute staff is prepared to provide support and consultation to new initiatives. Please do contact us with questions and to let us know what you're doing.

Understand your unique context

To launch an effective UD program you have to understand your specific context—the unique challenges and characteristics of your site, town, and region. While there is value to urine diversion in many different settings, Rich Earth can't speak to the cost-effectiveness and resource-efficiency in areas where we haven't yet worked. Different approaches to urine diversion are being tested worldwide, and simple home-scale urine diversion has a long history of use around the globe. While this guide is primarily intended for developing UD programs in the U.S., the following considerations will always be relevant.

What challenges are people facing that UD could solve?

What imperative are you responding to? Consider potential donors, town officials, local businesses and developers, farmers and other stakeholders. Look downstream as well. What challenges are people running into? Development limits? Nutrient pollution? Water scarcity? Cost of wastewater treatment? Availability of fertilizer (limited in some regions of the world). This is how you identify your business case.

What is the regulatory landscape?

Regulations are different for every town, city, state, and region. They are also changing. What permitting will be needed, if any, will vary widely. Take care to assess which regulations the UD program might fall under, and talk with regulators on how to make it work. Even if there is no relevant regulatory framework, as may be the case for home use of urine, be sure to apply principles of safe peecycling.

What is the physical landscape?

How close together are donors? How close are farmers? Are distances a challenge? What scale is relevant? What is your climate? These factors will affect your costs and what approaches work best for collection, transport, treatment, and application.

What is the local culture?

What matters to people? What aspects of UD will resonate with donors and stakeholders in your community? Are there strong social norms you will be challenging?

Rich Earth team marches in the Strolling of the Heifers Parade.

Have a plan for collection, transport, treatment & application

In starting a UD program, you will need to assess your options for collecting and treating urine, determine how you will work with farmers for urine application, and figure out how you will transport urine or urine-derived products between locations. This is not 'one-size-fits-all.' What works best for one UD program will differ from another based on your unique regional context, the scale of the project, and myriad details that affect economics and logistics.

Assess the costs of different approaches you are considering. Project scale (volume of urine processed) and transport distances change the cost structure of the project and may impact which treatment methods are most cost effective. Think through the whole UD program to get a sense of what factors will influence your choice of approach. For example:

- **Project scale and climate impact the treatment approach.** Storage is the easiest, cheapest, and most straightforward treatment for pathogen reduction. If you are working with a volume of urine small enough to store, consider this option. For large volumes in cold climates, pasteurization or other approaches will likely make more sense, but building an efficient pasteurizer requires technical skills and knowledge or the budget to purchase one.

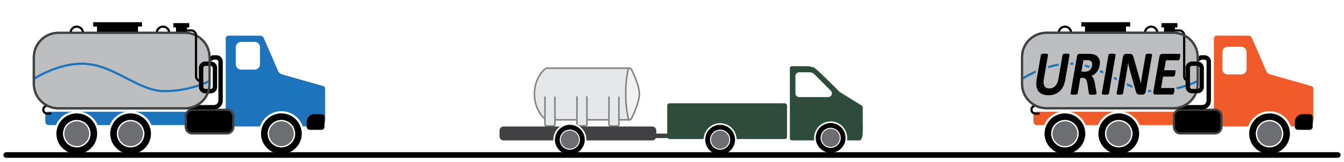
- **Density of urine donors impacts collection cost so consider size of tanks.** You don't want to drive long distances to fill a collection truck tank, so if donors are far apart give them larger tanks. If many donors are clustered in a small area, small tanks are fine.

- **Wider geographic area impacts treatment.** If you will be transporting urine long distances, consider doing volume reduction at regional collection facilities before transporting for further treatment or farm application.

- **Collection logistics matter.** For a community scale UD program, it has to be easy to fill up the transport vehicle and drive away. Make sure urine donors have containers you can pump out quickly – we once helped a urine donor empty 30 one-gallon jugs into the truck—that took some time!

At Rich Earth

At Rich Earth we have moved from on-farm treatment to treatment at our own central facility. We made this shift to reduce the infrastructure required from the farmers. We now deliver a finished fertilizer product to the farms. It is also simpler to do treatment where we work, particularly now that we are collecting with our own truck and delivering to multiple farms. Our current truck carries four 1000 liter tanks.



Overview and considerations

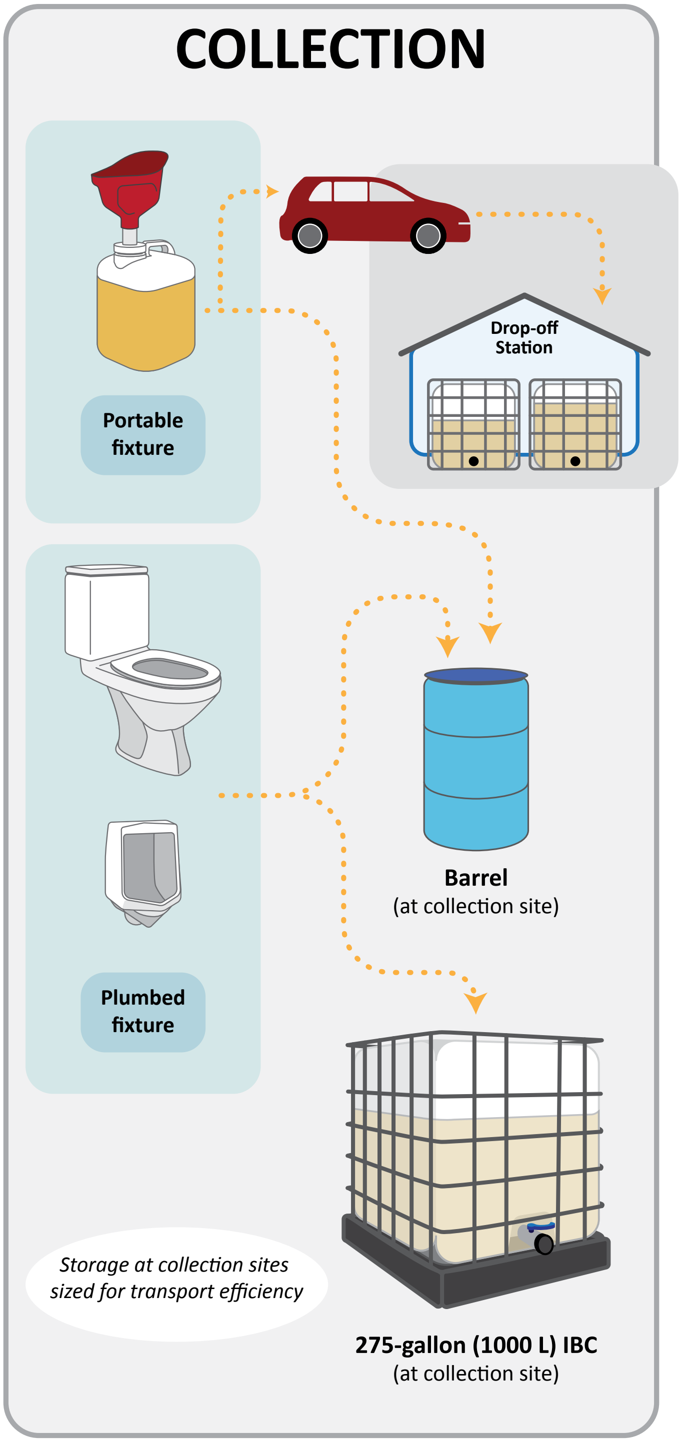
There are many ways one could set up collection for a community-scale UD program, depending on intentions for the system and community needs and characteristics. The Rich Earth Institute's aim was to develop a U.S-based urine-recycling pilot program explicitly focused on community engagement and using a variety of low-tech collection approaches in a rural community. In contrast, a UD program focused on serving commercial and institutional buildings, taking a high-tech approach using porcelain urine diverting fixtures and permanent plumbing, could require little to no engagement by donors. A city-scale UD program with dedicated citywide UD plumbing could have very different collection considerations than a UD program with urine transported in tanks by truck.

The following overview of Rich Earth's experience and knowledge pertains most directly to a similar low-tech, high-engagement approach, with some tips on UD fixtures and plumbing that are relevant to other systems. Regardless of the degree of proactive donor engagement, level of technology, and system scale, the key to success for any UD program lies in streamlined and cost-effective collection logistics and a positive user experience.

At Rich Earth

Rich Earth UD program participants are volunteer donors who use one of the following methods for urine collection:

6. A stand-alone urine-only unit with an exchangeable tank (see "Stand-alone/portable collection units" on page 12), or other small collection container. Participants use a personal vehicle to bring full containers to a central collection facility, where they empty their container at a vacuum pumping station. A pumper truck transports urine from the central collection facility to the treatment facility.
7. A stand-alone urine-only unit with an exchangeable tank, or other small collection container. Donors empty the portable containers into 55-gallon barrels or 275-gallon tanks outside the donor's home. A pumper truck collects urine from the container and transports it to the treatment facility.
8. A urine diverting toilet plumbed to a storage tank, typically 1000 L (275 gallon) capacity located in the basement or in-ground. A pumper truck pumps urine from the tank and transports it to the treatment facility.



Engaging donors

Given the novelty of urine diversion in the US, we expect that many UD program initiatives in the near term will want and need to focus explicitly on donor engagement. That said, certain projects could be designed to be virtually invisible to donors, such as a commercial urinal-only UD system, making donor engagement optional.

There has been very little social research on acceptance of urine diversion. Research currently in progress at the University of Michigan is looking at public acceptability of urine derived fertilizer, but there is as of yet no U.S. research on adoption of and adaptation to urine diverting bathroom fixtures. While we have no quantitative research, over time we have noticed a few patterns in how people relate to UD from our on-the-ground experience.

In our experience, people's reception of the concept depends highly on the messaging—both what you say and how you say it. We have found that people react more positively when we explain clearly and directly what we are doing and why, without sheepishness, apologies, or assumptions that they will think the idea is gross or comical. It is important to respect the 'ick/giggle factor' when it comes up, but most people we have talked with are much more open to the idea of urine diversion than we would have expected. A very common response is to be personally receptive to the idea of urine diversion, but doubtful that others will be so open-minded. It may be that we expect the taboo around human waste to apply to urine diversion more strongly than it actually does.

When potential donors learn the basic science and begin to understand their role in completing the food nutrient cycle, their interest in UD increases. We've seen people form an intensely personal connection to the process, getting profound satisfaction from the knowledge that something coming out of their bodies can give life to growing plants and do good in the world. Quite a few participants have become highly vocal advocates based on this understanding.

At Rich Earth

Hundreds of individuals have participated as urine donors since the program's inception in 2012, collecting approximately 30,000 gallons of urine. In 2018, we collected more urine than ever before—a whopping 6,584 gallons!

	Urine Collected	Water Saved	Total N Diverted (lbs)	Total P Diverted (lbs)
2012	600	18720	30	2
2013	1000	31200	50	3
2014	4423	137998	221	13
2015	4895	152724	245	14
2016	6162	192254	308	18
2017	6150	191880	308	18
2018	6584	205421	329	19
TOTAL	29814	930197	1491	87

FESTIVAL TOILETS

Rich Earth has developed portable toilets that we have provided to approximately 20 events over the last 2 years, collecting over 1,100 gallons of urine. Festival toilets are a great way to reach a broader audience with information about UD, and also quickly collect a large volume of urine. We have developed three portable toilet models: a urine-diverting sawdust composting toilet, a sawdust composting toilet with urine collection only from the wall-mounted urinal, and a pee-only toilet. We also use a four-position urinal structure imported from Europe that can privately serve four urinal users at once. For another US-based festival toilet example, based in Portland, OR, see www.naturecommode.com. Internationally, A Natural Event, in Australia, Europe, and the UK, has provided ecological sanitation for hundreds of events since 2002.

UD PROGRAM TOOLKIT:

- **Rich Earth introductory powerpoint**
- **Urine donor instructions**

Our initial outreach strategy was to recruit volunteers for a scientific research project. One board member announced the project at a community chorus rehearsal and another spoke at church on Earth Day, suggesting that this new project addressed sustainability and a new way of thinking about human waste. Some of the early donors who signed up based on those announcements became our best advocates, and the project has grown organically in this community over the years, primarily by word of mouth.

We also recruit new donors at public events. At some events we simply have a booth providing information and urine collection containers for new donors, while at others we provide the sanitation for the event with portable urinals and urine collecting toilets that visitors experience first-hand.

In 2015 we started the annual "Piss-Off Competition" where donors could engage in a friendly contest to see who could donate the largest volume. We didn't anticipate how invested our donors would become in it. People are very excited and competitive about tracking their donations, and every year we announce the winners at an award ceremony, issue a press release to local media, and present winners with framed certificates to display in their bathrooms.

Award certificate and trophy for winners of the annual Piss-Off Competition.

Stand-alone/portable collection units

The Rich Earth Institute has developed a low-cost, odor-controlling portable urinal with a detachable 5-gallon screw-top container for home collection. These stand-alone urinals can be used by all genders and are a simple and inexpensive way to quickly gather urine from volunteers for urine processing and field trials. They also give renters, and others who do not have the option of changing their toilet fixtures, a way to engage in urine diversion and collection.

Although not proposed as a permanent or mainstream collection method, these simple devices have proven very popular with male and female participants in the Rich Earth UD program. Some participants keep them for convenience in places without easy toilet access, such as bedrooms, studios or job sites, while others keep them beside the commode in the bathroom. Women use a variety of toilet inserts to collect urine, urinate directly into a smaller containers, or urinate directly into the urinal with or without a standing urination device (see sidebar). We are making a new urinal setup with a shorter container to make direct standing use by women more ergonomic.

The stand-alone urinal consists of a funnel assembly that screws tightly onto a 20-L polyethylene jug. Odors are blocked by a ping-pong ball that sits inside the funnel on a small plastic ring, floating up when urine is added and then sinking to seal the opening after the urine has passed. A small vent hole with a threaded cap allows pressure equalization within the collection container while minimizing odor diffusion or loss of ammonia through bulk air movement. A fabric sleeve covers the container for aesthetic purposes. Some donors use this "cozy" while others find it unnecessary.

Since these urinals do not flush, it is occasionally necessary to clean the collection bowl using a soft cloth wetted with vinegar or rubbing alcohol. To remove any mineral deposits that may attach to the plastic, dissolve citric acid powder (non-toxic and available online) in a small amount of water, use the solution to soak a paper towel, and lay the wet towel over the area to be cleaned. After an hour or so the minerals will begin to dissolve and can be gently wiped away.

P-style

Nun's cap

PSTYLE AND MORE!

There are a number of devices that make urine collection using our stand-alone urinals an accessible option for everyone. The nuns cap [Image #9] enables collection while sitting on a standard toilet, and urine can then be poured into the unit. There are now a wide range of devices such as the pStyle, SheWee, Lady J, and others, that make peeing from a standing position (directly into the unit) an option for almost anyone. These are typically lumped into the category of "Female Urination Devices" though they are used more broadly.

Rich Earth has made many adjustments to this design, in order to create a positive donor experience using portable containers. We had to ensure the smell, sight, and carrying weight were acceptable to donors. Aesthetic improvements were developed over time in response to feedback from donors. We added ping pong balls and venting for odor reduction. The funnel is placed at a comfortable height for all users. We give donors the option of adding vinegar to the portable unit to keep urea from converting to ammonia, for both enhanced odor control and to prevent nitrogen loss. Donors are also instructed on use of citric acid for cleaning.

If developing your own portable system, make sure the portable jug is of a manageable size for most adults and made of strong plastic with a watertight, gasketed lid. The container should remain sealed during use, other than a small hole for pressure equalization. The matter of sealing is less important if donors use vinegar.

Portable urinal with fabric cover.

Community collection facility

A self-service community collection facility allows small donors to participate in the program in a way that is convenient for both the donor and the program operator. The facility needs to be accessible, self explanatory, clean, and aesthetically pleasing for donors, as well as efficient for operators.

The Rich Earth Institute's Urine Depot is located in downtown Brattleboro in an uninsulated garage with parking. There is a code lock on the door, limiting access to participants only. The depot has two sections—a front room where donors use an automatic vacuum system to empty their container, and a large backroom with 1500 gallons of urine storage capacity.

A tour group visits the urine collection depot.

The donation room is brightly painted, with a crushed gravel floor. Large wall posters explain the donation process. The instructions describe how to use the vacuum system and how to log contributions in the Piss-Off Competition logbook.

To use the vacuum system, a donor places their container on the pump-out stand and pulls down the handle. This lowers a wand into the open top of the container and turns on the vacuum pump, which extracts urine completely from the container. The system then empties the collected urine into the storage tank. The exhaust from the vacuum system vents to the outdoors. Collection levels are monitored via level sensors in each tank, and the mass of urine collected by each pumping is logged online.

The donation room is separated from the urine storage room by painted plywood walls with a locked doorway, easily accessed by program operators. The urine storage room includes six 257-gallon IBC tote tanks connected together to provide 1500 gallons of usable storage. To allow our transport truck to easily and completely collect all the stored urine, permanent suction pipes with cam-lock connectors are installed in each tank. An EPDM liner (the material used for pond liners) acts as a bathtub around the primary storage system. This secondary containment was not mandated by our regulators, but we included it as a precaution against leaks, and believe it demonstrates a very high level of care. On the other hand, secondary containment is an added expense that is not necessary in all contexts.

Because the building is uninsulated, there is insulation around the tanks and a temperature controlled aquarium heater submerged in one of the tanks to prevent freezing of the storage system. Freezing would not damage the tanks, but it could impede flow through our interlinked tanks, and would prevent pumping out of any tank system. If a single tank is used and pump-out is not necessary during the cold months, the insulation and heater could be omitted.

Lessons learned:

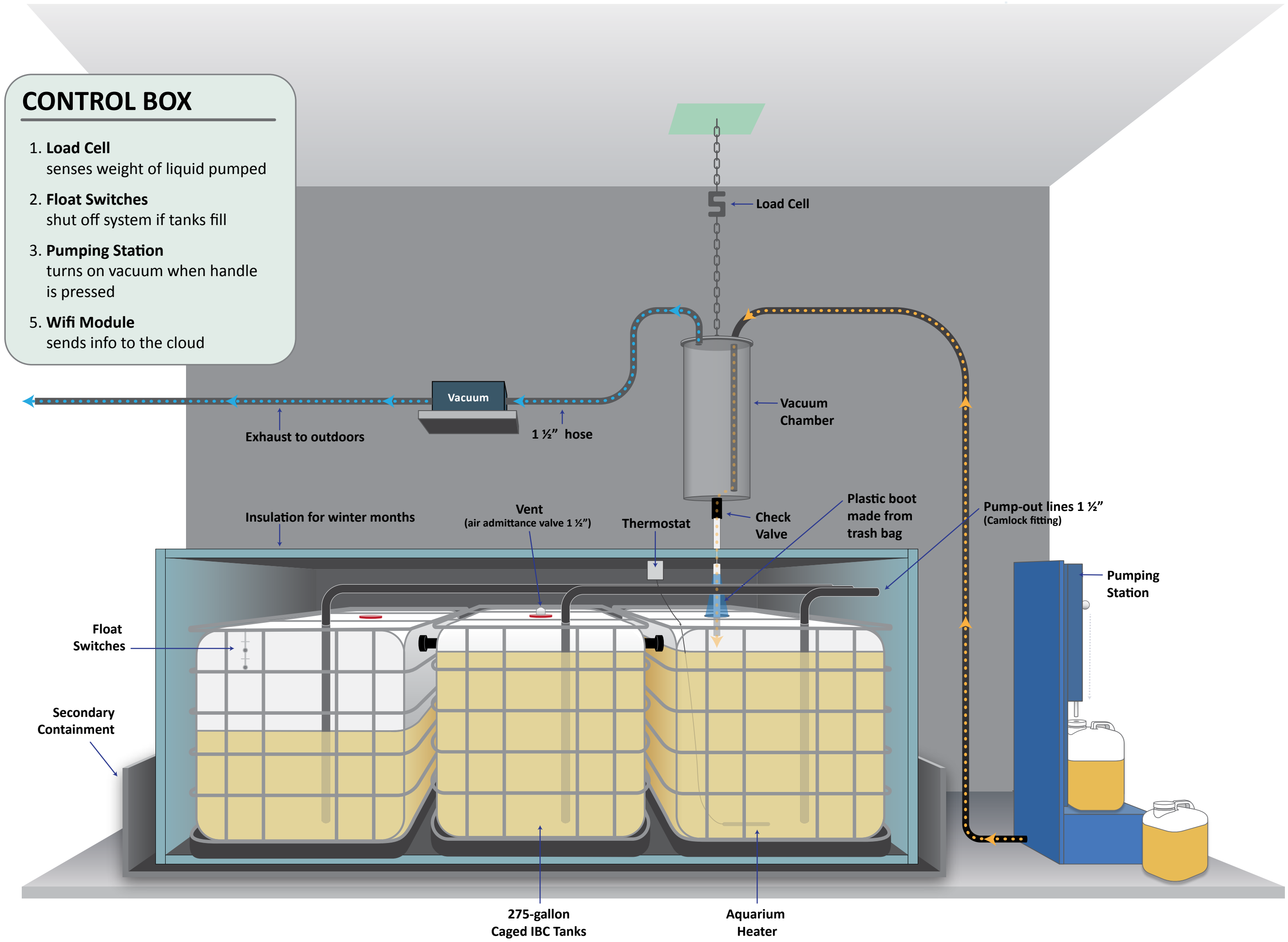
- Provide clear guidance with photos. Not everyone will figure out the finer points of using a pump-out station, (like tipping the container to suck urine out of the corner, or leaving the container under the wand for a few seconds to catch the drips.) Simple instructions with photographs help a lot. (Complex written instructions will fail.)
- Attach important announcements to the pump itself. Once people are used to using the system, they just pump and go. They're focused on pumping and don't notice signs on the walls.
- Tweak as needed. After a user pumps the urine out of their container, the wand drips very slightly into the empty container. When the container is removed, the drips fall onto the pump-out platform instead. To fix this problem, we added hole in the pump-out platform below the wand, so any last drips fall through the hole in the modified platform into a container filled with charcoal, which neutralizes odors.
- Provide alcohol-based hand sanitizer. Provide alcohol-based (not antimicrobial) hand sanitizer at the depot for people to use. It's also helpful for wiping down the pump-out station platform. Alcohol-based sanitizer can clean off minerals that don't come off easily with water.
- Ensure containers are robust and rugged. We started by using old 5-gallon (20 L) cooking oil containers from a local food business, but they were not designed as multi-use vessels and didn't have an adequate seal on the lid. This was sometimes problematic for people transporting urine in their personal vehicles, and we switched to a more expensive, thicker-walled, and leak-free container with a gasketed lid.
- Make record-keeping easy. Use a log book that is organized alphabetically so donors don't need to riffle through many pages looking for their own page. If the depot is a damp space consider using water-resistant paper like "Rite-in-the-Rain" paper.

Self-service vacuum pump-out station for emptying 5-gallon jugs of urine at the collection depot.

UD PROGRAM TOOLKIT:

- **Depot signage**
- **Urine depot specifications**

Central Drop-off Station



Bathroom fixtures/equipment

Bathroom equipment for urine collection includes waterless urinals, urine-diverting flush toilets, and urine diverting composting toilets, all of which can be plumbed directly to urine collection tanks.

Waterless urinals

Waterless urinals are becoming somewhat common in non-residential restrooms, and can be plumbed directly to urine collection tanks. At a commercial scale, this could enable rapid collection with no donor education or behavioral change. Note that many of these units have a proprietary trap cartridge. Once they fill with mineral deposits, these require replacement and disposal, or they will clog. ZeroFlush is one model that has a trap insert that can be flushed clean, potentially reducing the frequency and cost of replacements.

Urine-diverting flush toilets

Urine-diverting flush toilets require little user involvement for maintenance or other management. The toilet bowl area of a urine-diverting toilet is divided: the front half forms a basin with its own drain that is plumbed to the collection tank. When the user is seated, urine naturally falls into this basin and then flows to the collection tank. While the conventional wisdom is that men should sit to urinate in these, we have an EcoFlush installed at our office, and our male staff use it from a standing position without difficulty. Several participants in the project own urine-diverting toilets. The average time to fill a 1000 L tank, reported by one three-person family, is 8 months.

We have worked with both the Wostman EcoFlush and Dubbletten models. Additional models are available internationally. Rich Earth has also developed a low-tech urine-only toilet which was installed at Green Mountain Camp for Girls in 2018. This uses a bench seat with a standard toilet seat and an inset plastic funnel, and was used extensively at the camp in 2018.

Urine-diverting composting toilets

Urine diversion enables a low-maintenance composting toilet system that produces dry compost. These systems do not need a water supply or sewer connection, produce no flush water, and because of their inline ventilation fan can result in less bathroom odor than a flush toilet. While most of the nutrients from human waste are contained in the urine, a composting toilet system enables complete nutrient recovery, and can eliminate the need for separate blackwater treatment.

UD composting toilets do require user education for those accustomed to flush systems.

Once familiar, they are easy to use, but some attention (and behavioral change) may be needed to ensure everything ends up in the right place — for example, sitting down helps ensure the urine is diverted. It is important to clean the urine bowl regularly, particularly with public systems.

Composting toilets designed for urine diversion include the Separett[4] (insert and full unit), Full Circle[5], Nature's Head[6], and Air Head[7].

Plumbing and installation

Urine diverting bathroom equipment must be properly plumbed and installed. Thanks to the leadership of Recode, (which advocates for the inclusion of sustainable technologies in regulatory codes,) standardized guidance for plumbing and installation of urine diverting systems is now part of an official supplement to the widely-adopted Uniform Plumbing Code. The International Association of Plumbing and Mechanical Officials (IAPMO), which maintains the Uniform Plumbing Code, released the WE-Stand 2017 Water Efficiency Standard as an ANSI Standard for water efficiency and sanitation in buildings.

Supplementary codes such as WE-Stand cover innovative practices that are officially sanctioned but not required, meaning that in states that adopt this element of the Uniform Plumbing Code, the systems described are code-compliant but optional. Even in states that do not use the Uniform Plumbing Code or the WE-Stand Supplement, many plumbing boards or inspectors will have the discretion to approve systems that conform to WE-Stand because it is an ANSI standard.

These guidelines are applicable to both residential and commercial installations. The guidance on pipe composition, sizing, and pitch are critical for any installation. This is a significant step for advancing composting toilets and urine-diverting systems, but only if it gets used. Documenting and sharing installations permitted under this code language will help move urine-diverting toilets from the supplementary code into the Uniform Plumbing Code and beyond.

DESIGN TIPS FOR URINE COLLECTION PIPING

The biggest issue with UD piping is clogging of drain lines from mineral deposits. Avoid this through the following design tips:

- Pitch pipes as steeply as practical. We like at least a 1-inch drop per foot of run.
- Make sure there are no restrictions in the line. For example, don't insert a barbed fitting into the downhill end of a rubber hose.
- Avoid low spots or liquid traps where urine will pool.
- Provide cleanouts at bends, or make pipe/hose connections removable.

4 https://www.separett.com
5 http://fullcirclecompost.org/ *Disclosure: owned by Rich Earth's Research Director Abraham Noe-Hays*
6 https://natureshead.net/
7 https://airheadtoilet.com/

Rich Earth participated in development of the Recode / WE-Stand guidelines, a process which is further described on the Recode website.[8] While WE-Stand can be purchased online,[9] it is based on Recode's nearly-identical Model Code for Composting and Urine Diverting Toilets,[10] which is a publicly available document that can be downloaded free of charge. Questions regarding these codes and guidelines can be directed to the Composting Toilet Code Committee Chair Mathew Lippincott.

At Rich Earth

Rich Earth staff and affiliated contractors have inspected and plumbed numerous urine diverting toilets and urinals in VT since the project start in 2012. Most of these have been residential installations, but we are expanding our work into commercial facilities.

Rich Earth worked with the Green Mountain Girls Camp to install the first public, permanent urine collection system in Vermont in their new bath house in 2018. In January 2019, Rich Earth received an implementation grant from the Long Island Sound Futures Fund of the National Fish and Wildlife Foundation to add a number of commercial installations in Vermont, including at a brewery, two summer camps, and a school. The primary objectives of this grant are to (1) create replication sites to further adoption by showcasing UD technology, and (2) address nutrient pollution by increasing nitrogen capture and preventing it from entering Long Island Sound.

Urine collection tank connected to a urine-only toilet at a summer camp for girls in Vermont.

On-site assessment

The layout, plumbing, and storage capacity at each home or business facility is unique. In order to retrofit or install the most appropriate urine diversion technology in each location, a skilled practitioner must assess the site, determine a short list of options, explain these to the owner, and conduct the installation. In starting a UD program, this could be developed as an in-house capacity, or alternately, as a service independently provided by contractors skilled in UD systems. Find out who does related work in your region. This is potentially a business opportunity for builders, plumbers, and others, and the more widespread these skills become the easier it becomes to initiate UD programs across the country. Note that this is a very specialized skill.

At Rich Earth

Rich Earth conducts at least one site visit per location. These site visits enable Rich Earth to take photos and measurements, walk through the facility with the owner(s), and begin discussing the best options to suit the needs of the facility. Rich Earth staff, contractors, and board members have done these visits all over New England.

At Rich Earth we contract with Connor Lally of Nutrient Networks to handle many of our installations, so Connor often does the site visits. Following the site visit, Connor and Rich Earth staff discuss and determine a short list of the best urine diversion or other sanitation options that will be presented to the facility owner(s) in a written report.

8 http://www.recodenow.org/portfolio/developing-national-model-code-site-built-and-urine-diverting-composting-toilets/
9 WE-Stand 2017 Water Efficiency Standard (for purchase)
10 ReCode Composting and Urine Diversion Toilet Model Code (free)

Connor prepares an Ecological Sanitation Site Visit Report, which is approved by Rich Earth and then distributed to the facility owner(s). This report recommends technology options that help facility owner(s) determine the best ecological sanitation option. Information in this report includes model numbers, photos from the site visit, a site assessment, installation costs, output projections, narrative description of proposed technologies, reference information, and an aerial map (as appropriate).

UD PROGRAM TOOLKIT:

Example ecological sanitation site visit report produced by Connor Lally.

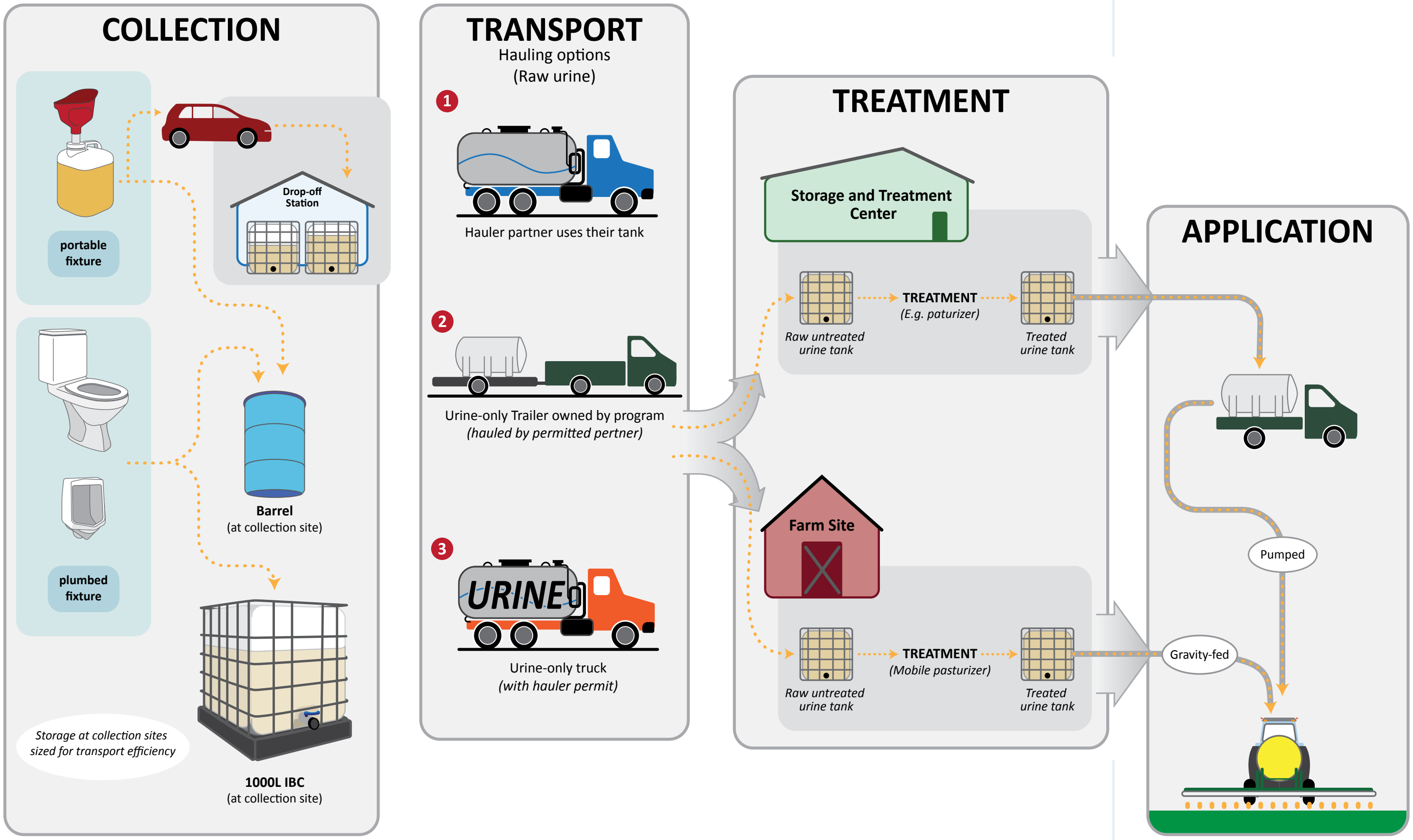
Rich Earth collects urine at public events using modified portable toilets.

Overview and considerations

This section covers bulk transport and storage considerations. Urine will need to be transported from distributed collection sites (homes, businesses, portable toilets) to centralized collection and treatment, and then to participating farms for application, or directly from collection sites to a participating farm.

In developing a UD program, costs and logistics of transport go hand in hand with decisions about where to do treatment and storage and what kind of treatment to do. Urine is bulky and heavy, and if your transportation strategy is too energy-intensive, the negative impact of fuel use could outweigh the positive impact of improved nutrient cycling. Pre-concentration can expand the viable distance between collection site and farm application.

Transportation and Storage



Keeping it clean

Make sure any jugs used for donor transport have gaskets. Containers used for cooking oil have lids that aren't watertight. This kind of jug can get pinhole leaks, and will drip in the car if it tips over. Use heavier duty jugs with rubber gasket built into the lid.

We instruct donors to use OxiClean™ to clean up any spill. Oxiclean turns into hydrogen peroxide in contact with water and is excellent at removing urine odors. We use it to clean up any urine spill or leak.

Hauler partners and permits

To transport large volumes of untreated urine from the collection depot to farms requires an appropriate truck with a septage license. Partnering with a septage hauler is a good way to get started. However, it's important to work with your hauler partner to understand how hauling urine for farm application will differ from their typical process.

Options

- Partner with a septage hauler using their equipment
- Partner with a septage hauler, but provide a dedicated tank or trailer with tank(s)
- Acquire a dedicated truck, and become licenced as a septage hauler

The Rich Earth Institute's urine hauling truck can transport 1000 gallons of urine at a time in four IBC totes.

Considerations

- **Check regulations for your area** – In Vermont, transporting urine in a small truck or trailer does not require a hauling permit if it is not for hire.
- **Transport after treatment** – Once urine is pasteurized using a permitted system, it is no longer regulated as human waste, and in Vermont no special permit is required to transport it. It may be provided freely to farmers and gardeners alike for transport in their own vehicles. Regulations may vary in other jurisdictions.
- **Quantity and frequency of urine transport** – For smaller projects, working with a septage hauler and using their existing equipment often makes the most sense; this changes as the UD program increases in scale.
- **Ease of washing** – Some septage tankers are better for washing out than others. Cleaning a septage tank can take considerable time for the hauler; or they may not be able to clean the tank at all. To get around issues with tank cleaning, a project could set up a trailer with a dedicated tank and pump.
- **Kinds of tanks** – We currently use a small vacuum tank with a hybrid vacuum pumping system that transfers urine into our large non-vacuum tanks (see 'Pumps' below for the different pumps we've tried).

Pumping urine into a freshly-washed septage hauling tanker truck.

- **Prepare for spills** – Slaked lime is typically used for sanitizing small spills in septage hauling. If you do your own hauling, cary a container of slaked lime for this purpose.

At Rich Earth

Rich Earth now has a septage licence/hauler permit, and our own truck for urine transport. Until recently, a local septage hauling company, Best Septic Services of Westminster, provided urine transport for the project.

Best Septic Services' innovative work developing methods for the practical and economical transport of urine using standard industry equipment was featured in Pumper Magazine.[11]

11 "Vermont Pumper Participates in 'Peecycling' Study," http://www.pumper.com/online_exclusives/2015/05/vermont_pumper_participates_in_peecycling_study

One of the company's portable toilet service trucks was configured with a dedicated tank compartment for urine, allowing the driver to collect urine while also conducting portable toilet service. Their urine transport fee of $0.10/gal was lower than their standard rate for septage because unlike sewage treatment plants, participating farms did not charge a tipping fee.

We stopped working with Best Septic for logistical reasons. Our hauler had one truck with a small tank divided into a 300-gallon partition for sewage and a 100-gallon partition for urine (originally for non-potable water). This was quick to operate but had a small urine capacity. Another truck with a 500-gallon septage tank was also available, but before hauling a urine load they had to spend significant time washing out the tank. As Rich Earth's demands grew this became unfeasible, and we have found having a dedicated truck to be more practical for our operation. Our flatbed truck can carry 1000 gallons in four standard IBC tote tanks, which are much less expensive than a septage hauling vacuum tank.

Pumps

Any UD program will need a range of pumps to transfer urine between different parts of the system. Pumps need to be non-corrodible, relatively easy to clean, and appropriately sized. We've tried a wide variety of pumps–and can say from experience that your choice of pump matters!

We use cam and groove (or camlock) style quick disconnects to enable a fast, gasketed connection for pump out. These fittings are operated without tools by moving levers that are integrated into the female fittings. Hoses can be stored without leaking by connecting the camlock ends together. Caps are also available.

Camlock Fitting

At Rich Earth

Rich Earth has tried a wide variety of pumps to transfer urine from storage tanks to the truck for transport. These include:

- **A single-diaphragm pump** – *which generally worked well until it wore out*
- **Multi-diaphragm pumps** – *which clogged easily*
- **Macerator pumps** – *which worked well*
- **gas-powered trash and water transfer pumps** – *which corrode*
- **Chemical transfer pumps** – like the water transfer pump, but all plastic – *which worked well*

We are now moving toward a hybrid system incorporating a vacuum pump (see the "Hybrid Vacuum Pumping System" illustration on page 23), which is a variation on the standard equipment for septic haulers. If pumping more than 100 gallons at a time, a vacuum pump or air diaphragm pump is likely the most effective, though a chemical pump is less expensive. For pumping 100 gallons or less, the macerator pump works well.

PUMPS WE'VE TRIED:

Flowjet quad head diaphragm pump 12v - 3 gpm

- Troublesome overall. The pump worked well with clear urine but clogged easily on mineral particulates at the bottom of tanks. With a prefilter, the pump didn't clog, but the prefilter would clog and need cleaning.
- One benefit was that the pump was not harmed by running dry.

Jabsco macerator pump 12v high current (10 amps) - 10 gpm

- Built for flushing marine toilets, this pump is very clog-resistant. It can pass mineral sludge or soft organic material, but not metal, wood, or stone fragments. We learned this the hard way, by twice sucking up metal fasteners from the bottom of brand new portable toilets. Fortunately the pump can be disassembled to remove the blockage. If there is any possibility of hard fragments, use a course intake screen (⅛") or inline filter screen to keep out foreign objects.
- Good for mobile use. It runs well off of a 12V motorcycle or car battery.
- Don't let this pump run dry for more than a few seconds.
- This pump can handle about 100 gals at a time before stopping automatically due to overheating.

Trash pump and water transfer pumps gas powered, 180 gal/min

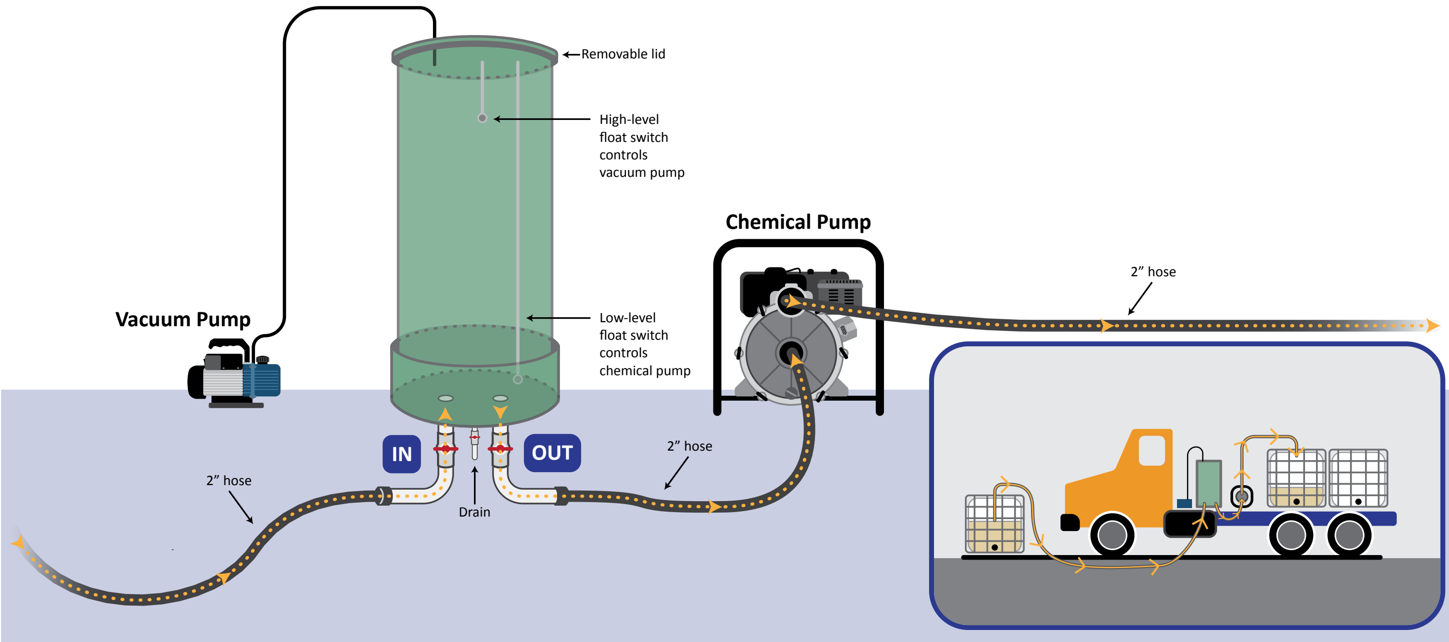
- The aluminum bodies of these pumps will corrode eventually. They work best if rinsed thoroughly after each use (but that's a hassle).
- Requires 2" "Tiger Tail" style hoses with camlock fittings.
- Chemical transfer pump gas-powered, 154 gpm.
- This plastic pump worked well overall but was difficult to prime. We mostly overcame this challenge by using a small diaphragm pump to pump urine into the upper priming port. When the pump is turned off, the 2" hoses remain full of urine, making them quite heavy (also true of trash and transfer pumps).
- Susceptible to damage by foreign objects. We sucked up gravel and broke internal parts of the pump, which required a $70 rebuild kit to repair. Add a strainer on the intake or an inline filter/screen to avoid this. We used a BANJO 2" inline Y strainer 6 mesh, which is very simple to remove for cleaning.
- Requires 2" "Tiger Tail" style hoses with camlock fitting.

Air diaphragm pump.

- An air diaphragm pump runs off of compressed air. We haven't used one yet but are considering it for the future because it is a simpler mechanism. However we are not sure it will be able to fully empty the transfer hoses, and it may take a large amount of compressed air.

Rich Earth Institute's prototype hybrid vacuum pump system.

Hybrid Vacuum Pumping System



3 CFM vacuum pump, 40 gallon vacuum tank,154 gpm chemical transfer pump

- Our current setup for pumping onto and off of our truck (see the "Hybrid Vacuum Pumping System" illustration above).
- The vacuum pump draws urine from the full onsite tank (the tank being collected from) into the vacuum tank, filling it. When the vacuum tank is full, a float switch shuts off the vacuum pump. The urine in the vacuum tank primes the chemical transfer pump, which is then started and does the rest of the pumping. The level of urine in the vacuum tank does not change, and it simply acts as a reservoir to keep the transfer pump primed. When the onsite tank finally empties, the the transfer pump draws down the urine level in the vacuum tank until a another float switch shuts off the transfer pump. Lastly, we clear the line by closing the intake valve, using the vacuum pump to build vacuum in the tank, and then opening intake valve, purging the line into the vacuum tank.
- Although slightly complex to operate, the reliable priming of the pump and vacuum purging of the intake hose make this our favorite system for pumping large volumes of urine.

Storage containers

Fertilizer demand is seasonal, so storage tanks must be sized to hold urine until it can be applied. Because the ammonia in stored urine is volatile, it must be kept in sealed containers. 275-gallon IBC totes and 55-gallon plastic barrels are widely available and work well. When venting for pressure equalization is needed, a hole and small-diameter (e.g. ¼") tube can be used. Additional measures such as air admittance valves, (available from plumbing suppliers,) should be included to prevent tank collapse if urine is to be removed from a closed tank with a fast transfer pump. Urine can be frozen in these containers as long as the container isn't so full it cracks. Given climate conditions and the expectation that stored urine may freeze, it is recommended to leave several inches at the top of a tank so that frozen urine will not break the tank. Freezing the urine does not impact the nutrient content.

The economics of urine recycling could be improved by methods for either concentrating the urine to reduce its volume, or stabilizing the nitrogen so that it could be held in less costly unsealed storage containers.

At Rich Earth

At the Collection Depot, participating farms, and some individual donor locations, urine is stored in 275-gallon (1000 L) polyethylene tanks (IBC totes). These tanks are widely available reconditioned for about $100 each, for a unit cost of $0.36/gallon of storage capacity. In the short term, tankage is the largest equipment expense for our program, though assuming a ten-year service life and one filling per year, tankage costs would drop to $0.04 per gallon of urine recycled.

- The collection depot uses 6 IBC totes joined together for a total capacity of 1500 gallons.
- Participating farms each have one or more IBC totes, depending on usage. The need for these is declining as we're moving toward on-demand delivery.
- Some donors have urine-diverting fixtures plumbed directly into a single large tank (see "Bathroom fixtures/equipment" on page 15).

We put covers over exposed containers to protect them from the sun, as they are not UV resistant. We have tried both EPDM plastic and a woven polyester "chain link fence privacy screen" for sun protection. The woven polyester is inexpensive and porous so it won't hold pooled water like EPDM.

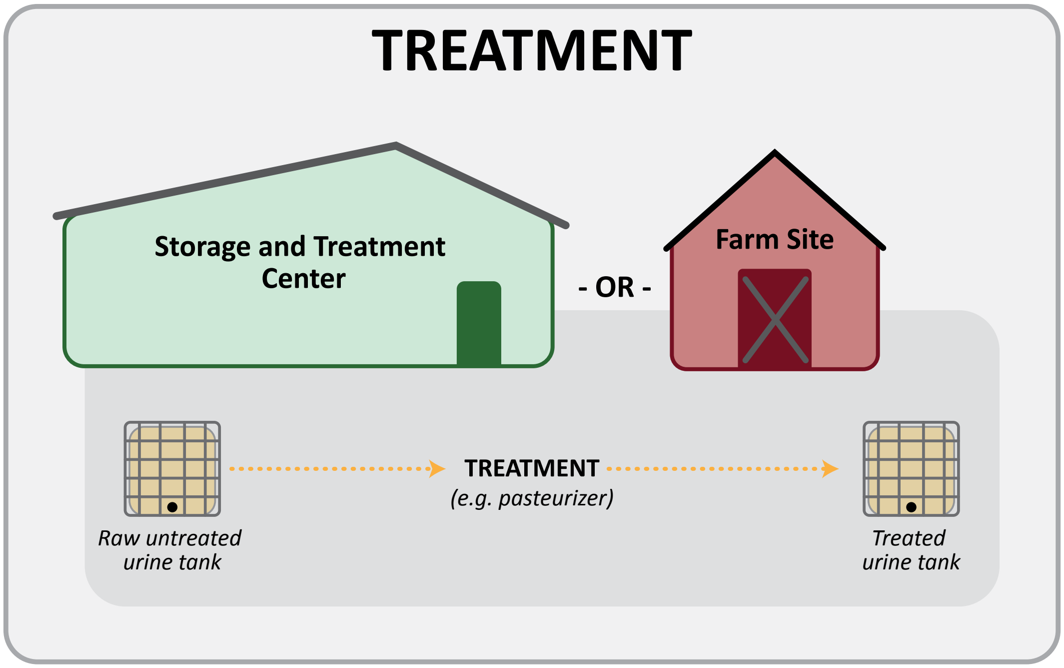
In 2019, we are shifting to centralized treatment and storage at the Rich Earth facility, and will bring treated urine to the farm on the day of application. Now that we're transporting urine in our own truck that is housed at Rich Earth headquarters, this is just simpler logistically.

IBC totes filled with urine. Note melting snow in foreground–these tanks store frozen urine throughout the winter without damage.

Overview and considerations

Urine collected in a urine diversion program can be treated using a variety of methods that can be organized into the following types of treatment: pathogen reduction (PR), concentration (C), pharmaceutical removal (Pharm), aesthetics (A), phosphorus reclamation (P), and nitrogen stabilization (NS).

Which types of treatments are necessary for a given community UD program will depend on the scale and specific details of the project. Pathogen reduction may be the only type of treatment necessary in many community UD projects. Which treatment options you use within a treatment type will also depend on the technical and engineering capacity of your team. Rich Earth has explored and refined a variety of treatment methods to inform both research and practice. These are summarized below in Treatment Options Summary table.



At Rich Earth

Prior to land application, all urine is sanitized using methods approved in Rich Earth's permit from the Vermont Department of Environmental Conservation. We have tested four methods of pathogen destruction, in order to assess their practicality at the scale of our UD program: 1) storage at 20°C for 30 days, 2) pasteurization at 70°C for 30 minutes using a solar heater, 3) pasteurization at 80°C for 1.2 minutes using an electric heater, 4) high-temperature composting. We currently pasteurize all urine using an electric heater and a high-efficiency (80%) heat exchanger.

To reduce volume, we have experimented on a small scale with both reverse osmosis and freeze concentration, using aged urine and acid-stabilized urine. We are working toward incorporating freeze concentration into our full-scale UD program.

To prepare small volumes of urine-derived fertilizer for field trials, we have produced struvite powder and used activated charcoal for pharmaceutical removal, but we do not use either of these methods on a regular basis.

Our experiences with all these treatment methods are described below.

TREATMENT OPTION SUMMARY

	What it does*	Feasibility/ Benefits
Long Term Storage (6 mo.)	PR	Lowest startup cost at small scale. Logistically challenging at high volumes.
Storage at 20 °C or higher (>1 mo.)	PR	Lowest startup cost at small scale. A viable strategy today in warm climates or indoors.
Pasteurization	PR	Short processing time, and recognized by the US EPA as a Process to Further Reduce Pathogens. Requires energy input. A heat exchanger can reduce energy cost by over 80%. Construction consultation available from Rich Earth, finished pasteurizer units available soon.
pH Adjustment using slaked lime (alkaline)	PR, A, NS	Simple in theory, limited lab demonstration. Works only with fresh urine. Requires purchase of lime. Most appropriate where agricultural soils benefit from added lime.
pH Adjustment using vinegar (acidic)	A, NS	Greatly reduces odors. Easy and reliable. Requires purchase of vinegar. Not practical for treating aged urine.
Biological Nitrification	A, NS	Produces the best liquid product in terms of odors and nitrogen stabilization. Technically challenging, and requires sophisticated controls.
Activated Charcoal/Carbon Sorption	Pharm	Capable of removing pharmaceuticals and other trace chemicals from urine. Not a necessary step in many UD contexts, but available if pharmaceutical removal is specifically required. Used for treating wastewater in some municipal and industrial treatment systems.
Evaporation	C	Simple and energy efficient when warm, dry air is available. Requires nitrogen stabilization of the urine prior to evaporation to prevent nitrogen loss.
Reverse Osmosis	C	Low energy consumption. Expensive equipment. Membrane clogging is an issue. Improved by nitrogen stabilization (acidification or nitrification) to prevent nitrogen loss and clogging.
Freeze concentration	C	More robust than reverse osmosis, but if using mechanical refrigeration may be somewhat more energy intensive. Potential for very low energy consumption if employing passive freezing and thawing in a cold climate at ambient temperatures, but only viable in winter.
Composting	PR, Aesth, C, NS	Produces an aesthetically pleasing product familiar to farmers and gardeners. For composting, urine must be paired with a very bioavailable carbon-rich feedstock (leaves, not wood shavings).
Struvite precipitation	P	Chemical reaction using added magnesium to precipitate struvite, a solid phosphorus fertilizer product. Useful when separate nitrogen and phosphorus fertilizer products are desired.

* Pathogen Reduction (PR), Concentration (C), Pharmaceutical removal (Pharm), Aesthetics (A), Phosphorus reclamation (P), Nitrogen Stabilization (NS).

Pathogen reduction

The treatment options described in this section apply to community-scale UD programs (for household use, see sidebar "Home-scale reuse" on page 4).

Urine itself contains very few pathogens that can survive outside the human body, and the primary source of pathogens in diverted urine is from fecal cross-contamination from UD toilets. For a community-scale UD program you will need to develop a pathogen management strategy that works in the context of the project scale, local climate, and regulatory environment. Long-term storage, pasteurization, alkaline pH adjustment, and co-composting are all options to explore.

Long term storage

The simplest treatment method available today for pathogen reduction is storage in a sealed container for 30 days or longer, to take advantage of the sanitizing effects of the high pH and naturally occurring ammonia found in aged urine. The WHO guidelines recommend long storage times and warm temperatures (20 °C/68 °F for 6 months) to produce a highly sanitized product recommended for all crops, or shorter storage times (30 days) or cooler temperatures (4°C/39°F) to produce a less-treated product for use only on certain crops. The 2006 WHO guidelines that established this method for pathogen reduction (see table below) were the basis for Rich Earth's first project permit.

Recommended guideline storage times for urine mixture[a] based on estimated pathogen content[b] and recommended crop for larger systems[c] (from 2006 WHO guidelines)

Storage temperature	Storage time	Possible pathogens in the urine mixture	Recommended crops
4°C	≥1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4°C	≥6 months	Viruses	Food crops that are to be processed, fodder crops[d]
20°C	≥1 month	Viruses	Food crops that are to be processed, fodder crops[d]
20°C	≥6 months	Probably none	All crops[e]

a Urine or urine and water. When diluted, it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/L.

b Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized as causing any of the infections of concern.

c A larger system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from which the urine was collected.

d Not grasslands for production of fodder.

e For food crops that are consumed raw, it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

At Rich Earth

Rich Earth's first permit included storage at 68°F (20°C) for 30 days. We did not try to get >6 month storage approved, as this wasn't a logistically sensible process for us.

To achieve the target temperature, four 275-gallon IBC totes (palletized tanks) of urine were placed in an unheated greenhouse constructed for the experiment. Temperature probes monitored urine temperature, as well as air temperature inside and outside the greenhouse. Of the methods we have tried, this one was the simplest to execute and document, requiring only the installation of a data logger with submersible temperature probes. Yet even with tanks enclosed in an unheated greenhouse, the target temperature was reached only between June and September, limiting usefulness in our temperate climate.

Pasteurization

Pasteurization kills pathogens with heat. The primary advantages of pasteurization over long-term storage are speed, cool-weather operation, and official recognition by the US EPA and state environmental departments as an approved method for destroying pathogens in human waste. Because so much energy is required to heat urine to pasteurization temperature, it is very important to design urine pasteurizers with efficiency in mind–otherwise the energy consumption of pasteurization could negate the benefits of urine diversion.

Solar pasteurizer: solar panels on left, insulated urine tank behind on right.

At Rich Earth

Efficient pasteurizers are challenging to build. Rich Earth has developed two custom-built urine pasteurizers and is working on a third. Our aim has been to create a highly energy efficient and practical system. Urine recycling is in theory much less energy intensive than alternative nutrient management approaches, and Rich Earth is focused on ensuring that it remains so in practice.

Our first pasteurizer was a solar powered system using solar thermal panels. This batch system could process 40 gallons (150 L) of urine per sunny day. At the time we didn't have much urine to process, and we only worked at one farm location. As Rich Earth expanded operations to two farms, we decided it would be too challenging to mount the large, heavy solar panels to a mobile trailer, and the treatment rate in the batch system was not high enough to keep up with our growing needs.

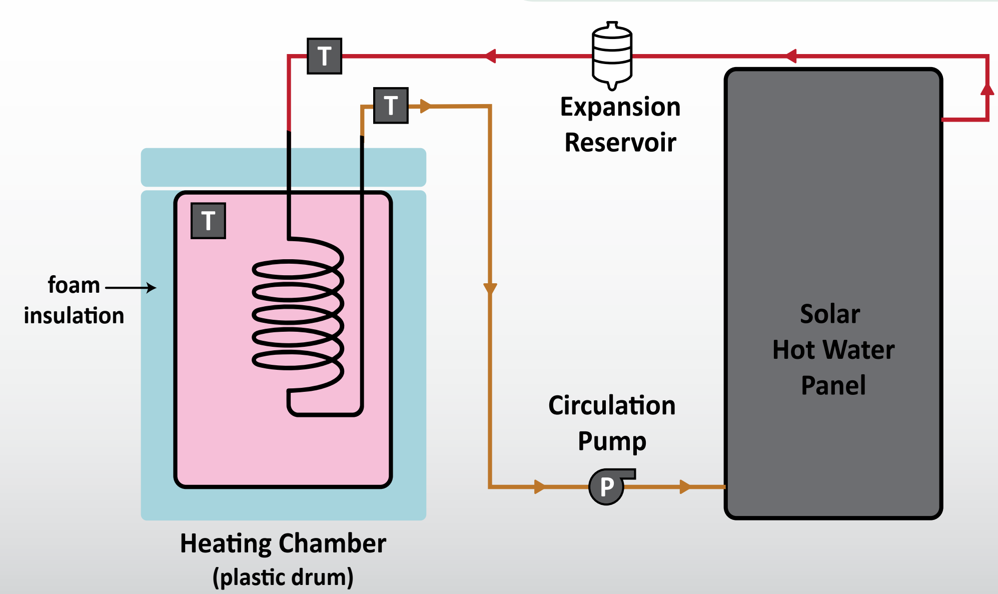
Solar Thermal Batch Pasteurizer Schematic

LEGEND

P Pump **T** Temperature Sensor

NOTES

1. Urine is pumped manually into the heating chamber (not illustrated).
2. Circulation pump moves hot water or glycol through solar panel and heat exchange coil, transferring heat to urine.
3. Leftmost temperature sensor indicates when urine has reached pasteurization temperature.
4. After pasteurization, urine is pumped out manually (not illustrated).



We next built a mobile electric-resistance pasteurizer that could process 750 gallons (2850 L) of urine per day. This increase in processing speed was achieved partly by moving to electric heating, but mostly by switching from batch operation to continuous flow with a heat exchanger. We kept the energy demand low (and enabled the high processing speed) by using a heat exchanger to reclaim 80% of the heat from the pasteurized urine as it exited the system, and redirecting it into the raw urine that was entering. The energy used for sanitizing urine with this system is about 50 watt-hours/gallon (13 watt-hours/L), for a cost of a little under $0.01/gallon. The electric-resistance pasteurizer, operated under a 10-year state permit, is mounted on a lightweight 4′ × 8′ trailer. It is fully automated with automatic temperature and flow controls, redundant high water cutoffs, and overflow containment.

We have made schematics of both of our pasteurizers available open source for others to work from. In return, we would appreciate hearing back about other successful systems. Please contact us if you are interested in having us build you a pasteurizer. We have not found any off-the shelf pasteurizers available for purchase that are appropriate for this application.

Possible improvements that could be more efficient than our current system: 1) solar thermal panels paired with our new continuous flow, heat-reclaiming system; 2) using a heat pump instead of electric resistance to heat.

Electric resistance pasteurizer with heat exchanger for energy recovery.

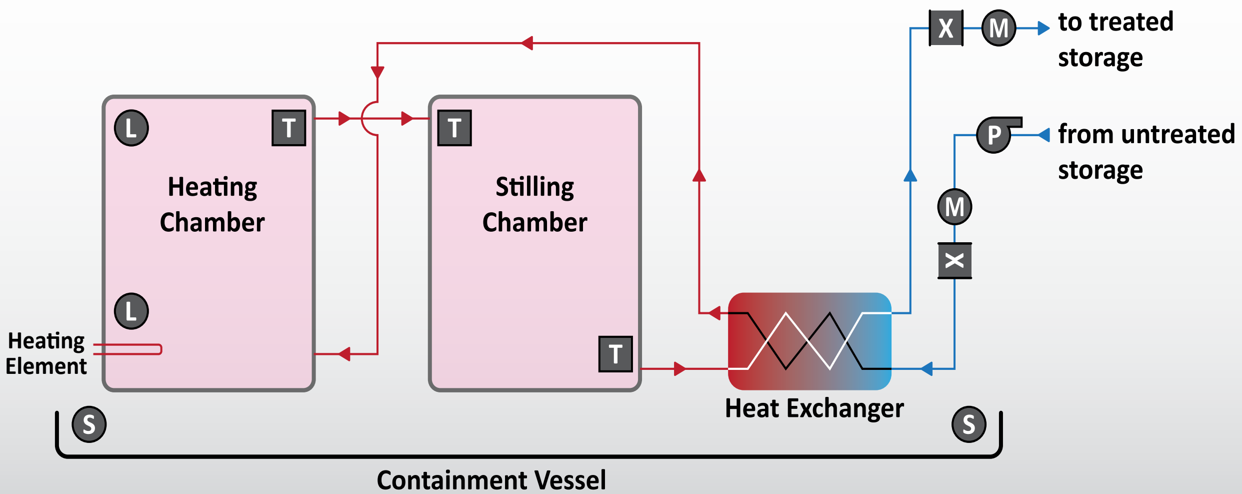
Electrical Resistance Pasteurizer Schematic

LEGEND

- P Pump
- S Level Switch
- M Flow Meter
- T Temperature Sensor
- X Valve
- L Level Sensor

NOTES

1. Temperature sensors, level sensors and flow meters are connected to a digital logic controller.
2. Level switches are connected to independent pump shut off.
3. Flow rate and heater output are regulated by the logic controller to ensure that residence time and temperature within the stilling chamber are sufficient to meet treatment requirements.



Specifications of Rich Earth Institute's two pasteurizer systems

Solar Pasteurizer:

- 160 L/day capacity.
- heated by solar thermal panels
- batch mode

Electrical Resistance Pasteurizer:

- 3000 L/day capacity.
- electric resistance heating and a heat recovery system
- continuous flow
- energy consumption ~ 13 Wh/L of pasteurized urine
- at current electric rates costs under $0.01/gal ($0.003/L).

SOLAR THERMAL OR ELECTRIC?

Solar thermal and electric pasteurizers are both worth considering, but don't just assume one is better for the environment or budget. Solar thermal systems use less electric power, but electrically heated systems require fewer materials to construct. Here are some things to consider:

Solar thermal could work well in an operation with a large and regular urine supply that could be pasteurized on a semi-continuous basis. An electric system may be better for rapid processing or mobile operation.

Do an energy calculation for how much electricity it would take to do pasteurization with an electric heating element and heat exchanger. Consider the embodied energy and cost of thermal solar panels in comparison. With heat recovery through a heat exchanger, an electric system could end up being faster, less resource intensive, and less costly. Or with steady operation over a multi-year timeframe, solar thermal pasteurization could come out ahead.

Do you have a site with good solar access? If so, compare solar thermal panels dedicated entirely to pasteurization vs. solar photovoltaic panels that could power an electric pasteurizer when in use, and other power needs at other times.

Whether you use solar or electric, consider how you might employ a heat exchanger for heat recovery—recycling 80% of the heat from pasteurized urine to warm incoming unpasteurized urine.

High pH adjustment

Raising the pH of fresh urine above 12 by adding slaked lime (aka hydrated lime or $Ca(OH)_2$) has several effects. It kills pathogens, prevents odors from forming, and stabilizes nitrogen by keeping it in the urea form. It is simple, fast, and, like pasteurization, is already recognized in existing wastewater regulations and familiar to regulators as a sanitization method. Inexpensive meters are available to measure pH.

A substantial practical challenge with this method is that the slaked lime must be mixed into the urine while the urine is still fresh. Fresh urine cannot simply be added to a tank containing slaked lime–the tank must be mixed, probably several times a day on an automatic timer. This strategy requires purchase of slaked lime, with the associated cost and carbon footprint. In regions where lime is used as a soil amendment, this method would have the additional benefit of adding approximately 70 lbs of lime/acre per 1000-gallon urine application. This may not be an appropriate strategy where soils are already alkaline.

At Rich Earth

Rich Earth has only recently begun exploring high-pH adjustment of urine. From preliminary tests in early 2019, it appears that high-pH adjustment using slaked lime works on fresh urine but not stored urine. In storage, the urea in urine breaks down into ammonia and bicarbonate, both pH buffers, which prevent the treated urine from reaching a high pH.

Rich Earth will likely explore high-pH adjustment further in the future, for UD flush toilets and urinals where we can raise the pH of the urine immediately at the point of production.

Pharmaceutical removal

For those setting up a UD program, it's important to understand how existing wastewater systems deal with pharmaceuticals, and understand what happens differently when urine diversion is practiced. Rich Earth is often asked about this, and is supporting academic research on the topic.

Pharmaceuticals are present in urine, and many of them pass through sewage treatment plants largely unchanged. This is why pharmaceuticals are commonly found in rivers and drinking water supplies. By collecting urine and keeping it out of the wastewater stream, we can contain the pharmaceuticals before they reach sensitive aquatic ecosystems and water supplies.

When applied as fertilizer, urine enters a complex and biologically active soil ecosystem. Instead of passing through a wastewater plant in about 24 hours, it can remain in the active topsoil zone for weeks or even months, allowing much more time for any pharmaceuticals to be biodegraded. For this reason, using urine as fertilizer appears to be a better strategy for protecting water quality than flushing it down the sewer.

It is possible for pharmaceuticals to be taken up from the soil by crops, raising the question of whether pharmaceuticals in urine could cause a problem if used to fertilize food crops. In a joint research project with the University of Michigan, University at Buffalo, and the Hampton Roads Sanitation District, Rich Earth has been studying the presence and persistence of pharmaceuticals in urine-derived fertilizers, soils, groundwater, and crop tissues. Preliminary results from field trials using urine to fertilize vegetables revealed only trace levels of pharmaceuticals in the crops. For example, to get the same amount of caffeine as a cup of coffee, or acetaminophen as a Tylenol tablet, a person would have to eat a pound of lettuce from the study plot every day for about 1000 years.[12]

For those considering pharmaceutical treatments, there are two primary methods: activated charcoal/carbon filtration and advanced oxidation. These technologies are scaleable and used for many wastewater systems. Supplies are widely available.

At Rich Earth

The Rich Earth Institute is not required to monitor or control for pharmaceuticals, an we do not do any pharmaceutical treatments for our regular UD program.

In support of the research described above, Rich Earth has tested activated charcoal/carbon filtration but not advanced oxidation. We used fine activated charcoal packed into a column, with urine slowly forced through the column.

Weighing carrots from pharmaceutical trial.

12 http://richearthinstitute.org/wp-content/uploads/2015/10/Pharmaceuticals-in-Urine-and-Related-Products-ACS-Poster.pdf

Nitrogen stabilization

When urine leaves the body most of the nitrogen is in the form of urea, but it quickly transforms into ammonia (see "The science of urine" on page 2). Care and proper equipment are needed to prevent the ammonia from evaporating and being lost during storage, treatment, and field application. Even so, some loss is inevitable. Alternately, urine can be treated to stabilize the nitrogen in forms other than ammonia (NH_3), which include urea, nitrate, organic nitrogen, or ammonium (NH^+_4). Nitrogen in these forms does not evaporate, and can be handled more easily without risk of loss. Stabilizing nitrogen could reduce the cost of storage, handling, and field application by eliminating the measures that would otherwise be required for preventing ammonia loss.

Biological nitrification

Biological nitrification uses bacteria to transform ammonia into nitrate inside a controlled processing reactor. This transformation causes the rest of the ammonia to convert into ammonium (due to lowered pH), with the result that nearly all the nitrogen is stabilized and can no longer evaporate. It also provides other benefits such as odor control.

Biological nitrification is done routinely at wastewater treatment plants with relatively dilute wastewater. It is much more challenging to do with higher strength materials, such as diverted urine. Rich Earth has not explored the use of biological nitrification for diverted urine. However other researchers have developed a nitrification system that, while technically challenging, produces a stable urine product with very little loss of nutrients (see sidebar "EAWAG Complete nutrient recovery system (Nitrification + distillation)" on page 34).

pH adjustment – acid and alkali

Adding acid (such as vinegar) or alkali (such as slaked lime) to fresh urine can prevent the urea from breaking down into ammonia (see "The science of urine" on page 2) This stabilizes the nitrogen, because urea does not evaporate. By stopping most biological activity, it also prevents odors from forming, which is helpful if the urine collection system is not designed for odor control, or if a low-odor fertilizer product is desired.

It is very important that the the acid or alkali be combined with the urine while the urine is still fresh. If the urea has the chance to transform into ammonia, (which can even happen in the time it takes for urine to flow down a long pipe,) pH adjustment will not transform it back. In fact, even transformation of a fraction of the urea can stop pH adjustment from being effective, leading to transformation of all the urea.

Dr. Dyllon G. Randall, a professor at the University of Cape Town, has done considerable research on high-pH adjustment of fresh urine to stabilize urea and prevent ammonia formation, and has published a detailed account of the chemical processes involved.[13]

13 A novel approach for stabilizing fresh urine by calcium hydroxide addition
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4857702/

At Rich Earth

We have worked extensively with acetic acid (vinegar) for pH adjustment, particularly in conjunction with the reverse osmosis method of volume reduction (see below). During one trial period, our urine donors added 4 L of vinegar to their empty 20 L containers before connecting them to their urinals, and this was effective for stabilizing the urea for a period of weeks. Pre-loading an empty container with slaked lime was not effective, because the lime did not dissolve and disperse throughout the freshly collected urine effectively enough to prevent the urea from transforming to ammonia. Dr. Randall has reported that manually shaking the container periodically is enough to mix the lime, and our next step will be to work on an automatic method.

Volume reduction

Urine is made up of over 95% water. Concentrating urine to reduce volume has the potential to lead to cost savings and reduced environmental footprint. Whether concentration has these benefits, however, depends on the cost of urine storage and transport, transport distances, the concentration method used, and even local farming practices and seasonality. Concentration strategies include evaporation/distillation, freeze concentration, and reverse osmosis.

Evaporation/distillation

Distillation and evaporation can only be used to concentrate urine if the nitrogen in the urine has been stabilized, typically as either urea or nitrate. Without prior stabilization, most of the nitrogen is present as ammonia and will be be lost during evaporation or distillation, causing air pollution and greatly reducing the fertilizer value of the end product.

Distillation using an inexpensive single-stage system is extremely energy intensive, requiring about 627 watt-hours/L, negating the potential environmental benefit of concentration. Sophisticated and expensive vapor compression distillers, like the one used in the EAWAG system (see sidebar), can reduce energy use by up to 85%, but are still very energy intensive.

Evaporation, in contrast, is an efficient option to consider in a dry environment, a greenhouse, or where low-grade waste heat is available. Rich Earth has not focused on these concentration methods for the UD program in Vermont.

EAWAG COMPLETE NUTRIENT RECOVERY SYSTEM (NITRIFICATION + DISTILLATION)

The system pioneered by the Swiss Federal Institute of Aquatic Science and Technology (EAWAG)[14] combines biological nitrification with distillation to create a stabilized liquid fertilizer with 42g/L nitrogen and 4 g/L phosphate. This system collects urine, allows the urine to hydrolyze into ammonia, and then uses an aerated column with nitrifier bacteria to turn the ammonia into ammonium nitrate, stabilizing the urine before distillation. Their vapor compression distiller recycles 85% of the energy back to the reactor, making it much more efficient than regular distillation, but this step is still quite energy-intensive.

Aurin is developed and commercialised by [Vuna]

14 Fumasoli, A.; Etter, B.; Sterkele, B.; Morgenroth, E.; Udert, K. M., Operating a pilot-scale nitrification/distillation plant for complete nutrient recovery from urine. Water Sci Technol 2016, 73 (1), 215-22.

Reverse osmosis

Reverse Osmosis (RO) is a process used in desalination facilities to produce pure water from salt water. It is used in some water purification systems and wastewater treatment systems, and can also be used to concentrate urine.

At Rich Earth

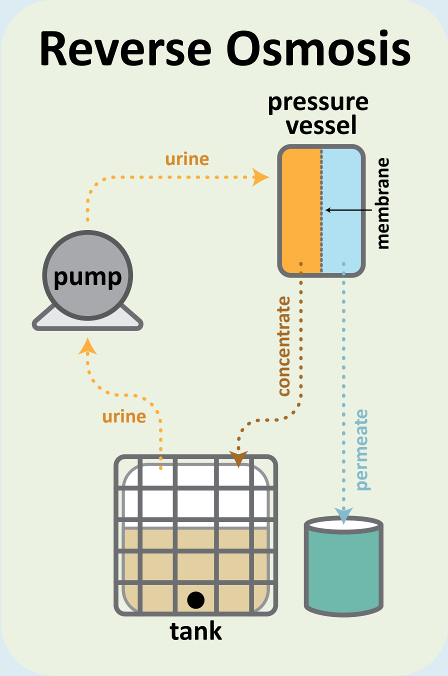
In our experiments with an off-the-shelf RO system designed for desalination, we have been able to produce a product with five times the concentration of urine. This requires roughly a dozen cycles through the RO system. Electricity consumption is only about 26 watt-hours/L of water extracted (about 24 times more efficient than single stage distillation, and 3.5 times more efficient than Eawag's vapor compression distillation). An RO system configured for concentration rather than desalination could improve energy efficiency significantly.

The urine we process with RO was treated with vinegar at the point of collection to prevent the urea from converting into ammonia (as described on page 2 "Acidifying urine to preserve urea" and the "pH adjustment – acid and alkali" section on page 33). This has the following benefits in an RO process:

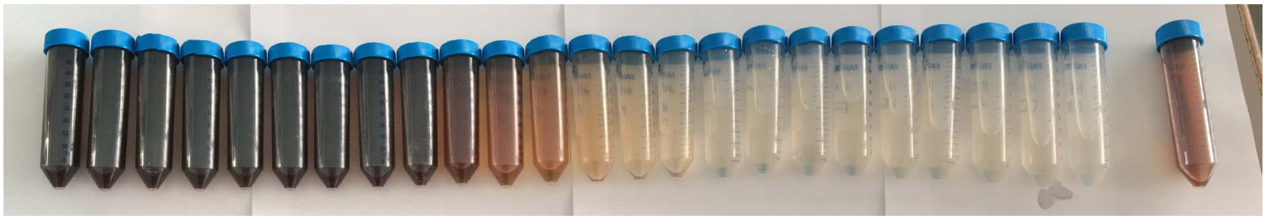
- Because urea molecules are bigger than ammonia molecules, the RO membrane retains urea better than ammonia, resulting in more nitrogen in the concentrated end product.
- When urea molecules turn to ammonia, the osmotic pressure of the urine rises, which inhibits the RO process. Keeping the nitrogen in urea form allows the RO system to achieve higher final concentration.
- Acidity prevents minerals from precipitating out and clogging the RO membrane.

Even with acidification, the RO membrane and prefilter are prone to clogging over time. Although highly effective, both RO systems we tried were expensive and required careful maintenance to deal with fouling membranes and pre-filters. We began development of freeze concentration, below, to address the finicky nature of RO.

HOW DOES REVERSE OSMOSIS WORK?



A reverse osmosis system pushes a water solution (like seawater or urine) against a membrane with extremely small holes, at high pressure (hundreds of psi). The holes in the membrane are large enough for water to pass through, but too small for most chemicals dissolved in the water. When RO is used on urine, relatively pure water (called permeate) is forced through the membrane, while the nutrients and salts that cannot pass through the membrane are retained in the concentrate. As more and more water is extracted from the urine, the "osmotic pressure" of the concentrated urine eventually matches the mechanical pressure generated by the RO pump, and the process stops.



Products of freeze concentration. Vials at left contain concentrate. Vials at right contain separated water. Vial at extreme right contains urine feedstock.

Freeze concentration

Freeze concentration uses the same process that colonial New Englanders used to make strongly alcoholic applejack out of weaker hard cider. By slowly partially freezing a liquid and removing the ice, also called “fractional freezing” or “freeze-distillation,” it is possible to separate out substances with different freezing/melting points. In the case of urine, a concentrated solution of nutrients and salt remains liquid can be drained away, leaving behind nearly pure ice.

In a cold climate like Vermont’s, a low-tech variation of the freeze concentration process would be to simply let a tank freeze during the winter, and then as it thaws in the spring, drain the concentrated liquid into a separate tank. However, storage tanks are a significant cost in a UD program, and large storage capacity could be needed if concentration could only happen one time of year.

At Rich Earth

To address the energy intensity, equipment cost, and operational challenges of both the distillation and reverse osmosis methods, Rich Earth is developing a freeze concentration method for reducing the volume of urine. With the Rich Earth system, urine is partially frozen in a sealed container. A fertilizer liquid with 4.5x the concentration of urine is drained off and stored. This is a similar concentration to what we have been able to achieve with reverse osmosis, and we have achieved even higher concentrations through freeze concentration in preliminary experiments.

Our freeze concentration device is the subject of a provisional patent, and under active further development. In the future we hope to make a system available for sale to others. We would also be happy to collaborate with someone interested in applying this method using their own engineering team, to adapt it to the appropriate scale for their project or license it for sale.

Frozen urine in experimental freeze concentration chamber.

Solid urine-derived fertilizer products

Compost and biochar

Urine can potentially be used to enrich compost or biochar, producing a nitrogen-enhanced fertilizer with better handling, storage and application characteristics than untransformed urine. The nitrogen is bound more securely, odor is reduced or eliminated, and it can be spread using solid manure or compost spreading equipment.

Co-composting urine along with a solid high-carbon feedstock (such as dry leaves) makes it possible to incorporate nutrients from urine into compost, transforming the ammonia into non-volatile nitrate or organic nitrogen, while driving off excess moisture as vapor during the composting process. This stable, more concentrated fertilizer could be stored inexpensively in open-air windrows and applied using familiar equipment and methods, such as manure spreaders.

At Rich Earth

Rich Earth has been researching co-composting approaches since 2014. Through multiple trials, we demonstrated that it is possible to use urine to create high-nitrogen compost with safe ammonia and salinity levels. This compost has a higher nitrogen:phosphorus ratio than typical animal manure compost (N:P ratio of over 5:1 using NPK analysis units, or about 13:1 by elemental basis).[15] Additional study is needed to optimize composting methods involving urine and bring them to scale, including assessing the suitability of additional high-carbon feedstocks currently available in the Northeast, and conducting mechanically turned windrow trials. We have yet to explore urine-enriched biochar but expect this to be an area of future work.

Adding pasteurized urine to leaves in experimental composting chamber.

Our research includes a multi-year benchtop composting trial in a bench-top incubator, followed by a self-heating bin composting trial with two insulated 1.8-m^3 compost piles that was intended to mimic commercial scale composting. We co-composted urine with different feedstocks (wood shavings, horse manure, and dry leaves) to evaporate excess water and assimilate nitrogen and other nutrients into a stabilized compost product. We also conducted an unsuccessful trickling biological nitrification trial, using finished compost as a nitrification medium for transforming urine into a stabilized liquid product. In this trial urine was applied slowly to compost and the leachate analyzed.

Hardwood leaves performed better than a horse manure/wood shavings mixture for co-composting urine (higher volume of urine incorporated, better N retention, and more favorable odor). Saturating dry leaves with urine provided a good recipe for composting, but saturating dry leaves with urine concentrate (produced with reverse osmosis) supplied too much nitrogen, leading to nitrogen loss. Since a small volume of concentrate can supply a large amount of nitrogen, urine concentrate could be an effective way to add nitrogen to wet, high-carbon feedstocks that cannot accept much additional moisture. When adequate moisture levels are maintained, a leaf/urine concentrate recipe is capable of retaining most of the starting nitrogen present in the mix. Not all urine/leaf composts were suitable for growing seedlings, possibly due to high ammonia content. This same ammonia content, however, would make such compost an effective fertilizer if it were incorporated into soil for row cropping.

Struvite production

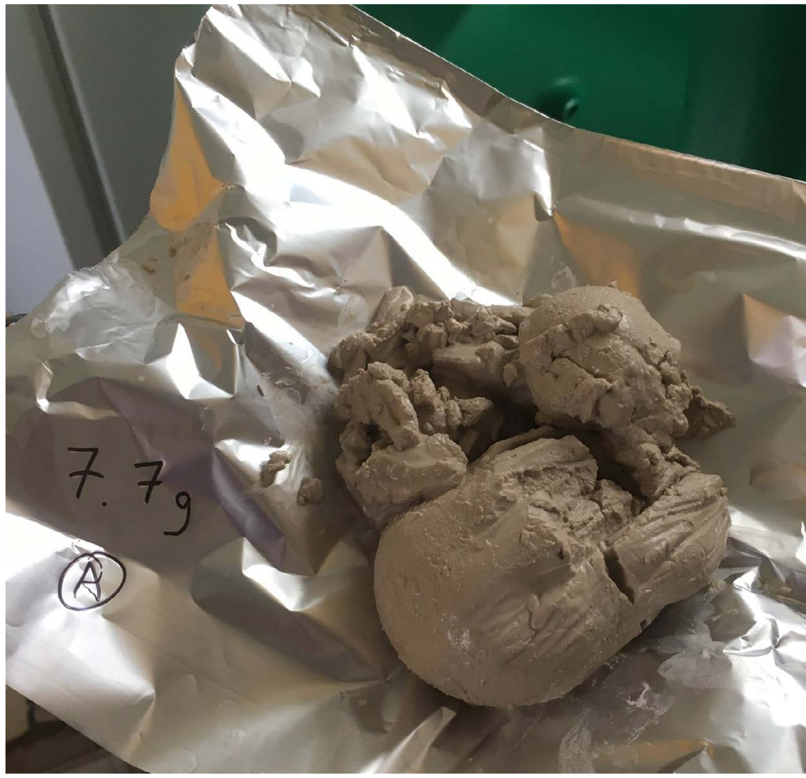
Struvite (aka magnesium ammonium phosphate) is a high-phosphorus compound that naturally precipitates from aged urine. Struvite also forms in wastewater treatment plants where it can create problems by forming deposits on the piping system, reducing the effective pipe diameter and thus reducing the efficiency of the process. To alleviate this problem, some centralized wastewater treatment systems include processors that intentionally precipitate struvite in the form of solid fertilizer pellets that are then removed and sold.

Note that struvite accumulation in equipment, piping, and containers can also be a cleaning challenge for a UD program. To clean a jug coated lightly with struvite, you may have success filling it with clear water and letting it soak for a few days.

15 Value-added products from urine: Enriched compost and stabilized liquid fertilizer, Final report from 2015 SARE grant project https://projects.sare.org/project-reports/one15-244/

To make struvite from urine, the pH of the urine must be high, which is easily achieved by letting the urine age, causing the pH to rise to about 9. Then a solution of magnesium ions (from $MgCl_2$ or another magnesium source) is added and stirred into the urine for a period of time, which causes tiny struvite crystals to form. The urine is then drained or pumped through a filter, which catches the crystals as a struvite paste that can then be dried into powder. Considerable research has been done on struvite production with source-separated urine.[16]

Struvite production results in two different fertilizers: a high-phosphorus fertilizer (the solid struvite), and a high-nitrogen fertilizer (the remaining liquid). This separation could be helpful in agricultural settings where soils are already overloaded with phosphorus. In such a situation, the high-nitrogen liquid could be used locally and the solid struvite exported to regions that need phosphorus fertilizer.



Struvite produced using urine, before drying.

At Rich Earth

Rich Earth Institute has some experience with struvite production, but we have not incorporated it into our regular treatment process.

16 Low-cost struvite production using source-separated urine in Nepal. Etter B1, Tilley E, Khadka R, Udert KM. Water Res. 2011 Jan;45(2):852-62. doi: 10.1016/j.watres.2010.10.007. Epub 2010 Oct 16.

APPLICATION

This section focuses on application of urine-derived fertilizer in liquid form, rather than solid form such as compost or struvite.

Overview and considerations

While predominantly a nitrogen fertilizer, urine contains substantial levels of phosphorus and potassium, as well as a range of secondary nutrients and micronutrients. As with synthetic fertilizers, the nutrients in urine are readily available to crops, which helps plants grow but does not add organic matter to the soil. If urine-derived fertilizer is the main source of nutrients for a farm or garden, it is important to either add organic matter from some other source (like composted leaves), include soil-building cover crops, or use the urine to grow a crop that builds organic matter through its own roots (like hay). Appropriate fertilization with urine means applying it where and as much as is needed, and in such a way that nutrients are retained in the soil. A good working relationship with partnering farmers is critical for a UD program to productively cycle nutrients back into the soil.

At Rich Earth

Rich Earth decided early on to work with farmers to apply urine to hay fields instead of food crops. We did this both because hay is one of the primary crops in our region, and for reasons of public perception. In our experience, farmers initially weren't ready to market food fertilized with urine, but that may be changing.

In 2018 we had two participating farms, and we are adding a third farm for the 2019 growing season. We have a longer list of interested farmers, but not enough urine to supply them all. Farmers get involved for different reasons. One of our farmer partners doesn't have an on-farm fertilizer source and can't afford the cost of chemical fertilizer. Another farmer is motivated by the idea of sustainable nutrient cycling. Our new farmer partner will be using urine to reducing synthetic fertilizer use. Many farmers in our area are already using other low-concentration fertilizers such as liquid animal manure or digestate.

We are continually adjusting our systems to make them as efficient as possible for farmers and Rich Earth staff. For instance, we have centralized pasteurization and are planning to set up gravity-feed systems on farms that provide pasteurized urine at the turn of a valve. This will mean that after a fertilizer delivery from Rich Earth, the farmer will be able to load urine into the field applicator tank without further assistance from Rich Earth.

We have learned that if anything is a hassle for the farmer, it isn't going to happen. We originally did on-farm pasteurization, with the idea that the farmers would eventually take over operation of the pasteurizer. This transition didn't happen, because it required extra attention and time from the farmers, so we shifted to a system where we pasteurize and store urine at our own facility, and bring it to the farm when it is ready to use.

Jesse Kayan, co-owner of Wild Carrot Farm in Brattleboro, says,

"Our farm uses land that has been the recipient of Rich Earth's urine applications for many years now. Having used their product as fertilizer on our small, diversified farm we have had the opportunity to experience the benefits of this system directly. As a result of past destructive practices, our hay land was fragile and low-yielding. Over the several years the Rich Earth Institute has applied urine, and we have watched our yields increase dramatically. As a result, we can now make a whole additional cutting of hay each season, increasing our productivity and profits. The urine has not only increased our land's value, it has helped make significant improvements to the soil's fertility and resilience. We feel extremely good to be building our soil while removing a pollutant from the waste stream."

CHARACTERISTICS OF URINE AS A FERTILIZER

These excerpts from the Stockholm Environment Institute report, *Practical Guidance on the Use of Urine in Crop Production*[17] summarize key aspects of urine as a fertilizer:

- *Urine is a well balanced nitrogen rich fertilizer which can replace and normally gives the same yields as chemical fertilizer in crop production.*
- *Urine should be applied according to the needs of the plants.*
- *Urine contains most of the macronutrients as well as smaller fractions of the micronutrients excreted by human beings. Nitrogen, phosphorus, potassium and sulphur as well as micronutrients are all found in urine in plant available forms.*
- *The nutrient content in urine depends on the diet.*
- *Source separation of urine results in one of the safest and cleanest fertilizers available to the agricultural community.*
- *Health risks associated with the use of human urine in plant production are generally low if there is no or little faecal cross-contamination.*
- *Urine use in areas where salinization [increasing salt content in soils] is an issue should be monitored.*
- *Urine can be applied neat [undiluted] or diluted with water.*

17 Practical Guidance on the Use of Urine in Crop Production EcoSanRes Series, 2010-1
https://www.sei.org/publications/practical-guidance-use-urine-crop-production/

Working with farmers

Establishing a good working relationship with your farmers is critical for a well-functioning UD program. Do not assume every farmer will be excited about this–but it is important to find a farmer partner who is. Work to understand the needs and concerns of your farmer partners, and ensure the information you provide and the system you set up addresses those needs and concerns.

Loading urine into the applicator.

First and foremost, make the process easy for farmers! Farmers work very hard. If using urine is cumbersome, they will be less interested. Communicating with potential farmer partners early, well before they will make their fertilizer purchases for the year, is essential.

We do not charge farmers money for our product, nor would we recommend that any startup UD program do so. Understand that while a farmer will appreciate the economic value of the nutrients in urine, they are assessing their overall return on investment, which weighs the time and hassle of implementing a new process against the (generally low) cost of alternative fertilizers. (See "Economics" on page 46, for overall economics and potential funding sources; it's not from the farmers.)

Farmers will have a range of different questions and concerns about the use of urine-derived fertilizers. Get a manure analysis (including metals) from your state extension laboratory so farmers will know the chemical properties of the product you are providing. Farmers need to know what they are getting, for their own purposes and to be able to communicate with their customers.

In our interviews with a range of farmers about potential use of urine derived fertilizers, some had concerns about "micro-constituents" in urine such as pharmaceuticals (especially antibiotics), hormones, opioids, and heavy metals. Some farmers expressed concerns about how these constituents might affect soil health (e.g., health of soil microbes and other microfauna); others were concerned about possible impact on their livestock (e.g., animals eating hay forage). It is important to communicate clearly to farmers what we currently know and don't know about these issues.

Farmers are also interested in better understanding the nutrient value of urine including the secondary and micronutrient contributions. Many also appreciate data from yield trials. Establish ongoing relationships with farmers to provide this type of data as it becomes available. Developing on-farm research trials with participating farmers would also help solidify strong farmer partnerships.

"We have relationships with our customers, we're able to explain to them our practices, show them into the barn and they can look at the stack of fertilizer that all is organic labeled. Or take them out into the fields and show them how we do it. There's that level of trust that our customers have in us. It is good for us to be able to comfortably say what we are doing…" [Local Farmer]

Application theory and methods

Urine is predominantly a nitrogen fertilizer even though it also includes P, K, and a range of secondary and micronutrients. Urine is highly soluble, so in liquid form it acts more like a chemical fertilizer than like a compost, and its nutrients are readily available to crops. Urine is easily leached, so smaller applications applied with greater frequency lead to greater retention. Rich Earth is researching the effect of different application methods on ammonia loss, with attention to timing and weather conditions.

Higher ammonia concentrations (found in aged urine and certain other treatments) can lead to to greater evaporation during application. This can be partially controlled by incorporating the urine directly in the soil immediately after application, either via tilling, pouring urine into a furrow and covering it, watering the urine in, or distributing urine along with irrigation. In general, applicators should pour, not spray.

Application options:

- Immediate incorporation or 'fertigation'
- Application to moist soil or during rain
- Application followed by irrigation

Urine application.

At Rich Earth

Rich Earth Institute has conducted field trials to quantify the relative effect of sanitized urine fertilizer on hay yields compared to synthetic fertilizer. The results showed that urine is an effective replacement for synthetic fertilizer for growing hay, and the demand for urine fertilizer among participating farmers is currently higher than the available supply.

A major focus of this research has been to test whether yields are affected by diluting urine with water at the time of application. Dilution with three parts water (or more) to one part urine is commonly recommended to prevent damage to plant tissues by free ammonia, but the added labor and expense involved with dilution water is a barrier to adoption at the farm scale. The results confirmed previous findings that diluted and undiluted urine are both effective fertilizers, increasing yield in second-cut hay. There were no statistically significant differences in yield between plots fertilized with urine, diluted urine, and synthetic fertilizer.

Left: *raking hay from small field trial plots.*

Right: *baling hay from large field trial plots.*

Calculating application rates

Gardeners and farmers can use nutrient equivalencies to determine appropriate application rates. The NPK fertilizer value of stored urine varies, but is roughly 0.6 - 0.1 - 0.2. Put another way, 5 gallons of urine supplies the same plant nutrients as one pound of 24.5 - 3.6 - 9.3 fertilizer. One thousand gallons of pasteurized urine contains the equivalent of 109 pounds of urea, 13 pounds of triple superphosphate, and 29 pounds of muriate of potash (KCl).

Farmers and gardeners can use NPK fertilizer values to calculate appropriate application per acre or per square foot for different crops, using published guidelines for specific crops.[18]

At Rich Earth

For partnering farms, Rich Earth applies 1000 gallons of urine per acre of hay per application (providing 50 lbs. nitrogen/acre).

Seasonality of application

People pee all year long, but in many climates fertilizer application is seasonal. This seasonality must be accounted for in determining the storage capacity needed for a UD program. Work with your farmers to understand the timing of their fertilization needs, and plan so as to have the urine ready when the farmer needs it.

At Rich Earth

Our main strategy is to apply urine after the first cut of hay. We also sometimes apply in the spring, and in the fall once the soil is cold, which is conducive to retaining ammonia until the soil warms up in the spring. Ammonia retention is better on cold ground.[19]

TO DILUTE OR NOT DILUTE

(HINT: DILUTION IS NOT ALWAYS NEEDED)

There are many opinions about whether and how much to dilute urine before application. Others have suggested dilution with 10 or even 30 parts of water per part of urine. In our experience, dilution is only needed for some applications. Dilution is not necessary if applying to hay fields, to wet soil, or to areas where you are going to till the soil immediately.

For garden plants, we have found that using 3 parts of water to 1 part of urine gives good results and does not harm plants, provided that the soil is moist before fertilization. If the soil in the root zone is dry, higher dilution rates can be used, or the urine fertilizer can be watered in after application. When the soil is sufficiently moist, dilution may not be necessary.

Higher dilution rates are recommended for dry soils and for sensitive plants.

18 Extension agencies often have documentation on agronomic loading rates that are regionally tailored, such as this VT document for field crops. http://pss.uvm.edu/vtcrops/articles/VT_Nutrient_Rec_Field_Crops_1390.pdf

19 https://crops.extension.iastate.edu/cropnews/2014/10/fall-nitrogen-applications-and-soil-temperature

Application equipment

In designing application equipment, the aim is to get urine to the ground surface as directly as possible with a minimum of evaporation or aerosol production. This means the applicator should dispense low-velocity streams (pour, not spray).

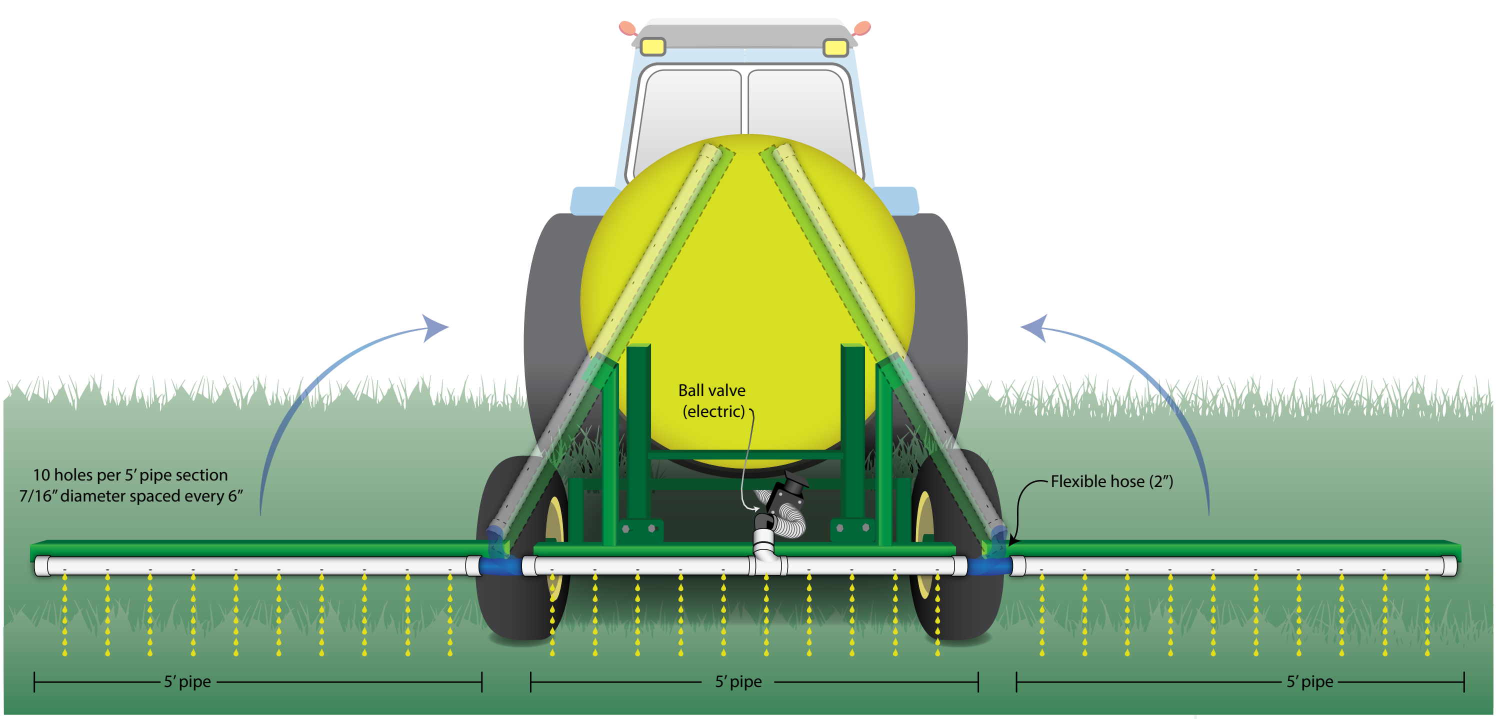
At Rich Earth

Urine is applied using a purpose-built urine applicator consisting of a 500-gallon trailer-mounted tank plumbed to a transverse, perforated boom. An electric valve between the tank and boom allows the driver to easily initiate or shut off flow when the applicator reaches the end of the field. The valve is a $500 part, but greatly eases application.

Our next applicator will use an electric pump instead of gravity feed. This will enable more even and consistent distribution along the length of the boom, as well as faster, more consistent application.

Design tips:

- An inexpensive, simple applicator for a small amount of urine could consist simply of an IBC tote on a trailer, plumbed to a perforated pipe for a boom.
- A design limitation of the gravity flow system is that flow can be uneven, with the rate decreasing as the tank level decreases, and uneven flow from the two ends of the boom when driving across sloped land. Locating the tank as high as possible and the boom as low as possible reduces this issue by increasing the operating pressure.
- Liquid manure application equipment—trailing shoe technology—enables subsurface application of urine. A knife slices open the ground, liquid is applied with hoses, and the ground is closed back up. We have never used broadcast liquid manure spreaders, because ammonia losses and odors would probably be very high.
- On-farm logistics are improved by locating storage tanks uphill so that the applicator tank can be gravity-fed rather than requiring a pump.



PERMITTING

Not all countries around the globe have effective regulations addressing human waste, but the regulatory framework in the U.S. is generally highly codified and detailed. This system varies significantly by state, and even county, and continues to evolve. Because community-scale urine diversion and farm application is new in the U.S., there is little direct precedent for regulators. Due to this lack of familiarity, responses by regulators can vary widely. Rich Earth has worked closely with regulators in Vermont to set precedent for others. However, while UD program initiatives in other states can point to Vermont precedent, states will vary in approach.

There are a variety of different regulatory frameworks that may be relevant for permitting of UD programs in different states. Some regulations are not related to permitting, but may impact the economics of a UD program—for example nutrient pollution limits put in place to protect waterways create an economic rationale for urine diversion (see "A lower-cost nutrient removal solution" on page 47).

MOVING FORWARD WITH PERMITTING

Give us a call first! –
While Rich Earth is currently focused on Vermont and New England, we may know of work in other states, so let us know you're interested. Nutrient Networks (nutrientnetworks.com) and Recode (recodenow.org) are also good resources.

Contact the right agency to find out what's going on in your state –
They go by different names, but the agency or state department that handles environmental protection, environmental services, natural resources, watershed management, or 'residuals management.'

Find out if you are in an "EPA state" or an independent state –
In some states wastewater treatment plant discharge permits and/or residuals (sludge/biosolids) permits come from the state; in others the U.S. Environmental Protection Agency (EPA) is highly involved in permitting. Although only eight states (UT, OK, WI, TX, AZ, OH, MI) are formally delegated to administer programs under 40 CFR 503, the EPA is actually performing the permitting for these activities in only a few jurisdictions.

Find out if there are TMDLs in your watershed –
Total Maximum Daily Load requirements (TMDLs) are implemented for many watersheds across the country to reduce nutrient pollution. For municipalities dealing with these added nutrient requirements, a UD program may be a highly advantageous and cost-effective alternative to conventional approaches (see "A lower-cost nutrient removal solution" on page 47).

Inform first –
Help regulators understand the characteristics of urine that distinguish it from the other ingredients of wastewater, and why it makes sense to divert it from the wastewater stream.

Emphasize that urine is not a sludge or biosolid –
Urine has a very different composition and hazard profile than sludge. While urine could be regulated as sludge due to lack of precedent, this is not ideal, and is something to avoid if possible.

Make it a multi-step process –
Don't expect to receive a long-term permit immediately. Give regulators information and time to think it through. This is a long-term partnership. Get regulators comfortable by starting with an experimental or research permit. If you develop a good working relationship, they are in a position to save you considerable time and aggravation by walking you through the permit application process and explaining how to fit the square peg of your urine diversion project into the round hole of the application requirements.

Get technical help! –
Rich Earth enlisted a sympathetic wastewater treatment engineer to spearhead writing our first permit pro bono. Find people with the expertise you need to do it right.

Vermont

From the start, Rich Earth has engaged VT state regulators as partners in the project. With our early work, treatment was allowed through a short-term discretionary permit. Our first temporary permit allowed land application after storage at 20°C for 30 days, and at one point our permit allowed us to remove pathogens by high-temperature composting, although we didn't exercise that option. Originally our permits were for site-specific application. Under our current permit we can distribute pasteurized urine to anyone—both farmers and gardeners—for use throughout the state.

The current permit for our UD program is the result of several years of collaborative discussions with state regulators, which resulted in an evolving permitting pathway for the treatment and land application of urine, under rules that had never anticipated a project of this nature. Our regulators recognize that urine is neither septage nor sewage sludge, and our product is not a biosolid, but lacking any urine-specific rules they wrote our current permit using treatment requirements taken from the sludge and biosolids rules[20]. Our permitting and reporting are therefore handled under the Residuals Management program, within the Waste Management and Prevention Division of the Vermont Department of Environmental Conservation, which regulates the treatment and land application of biosolids. Annual fecal coliform and heavy metal testing are required prior to land application.

Massachusetts

Since 2017, Rich Earth has supplied urinals and urine-diverting, composting portable toilets to the annual North Quabbin Garlic & Arts Festival, in Orange, Massachusetts. In the first year, we also applied the collected urine to the farm field where the festival occurs. To do this, we worked with the Massachusetts Agricultural Department to get one-time permission to pasteurize the urine, test it for fecal coliform, and then apply it as fertilizer on the festival site. The permit application included references and letters of support. We received approval letters from three Massachusetts agencies. The following year we did not apply for a treatment and application permit, (because we brought the urine back to Vermont instead, for use in our research program,) but we hope to do so again in the future with a longer-term permit.

Hauling septage through Massachusetts requires a separate permit from every town along the hauling route. The town of Orange required us to buy a septage-hauling permit for hauling urine, but the town to the north, Warwick, did not. The remainder of our route was through New Hampshire and Vermont, which issue statewide hauling permits.

New Hampshire

Rich Earth has also established relationships with key regulators in New Hampshire. While we haven't yet sought a permit to apply urine, regulators are generally supportive, and we're working on establishing permitting for a project soon. Rich Earth has a New Hampshire septage hauling permit, and can legally haul urine throughout the state. In New Hampshire, hauling permits usually apply to individual tanks, but our regulators wrote our permit to apply to our flatbed truck, which can carry up to four interchangeable 275-gallon IBC totes.

UD PROGRAM TOOLKIT:

Rich Earth Institute's permits for urine treatment

20 Federal 503 sewage sludge rule: https://www.epa.gov/biosolids/land-application-sewage-sludge

Collecting and recycling urine saves money and supports local economies by conserving drinking water, reducing wastewater treatment costs, producing fertilizer, and improving water quality in marine and freshwater ecosystems. This innovative nutrient removal strategy may also unlock economic development in areas where development or expansion are restricted because conventional technologies are unable to meet nutrient pollution limits. UD programs also have the potential to provide local jobs (plumbing, engineering, etc.) and new opportunities for local business (such as septage haulers, manufacturers, etc.). Reducing nutrient pollution also has the economic benefit of increasing the recreational value and biological productivity of rivers, lakes, and bays.

The economic benefits of urine diversion are potentially quite significant, but there is little analysis to date that quantifies the economic value of these benefits. There is also very little research or commercial data to quantify the costs of widespread implementation of UD programs. This section collects the information and insight we have gained from our own operations and from research partners in support of developing a UD program. We welcome collaborators in further developing our understanding of the economic impacts of urine diversion. That said, in many instances a strong business case can already be made for setting up a UD program today.

The business case for a community/municipal scale UD program

The strongest business case for a UD program in the U.S. today is in avoided costs for pollution prevention. If your municipality has a mandate to remove nutrient pollution from wastewater, it may be in their interest to invest in a source-separation program to reduce the operating costs of nutrient removal systems, or to avoid having to install expensive new sewers or treatment equipment in the future. This has real financial value that could possibly translate into direct funding for a UD program.

Water savings from use of UD toilets and waterless urinals also has financial value. Where water is expensive, the money saved on water may be a major benefit of a community-scale UD program. In drought-stricken areas or where good quality water is in short supply, it may be of financial benefit to a municipality to reduce the quantity of drinking water treated and supplied. For individual building owners, installation of water-efficient fixtures can cost effectively lower water and sewer bills. Water-efficient UD fixtures can be installed instead of other water-efficient options for additional utility cost savings. People with challenged septic systems would also benefit from reducing the hydraulic load to their leach fields and preserving the systems' longevity.

In contrast, generating income by selling urine-derived fertilizer appears to currently be a much less viable business model. It is unlikely a U.S.-based UD program could be supported by revenue from conventional farmers due to the low cost of synthetic fertilizer [ref]. Marketing of urine-derived fertilizer to retail consumers or to ecologically oriented farmers seeking non-synthetic fertilizer could provide higher sales income by competing with organic fish emulsion or other expensive natural fertilizer. Mined phosphorus is currently an inexpensive soil amendment but is also a finite resource. While it may not be possible currently to build a business around sustainable phosphorus supply, this could be a market driver for UD program products in the future.

The business case and potential revenue streams for a UD program may vary by region or market and shift over time. Further analysis is needed to identify the full range of settings where urine diversion is currently cost-competitive.

A lower-cost nutrient removal solution

Urine diversion is already receiving notice as an inexpensive and effective wastewater solution with bottom line savings.[21] It can be a cost-effective way to meet new nutrient pollution limits being implemented in sensitive watersheds (See sidebar "Total Maximum Daily Loads (TMDLs)" on page 48). The cost of nutrient removal using conventional means can be staggeringly high, with costs sometimes in the hundreds of dollars per pound of nitrogen removed (See table below). For reference, a single adult produces about 9 pounds of nitrogen per year in their urine.

Estimated Annual cost per pound of nitrogen removed ($/lb/yr)[22]

	Low	Base Case	High
Individual N-removing systems	$550	$770	$830
Cluster systems 8,800 gpd	$500	$710	$790
Satellite Systems 50,000 gpd	$480	$680	$720
Satellite Systems 200,000 gpd	$380	$510	$550
Centralized Systems 1.5 mgd	$250	$305	$319
Centralized Systems 3.0 mgd	$230	$285	$295

Estimated costs in Cape Cod to remove nitrogen by upgrading individual septic systems or extending sewer lines to connect more houses to centralized treatment.

Where site development is constrained by septic and sewer limitations, the return on investment could be much higher if a UD retrofit enabled additional development. For towns where wastewater treatment capacity is limited and/or secondary nutrient treatment is a new added requirement, this can drive up wastewater treatment costs or be a barrier to development and expansion. A UD program could be particularly valuable by enabling increased density or intensity of use, for instance in village centers. Municipalities subject to TMDLs have strong incentive to develop and support UD program technologies and policies where removal of nitrogen from water bodies can be ensured.

21 Cost-effectiveness of nitrogen mitigation by alternative household wastewater management technologies, Alison Wood Et al. https://www.sciencedirect.com/science/article/pii/S0301479714004927

22 Comparison of costs for wastewater management systems applicable to Cape Cod: https://www.apcc.org/waterquality/CapeCodWastewaterCosts--April2010.pdf

TOTAL MAXIMUM DAILY LOADS (TMDLS)

The first step to making a business case to your town for a UD program is to find out if there are Total Maximum Daily Load (TMDL) limits for nutrient emissions in your watershed.[23] Derived from the U.S. Clean Water Act, TMDLs identify the maximum amount of a pollutant that a body of water can receive from all sources while still meeting water quality standards. These TMDLs are in place in watersheds across the country. For example, various watersheds on Cape Cod, Massachusetts have TMDLs for nitrogen,[24] and Lake Champlain has TMDLs for phosphorus in both Vermont and New York.[25] This means that any river that flows into the regulated river is also regulated, and all towns on those rivers are impacted.

- **CENTRALIZED: Treatment plant requirements.** Treatment plants are only allowed to emit a set amount nutrients each day. If a plant is operating at its limit, it cannot accept more nutrients (e.g. from new homes or businesses) without investing in expensive upgrades. An alternative approach to expanding capacity is to reduce the amount of nutrients that are entering the sewer, for instance through urine diversion.
- **DECENTRALIZED: Septic requirements.** Some jurisdictions have regulations requiring nitrogen removal from septic systems. This kind of treatment is expensive to install and to operate, and in many cases is not as effective as UD at nutrient removal. National Onsite Wastewater Research Association (NOWRA) is working to increase national focus on onsite systems and water quality.

23 Resources, Tools and Databases about Impaired Waters and TMDLs: https://www.epa.gov/tmdl/resources-tools-and-databases-about-impaired-waters-and-tmdls
24 https://www.mass.gov/lists/total-maximum-daily-loads-by-watershed#cape-cod-watershed-
25 http://www.lcbp.org/water-environment/water-quality/nutrients/tmdl/

Environmental Life Cycle Costs

Partners of the Rich Earth Institute in Michigan recently completed a Life Cycle Assessment (LCA)[26] of city-wide urine diversion and conversion into fertilizer products, compared to conventional wastewater management. Urine diversion was shown to reduce environmental impacts in a range of different settings, though the benefits and tradeoffs varied significantly.

As part of the project, the University of Michigan team created a user-friendly Excel-based LCA tool to assist water professionals in assessing the potential environmental benefits of these systems. This is intended as a first-pass screening tool.

Costs of setting up and running a UD program

Rich Earth is a research institute that relies on grant funding to operate, most of which goes toward research, rather than the urine recycling process itself. By sharing the knowledge we have gained, we hope to help aspiring UD programs skip much of the trial and error we have necessarily worked through, in order to offer urine diversion services to their communities at an affordable and competitive price.

Estimating costs as you develop your strategy for collection, transport, treatment, and application is a critical part of developing a financially viable program. Long transport distances, high facility costs, or other challenges unique to your situation will impact your strategy. Estimate first costs, as well as operations and maintenance costs, and consider the lifespan of equipment.

26 Life Cycle Assessment of Urine Diversion Wastewater Treatment STAR-Na1R14/4899
Note: this is designed for estimating life cycle environmental costs, but could also be useful to review in evaluating a UD program cost structure and assessing treatment costs.

Costs to consider

- **Equipment for collection, storage, treatment, and application**
  - Purchase, operation, and maintenance
  - Research & development (if any)
- **Transport costs**
  - Hauler fees and/or purchase and maintenance of own truck or trailer with hauler license
  - Cost of collection, accounting for the geographic distribution of collection points
  - Cost of delivering treated fertilizer to farmers
- **Total cost of different treatment options (equipment, energy, labor, supplies)**
- **Staff and administrative support costs**
  - Also account for volunteer hours and in-kind donations if you are pursuing grants
- **Facilities**
  - Centralized collection and/or treatment
- **Insurance**

UD PROGRAM TOOLKIT

- Urine collection costs and transport efficiencies (Sample Pump Out Efficiency Spreadsheet)
- Nitrogen Removal Cost Estimator for a single-family home
  - Estimates per-pound nitrogen removal costs using urine diversion in a two-bathroom, single-family dwelling. This captures facility and transport costs, but not a percentage cost of a complete UD program program (staff, etc).
- Nitrogen Removal Costs and Water Conservation Cost Savings for Small-scale community UD program using stand-alone units Cedarholm spreadsheet
  - Shows actual costs of the project and calculates N removal costs at $11.79/lb N.
  - Estimates the cost savings from conserving water at $0.24 to $0.39 per gallon of urine diverted.

WHERE CAN WE GO FROM HERE?

There are a number of applications where urine diversion is applicable and cost-effective right now — from the individual homeowner with a small garden to municipalities in sensitive watersheds facing increased wastewater treatment costs. As early adopters address today's challenges in practical and cost-effective ways, UD technologies and techniques will continue to evolve, along with social norms, government policy, and related businesses. This lays the foundation for larger projects and new applications. As these approaches are further developed and tested in different settings, additional applications will emerge.

Elements of a UD future

We can imagine a future where urine diversion is widely accepted and part of regular practice in both rural and urban areas. In this future, UD program infrastructure is commonplace. UD is supported by regional and national policy, and UD programs are incorporated into municipal planning and budgets as a cost-effective wastewater management strategy. The business potential in UD program is recognized by related industries. UD program is championed by a broader range of sectors that recognize ancillary benefits (such as healthier waterways and fisheries).

Below are some of the elements we might see:

- Private homes have UD toilets and buried collection tanks, with sensors that alert a service contractor when they need to be pumped.
- Public restrooms have UD waterless urinals and UD toilets.
- Domestic manufacturers produce UD equipment (including fixtures and treatment equipment).
- Septage haulers include urine transport as a regular line of business, pumping urine from tanks and transporting to participating farms or urine treatment facilities.
- Farmers use urine-derived fertilizer in a variety of forms: liquid, concentrated liquid, or further-refined urine-derived fertilizer products.
- New fertilizer products are created from urine that are concentrated and stabilized for ease of handling.
- UD-related code language is written into the Universal Plumbing Code, International Plumbing Code, and state codes.
- Guidelines are established for the use of urine-derived fertilizers on certified organic farms.
- Cities develop dedicated UD piping and urine concentration facilities that facilitate the export of fertilizer to nearby agricultural areas.
- Professionals in a wide range of industries are trained with UD-related skills, including plumbers, engineers, agronomists, city planners, and septage haulers.

TO THOSE WHO ASK *"WHY BOTHER?"* OR *"IS IT A BIG ENOUGH SOLUTION?"*

Some will argue that urine diversion is an improbable or impractical solution that cannot be implemented at a large enough scale to matter. Note that there are always those who focus on the obstacles to implementing any new and alternative approach, be it computers, cell phones, or solar power—while others go ahead and transform the world. As urine diversion starts solving specific environmental and nutrient issues, community by community and farm by farm, we will see the real-world examples that will set the stage for UD programs to be implemented on a large scale.

CLOSING THOUGHTS

This document was designed primarily to support those seeking to start UD programs in their own regions. We hope it helps you to roll up your sleeves and get started. Projects at every scale have value. Even a home use project moves us forward, as you are educating yourself and those you know. We welcome you to use this document and the associated online UD Program Toolkit in any way that is helpful in working with your communities, local stakeholders, or professionals to address sanitation challenges and begin to close the food-nutrient cycle. Even if you aren't planning on starting a project, we hope this document helps you become an informed advocate who can bring the idea of urine diversion to your community and spark the interest of others to initiate a program.

This document represents a snapshot in time, capturing the current achievements of the Rich Earth Institute as a unique research platform, and the progress of our Urine Nutrient Reclamation Program in Vermont. The Rich Earth Institute's work is built upon foundational research done in Europe, as well as upon the long history of urine reuse globally. TTo this we add seven years of practical experience and applied research, which we hope will help others in bringing urine diversion into their own communities.

Before we send you on your way, we want to remind you of the following make-or-break points:

- Engage everyone respectfully, as a potential partner, whether or not they are initially supportive.
- Respect the role of regulators in safeguarding public health and our environment–remember that going through the permitting process, while time-consuming, blazes a trail for others to follow and brings UD into the mainstream.
- Make sure you have–or acquire–the capacity to implement and manage all aspects of your operation competently, in a way that will inspire confidence and support from participants and observers.
- We are still in the early stages of infrastructure transformation, advocating for a paradigm shift from waste management to nutrient reclamation. Currently the biggest opportunities for impact lie not in maximizing gallons of urine collected, but in clearly establishing that UD can be practical, legal, and desirable.
- Please let us know if you start a UD program. We would love to hear about your project and assist as we are able! Please contact us with questions, and to let us know what you're doing.

UD PROGRAM TOOLKIT ITEMS

UD Program Toolkit items referenced throughout the doc are listed below. The items that are available online are linked directly. Those without links are available on request. Rich Earth makes these resources freely available to support new programs. We welcome your thoughts on how to make the Toolkit more useful for others. The toolkit will continue to evolve. Feel free to browse online!

- **Rich Earth Introductory Powerpoint**
  This annotated powerpoint may be used as-is or adapted with attribution to introduce stakeholders to UD program.
- **Rich Earth videos - these videos are available from our website**
  - NSF "Science Nation" video
  - Uri Nation animation
- **"Just the Facts" brochure**
- **Urine Donor Instructions**
- **Depot signage**
- **Urine Depot Specifications**
- **Example Ecological Sanitation Site Visit Report produced by Connor Lally**
- **Urine collection costs and Transport efficiencies**
  - Sample Pump Out Efficiency Spreadsheet
- **Nitrogen Removal Cost Estimator for a single-family home**
  - https://drive.google.com/file/d/1HI-ZhXUYCluBT9maIz9WSb2JK4ksFbIR/view
  - Estimates per-pound nitrogen removal costs using urine diversion in a two-bathroom, single-family dwelling.
- **Nitrogen Removal Costs and Water Conservation Cost Savings for Small-scale community UD program using stand-alone units Cedarholm spreadsheet**
  - Shows actual costs of the project and calculates N removal costs at $11.79/lb N.
  - Estimates the cost savings from conserving water valued at $0.24 to $0.39 per gallon of urine diverted.
- **Rich Earth permits**
- **Additional items:**
  - UD Summit Reports
  - Final reports from 2013, 2014, 2015 SARE grants