Chapter 1

Introduction

What We Cover

THIS VOLUME OF THE *SUSTAINABLE BUILDING ESSENTIALS SERIES* focuses on residential compost toilets for the North American audience. It is a comprehensive reference for selection, design, installation, management, best practices, and safety concerns. This book is for homeowner/builders, contractor/builders, architects, designers, and ecological design students. Regulators and policy makers will also find value in the content. Various compost toilet systems will be presented along with the evaluations of each system that will help the reader select specific design applications.

With home-scale compost toilet systems, the homeowner has the primary responsibility for the day-to-day use, care, functioning, and servicing of the system. For this reason, it's the homeowner who needs to choose a system with full knowledge of the implications. The information in this book is designed to ensure the owner or design professional fully understands the choices. This book references regulations and research from North America and Europe; it is technical enough to be used by regulators and policy makers, yet practical enough to be understood by homeowners, contractors, and designers.

Although we have attempted to define terminology throughout, there will be times when the reader may find it useful to reference the Glossary included near the end of the book.

The regulatory environment is changing for all building technologies. It is moving away from prescriptive building codes to ones that are objective in nature, based on guidelines that make room for the plethora of proven alternatives — as long as they meet the functions and objectives of the regulations. This book attempts to bridge the gap between regulatory jargon and regular language. After all, going to the bathroom should be a simple, natural, and safe process. No degree should be required to complete the task!

This book begins with the most basic question of whether compost toilets are suitable for you (or your client). From there, we explore the importance of regulation and the biology of composting and pathogen death, with the primary goal being safety. Next, we discuss fundamental components of systems, design considerations, and calculations on system sizing. Not every reader will need to work through all the calculations, but we felt it was important to include this section for those who desire this level of detail. With these basics under your belt, we lead you through the different types of compost toilet systems, looking at design, key considerations, and their strengths and weaknesses. This "flows" into fluid management for urine and leachate, and we lay out a step-by-step process for sizing leachate tanks and calculating soil infiltration. We finish with a brief glimpse into the paradigm shift for hi-tech toilet technology currently underway — an effort to completely reinvent the toilet. It's a development poised to disrupt the way we view waste management.

Compost toilets are often linked with greywater systems, but greywater treatment is its own very specific topic, requiring discussions about soils, dispersal methods, and science that this book does not cover.

A homeowner's choice to incorporate a compost toilet may involve dealing with health officials and regulators; understanding the science and language that they use is critical. Their job is to manage public safety.

For the regulators who read this book, we urge you to evaluate your preconceptions and assumptions surrounding compost toilets and human waste. The science that dictates how we treat human wastes in large, centralized sewerage systems is the very same science that governs the processes involved with compost toilets; in both cases, the objective is to ensure that outputs are safe and pollution is avoided.

Not Just a Rural Solution

When we began writing this book, we had the misconception that the best way to service urban populations was still the standard water-based infrastructure. Our extensive review of the scientific literature has led us to a different conclusion: compost toilets have significant applications even in suburbs and cities.

A movement away from water-based sewerage systems for cities has become a growing focus for researchers and planners. How could this occur? And why should this occur? It's not lost on scientists studying agriculture, nutrition, engineering, epidemiology, sociology, and ecology, that our present water-based sewerage systems are complicit in negatively impacting our health and the environment. This converging science is exciting, yet we are still witnessing delays in policies and regulations to keep up with that science. Biases and preconceptions are strong, and it will take many more initiatives similar to the "Reinvent the Toilet Challenge" by the Gates Foundation (see Chapter 10) to drag Western culture into acceptance of viable alternatives.

Big problems with waste treatment and nutrient deficiency in soils could both be solved through appropriate technology and design. One solution: Composting toilets.

Composting toilets do not exist — because composting does not happen IN the toilet.

From Waste Stream to Mainstream

So, let's get started. First of all: *There is no such thing as a composting toilet.*

You might think it odd that we would start a book about compost toilets by stating that no such thing exists. But this book challenges the idea that a toilet can compost its contents. It can't. Composting is a specific process, one that occurs under specific conditions — and those conditions do not exist in any toilet. No doubt, stating this will raise the ire of many manufacturers of "composting toilets." Manufacturers, don't despair! We share the same aims. But our intent here is to make sure homeowners and regulators understand what it takes to design a *compost toilet,* one capable of converting raw materials into a sanitized, benign material through biological means.

Compost toilets come in a wide variety of shapes and forms, from site-built systems to systems that manufacturers have invested millions of dollars to research, design, fabricate, certify, and market. Think of that the next time you have the idea that these systems are not common. These systems fill market needs throughout the world and are commonly found in modernized countries like Australia, Sweden, Finland, Norway, Germany, New Zealand, as well as a host of East and Southeast Asian countries (North America is behind on this trend). In some places, their use arises from necessity, as a result of escalating water shortages. In others, their use arises from societal values placed on resource recovery. Regardless of the motivation, all rely on an understanding of the science around *ecosan* (ecological sanitation).

With global population expected to rise to 8.6 billion by 2030, 9.8 billion in 2050, and 11.2 billion by 2100, increased stressors will be placed on the availability of food, clean drinking water, and enough water for agriculture. Additionally, there is a large migration from low- and middle-income countries to high-income countries. All of this is, and will continue to be, exacerbated by a climate changing so rapidly it is outpacing even the worst-case predicted scenarios (Wuebbles et al., 2017). Centralized, water-dependent waste systems will become luxuries; they will not be able to keep up to overwhelming growth. Additionally, limited availability of the nutrients required to support agriculture make it senseless to continue flushing them down the toilet (Department of Economic and Social Affairs, United Nations, 2017).

Though plant-nutrient flows should be circular, present waste-handling makes them linear; both septic systems and flushing permanently remove nutrients from the natural soil cycle. And we can't afford to lose them. Phosphorus, for example, is a critical element used in agriculture. With five countries controlling 85% of the reserves, and a dwindling supply due to over-mining, we are seeing massive price shocks — as demonstrated in 2008, when there was an 800% increase in the price of phosphorus (Cordell and White, 2014). Recovering that dwindling resource from the waste stream will soon become an economic imperative.

Compost toilets (CTs) are essentially a progressive system that collects and handles human feces and urine so that they can be safely composted. Where they already exist, CTs form part of the infrastructure used in removing compostable and biodegradable solids from a hydraulic (water-based) sewage disposal system, thus allowing the opportunity to convert the waste materials (resources) into an ecologically beneficial nutrient source in a safe and hygienic manner — that is, sanitized.

The toilets themselves do no composting: "Composting is a managed process of bio-oxidation of a solid heterogeneous organic substrate including a thermophilic phase" (Canadian Council of Ministers of the Environment and Compost Guidelines Task Group, 2005). In other words, true composting meets three conditions:

- It is managed by humans (it is rare for it to occur in nature).
- It is aerobic, requiring oxygen.
- It generates its own internal biological heat.

If these three conditions don't exist, it's not composting. Inside a compost toilet, biological decomposition processes do occur as soon as all that stuff leaves our body and becomes exposed to the air, but that is not technically composting. And extended periods of decomposition may transform materials, but true composting is a much more rapid process. We'll have a complete discussion of decomposition and composting in later chapters.

The basic aspects of using a compost toilet are straightforward: 1) You go to the bathroom. (Any questions?); 2) The deposit is collected in vessel; 3) That collection is then either minimally processed to a mature-enough state that it can be buried and thus safely reintroduced to the environment, or, better yet, it is further composted to a state that sanitizes and reduces pathogens to a level so safe it can be used as a beneficial nutrient resource.

Though we will look more closely at the concepts of maturation and sanitization later

North America needs an urgent update to our cultural belief to match the overwhelming scientific consensus on how to safely compost human manure.

Waste doesn't exist in nature. There are only *resources.*

(in Chapter 2), it is timely to introduce them here: *Mature composts* are those that have decreased nitrogen, no odor, and are safe to plants and animals; *sanitized composts* have no disease-causing organisms. Safety and best practices ensure the creation of a product that meets standards for intended use.

Compost toilets ARE NOT pit toilets or outhouses where deposits are collected in saturated anaerobic conditions that ultimately become highly unpleasant (unless you're a fly) and potentially harmful.

Our notion of the "smelly outhouse" arises from saturated anaerobic conditions. Waste in this form tends to be unpleasant.

When we take composted or sanitized materials and reincorporate them into the environment with no negative impacts, we, in essence, do not create waste. Compost toilets are a tool for collecting and processing materials so they do not become waste.

Geographic regions in the world where water and/or agricultural soil amendments are scarce have been beneficially composting their resources for generations. Certain cultures, such as the Hunza in Pakistan, have been using human manure composting systems responsibly for thousands of years in a cycle of food production and human resource recovery. However, the collection and spreading of raw, unprocessed human manures as field fertilizer (referred to as *night soil*) — although a common practice in many regions — is a dangerous practice. It should not to be confused with the distribution of humus-dense organics derived from properly composted excreta.

Excreta = poo + pee + toilet paper

We, in Western culture, have collectively developed a fear — what Joseph Jenkins refers to as *fecal phobia,* a fear of our own shit. Jenkins's book, *The Humanure Handbook,* (2005) is more than just good bathroom reading; it's a book exploring the philosophy and science of human manure that simultaneously informs, educates, and entertains. We highly recommended reading it as part of your considerations of CTs. His book dives into culture and science to remove fears and preconceptions around human waste. Research has clearly shown that when the collection, processing, and treatment of these resources is done properly, hazards are reduced and resources are created.

The Questions

Here at home, we have performed hundreds of tours of our systems, and the compost toilet generally piques a lot of interest. People are intrigued, and they wonder about installing one for themselves. However, they have many questions:

- Does it smell? Will there be flies in my house? Does it look gross?
- Can I put toilet paper in the toilet? Do I need to use special toilet paper?
- Can I put other materials in the toilet, like kitchen compost?
- Will rats, bears, or other animals be attracted to my compost pile?
- Do I have to turn my compost pile?
- Should I cover my compost area with a roof?
- What cleaning products are safe for my compost toilet?
- Can I put menstrual supplies, baby wipes, or similar into my compost toilet? (NO! And not in your standard toilet, either).
- Can I build my compost toilet on a second or third floor of my house?
- Is it expensive? How much will it cost? Can I build it myself?
- Are the materials to build a compost toilet easy to find? Where do I find the parts?
- Can I buy pre-built compost toilet kits?
- Can I modify my existing bathroom?
- Do I need electricity?

- Can I have a compost toilet without a fan? If so, how should I design?
- Can I use my compost in the garden for flowers, ornamentals, fruit trees, or vegetables?
- How do I decide which system is right for me?
- Is it legal?
- Can I still use my compost toilet even though I am taking pharmaceuticals? Will cancer treatment drugs harm my compost? Birth control pills?
- How much work is it?
- Can I use wood shavings from my workshop or wood chips from my chain saw?
- What if I don't have straw?

By the end of the book, you will be able to look at the above questions not just as entertainment, but with understanding of the considerations of the system that is most suitable for your needs.

Where to begin? The essential considerations about whether a compost toilet will work for you, and if so, which system to choose, will require evaluating your "needs" and desired outcomes.

Why Choose a Compost Toilet?

The choice to use a compost toilet system over a standard flush toilet (water closet) can be motivated by a variety of factors:

- Water conservation
- Limited or too-expensive access to septic or sewerage services
- Resource recovery
- Financial cost of septic infrastructure
- Absence of electrical supply for on-site septic infrastructure
- Desire for a no-smell bathroom
- Easier-to-clean toilet
- Resilience (less vulnerable to earthquakes, floods, droughts, economic shocks, etc.)
- Philosophical ideology
- Remote location — need to be site-built, using common materials
- Desire to reduce one's ecological impact and carbon footprint
- Wish to discourage visiting relatives
- Wish to educate friends and family

System choice will be guided by the motivations above, and by identifying the purposes and desired outcomes for your compost toilet (e.g. are you prioritizing volume reduction, cost, ease of use, pathogen removal, resource recovery, etc.?).

Some important but typically unconsidered benefits include:

- Proper composting reduces the impacts of pharmaceuticals entering the environment (Carballa et al., 2004; Ternes and Joss, 2008), addressing the massive risk of antibiotic resistance that is magnified by our present water-based conveyance systems.
- Soil containment of the wide distribution of micropollutants (micro-plastics) (Simha and Ganesapillai, 2016).

As you think about your individual reasons why you would like a compost toilet, remember that you can view this with a large lens. Composting of human excreta and returning the sanitized compost to the land may solve a societal time bomb we are just beginning to understand.

Decrease reliance on water

Flush toilets consume 25%–30% of the indoor water consumption of the average home in North America (Canada Mortgage and

Housing Corporation, 2002; DeOreo et al., 2016). Water consumption of toilets poses problems for people not connected to municipal (piped) water, those subject to water restrictions, those who rely on alternate water supplies like rainwater cisterns, or those with low-performing wells. Decreased reliance on water builds resilience, cushioning you from the impacts of water availability fluctuations.

Can a case be made for compost toilets even if you are using piped water? Sure. Piped water has been collected from somewhere, filtered and treated to potable standards, and then distributed through sizeable infrastructure; all stages (collection, storage, treatment, and distribution) require careful management, which comes at a cost. Once flushed, wastewater has to be transported and treated — at a further cost. Both philosophically and economically, there are good reasons to avoid using a precious and highly treated resource to defecate in and flush away.

For those homes that require filtration and treatment of their own water source, more water use means more frequent filter cleaning or replacement. A waterless compost toilet could reduce that recurring cost by 25%.

Recycle nutrients

Conventional sewer disposal systems, which use hydraulics (water flows) to transport waste for disposal, rarely allow nutrient capture, processing, or redistribution to the terrestrial landscape. Large centralized infrastructure, though it has the advantages of efficiency that come with size, is also subject to the toxic waste stream of industry, further complicating the separation of resources. Compost toilets, due to their small scale, allow for a cost-effective and simple method of gathering and processing nutrient-dense resources, with the option of beneficial reuse.

The difference between waste and resource is one of scale. Unused resources become a waste when introduced into the environment at volumes and in practices where ecological systems cannot utilize the nutrients, thus negatively impacting that ecosystem. Those same resources, with a better-managed introduction, can benefit the ecosystem by, for example, aiding in carbon sequestration or feeding the soil.

NOTE: When we discuss reuse of humanure compost, we are not recommending using fully matured and cured compost (defined shortly) on food gardens *unless there is thorough lab testing showing finished compost meets regulated compost standards.* If you do not test, we recommend using your finished product on woody trees and ornamentals; or, it can be buried under 15–30 cm (6–12 in) of cover material. More on this in Chapter 3.

Reduce pressure on septic or sewerage systems

All conventional systems that serve the function of disposing of human waste for single-family residences or small communities rely on infrastructures that have limited lifespans. Reducing septic and sewage flows can in some cases extend the lifespan of an existing system by reducing hydraulic (water) volume on failing distribution fields or treatment plants. Some homeowners may find financial relief in being able to delay or avoid repairs and instead use other disposal systems (including greywater and compost toilets) that minimize the pressures that may otherwise accelerate system failure.

Some jurisdictions charge user fees for the metered amount of sewer water that travels to the regional sewerage system. Cities and towns charge individual homeowners the costs associated with enlarging sewer mains. In some cases, homeowners may find that user fees are reduced or avoided after they install compost toilets.

Site constraints

Some sites have a reduced ability for traditional on-site septic systems, because not all sites have capacity for percolation. Sites that have fractured rock (or little soil) do not offer proper separation of wastewater, which would result in contaminants entering groundwater or surface flows. In instances like this, having a toilet system that avoids requiring percolation is the only option. Properly designed and placed compost piles with absorbent biological mats (of straw, wood chips, peat, or deep soil that allows water to easily percolate through it) can easily handle the moisture from many compost toilet systems.

Emergency resilience

Using a system not dependent on outside sources of water or sewer fits well with resilience/emergency planning. In the event of large power outages or earthquakes, when water and sewer services can be cut off, it's critical to have an emergency backup option to avoid the resulting sanitation disasters that often follow the initial disaster.

Remote locations

Remote off-grid homes, cabins, or lodges are often inaccessible for the installation of a sewer system. On coastlines, it has been common practice to send the sewage pipe into the ocean. In many remote locations, digging a pit toilet might seem to be the only option. But these can be vectors of disease, and they can easily pollute shallow groundwater sources. Compost toilets provide a safe, clean, odorless alternative in all these situations.

Philosophical ideology

Some say that because we don't have flippers or fins, our shit doesn't belong in the oceans. We should take responsibility and not place our waste in someone else's backyard and leave it for some future generation to deal with. Others say, no sense spending more money if you don't have to. Some just want to be off-grid from everything. Some are worried about disasters. Call it the way you see it, but ideology is one of the main drivers in the adoption of compost toilets.

Basic Goals

Whatever your reasons for choosing a compost toilet (CT), and regardless of whether or not you are seeking approval from local authorities, CTs should meet your goals and objectives AND the safety requirements for reducing risks of the following:

- exposure to human or domestic waste
- consumption of contaminated water
- inadequate facilities for personal hygiene
- creating contaminated surfaces
- exposure to contact with vermin and insects

In addition, you need to ensure structural safety for both the user and the structure. All of this and more can be accomplished. Another way of stating this list of requirements would be:

- You don't want gross.
- You don't want soggy.
- You don't want smell.
- You don't want maggots, flies, or rodents.
- You don't want accidents.
- You don't want dangerous.

In short, through good system design and hygienic operational practices we can control for potential pathogen spread to create a safe and pleasant bathroom experience.

The city of Portland Oregon offers a useful publication: "A Sewer Catastrophe Companion: Dry Toilets for Wet Disasters." (Danielsson and Lippincott, n.d., www.portlandoregon.gov/pbem/article/447707)

Certification Standards

The NSF (National Sanitation Foundation, now called NSF International) sets various international standards relating to health and sanitation; it tests products, educates, and provides risk management for the public. For compost toilets, *NSF/ANSI 41: Non-Liquid Waste Systems* is the relevant standard. (ANSI stands for *American National Standards Institute.* It's the organization recognized as the administrative authority for coordinating standards for products and processes.)

NSF/ANSI 41 is a certification for *"composting toilets and similar treatment systems that do not use a liquid saturated media as a primary means of storing or treating human excreta or human excreta mixed with other organic household materials. The standard requires a minimum of six months of performance testing, which includes design loading and stress testing"* (NSF International, "NSF/ANSI 41: Non-Liquid Systems").

The standard does not cover processing, just whether the design can handle the loads and volumes that manufacturers claim. As processing is a minimum two-year time frame, NSF 41 misses the target for determining if the system does what it claims to. This means that a NSF 41-certified product can structurally meet its intended use, but the standard does not assess the functionality of the product to actually process as it may claim to do and thus does not guarantee that materials are decomposed, composted, or safe for disposal. In short, the certification is not intended to determine if a product works.

It costs manufacturers between $15,000–$20,000 per year to test and maintain their NSF 41 certification. This testing, related to volume loading and structural safety, does not cover actual performance or end product. Regulators unaware of the narrow scope of this standard still often use it as a benchmark for accepting manufactured systems and dismissing site-built systems. However, many of the compost toilet manufacturers have dropped their NSF certification, instead relying on evolving performance-based guidelines (such as those introduced in the Province of British Columbia) that show how to meet all the objectives and functions as required in the codes (Lippincott, 2010).

The takeaway point is that NSF 41 is not a standard proving function and performance. If you ever need to verify a manufacturer's claim, you can use the calculations given in Chapter 4.

There is another certification that is often shown on the label of composting toilets. It is the ETL 3086410, which means the product conforms to UL 1431 (Standard for Personal Hygiene and Health Care Appliances) and CSA C22.2 No.68-92 (Motor-Operated Appliances for Household and Commercial). Retailers are promoting confusion as to this being the appropriate standard to apply to a particular style of toilet. In fact, this standard is tied to the electrical safety of a broad range of appliances, from shavers, massagers, garbage disposals, and other small electrical appliances. Thus, the ETL certification does not specify the functionality of the toilet, but is directly tied to its electrical safety.

Again, the functionality of a toilet is best looked at objectively, and designed to meet the needs of a specific application.

One final certification to mention is the very recent IAPMO WE•Stand (Water Efficiency and Sanitation Standard). IAPMO is the International Association of Plumbing and Mechanical Officials, a group that provides code development assistance, resulting in such items as the Uniform Plumbing Code and Uniform Mechanical Code. The WE•Stand is a performance-based standard released in November 2017 as an American National Standard covering water efficiency for both residential and non-residential applications. Within this standard are provisions for composting toilets (among many other items, including greywater and rainwater), with the first set of comprehensive codified requirements for the installation, safe use, and maintenance of composting and urine diversion toilet fixtures. Requirements include separate collection devices (commodes), and compost processors that are covered and vermin proof, durable construction materials, proper handling of fluid (leachate) discharges, and discharge requirements. The first system to apply this standard was a humanure system in Portland, Oregon, in May 2018. This standard closely mirrors the Provinces of BC's guidelines in the Manual of Composting Toilets and Greywater Practice released in September 2016.

Objectives

Do your objectives and goals prevent you from meeting the objectives and goals of regulators? As noted above, homeowners may have their own rationale for choosing a compost toilet, such as personal philosophy or costs. When owners attempt to initiate actions to meet their goals, they often bump into inspectors with an extremely narrow and prescriptive understanding of building codes and health regulations. Often, there are poor outcomes, and even conflict.

Obviously, if you are the homeowner or the contractor, you want to ensure the safety of everyone using a system, and you want to avoid polluting groundwater or gardens. You also wish to avoid odors, fire risks, and poor hygiene. It is important to understand that the regulators' mandate is to focus on a narrow subset of your objectives; their mandate is not the big picture. The big-picture items are outside the jurisdiction of a building official or health officer, and their training is around the details within their focused scope.

The essential takeaway point is that it is up to those wanting to design and use a compost toilet to understand the role of the regulator and to clearly identify how your choices to incorporate such a system meets the objectives of the regulators. It comes down to understanding and good communication.

Figure 1.1 shows the different perspectives of homeowners and regulators. The homeowner's bigger picture is inclusive of the narrower focus of the regulators'.

If you choose to have your system permitted, how do you communicate these broader goals to officials? To begin with, it is perhaps wise to stop and look at the history of building codes and how they have evolved. Most codes are created to address

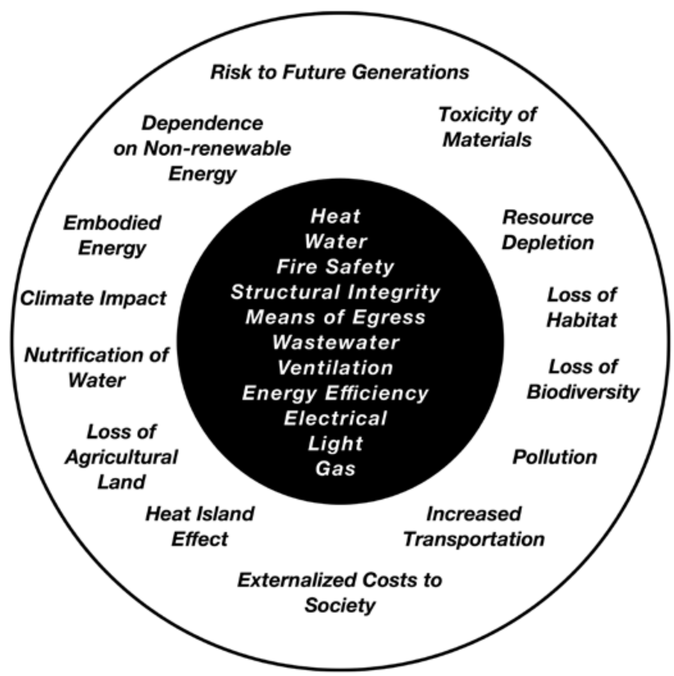


Fig. 1.1: *Regulatory Code Lens. Risks as viewed by the regulators is a subset of a wider set of risks as they might be viewed by the homeowner, designer, or contractor.*
ILLUSTRATION CREDIT: DAVID EISENBERG, DCAT, 2010

accidents or injury that already occurred; because they are based on past failures, they instruct us what NOT to do. Early codes tend to be prescriptive in nature (specific and precise), in essence providing lists of checkboxes for the inspector. If a box couldn't be checked off, the item in question would not be allowed. Europeans began to realize that this approach stymied innovation and creativity and thus began moving away from prescriptive codes to performance-based ones, wherein you had to demonstrate how something performed. This helped Europe become a leader in building innovation, witnessed in both the success of Passive Haus and the implementation of modern compost toilets systems becoming commonplace. In North America, there was also this understanding that the codes needed to be modernized, but there was a stronger attachment to the prescriptive nature, therefore regulators (particularly those in Canada) began to investigate how to mesh the prescriptive and performance-based approaches. The outcome was *objective-based codes* (Potworowski, 2010).

The intent of objective-based codes was to create regulations that allowed innovation and creativity while still giving a minimum standard that had to be adhered to. These minimum standards were originally the documented rules in the prescriptive code but are now called "acceptable solutions." What a concept! By listing minimum standards (acceptable solutions) and by stating the objectives and the functions that had to be met, the door opened to *alternative solutions,* — solutions that meet the intent of objectives, rather than the letter of the law.

Today's codes set out the WHY (objectives) and WHAT (functions) and provide us the opportunity to present the HOW (solutions).

In summary, there is now opportunity for deviation from older codes to new, novel, and innovative "alternative solutions." When we can demonstrate that the rationale of an alternative solution meets the objectives and intents of code, then we can be allowed to implement new ideas while still providing a reasonable degree of risk control.

Learning the language a regulator might use may facilitate better communication and head off problems before they begin. In light of this, the rest of this section gives a basic overview of objectives and functions as understood by a regulator.

Objectives lists

Objectives are the WHY. Below are some of the objectives your inspector will be considering when evaluating your project — in the language they use in their codes.

- **Safety** — Design should limit the probability of exposing any person in or around a building to unacceptable risk or injury.
  - Structural Safety — Design should ensure that the system can bear the weight loads placed on it, and that the system does not place undue loads on other aspects of the structure, which could cause collapse or failure, or cause deterioration of the building elements.
  - Fire Safety — Design should ensure that the system does not create a fire or explosion risk, or impair the functioning of a fire suppression system, or impede access of evacuation.
  - Safety in Use — Ensure that the system limits the probability of slips, trips, falls, contact with hot surfaces, and exposure to hazardous substances, and that hazardous substances are fully contained.

- **Health** — Design and construction should limit a person's exposure to unacceptable risk.
  - Healthy Indoor Environment — Ensure the design of the system ensures good indoor air quality, a lack of contact with moisture, and adequate thermal conditions.
  - Sanitation — To ensure that the design and install of the system does not expose those who use it to human waste, cause or create the opportunity for the consumption of contaminated water, contact with contaminated surfaces, lack of access for personal hygiene, or contact with vermin or insects.
  - Noise and Vibration Protection — Ensure that people are not exposed to dangerous levels of noise or vibration.
  - Hazardous Substances — Ensure that people in or around a building are not exposed to hazardous substances.
- **Protection against Water and Sewer Damage** — To ensure the system does not leak water or sewer/septage.
- **Energy Efficiency** — To ensure that the system does not negatively impair the energy efficiency of the building.
- **Water Efficiency** — To ensure that the system demonstrates higher water efficiency than the standard water toilet/closet system.

Functions

Functions are the WHAT. It's the thing that delivers functionality as required under the various objective-based codes (Building, Plumbing, and Fire). Our alternative toilet solutions need to explain HOW we will address WHAT the code requires. The following is only an example of a few *functions,* as one would see in a building code. The way to read the subsequent phrases is to follow up each statement with the action.

Example: To resist the entry of vermin and insects...

I would screen all vent pipes, reduces excess moisture by actively venting with a fan and diverting urine, and seal off compartment doors with snug weather stripping.

- To minimize slipping, tripping, falling, contact, drowning, or collision…
- To minimize contact with hot surfaces…
- To limit the level of contaminants or the generation of contaminants…
- To minimize the risk of release of hazardous substances or spread beyond their point of release…
- To minimize the risk of contamination of potable water…
- To limit moisture condensation…
- To provide facilities for personal hygiene…
- To provide facilities for the sanitary disposal of human and domestic wastes…
- To minimize the risk of malfunction, damage, tampering, or misuse…
- To minimize the risk of inadequate performance due to proper maintenance or lack thereof…

You need to find out what ordinances and codes are relevant in your locale. In the U.S., one tool is the MuniCode, https://library.municode.com; follow the links from State to City/County. In Canada, no such tool exists; you will need to directly contact your local government.

It's like when traveling in a foreign country: if you make the effort to learn the basic aspects of the language — and others see you working at it — you are likely to have a better outcome in your communications.

Collection Systems: A Brief Overview

This section is a brief introduction to the different types of systems. They are discussed in more detail in Chapters 5 through 7. Although this results in some duplication, many readers will appreciate this early introduction.

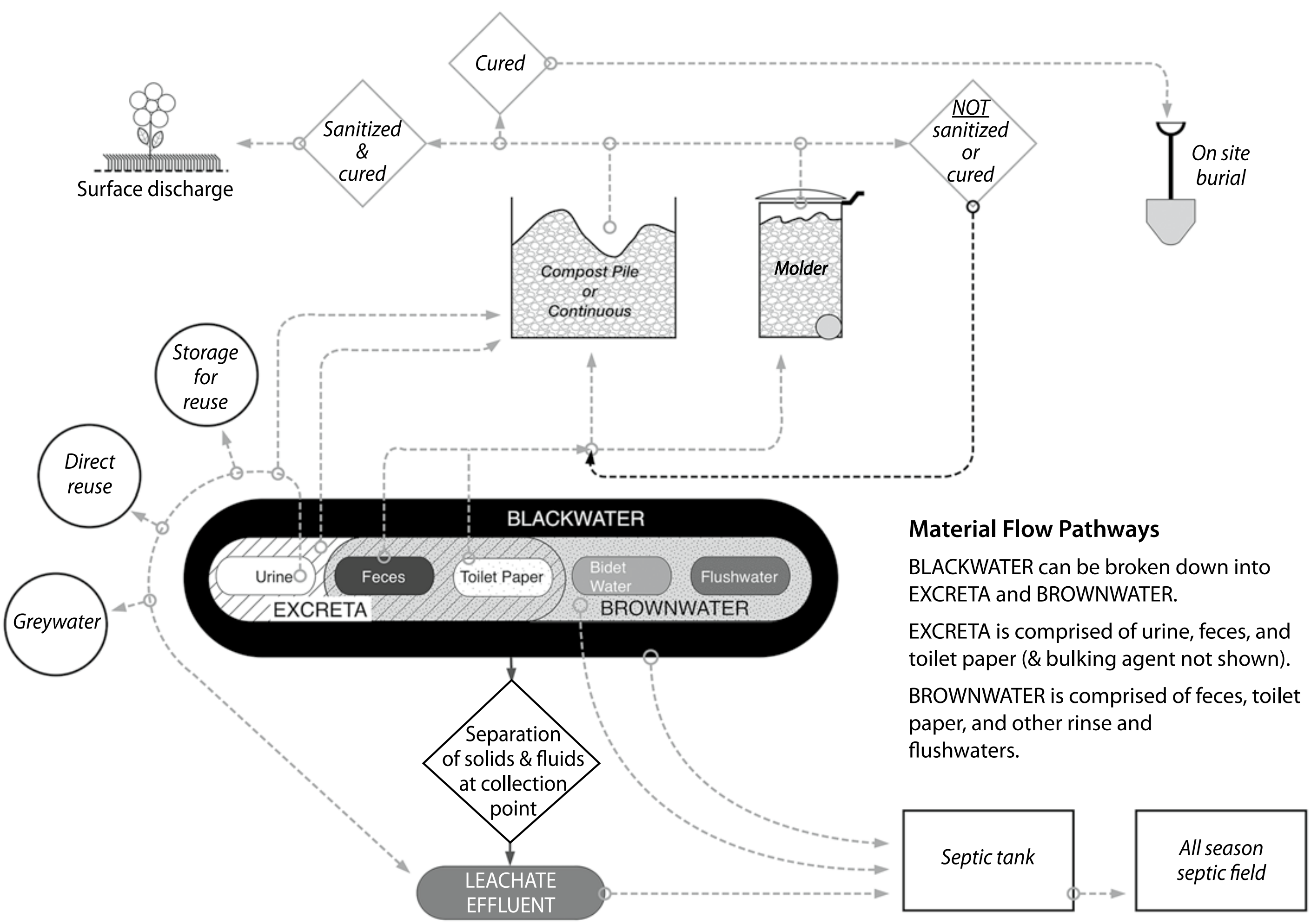
There are many manufactured brand-named toilets available to you (including discontinued brands). In our review, we classified toilets based on how they function, and we picked just a few brand names to use as examples. There are many manufactured compost toilets on the market, so it would not have been practical to include all their brand names. The goal is to understand the basic categories and then seek out locally available products and systems to meet your needs. Many countries and geographic locations (i.e. North America, Europe, and Asia) will have different names for exactly the same system or even the same manufacturer.

Compost toilets systems are separated into two categories: *batch* and *continuous*. All systems follow the same general principles of material flows as seen in Figure 1.2.

Batch Systems

Batch systems generally collect raw materials into a receptacle (a bin or bucket), which, when full, is removed from the collection

Fig. 1.2: *Material Flow Pathways. There are a host of directions materials can flow, and choice of system will determine which pathways are followed.* ILLUSTRATION CREDIT: GORD BAIRD



Material Flow Pathways

BLACKWATER can be broken down into EXCRETA and BROWNWATER.

EXCRETA is comprised of urine, feces, and toilet paper (& bulking agent not shown).

BROWNWATER is comprised of feces, toilet paper, and other rinse and flushwaters.

area. The contents of the full receptacle are then processed. The processing for batch systems can either involve emptying the bin into a compost pile for immediate composting (commode batch), or one can store the contents in the very same bin for long periods of time (chambered batch, or moldering systems). Either way, these batch systems all have a distinct separation between the collection and the aging processes.

Commode Batch Systems

Commode batch systems, commonly referred to as the *humanure* or *bucket system,* have smallish 20 L (5 gallon) buckets under the pedestal (the commode). When a person leaves a deposit, they "flush" by adding sawdust to cover the deposit. The buckets fill up regularly (constituting a *batch*) and are swapped out routinely; full ones are stored until there are enough to make dumping them into the compost pile worthwhile (4–12 buckets). Some commode batch systems use larger, wheeled bins — up to 80 L (20 gallons).

The active compost pile is "added to" for a year; then it is left to sit dormant for a year, allowing it to cycle through the composting stages.

Commode batch systems are discussed in greater detail in Chapter 5.

Chambered/Moldering Batch Systems

In chambered/moldering systems, material is left to sit for extended periods of time (thus, it *molders*). Chamber/moldering batch toilets are different from the commode batch in that the collection receptacles are much larger (bigger *batches*), and they usually involve urine diversion and leachate drainage. They are not transferred and dumped into a compost pile once they are filled. Instead, the solids are held in the collection chamber or bin to age in place for one or more years. Only after this time has passed are the contents either placed into a compost pile (if more processing is needed) or used as a soil conditioner. Moldering systems tend to have a couple of basic configurations: they either incorporate large containers (200 L/45 gal or larger); or they are stationary chambers/vaults that are integrated into a building's design.

Chambered/moldering batch systems are discussed in greater detail in Chapter 6.

Continuous Systems

In continuous systems, new materials are collected and a degree of decomposition is undergone, all within one unit. There are two basic types:

- **Self-Contained Continuous** — small, all-in-one units designed primarily for cabins, seasonal, or recreational use.
- **Centralized Continuous** — large systems designed for regular daily usage.

Despite there being a degree of decomposition within the unit (to the level a manufacturer might call "finished,"), the materials are *not* matured or sanitized (maturity/sanitation is discussed in Chapter 2). Any system that receives continuous raw inputs offers the opportunity for nitrogen and pathogen-rich liquids to re-contaminate all materials in the chamber regardless of their state of decomposition. For this reason, we will continually restate the requirement that "finished" materials from a continuous system receive batch processing (composting) to make them safe.

Many systems incorporate mechanical mixing devices of one form or another (i.e. rotating drums, tines, scraper arms) to aerate and move materials from the raw stage to a stabilized (partially matured) stage and into a location or compartment that can be accessed for removal. These systems can be more complicated because they incorporate active components to speed processing (pumps, heating elements, motors, etc.).

Moisture management for these systems can include any combination of the following:

- urine diversion
- heating elements
- fans and ventilation
- leachate drains

Sizing these systems to match usage patterns is critical because these systems can only decompose materials and eliminate moisture at a specific rate (which is often temperature dependent). If new materials are added beyond its processing capacity, the system will fail. Manufactured systems come with recommendations for the number of continuous daily users the system was designed for.

Continuous systems are discussed in greater detail in Chapter 7.

Vermicomposting Systems

Vermicomposting has aspects that allow its incorporation into both continuous systems and batch moldering systems. Worm introduction requires good moisture control and can offer more complete decomposition within shorter time frames. The speed of decomposition does not greatly impact sanitation, but it enables a system greater flexibility in receiving higher use (more people) and can reduce the need for servicing a system.

After materials are processed by worms, they are highly stabilized; the materials can be buried or transferred to a compost processing pile for further maturing and pathogen attenuation. "Highly stabilized" refers to the creation of a material that is very homogeneous in appearance and has low nitrogen and other phytotoxins, making the materials safe for plants.

Vermicomposting systems are discussed in greater detail at the end of Chapter 7.

Chapter 2

Safe Composting

The most critical aspect of compost toilets is the composting process. There are many important concerns. Will it leach pathogens into the environment or my well? Will it attract vermin? Will it smell? Will dogs get into it? Will kids play in it? Is it safe? Will the local authorities take my kids away?

The answer to all these could be "yes" if the composting system is not designed well. What it comes down to is controlling for *moisture, oxygen, time,* and *temperature,* and, perhaps most importantly, *controlling for pathogen containment.*

Compost Life

Composting is the process of breaking down organic materials through processes of decay and digestion within an oxygen-rich (aerobic) environment. The primary organisms at work in the decomposition and composting processes that degrade pathogens includes *microorganisms* and *soil animals.* Microorganisms include bacteria, actinomycetes, fungi, algae, slime molds, yeasts, viruses, and lichens. Soil *animals,* which aid in aeration, bacterial predation, and degrading surface litter, include protozoa, earthworms, arthropods, amoebas, and nematodes. How fast these organisms work is dependent on available nutrients, environmental factors, and the number and health of the organisms.

These organisms are the workhorses that break down the original materials to a variety of qualitative states (*raw, stable,* and *matured,* as discussed below). Microbes play a larger initial role in processing from the raw to stabilized states, while soil animals play more of a role in the maturing process. Conveniently, the conditions that support and enhance composting organisms' health are generally the same conditions that promote and enhance pathogen death. If you enable a healthy composting process, sanitization will naturally occur over time.

Inconveniently, the chemicals we use on our bodies and for cleaning are often *anti-life.* We need to avoid using anti-bacterial soaps, ammonia, chlorine, and other harsh products in and around ourselves and our toilets if we want compost organisms to flourish.

Pathogens can be bacteria, worms, amoebas, protozoa, viruses, fungi, or prions. All are potentially harmful to humans.

Critical Environmental Factors

Aeration — Without oxygen, the organisms we want to flourish will die, so it is imperative to create conditions for good air exchange in each stage of the process. What you are trying to do is create mechanical means of entry for oxygen and escape for the carbon dioxide given off by decomposition. Achieving a good surface area-to-volume ratio through a combination of a loosely textured material and air pockets (pores) within the pile is important. A good ratio can be created by the regular addition of coarse bulking agents (like sawdust) or the introduction of earthworms in the advanced stages. It is also possible to use mechanical means to stir the pile to add oxygen. Increasing air flow by actively venting the material aids in gas exchange (and evaporation of excess moisture). If the materials become too wet, then the open pore spaces don't exist, and anaerobic

Aerobic compost smells sweet; anaerobic smells foul.

Above 75% moisture, you would be able to squeeze material and have it drip — not that we are suggesting you do this of course, but this is a method of testing applied to conventional composts.

conditions occur — leading to a *different* population of bacteria (*anaerobes*), which release noxious gases like hydrogen sulfide, ammonia, and methane gas. Yuck!

Moisture — A moisture content between 45%–70% (a wide margin) is the target. Below this range, it is too dry for organisms to thrive; above this range, the pores begin to fill with fluid, creating those anaerobic (without oxygen) conditions just mentioned.

Temperature — Different temperatures support different biological lifeforms, activity, and processes (e.g. earthworms won't survive high temperatures of 45°C to 80°C [113°F to 176°F]). The Q10 temperature coefficient applies to composting: for every 10°C (18°F) in temperature rise, the biochemical activity doubles — until pasteurization temperatures are reached, at which point biological activity drops off. Pasteurization is not defined by a particular temperature per se, but rather as a temperature range that results in the death of organisms exposed to it over a certain period of time.

In ideal compost conditions, the compost pile hits both the running-out-of-food limit (carbon) and the building blocks limit (nitrogen) at the same time. Achieving the right balance is surprisingly easy: the carbon is derived from the poo, toilet paper, and bulking additives, and the nitrogen comes from our urine. When limits are hit, temperatures drop, which allows the next stages of the process to occur: soil animals and fungi flourish and carry out the long-term aeration and the conversion of lignin (a complex carbohydrate found in plant cell walls), and the remaining carbon into simpler forms (Del Porto and Steinfeld, 1999).

There are three main classifications for microbial communities; they are grouped together by the temperature ranges in which they survive and thrive. For the purposes of composting/decomposition, each group acts differently and serves a different purpose.

The warmer the temperatures, the bigger the bacterial compost party — until they cook themselves (kind of like human-induced climate change). In composting toilets, given the right environmental factors, early processing will self-generate temperatures that promote more biological activity; that activity creates warmth. At some point, one or more of the limits to growth are hit. These limits include a too-high temperature, running out of food, a shortage of water, or lack of oxygen. Available nitrogen also plays a critical role in that it allows bacteria to build cell walls and to multiply; if nitrogen levels drop, bacteria run out of the building materials they need to reproduce.

Psychrophilic: -10°C to 20°C (14°F to 68°F)

- In low temperature decomposition, *psychrophiles* dominate. Predominant organisms include actinomycetes, fungi, and larger soil animals (like worms and arthropods).
- Pathogen attenuation (reduction) is greatly inhibited. In some cases, pathogen *preservation* results — in the same way we use a fridge to preserve food (the cold doesn't kill bad things, it just slows them down).
- There are few cool-temperature psychrophiles that are human pathogens.
- Cool-temperature conditions can be found in "moldering" systems and in late-stage curing of matured composts.
- Composts that never exceed this temperature profile are not considered sanitized; they therefore require testing before direct burial at 30 cm (1 foot) or deeper. Otherwise, they require thermophilic (high-temperature) treatment or other sanitization process to be considered safe.

Mesophilic: 20°C to 44°C (68°F to 112°F)

- In warm temperature decomposition, *mesophiles* dominate. Predominant organisms include bacteria, fungi, actinomycetes, and some soil animals like protozoans, rotifers, and worms.
- Mesophilic activity is supported by warm ambient air temperatures or external heat sources.
- Mesophilic conditions are the most common in all types of compost toilets and processors, they precede and follow the thermophilic temperature phase.
- Composts that do not exceed this temperature are only considered sanitized after a minimum of two years; at that point, they can be directly buried at 30 cm (1 foot). Otherwise, they require further thermophilic treatment or other sanitization process to be considered safe.

Thermophilic: 45°C to 80°C (113°F to 176°F)

- In this high temperature range, *thermophiles* dominate.
- Most thermophiles are bacteria; soil animals do not survive such high temperatures.
- The regulatory agencies that set composting standards and guidelines define true composting as one that undergoes biological processes at these high temperatures.
- Commonly called *hot composting.* Pathogen death rate increases as temperatures rise.
- Ideal conditions for hot composting require a carbon-to-nitrogen balance (C:N ratio) that is roughly 30:1 (carbon for food, and nitrogen for amino acid and protein production). Too much carbon slows the process down and causes a cooler pile; too much nitrogen will cause unpleasant odors (Richard and Trautmann, n.d.).

An adequate volume of material (>1 m^3 or >1 yd^3) is required to retain the self-generated heat from the bacterial activity, retain moisture, and insulate the contents from the cooling influence of ambient air temperatures (this volume will protect compost temperature even in freezing temperatures). Because such conditions are rare in nature, thermophilic compost doesn't naturally exist (except in relatively rare situations). Additionally, diversity supports more microbial activity, more oxidization, and more heat.

If you have a smaller compost pile, you can facilitate decomposition by adding straw

Fig. 2.1: *Thermophilic temperatures signal a very biologically active compost pile, creating a hostile environment for pathogens and a rapidly stabilizing mass.* Photo credit: Gord Baird

We often start a new pile with a dead rodent, chicken, or something with intact intestines, then we add all our kitchen scraps; this adds to the initial microbial life present, allowing the pile to more rapidly reach hot temperatures.

insulation and/or more garden materials, putting a seasonal roof over the compost — or having more kids to help make more compost.

In summary, thermophilic conditions are the key defining aspect of what delineates true composting from decomposition. Mesophilic bacteria thrive in the most common temperature range on the planet, including in the body temperature range of most mammals. Psychrophilic bacteria like it cool and function at temperatures not associated with pathogen death; in fact, they aid in preserving them in a dormant form. Compost *toilets* have psychrophilic and mesophilic phases; compost *piles* will transition through all three temperature ranges.

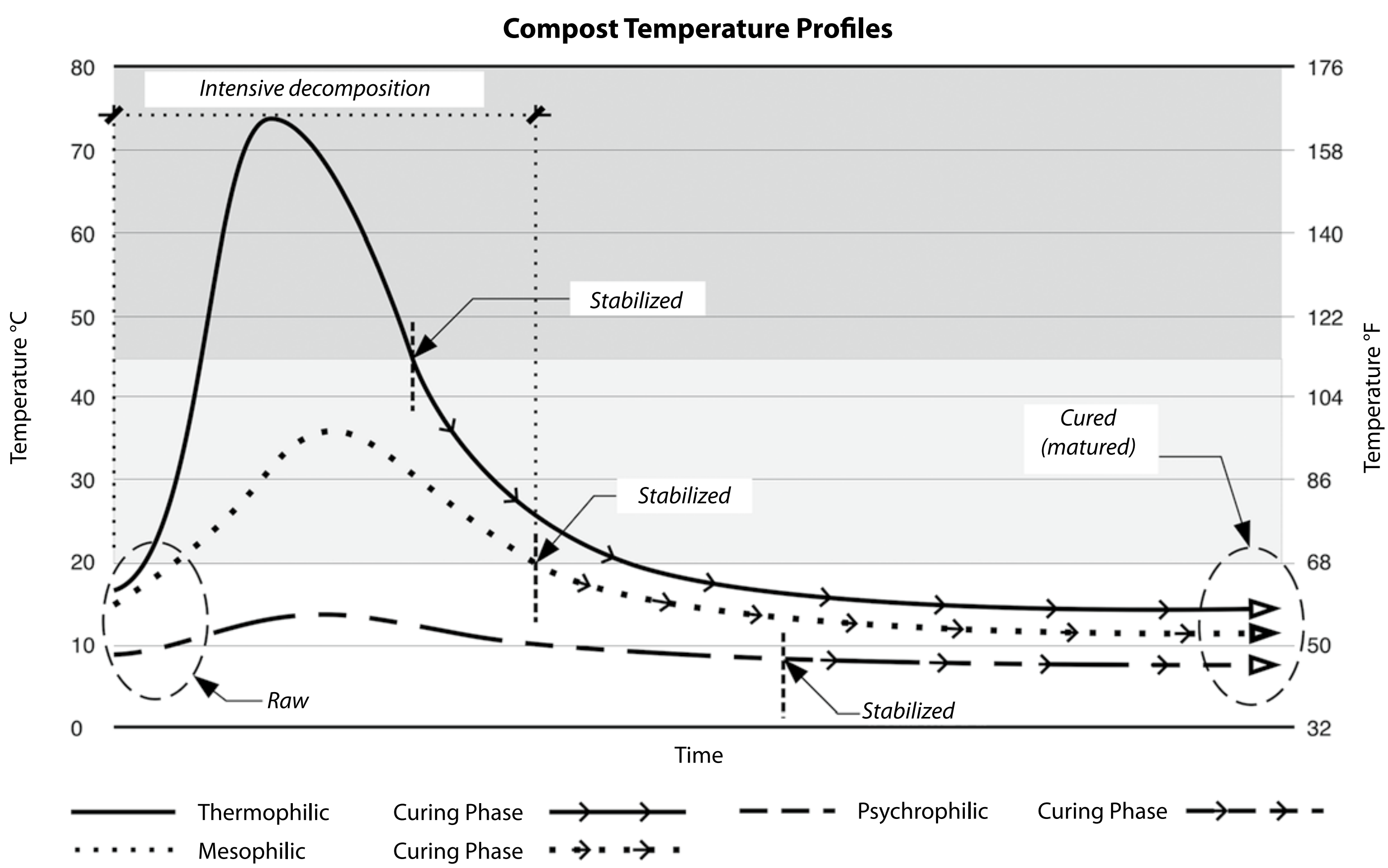
Temperature Profiles

If we were to chart the temperature of a pile of raw materials from the start of new additions till the end, when everything is decomposed, we would witness a pattern. The pile starts out cool, but quickly heats up as biological life becomes active. Temperature peaks when resources start to decline (like nitrogen, carbon, water, and oxygen), then there is a long cooling stage (see Figure 2.2).

Snapshot of the ideal compost conditions:

- Carbon-to-nitrogen ratio of 20–35:1
- Moisture content: between 40%–60%, and not above 75%
- A pH between 5.0 and 8.0 (pH 0 [acid], pH 7 [neutral], pH 14 [basic])
- Porosity, or air spaces: 30% of the materials should have their surface area exposed to air to allow for air flow and gas exchange; particle sizes should not be too small because that allows compaction. You want a fluffy compost.

Fig. 2.2: *Comparison of compost temperature profiles.*
ILLUSTRATION CREDIT: GORD BAIRD



Materials and Processing States

There are three distinctive processing states that can be differentiated by their physical qualities. These are *raw, stabilized,* and *matured,* and they are linear in progression. The compost toilets system employed will determine the progression as various toilets manage the critical factors just discussed differently; they rely on different temperature profiles to carry out their processes.

Raw Materials: Excreta

As an adult reading this book, your mental image of what raw materials are and look like is likely pretty accurate, so we will spare you the details. Well, maybe not. For our purposes, we often refer to raw materials as *excreta,* which includes feces, urine, and toilet paper that has not undergone any form of processing related to time and/or temperature. This raw stage is where there is the highest opportunity for pathogen transfer and potential for nitrogen to leach from soils into waterways (Wichuk and McCartney, 2010).

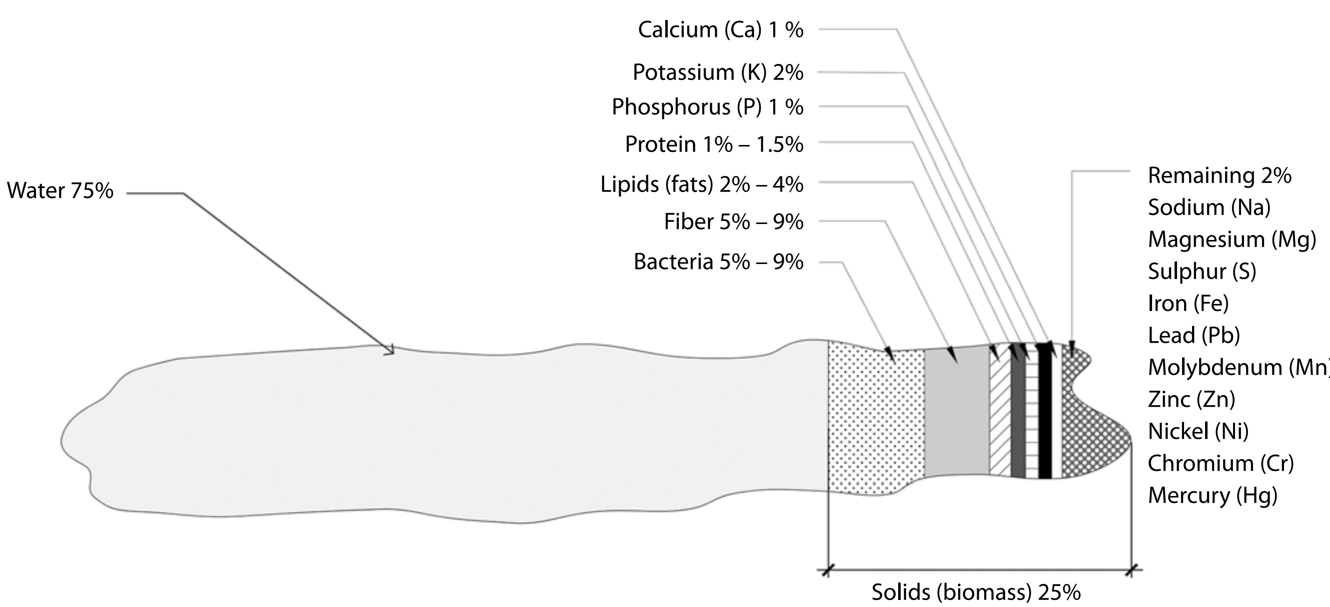
Raw materials also include other additives. Usually, you will add to the excreta some type of biodegradable bulking agent, like peat moss, chipped leaf mulch, fine wood shavings, coarse wood sawdust, or shredded toilet paper tubes.

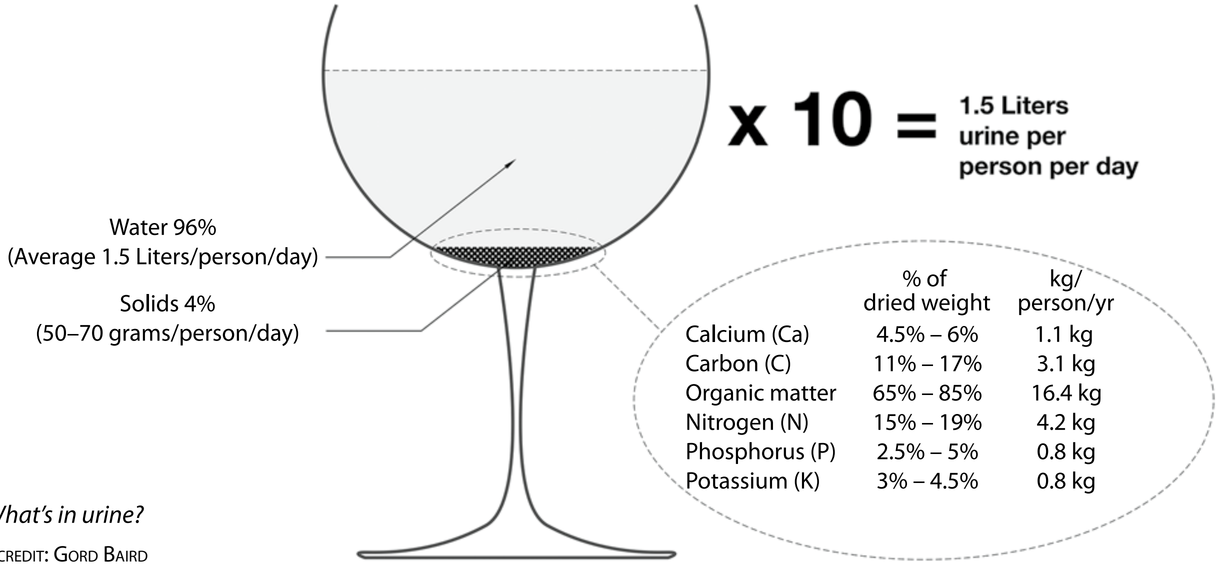
In the thermophilic compost, there are other raw materials that are often included (some manufacturers specify it) — items that are not normally appropriate for your garden compost, such as bones, meat scraps, or egg shells. Surprisingly, in thermophilic conditions, such items are consumed rapidly by bacteria; we, ourselves, have witnessed dead chickens completely consumed within four days, and animal processing yards use a thermophilic system to address their wastes. However, for those compost toilet processing systems that rely on moldering, these items will not be appropriate.

Looking deeper (sorry, this is important), feces is roughly 75% moisture and 25% solids. Figure 2.3 illustrates the breakdown even further. The solids are two types of solids: the volatile organic solids (carbon-based solids that, when dried, will burn, including proteins, fats, carbohydrates, dietary fiber, and total nitrogen); and fixed solids, also known as minerals, which do not decay.

Urine is 96% moisture and 4% solids, wherein the solids are primarily fixed (mineral); Figure 2.4 shows the breakdown of what's in your urine.

Fig. 2.3: *What's in your feces? Composition of a turd.*
ILLUSTRATION CREDIT: GORD BAIRD





	% of dried weight	kg/ person/yr
Calcium (Ca)	4.5% – 6%	1.1 kg
Carbon (C)	11% – 17%	3.1 kg
Organic matter	65% – 85%	16.4 kg
Nitrogen (N)	15% – 19%	4.2 kg
Phosphorus (P)	2.5% – 5%	0.8 kg
Potassium (K)	3% – 4.5%	0.8 kg

Fig. 2.4 : *What's in urine?*
ILLUSTRATION CREDIT: GORD BAIRD

Fig. 2.5: *Raw Materials: Coarse sawdust/shavings.* PHOTO CREDIT: GORD BAIRD

- Ninety percent of the nitrogen that is excreted from the body is in the urine.
- 1.5 L (1.6 quarts) of urine is excreted on average per person per day (10 full wine glasses).
- 0.18 L (0.19 quarts) of feces is excreted on average per person per day.
- More solids come out of your urine (4% of 1.5 L) per day than your poo (25% of the 0.18 L).
- Of all the solids or biomass, 25%–50% is bacterial bodies. SERIOUSLY!
- Feces is pH 6.6 (neutral) and urine is pH 6.2 (slightly acidic).

The photos in Figures 2.5 through 2.10 provide visuals of… stuff. They clearly show what different materials look like and how they are deposited into the center of the compost pile. Figure 2.10 shows the appearance of the pile with the cover materials added and thermometer installed. The compost pile in these pictures ranges between 60°C–76°C (140°F–170°F) at peak temperatures throughout all four seasons.

Fig. 2.6: *Raw Materials: Kitchen compost including vegetables, egg shells, coffee grounds, and meat and bones.* Photo credit: Gord Baird

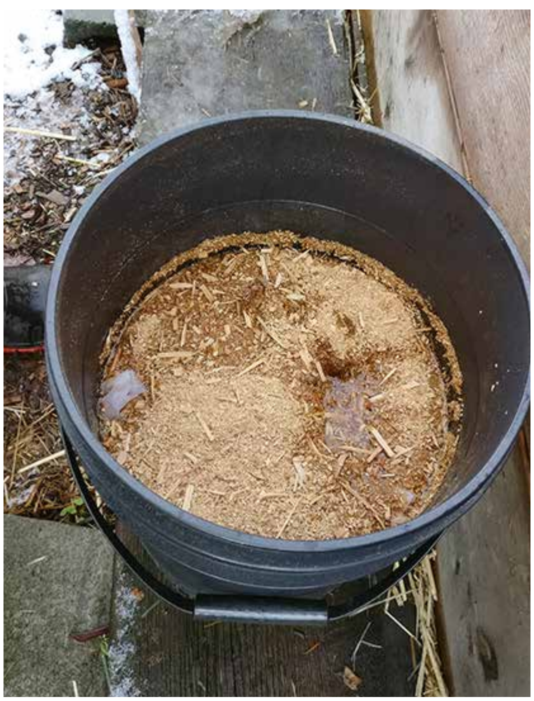


Fig. 2.8: *Raw Materials: Batch commode bucket two-thirds full — visually more appealing than the kitchen compost and less fragrant.* Photo credit: Gord Baird

Fig. 2.7: *Raw Materials. Kitchen compost is the first component to be dumped into the pile — unsightly and fragrant.* Photo credit: Gord Baird

Fig. 2.9: *Raw Materials: Collected excreta added atop kitchen compost — visibly high in carbon (sawdust/shavings).* Photo credit: Gord Baird

Fig. 2.10: *Raw Materials: The new additions are flattened with a dedicated rake and covered with 6"–8" of loose straw (or spent animal bedding, leaves, shredded paper, etc.).* Photo credit: Gord Baird

Raw = unprocessed excreta

Stabilized = materials that have low-to-no odor and unrecognizable components

Mature = stable forms of nitrate with no ammonia, decreased and stable CO_2, and no odor

Sanitized = safe for humans.

Raw materials for large batch chamber compost toilet systems (aka moldering systems) or continuous system are visibly very different, as pictured in Figure 2.11. These systems employ moisture diversion, therefore less carbon bulking agents are required. Less bulking agents make the pile less aesthetically pleasing, but in these systems you don't have to look at it, so who really cares? Even though bulking agents are not required to absorb moisture in these large systems, they are often still applied to provide porosity (air spaces) to the materials.

Fig. 2.11: *Raw Materials: Raw excreta deposited into a Terra Nova compost toilet, viewed through the rear inspection port.*
PHOTO CREDIT: A. SCHÖPE, SUSTAINABLE SANITATION ALLIANCE

Fig. 2.12: *Stabilized Materials: No identifiable constituents of the raw materials are visible — there is no odor, but the material is still potentially a carrier of pathogens.*
PHOTO CREDIT: GORD BAIRD

Compost Stages

Stabilization

Stabilized Compost Compost toilets start with the collection of raw, unprocessed materials. These organic materials have high levels of nitrogen, bacteria, and potentially dangerous pathogens. As these materials decompose, they undergo biochemical changes that break organics into smaller, more homogeneous pieces, reducing the pathogens and converting the nitrogen to a state with decreased phytotoxicity (toxicity to plants). Eventually the materials reach a stabilized state, qualitatively characterized by having no discernable original materials, low-to-no odors, and a high nutrient content to support moderate biological activity. This stage will likely still have pathogens. Only the highly stabilized versions will not tie up nutrients in the soil or reduce oxygen availability (Ralston, 2016). Stabilized materials are NOT yet ready for dispersal.

Stabilization can be achieved through any of the three processing temperatures, but it usually occurs in the mesophilic and thermophilic ranges. However, a longer time at lower temperatures will also achieve stabilization.

Stabilization is also marked by the quality of resisting further decomposition. As the microbial activity consumes the carbohydrates and nitrogen, activity slows, resulting in less decomposition (Wichuk and McCartney, 2010).

Maturation

Mature (Cured) Compost Microorganisms continue to convert the organics to smaller particles, as these organics are their "food source." In the presence of this abundant food, the microorganisms grow and reproduce, using the volatile forms of nitrogen (urea and ammonium) to build their cell walls, and in this process are converting these volatile forms of nitrogen into stable, safe forms for plants (discussed in Chapter 7). Microorganism activity slows when resources decline, due to decreased food (carbon) and nitrogen, which is indicative of completed decomposition. At this stage, the contents rest at ambient temperatures (psychrophilic and mesophilic), in an aerobic condition, for a specified time.

Mature compost is qualitatively characterized by homogenous small particles and no odor; nutrient sources have been consumed to a point where biological activity has slowed and stabilized. This can be demonstrated through testing (discussed in depth later). The mature stage ensures that materials are safe for plants and can be introduced into the soil, though it still does not mean that all potential pathogens are dead (i.e. the compost is not *sanitized*) (Ralston, 2016; Wichuk and McCartney, 2010).

The maturation pathway is slightly different for thermophilic and non-thermophilic processes (see Figure 2.13). In thermophilic processing, maturation starts when the temperatures drop down into the mesophilic range, and it continues over time as long as pile temperatures are ≥ 5°C (41°F). In non-thermophilic piles, maturation is defined by the period of time at a particular temperature. During this long period, the cooler temperatures allow for insects and fungi to enter the pile and continue biological processing. Insects mechanically break down materials — they literally chew it all up. But more importantly, they re-create tunnels and airways throughout the compost pile to allow for gas transfer (primarily oxygen

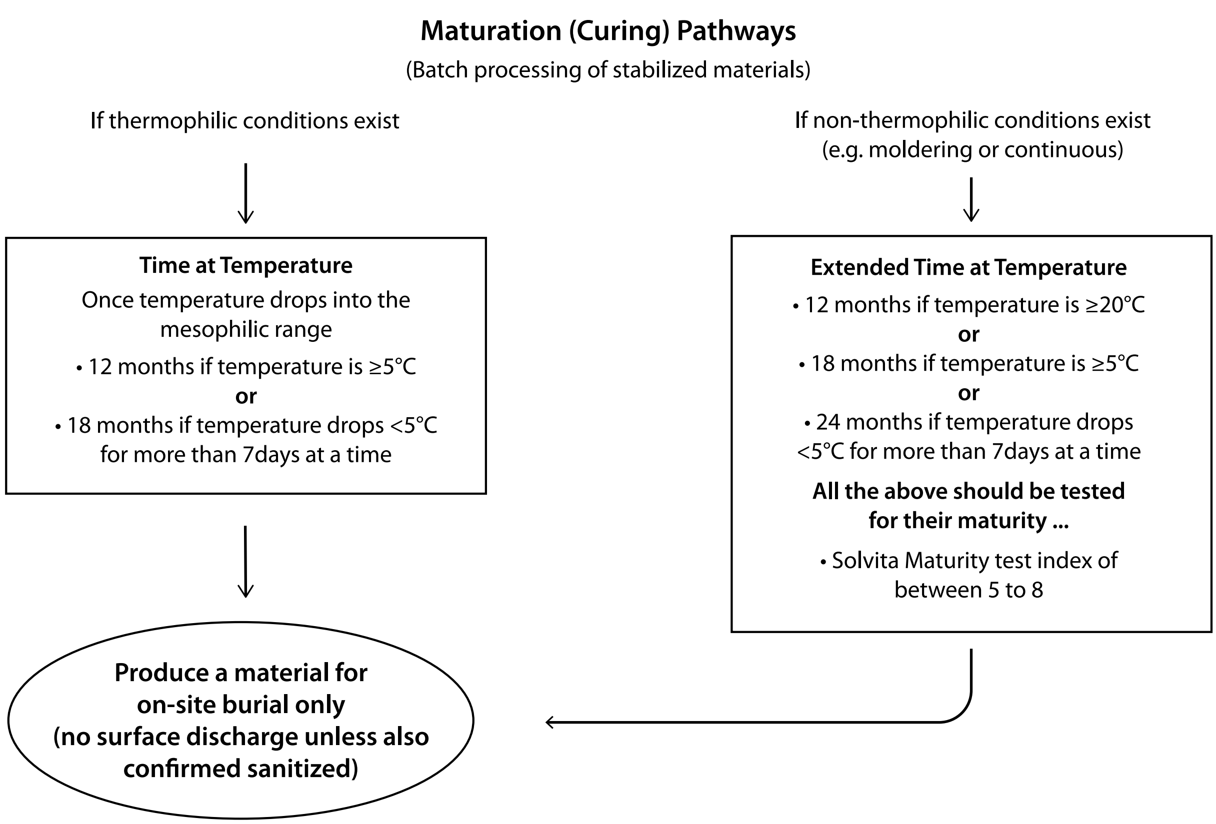


Fig. 2.13: *Maturation pathways for thermophilic and non-thermophilic processes to be considered cured or matured and ready for burial only.*
ILLUSTRATION CREDIT: GORD BAIRD

and carbon dioxide). Fungi also work on the woody cellulose to break down the lignin, thus playing a huge role in further homogenizing the materials, as seen in Figure 2.14.

Again, it is important to reiterate that despite certain qualities defining a compost as mature, or cured, the compost is still not sanitized. Sanitization processes are extremely likely to coincide with maturation processes, but we cannot always assume this.

Fig. 2.14: *Matured Materials: More finely textured than the stabilized materials and no trace of phytotoxic compounds.* PHOTO CREDIT: GORD BAIRD

Sanitization

The final procedure, sanitization, is dependent on the time frame the materials are held at given temperatures. This process can be further manipulated by some other action such as the addition of ammonia, changing the pH, or pasteurizing with external heat or other chemical process. Ultimately, *sanitized* means that the pathogen levels are below the threshold to cause disease. Just as *cured* does not ensure sanitization, sanitization does not ensure maturation (you could conceivably take raw materials and heat them up to kill pathogens, thus sanitizing it, but you could still be leaving high levels of nitrogen that would be unsafe for plants).

All types of pathogens (viruses, bacteria, fungus, protozoa, and parasitic worms, or helminths) (Alberts et al., 2002) will die through one of the several pathways. The process of reducing a pathogen load is called *pathogen attenuation,* which in regular language means *killing the disease-causing bugs.* When pathogens loads have been reduced to levels that are no longer dangerous to humans (making the compost safe for handling and discharge into the environment), we call this *sanitized.* But sanitization is NOT to be interpreted as disinfection or sterilization; sterilization is the elimination of virtually all microbial life.

To understand the sanitation process, we need to briefly touch on pathogens and how they spread.

Pathogen Spread

There are many routes by which pathogens spread. Our primary goal to stop any possible contact of feces with the face; to do this, we use *the multi-barrier approach.* (See Figure 2.15 showing the "F Diagram.") The multi-barrier approach is used to:

- Avoid direct contact with human excreta.
- Limit vector-borne transmission via rodents, insects, birds, pets, or mischievous small children.

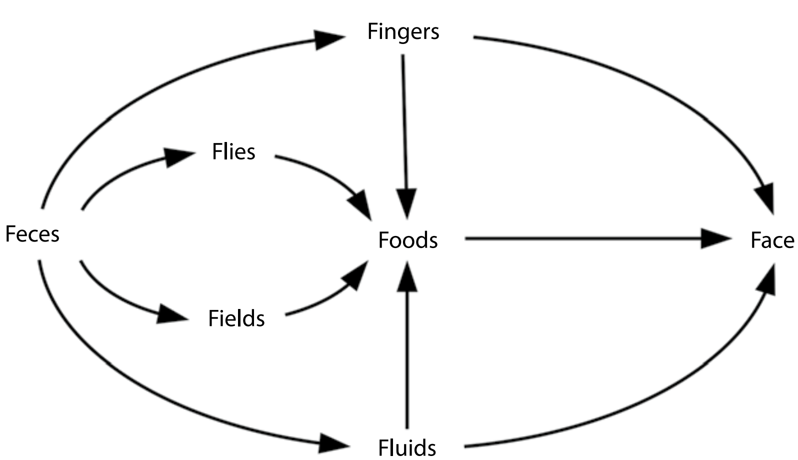


Fig. 2.15: *The "F Diagram" summarizes the main ways fecal pathogens are spread from the feces to the face.* ILLUSTRATION CREDIT: GORD BAIRD, ADAPTED FROM WINBALD ET AL., 2004

- Ensure no inhalation of dusts or aerosols from use of materials before fully treated.
- Avoid misapplication of unsanitized materials on food crops.
- Avoid leaching pathogen-rich fluids into waterways that would affect drinking water or foods harvested from those waters.
- Stop domestic and agricultural animals from consuming human excreta and posing as new hosts or transmission sources.
- Keep facilities clean.
- Promote personal hygiene, halting secondary spread among the population.

By *barrier* we don't just mean physical obstruction. A barrier can also be an action or an approach. All of the following can be part of a multi-barrier approach: personal sanitation, toilet design, vermin control, leachate management, compost confinement, temperature/time and moisture management, and safe-handling practices. You may notice that these barriers are reminiscent of the regulatory objectives in Chapter 1.

Here are some barriers to employ that prevent pathogen spread:

- **Don't allow animals to gain access to unsanitized materials** (e.g. dogs, pigs, cattle, or birds). Using seagulls as an example, we know that tapeworm can be transmitted from human feces to birds, whose droppings can land on roofs and enter rainwater cisterns. If the birds cannot gain access to unsanitized human feces, then you have a sanitary barrier. Keep creatures out of your compost pile.
- **Don't allow human feces to enter the soils or water systems unless treated.** Some worms require fish or snails as a host. Remove the possibility of aquatic contamination by collecting and treating leachate or by using absorbent biological sponges under compost piles. If excess moisture will be an issue, roofing over the compost bins will avert a waterlogged sponge.
- **Insect vectors can be easily reduced.** Inside the area that houses the collection receptacle, the use of specialized flytraps can help limit their populations. (See Figures 6.15, 6.16, and 7.6.) Always ensure that there is no pooling liquid by using proper drainage; keep buckets and bins tightly closed until composting time; keep lots of cover materials on compost piles, and consider covering the entire pile with some sort of roof structure; use appropriate safety mask and gloves when dealing directly with the composts.
- **Heat is another form of sanitary barrier.** Flies are attracted to fresh feces, and they lay their eggs in it; however, adults, larvae, and eggs cannot survive temperatures above 122°F (50°C) — another good reason to use thermophilic composting.

Pathogen death

Pathogens are classified based on three qualities:

1. Virulence — severity or harmfulness of a pathogen
2. Latency — period of dormancy of a pathogen before acute signs of infection are visible
3. Persistence — the degree to which a pathogen can fend off its destruction

Whatever methods we choose to treat our excreta, we need to account for the most virulent pathogens with the longest latency and the most persistence. Any and all of our interactions with unsanitized material require precautions so as not to infect ourselves or others (which is surprisingly easy, as discussed in Chapter 3).

Of all the pathogens that exist in the five geo-climatic zones, the most common and persistent pathogen, and the one used as a key indicator for sanitation, is the very persistent *Ascaris lumbricoides* (roundworm). (Buswell et al., 1998; Webber, 2016). *A. lumbricoides* resides as an egg (ova) that requires a lengthy dormancy before it is developed enough to infect a host. This pathogen is the primary target to control for.

Factors influencing pathogen attenuation include:

- **Exit from the body** is the first stage to pathogen death. All organisms have an ecosystem in which they thrive, and when removed from their life support systems, survival is compromised.
- **Time** away from life support systems increases pathogen death. Given long enough with no opportunity for a new host, they will die. Time in hostile conditions speeds up the death rate.
- **Temperature** is extremely effective at physical deactivation — otherwise known as killing the pathogen. Additionally, when this heat is a product of thermophilic processing, there will be more microbes present to chew up and spit one another out.
- **Competition and predation, alluded to directly above,** is another factor that leads to pathogen death. A large and diverse population of organisms will tend to compete for the same foods and see one another as food sources. Yup, they eat each other. When food sources decline, they begin to consume their own structures (protoplasms), which weakens them further. Fancy way to say they starve to death.
- **Antagonism** also promotes pathogen death, via the creation of toxic substances that kill other organisms (some bacteria and fungus create antibiotics). Yup, toxic warfare in the compost pile.
- **pH** both high (alkaline) and low (acidic) will be effective at reducing pathogens. High pH is marginally effective over pH 9 and very effective at pH 12. In mesophilic situations in which pH is raised to over 9.4 and urine is collected with the other raw materials, Ascaris eggs are killed in three months (Jensen, et al., 2009).
- **Ammonia** provides another tool to reduce pathogens. However, if ammonia is used in the process, it should be combined with other methods: research done in 2015 showed that some bacteria are evolving to survive ammonia compounds (Jennings et al., 2015). In composts where urine has been diverted (and so is low in ammonia), longer storage is required to kill Ascaris worm eggs (Jensen et al., 2009).
- **Sunlight** oxidizes and kills microorganisms (Webber, 2016, p. 5; Feachem et al., n.d., p. 79).

Thermophilic digestion is perhaps the lowest-cost process that causes near 100% destruction of pathogens (Feachem et al., 1983). Even the lead researcher of the world's most advanced toilet, winner of the Gate's Foundation "Reinvent the Toilet Challenge" (discussed in Chapter 10), notes that the simple thermophilic compost pile is the simplest, most appropriate and effective technology to sanitize human excreta.

Chemical Pollutants

Chemical pollutants may show up in our compost pile from the food we eat, the pharmaceuticals we take, the air we breathe, or even from the personal care products absorbed into our bodies through our skin. Examples of chemical pollutants are pesticides, plastic residues, endocrine disrupters (like Bisphenol A and phthalates), fragrance chemicals we breath, and pharmaceuticals, including cancer drugs, pain killers, and hormones (birth control pills). Chemical pollutants are a little different from pathogens: they are not disease-causing organisms. Yet the same biological processes that occur in composting to "sanitize" pathogens are also involved in transforming toxic chemical pollutants into less harmful or fully safe substances.

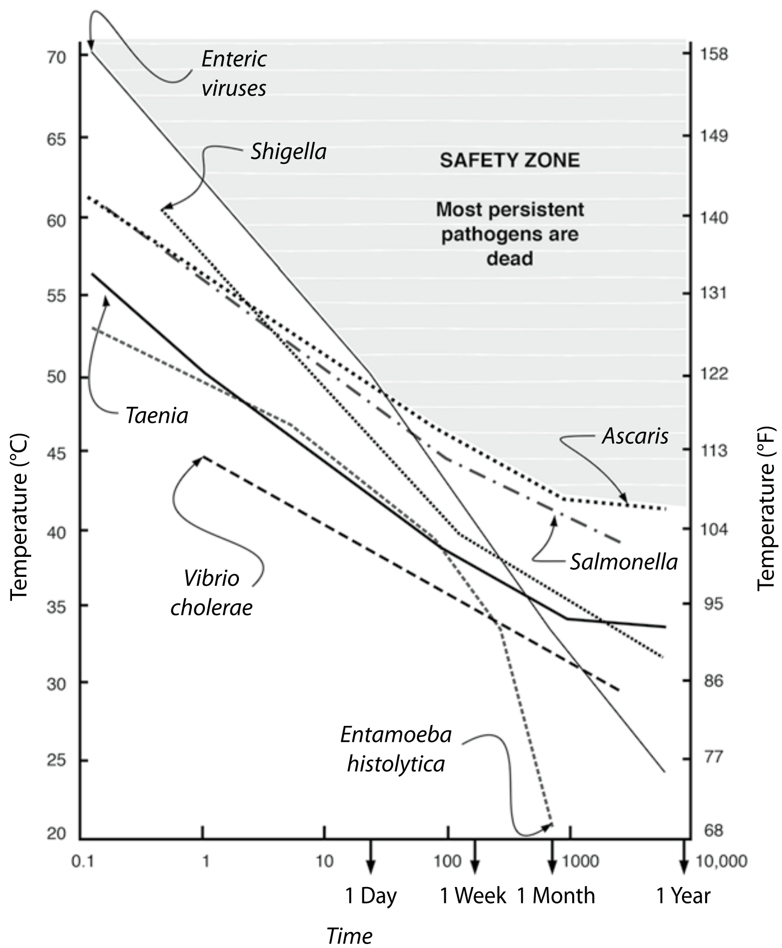
The main process of transformation for these pollutants is *oxidation,* a biological process involving a series of steps in cellular digestion. Oxidation relies on water, enzymes, salts, and acids for extracting energy for cellular use. The process breaks apart chemical bonds in molecules, and swaps hydrogen atoms from one molecule to another, thus permanently transforming chemical pollutants to nontoxic molecules. This occurs in a biologically active compost through natural processes. Advanced oxidative processes (AOP) are used in municipal waste treatment systems to detoxify wastewater streams (an example of an AOP you likely learned in Grade 12 science is the Krebs cycle, which drives cellular respiration).

Achieving Sanitation

All organisms will eventually die a natural death. Death can be sped up by creating a hostile environment that promotes predation, competition, heat, starvation, mutation, or other conditions that cause mortality. Yup, it's all-out war on disease-causing bugs in the compost pile.

A pathogen's ability to survive when excreted from its host is called *persistence.* One that survives for a long time is to be considered highly persistent; those that die off quickly, soon after excretion, have low persistence. The greater the persistence of a pathogen, the more we have to rely on either harsh conditions or just time itself. It is important that we recognize the role of time, even when we have created an ideal hostile environment.

Sanitization can occur in both thermophilic and non-thermophilic conditions. (Sanitation pathways are shown in Figure 2.17.) Both conditions, though, share a common rule: the sanitization process does not



This figure indicates time temperature requirements for pathogen death are at least: 1 hour at > 62°C or 1 day at > 50°C or 1 week at > 46°C

Fig. 2.16: *Influence of Time and Temperature on selected pathogens in night soil and sludge.* Illustration credit: Gord Baird, adapted from Feachem et al., 1983, page 79.

allow for any new additions, hence sanitization only happens as a *batch process* — one "batch" at a time. (*NOTE:* Throughout this book, we will disagree with manufacturers' claims that continuous toilet systems can produce materials that can be immediately buried. These materials may look decomposed, but due to constant additions of raw materials and the corresponding leaching, the levels of volatile nitrogen and pathogens are elevated, which make them unsafe for burial.)

As shown in Figure 2.17, compost sanitation can be achieved by various methods including holding the compost at certain temperatures for certain amounts of time, applying chemical additives, or changing temperatures.

In thermophilic conditions:

Transition to sanitized happens very quickly, requires the least amount of time, and is perhaps the most simple. This essentially is the most common process for the homeowner for this reason. The worst case scenario: procrastinate and let it sit 12 months once temperatures drop.

In non-thermophilic conditions:

Those systems that "molder" can achieve sanitation in several ways. Patience and allowing it to sit for extended times is, of course, the easiest option, but if storage space is limited or nonexistent, then additional options exist: adding external heat to essentially pasteurize the pile; increasing the pH to, in essence, chemically burn the life out of the pile; or boosting the ammonia gas.

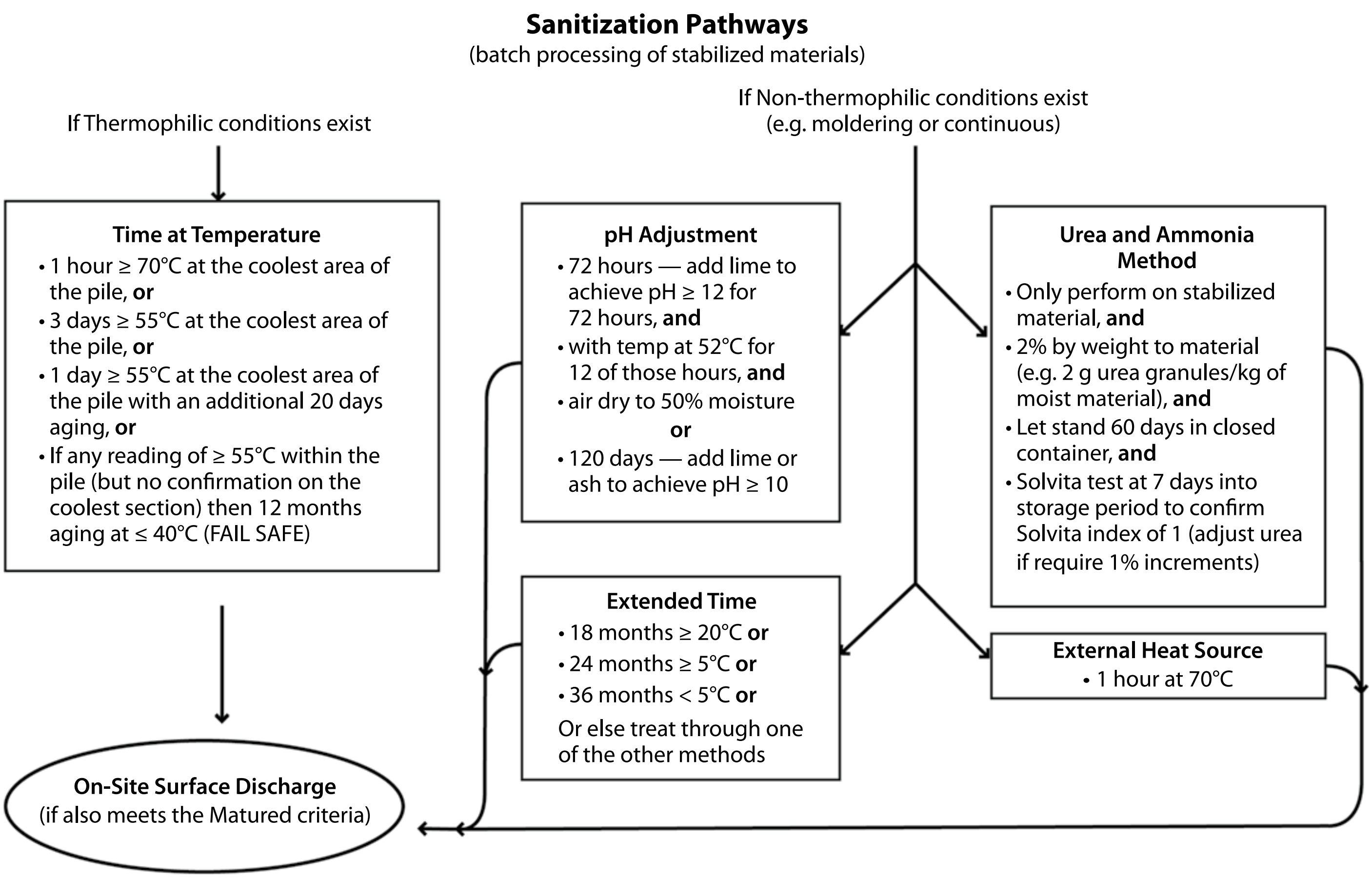


Fig. 2.17: *Sanitation pathways for matured materials from thermophilic and non-thermophilic materials sources.*
ILLUSTRATION CREDIT: GORD BAIRD

- Add urea to induce ammonification (ammonia gas to sanitize).
- Change the pH to chemically burn (denature) protein structures.
- Provide external heating to induce "pasteurization."
- Follow time frames as listed.
- Materials can re-composted in a manner that allows for thermophilic processes to occur; they then need to meet one of the thermophilic pathways, as shown.

Using the most conservative data on pathogen death of the most persistent and virulent pathogens (including *Ascaris lumbricoides*), Figure 2.16 shows the safety zone, representing 100% death. No matter what method of processing you use, so long as it meets the "TIME" at the "TEMPERATURE" curve, and places you in the safety zone, you are assured safety.

Another method that is used as an indicator of sanitization is mentioned by Dr. Jörn Germer. Hardy tomato seeds are deactivated by the same conditions that deactivate parasitic worm eggs (*A. lumbricoides*), and thus the tomato seeds provide an indicator of pathogen death. If the seeds are added at the same time as raw materials, and undergo the same processes, when samples no longer have germinating seeds, then one can be reasonably assured that any potential parasitic worm eggs are destroyed (Germer et al. 2009. "Temperature and Deactivation of Microbial Faecal Indicators.")

Table of Microbiological Risks

Viruses	**Death in days at ≥ 55°C (131°F)**	**Natural death in days at 20°C – 30°C (68 – 86°F)**
Polioviruses	14	40
Hepatitis A	14	210
Rotaviruses	14	365
Coxsackie viruses	14	50–270
Adenoviruses	3	60
Norwalk	<1	3
Enteroviruses	14	180
Bacteria		
Salmonella typhi	30 min	60
Salmonella other	1 hr	365
Shigella	1 hr	40
Vibrio cholerae		30
Pathogenic *E. coli*	1 hr	365
Leptospira (spp.)	< 1 hr	< 365
Campylobacter	< 10 min	7
Protazoa		
Entamoeba histolytica	<1	20
Giardia lambia	<3	90
Cryptosporidium	<3	>70
Helminths		
Ascaris lumbricoides Roundworm	1 hr	730
Enterobius vermicularis Pinworm	1	30
Taenia (spp.) Tapeworm	<1 hr	10
Trichuris Whipworm	<1 hr	545
Schistosoma	1	
Necator americanus Hookworm	1 hr	

There are lots of species of Ascaris, but *A. lumbricoides* is the most problematic, most resistant to death, and has the longest latency; therefore, it is an "indicator" pathogen that is used in research.

Compost Quality

Of course, we'd like our finished compost to be of as high a quality as possible. To judge quality, compost can be assessed by testing for its trace mineral element composition (Figure 2.18) and its pathogens and stability (Figure 2.19).

The old adage of GIGO, *garbage-in equals garbage-out,* rings true for what we take into our bodies — from the food we eat to the other toxins we expose ourselves to, from hormones, pharmaceuticals, and body care products. It is possible to test the product of a composting toilet to get a chemical analysis of what went into the toilet. Consider compost testing as akin to a broad-spectrum stool analysis; an opportunity that does not come with your standard flush toilet. If compost testing comes back outside the ranges of Type B Compost in Figure 2.18, then serious consideration needs to be given to changing one's food, water supply, and activities.

Figure 2.19 is the California Department of Resource's Recycling and Recovery's Compost Quality Standards. These qualitative and quantitative measures are used to confirm that a compost is matured, and does not offer harm to the environment.

A fairly new concern has been raised only recently: pharmaceutical contaminants that make their way into the toilet. Many of these chemicals are *not* destroyed by digestion or in regular composting processes, so there is legitimate concern about whether the resultant product is safe. New methods are being developed to investigate pharmaceutical contaminants that are not covered in the standards or compost tests just mentioned. Dr. Gary Andersen, head of the Dept. of Environmental Science, Policy and Management at UC Berkley is doing research in this area. Stay tuned.

Risk aversion by government regulators often overrides scientific facts. All compost regulations and guidelines in North America recommend application only to soils and subsoils around perennial plants; they never recommend application in and around vegetables. We think this is incorrect. If a compost is tested and it exceeds the parameters for maximum concentrations of metals as laid out in Figure 2.18 (Category AA compost) and it also meets the minimum requirements for finished compost quality as laid out in Figure 2.19, then it should be assumed safe for garden use. However, compost testing for the homeowner is probably not feasible. It will be up to the user to determine, but we recommend that if final compost testing is not performed, apply the products only around ornamentals, trees, and shrubs; otherwise, it should be buried and capped with 15 cm (6 in) of soil.

The last thing you want is an immature composter in a mature compost, or perhaps the other way around (Figure 2.20).

Fig. 2.18: *Ontario Compost Quality Standards, 2004, maximum concentrations of metals in compost.*

Item	Column 1: Metal	Column 2: Category AA Compost (mg/kg dry weight)	Column 3: Category A Compost (mg/kg dry weight)	Column 4: Category B Compost (mg/kg dry weight)
1	Arsenic	13	13	75
2	Cadmium	3	3	20
3	Chromium	210	210	1060
4	Cobalt	34	34	150
5	Copper	100	400	760
6	Lead	150	150	500
7	Mercury	0.8	0.8	5
8	Molybdenum	5	5	20
9	Nickel	62	62	180
10	Selenium	2	2	14
11	Zinc	500	700	1850

Indicator	Quality Standards for Finished Compost	
Visual	All material is dark brown (black indicates possible burning) Parent material is no longer visible Structure is a mixture of fine and medium size particle and humus crumbs.	
Physical	Moisture: 30–40%, fine texture (all below ⅛" mesh)	
Odor	Smells like rich humus from the forest floor; no ammonia or anaerobic odor.	
Nutrient	Carbon:Nitrogen ratio	<17:1
	Total organic matter	20–35%
	Total nitrogen	1.0–2.0%
	Nitrate nitrogen	250–350 PPM
	Nitrite nitrogen	0 PPM
	Sulfide	0 PPM
	Ammonium	0 or trace
	pH	6.5–8.5
	Cation exchange capacity (CEC)	>60 meq/100g
	Humic acid content	5–15%
	ERGS reading	5,000/15,000 mS/cm
Microbiological	Heterotrophic plate count	$1 \times 10^8 – 1 \times 10^{10}$ CFU/gdw
	Anaerobic plate count	Aerobes:Anaerobes at 10:1
	Yeasts and molds	$1 \times 10^3 – 1 \times 10^5$ CFU/gdw
	Actinomycetes	$1 \times 10^6 – 1 \times 10^8$ CFU/gdw
	Pseudomonads	$1 \times 10^3 – 1 \times 10^6$ CFU/gdw
	Nitrogen fixing bacteria	$1 \times 10^3 – 1 \times 10^6$ CFU/gdw
	Compost maturity	.50% on Maturity Index at dilution rate appropriate for compost application.
	Compost stability	<100 mg O^2/Kg compost dry solids/hour
	E. coli	<3 E. coli/g
	Fecal coliforms	<1000 MPN/g of dry solids
	Salmonella	<3 MPN/4g total solids

Fig. 2.19: *California Compost Quality Standards, California Department of Resources Recycling and Recovery.*

Fig. 2.20: *Mature compost/Immature composter.*
PHOTO CREDIT: ANN BAIRD

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