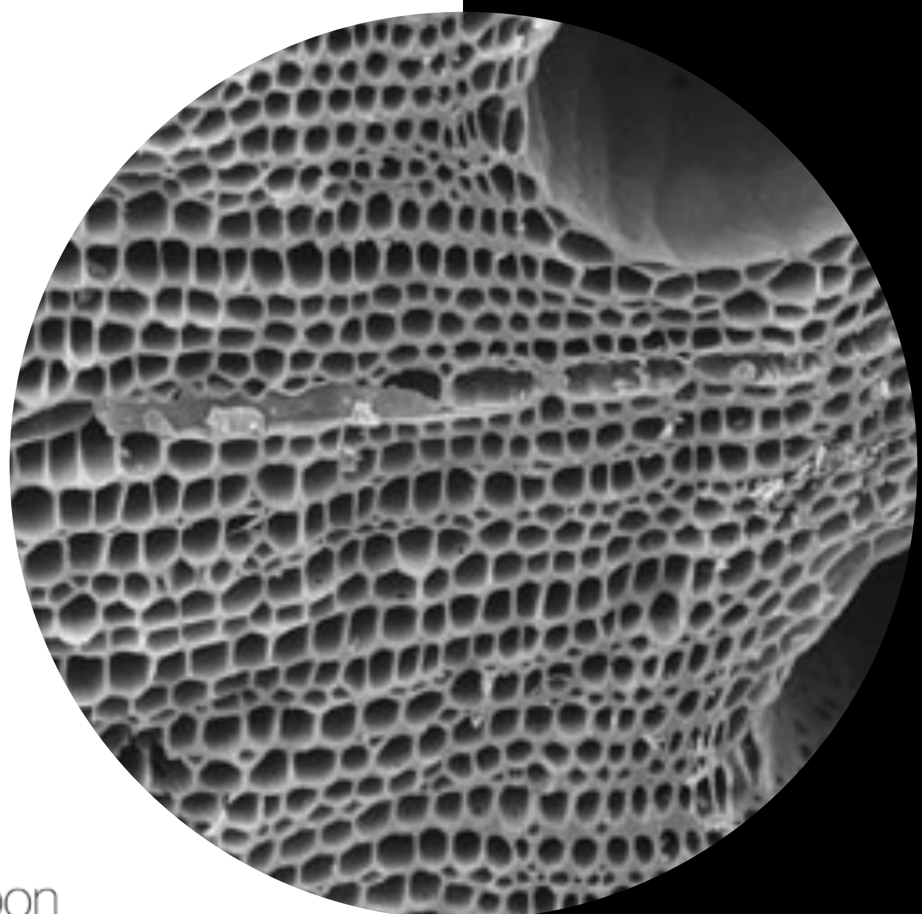
PREVIEW

DOT Biochar Design Manual

New standards for using micro-based solutions to manage macro environments.

2026



Carbon Intel llc

$35

1.0 Overview

This design manual is to establish a new methodology and product innovation pathway to use biochar to remediate soil and water, with carbon sequestration value, as mandated by MN DOT and other agencies across the US focused on stormwater.

DOTs are among the first of government agencies to take the next step to bring biochar public. This manual seeks to align with existing SOP's, protocols, budgets at state DOTs across the US. To achieve this, we support the ongoing process of ideation-to-application, providing access to expertise and product.

This fits current trends nationwide to take on environmental challenges the are beyond the scale and scope of traditional engineering, with a focus on micro-technologies and scalable to macro conditions.

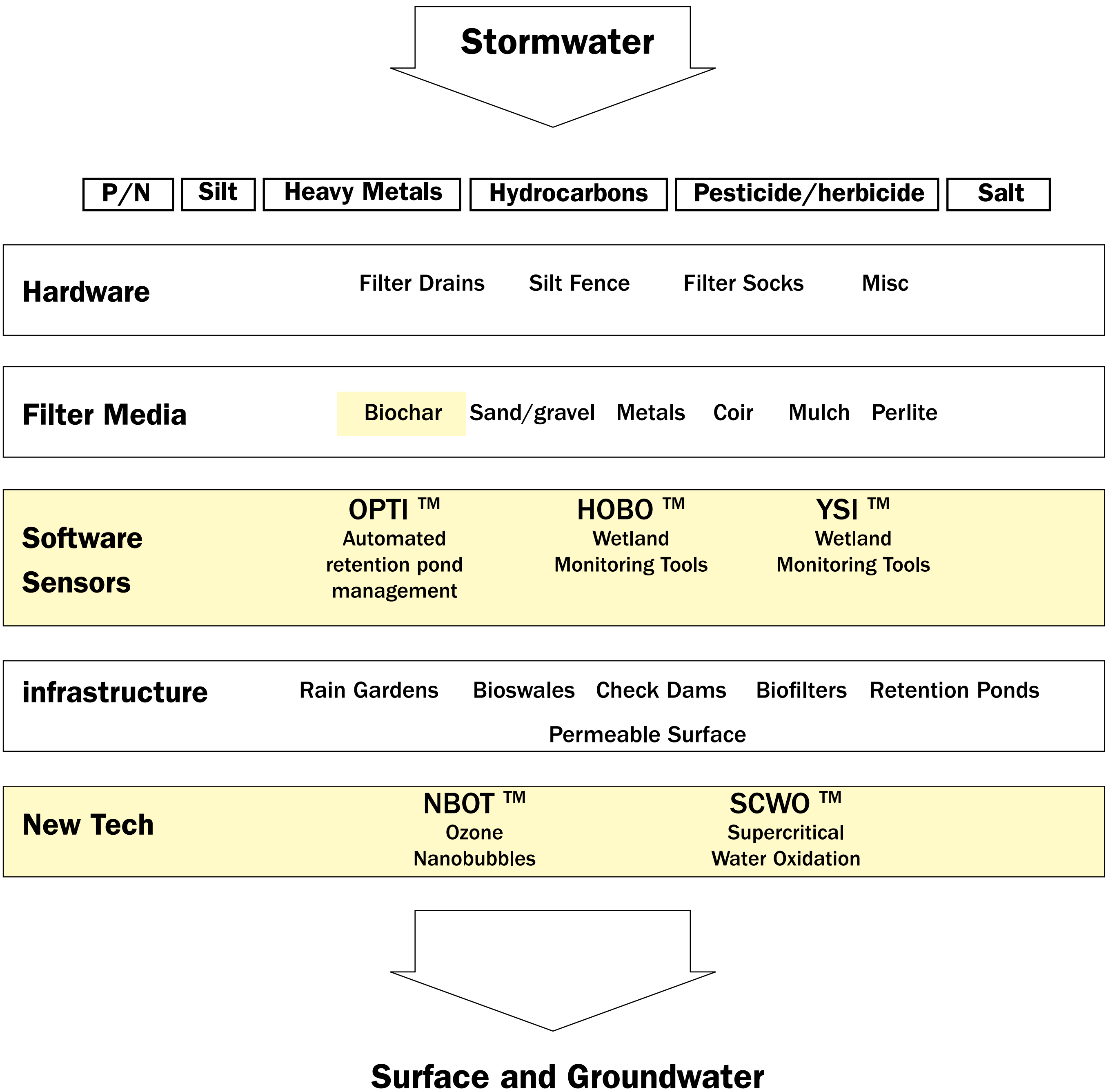
Biochar and Stormwater Industry

Biochar is a promising new tool for the stormwater industry across the US. Minnesota's role is key in establishing official standards to meet mandates. However, the implementation of biochar is still being standardized to align with Best Management Practices (BMP) for stormwater management, related to specific locations and contaminants, with phosphorous at the top of the list, followed by heavy metals, silt, etc. Decades of stormwater infrastructure has created a sold foundation of engineering, but scaling up requires lowering costs and increasing effectiveness of the filtration process. For biochar to work it has to find its place among rain gardens, bioswales, filter socks, etc. The issue of maintenance is key, as we see biofllter infrastructure projects lose some of their value over time, related to maintenance.

Carbon Intel, llc is a strategic innovation firm in Madison, WI focused on the cutting edge of what biochar represents, with its values for environment and economy. Our approach is to simplify complex models of technology. Biochar has the potential to improve both economic and environmental conditions, so our work is to develop solutions and programming that enable the process.

1.2 Integrated solutions

Biochar can fit into the mix of stormwater solutions that have been in development for decades. Added to that are new technology solutions.



2.1 Carbon forms

These three forms of charcoal vary by production method and end application. Biochar's value is continuing to grow, based on its unique potential for environment and economy.

	Biochar	Activated Carbon	Charcoal
Feedstock	Wood (preferred), biosolids, organic material	Wood	Hardwood
Production	Pyrolysis	Steam or chemical activation	
Temperature	< 700° C	800° C to 1000° C	
Cost	Low to Moderate	High	NA
Applications	Soil amendment, carbon sequestration, industrial innovations. INNOVATIONS 1. We advance the storm and wastewater industry using patented **biochar structural composites**, with improved performance compared to activated carbon. 2. We add fungi and pyrolysis as two options to destroy the contaminants in filter units, increasing their functional life cycle. 3. Structural biochar composites open a new pathway for insulated building materirals.	Industrial contaminant filter systems.	Cooking/ heating fuel

Summary

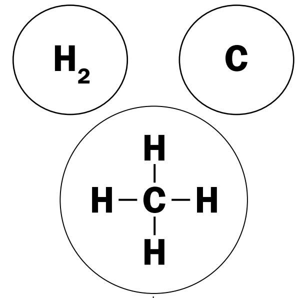
Activated carbon is the standard industry filtration medium. It has a higher surface area than biochar, due to high-temperature activation, but is expensive and energy-intensive.

Biochar advantages over AC: More abundant surface functional groups; Produced at lower temperatures, lower energy footprint; Reduced cost; Increased physical and chemical adsorption value. Structural composites for filtration and thermal insulation.

Charcoal's primary purpose is for cooking and it can contain original wood chemistry or with starch, limestone, sawdust, and borax, (to help form briquettes). It contains varying amounts of ash, volatile substances, and moisture.

2.2 Pyrolysis by-products

As a key component of the waste-to-energy industry, biochar is one of many products produced the pyrolysis process.



	Biocoal	Syngas	Pyrolysis Oil	Methane Splitting
Feedstock	Wood, organic waste	Wood, organic waste	Wood, organic waste	Methane
Production	Torrefaction, a low-temperature pyrolysis, 200° - 300° C	Residual of pyrolysis.	Residual of pyrolysis.	High end pyrolysis, 450° - 2000° C
Applications	Acts as a “drop-in” alternative to coal, offering high energy density, hydrophobicity (water resistance), and easier handling compared to raw biomass. A renewable alternative to fossil fuels, aiding in carbon neutrality by recycling organic waste. Primarily used for power generation, but also has potential in industrial, metallurgical, or agricultural settings. Helps reduce greenhouse gases by diverting waste from landfills or open burning, providing a sustainable, high-energy fuel source.	Syngas, or synthesis gas, is a versatile, combustible mixture primarily composed of hydrogen used to produce electricity, heat, methanol, ammonia, and synthetic fuels. Produced via high-temperature gasification of carbonaceous materials (coal, biomass, waste) it serves as a crucial, lower-emission, and renewable energy source. Created during biochar production, it can be used for drying biomass feedstock.	A liquid fuel produced by heating waste plastics or biomass. It serves as a sustainable alternative to petroleum for industrial heating, power generation, and as a raw material for refining into gasoline, diesel, and chemical feedstocks. Created during biochar production.	A low-carbon, energy-efficient technology that breaks methane into clean hydrogen and valuable solid carbon (graphite/graphene). This pyrolysis process produces no direct emissions, offering an alternative to traditional steam methane reforming with up to 80% less energy consumption, with up to 80% less energy consumption.

2.3 Biochar mechanics

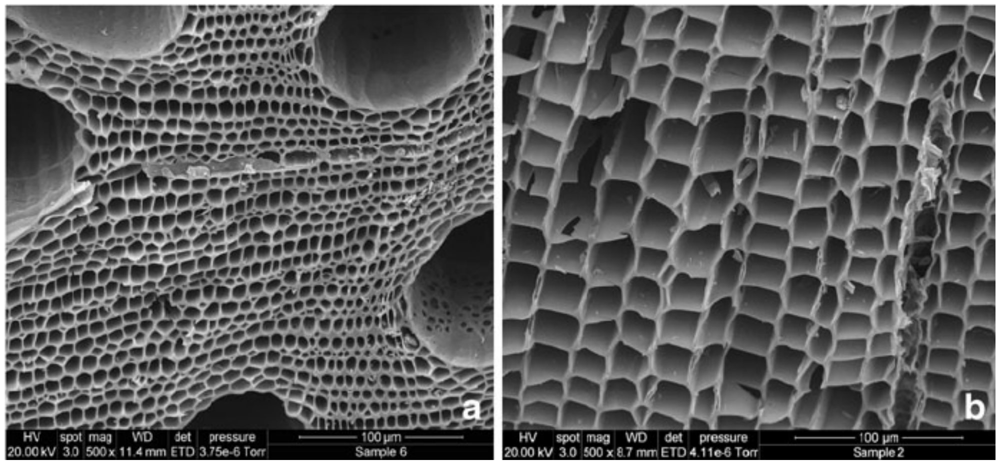
Biochar's value is its porosity, ionic charge and additives.

Biochar is a higher-end version of charcoal, or carbon, with more options to engineer the end product for increased effectiveness as an adsorbent for molecules and nanoparticles.

It is most commonly known for its capacity to sequester enormous amounts of CO_2 from the atmosphere into the soil. This is driving the industry growth, with the support of carbon credits backed by major financial and corporate entities.

It is able to restore depleted or contaminated soils. For farming and ecosystems it serves as a micro-medium to store water and nutrients, providing as well a platform to restore native fungi. Companies are now developing and promoting a variety of biochar soil products with customized amendments for specific crops.

For roadways, DOTs are interested in its capacity to reduce storm water contaminants as well as strengthening the plant ecosystem adjacent to roadways, which increases the overall biofiltration factors.
In addition, it can be added to asphalt, concrete or as an underlayment.



C Marta Camps Arbestain

One gram of hardwood biochar can contain a microscopic surface area of 1000 square meters. One metric ton of biochar equals 1,000,000 grams, with a surface area of a billion square meters, ideal for PFAs remediation.

Key Mechanisms of Chemical Adsorption by Biochar

Physical Adsorption (Pore Filling): Biochar possesses a massive, porous surface area, which traps smaller molecules inside its micropores, mesopores, and macropores.

Surface Sorption & Hydrophobic Interaction: Organic pollutants (phenols, pharmaceuticals) stick to the carbon surface. The hydrophobic nature of biochar attracts hydrophobic contaminants, removing them from water.

Electrostatic Interaction: The surface of biochar can be modified by pH. **Anionic (Negatively charged) pollutants:** Attracted at low pH, where high H+ concentration gives the biochar a positive charge. **Cationic (Positively charged) pollutants** (e.g., Heavy Metals): Attracted at higher pH, where biochar's functional groups (carboxylic, hydroxyl) become negatively charged, causing metals like lead to stick.

π–π Stacking/Electron Donor-Acceptor: Aromatic compounds can interact with the graphene-like structures in biochar, strengthening the bond between the chemical and the biochar.

Hydrogen Bonding: Functional groups on the biochar surface, such as hydroxyl and carboxyl groups, can form hydrogen bonds with pesticide molecules.

Absorb vs Adsorb

ABsorption *is where a liquid is soaked up into something like a sponge, cloth or filter paper. The liquid is completely absorbed into the absorbent material.*

ADsorption *refers to individual molecules, atoms or ions gathering on surfaces. The surface of a material is made up of atoms and bonds that are exposed to the air. For example, the surface of a piece of glass will be covered in silicon and oxygen atoms. Molecules or ions can interact with this surface via intermolecular interactions. This allows them to 'stick', or adsorb, to the surface. If a material has a very high surface area, then lots of molecules can stick to the surface.*

2.7 DOT categories

Aligning with existing DOT product categories can provide opportunities to develop new solutions, based on existing categories and budgets. Each of these line items suggest a potential role for biochar.

Item Group	Item Number	Item Description	Units	Quantity	Dollars (000S)	Average Price	Contract Occur.
2013	2013601/00120	GROUND WATER TREATMENT SYSTEM	LS	1.00	$5,900.00	$5,900,000.00	1
2013	2013609/00010	HAUL AND DISPOSAL OF HAZARDOUS WASTE	TON	24.00	$6.00	$250.00	1
2013	2013901/00025	ENVIRONMENTAL COMPLIANCE	LS	1.00	$150.00	$150,000.00	1
2016	2016601/00200	TOPSOIL MANAGEMENT	LS	1.00	$54.00	$54,000.00	1
2031	2031502/00110	FIELD LABORATORY	EACH	27.00	$1,127.89	$41,773.83	27
2031	2031502/00210	COMBINATION FIELD LABORATORY-OFFICE	EACH	31.00	$743.15	$23,972.65	31
2106	2106507/00070	GRANULAR EMBANKMENT (CV)	C Y	488,827.00	$8,002.10	$16.37	6
2106	2106507/00080	SELECT GRANULAR EMBANKMENT (CV)	C Y	1,723,479.00	$32,642.69	$18.94	58
2106	2106507/00090	SELECT GRANULAR EMBANKMENT MOD 5% (CV)	C Y	40,049.00	$350.43	$8.75	1
2106	2106507/00100	SELECT GRANULAR EMBANKMENT MOD 7% (CV)	C Y	76,020.00	$2,592.28	$34.10	10
2106	2106507/00110	SELECT GRANULAR EMBANKMENT MOD 10% (CV)	C Y	23,258.00	$570.98	$24.55	3
2106	2106507/00120	SELECT GRANULAR EMBANKMENT SUPER SAND (CV)	C Y	101,024.00	$2,469.03	$24.44	5
2106	2106507/00130	COMMON EMBANKMENT (CV)	C Y	2,942,139.00	$8,179.15	$2.78	91
2106	2106609/00220	HAUL AND DISPOSE OF CONTAMINATED MATERIAL	TON	101,937.70	$5,772.73	$56.63	28
2106	2106609/00230	HAUL AND DISPOSE OF CONTAMINATED SOIL	TON	9,722.00	$324.91	$33.42	2
2411	2411507/04060	GRANULAR BACKFILL MOD (CV)	C Y	3,224.00	$90.53	$28.08	2
2511	2511504/00011	GEOTEXTILE FILTER TYPE 1	S Y	361.00	$1.62	$4.50	1
2511	2511504/00013	GEOTEXTILE FILTER TYPE 3	S Y	6,222.80	$34.41	$5.53	21
2511	2511504/00014	GEOTEXTILE FILTER TYPE 4	S Y	46,974.30	$170.52	$3.63	42
2511	2511504/00015	GEOTEXTILE FILTER TYPE 5	S Y	55.40	$0.29	$5.20	1
2511	2511504/00017	GEOTEXTILE FILTER TYPE 7	S Y	15,858.50	$55.66	$3.51	15
2573	2573501/00020	STORM DRAIN INLET PROTECTION	LS	5.00	$27.78	$5,555.00	5
2573	2573501/00025	STABILIZED CONSTRUCTION EXIT	LS	69.00	$979.73	$14,199.03	69
2573	2573501/00030	EROSION CONTROL SUPERVISOR	LS	27.00	$230.75	$8,546.16	27
2573	2573502/00103	WATER TREATMENT TYPE SEDIMENT TANK	EACH	5.00	$102.50	$20,500.00	4
2573	2573502/00110	STORM DRAIN INLET PROTECTION	EACH	4,664.00	$935.09	$200.49	80
2573	2573502/00140	CULVERT END CONTROLS	EACH	1,122.00	$207.90	$185.29	61
2573	2573503/00020	SILT FENCE, TYPE HI	L F	63,445.00	$224.60	$3.54	28
2573	2573503/00022	SILT FENCE, TYPE SD	L F	950.00	$40.05	$42.16	3
2573	2573503/00023	SILT FENCE, TYPE MS	L F	289,303.00	$619.11	$2.14	52
2451	2451507/00080	GRANULAR BACKFILL (CV)	C Y	771.00	$19.66	$25.50	1
2451	2451507/00090	GRANULAR BACKFILL (MOD) CV	C Y	26,916.00	$810.71	$30.12	4
2451	2451507/00120	AGGREGATE BACKFILL (CV)	C Y	41.00	$2.05	$50.00	1
2451	2451507/00150	GRANULAR BEDDING (CV)	C Y	45.00	$2.57	$57.00	1
2451	2451507/00170	COARSE FILTER AGGREGATE (LV)	C Y	76.00	$5.31	$69.81	2
2451	2451507/00190	COARSE FILTER AGGREGATE (CV)	C Y	10,658.00	$760.34	$71.34	11
2451	2451507/00220	FINE FILTER AGGREGATE (CV)	C Y	4,677.00	$188.53	$40.31	5
2451	2451507/00240	FINE AGGREGATE BEDDING (LV)	C Y	3.00	$0.14	$48.00	1
2451	2451507/00250	FINE AGGREGATE BEDDING (CV)	C Y	33,199.00	$1,489.31	$44.86	55
2451	2451507/00270	COARSE AGGREGATE BEDDING (CV)	C Y	6,378.00	$527.01	$82.63	10

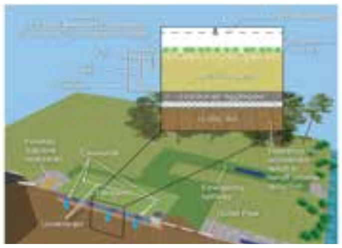
Coarse filter aggregate can be easily improved by adding biochar, produced onsite from available black ash feedstock.

2.9 DOT filtration examples

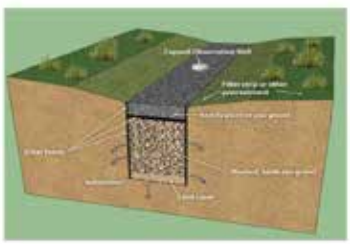
SOURCE: GA DOT

Biochar materials and engineered products can fit existing models of stormater engineering.

Sand Filter

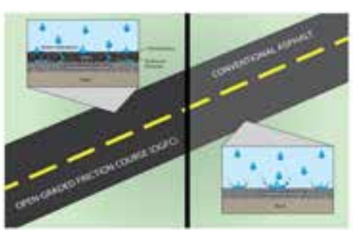


Infiltration Trench

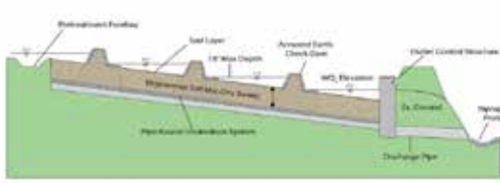


Bridge Drains

Open-Graded Friction Course



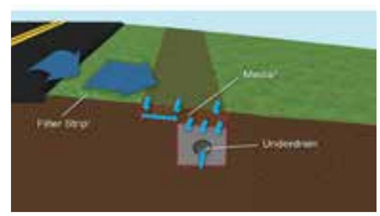
Swales & Check Dams



Forebay

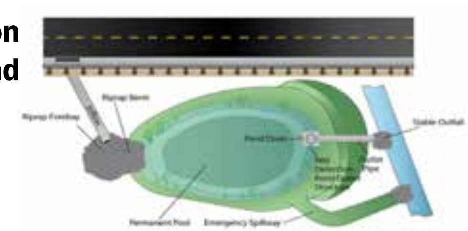
Grass Channel

Bioslope



Stormwater Wetland

Detention Pond



3.2 Lab-to-street transition

Biochar will be a very effective tool, but there is a lot to learn.

Twenty-plus years of extensive research, around the world, indicates that biochar is an amazing resource for all kinds of environmental remediation. Yet it's still very early in the process. The vast majority of research has been in the lab, so scaling up for highways and urban storm drains is going to be a learning curve.

What could possibly go wrong?

The proper development process will seek to get the most out of biochar for stormwater:

Triage Approach/ Hot Spots
Choosing pilot projects should focus on high-risk, or 'hot spot' locations, to solve problems that impact larger ecosystems. Over time the best practices will develop to fit a variety of contaminants and conditions.

Long-term Filtration
Filters get clogged and wear out, they lose their capacity to work. Effective life span will vary a lot, but over time we can expect to fine tune best management practices and design better filters.

Silt and Clogging
Preventing clogged filters will require designing methods and products that isolate contaminants in clean water for the biochar.

Maintenance
Increased maintenance will be required for the long term, representing training and workforce opportunities.

Monitoring, Testing & Reporting
Testing has to increase in quality, frequency and scope. New methods and technologies are available to manage the process and communicate the results faster and accurately.

Environmental Chemistry
An endless array of conditions and contaminants will require continuous fine-tuning of methods.

Circularity
Incrased circularity means maximizing the energy and economic values, using minimal resources to achieve maximum outcome. Locating biochar production as close as possible to the wood biomass source, in proximity to the affected roadways, is feasible.

Public Participation
Environmental awareness is increasing, despite setbacks, because, frankly, our survival depends on it. Trends support greater involvement by the public.

Communication
Increasing public participation starts with better communications. Working with existing community groups and nonprofits will help eliminate barriers.

Open-source online platforms, creative challenges and student workforce development are in place to leverage potential collaboration.

Industry Applications
Although this focus is on stormwater, adoption by industry and agriculture will support the expansion of biochar for all sectors.

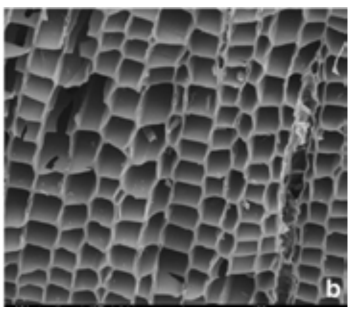
3.4 Maintenance & fungi

When filters get clogged they stop working. Current rain garden and biofilter devices that use media are usually not cost-effective when it comes to long term maintenance. A wide range of filter mixes have been developed for biofilters, which usually consist of three levels:

1. Silt prefilter.
2. Polishing, secondary filter.
3. Molecular filtering with biochar.

Additives are required for conditions, according to the type of contaminant, to manage adsorption or desorption. For example, media with various metals are effective for phosphorous adsorption, while a different mixture is used for desorption, releasing nutrients into the soil.

The cost of managing these filters needs to be factored into their application, a potential job-creating opportunity.

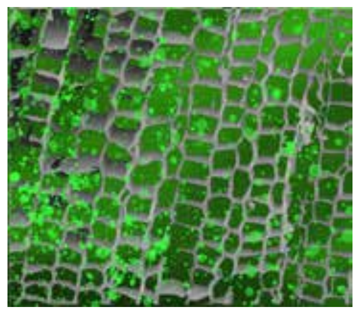


Clean biochar

Occluded

Like a sponge, biochar will adsorb silt and contaminants on a micro-level and eventually reach saturation. This may take days, weeks or months. Maintaining the system requires an effective method to pre-filter the silt snd creating the right ionic conditions to attract specific contaminants. Close monitoring will determine the timing for replacing the filter media.

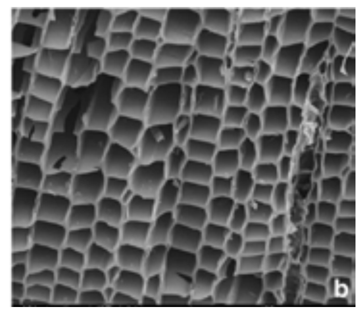
Specialized media mixtures are developed to fit contaminant conditions.



Fungi growth

There are two methods to clear out the pores, fungi and pyrolysis. Fungi is effective at destroying most contaminants and is low cost and scalable. However, it requires time and a stable environment for effective remediatoin, so a climate-controlled off-grid container is available to store filter media sections up to a few weeks.

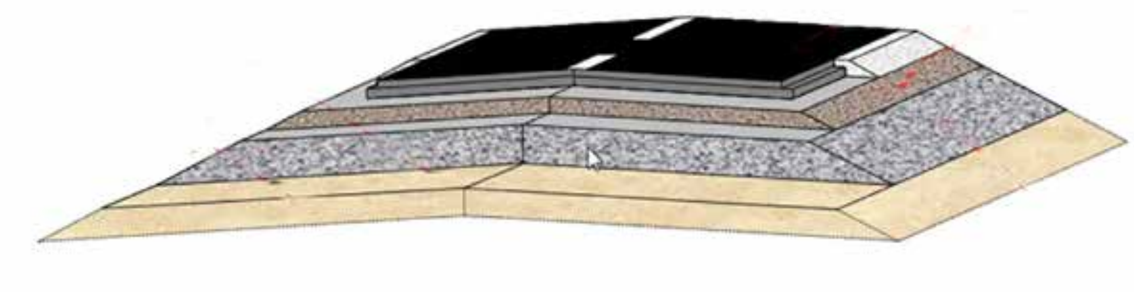
Pyrolysis is also effective, heating above 600° C for a few hours will destroy most contaminants and allow the filter media to return to service within a day.



Clean biochar

Fungal bioremediation represents a promising and sustainable approach to addressing environmental pollution by exploiting the natural metabolic capabilities of fungi to degrade and detoxify a wide array of pollutants.

3.6 Road amendments



Carbon-negative and permeable roadbeds with biochar are feasible. Having onsite control over biochar production will be a huge asset to bring costs down.

DESIGN CRITERIA

Carbon sequestration, with carbon credit values.

No compromise on life cycle or durability.

Temperature stability proven for application and life span.

Control over biochar specs and capacity to modify as needed.

Heavy metal sequestration.

Increased percolation.

Reduced worker risk from solvents.

Cold mix, to reduce energy usage.

Asphalt additive.

Biochar slurry, with customized amendments, depending on conditions.

3.7 Filter socks

Filter socks are the entry-level biochar product for easy DOT experimentation.

Biochar filter socks provide a cost-effective alternative to traditional activated carbon, with bulk media costing roughly $800 per ton (retail), compared to activated carbon, costing at least $1500 per ton.

Biochar industry for stormwater is early-stage and can be improved based on new DOT specs and the capacity for USDA biochar composites to bring a level of contral over porosity and feedstock.

Costs of filtration vary widely, depending on its effectiveness. A proper strategy will focus on protecting high-risk wetland areas, developing a channeling method that can be adapted.

Stormwater Oil & Sediment Filter
Oils, Sediments, Debris and Trash

$90 for 10’

Spilltration Fibers

Stormtration™ Char21™
Heavy Metal Stormwater Filter Sock

$217 for 10’

Chopped Switchgrass
Biochar
Re-Activated Carbon
Calcium Silicate Aggregate

Ultra Tech Ultra-Filter Sock
Activated Carbon

$234 for 10’

Sorb 44
Recycled rubber media
Phos Filter

Bichar Filter Sock

$60 for 10” x 22”

Drain Web

$129

Stormwater Biochar Filter

$129

DrainGuard® Catch Basin Filter

Fiber matrix

$45

Burlap / Wood chip sediment control

$27 for 27’

3.10 Problem areas

EV Fires & Hazmat

Electric vehicle (EV) technology has become commonplace, but there is very little response guidance for emergency responders. The nature of battery technology and EV manufacturing presents big challenges in effectively managing EV fires. There are substantial gaps in the science available to inform safe and effective approaches for identifying, confining and extinguishing these fires.

EMS responders must continue to adapt, as lithium and other heavy metals can have great impact on the surrounding ecosystem.

Biochar filtration products will be far more effective and should be easily accessible to first responders.

An ample supply of biochar can be stored and managed similar to road salt. While spill barriers can catch some of the toxic runoff, there is always some residual spill onto shoulders and ditches. This where a truckload of raw biochar, available within 50 miles, can be highly effective for emergency situations.

Fire agencies are included in our hazmat programming package so that they can be collaborators in emergency spills.

Road salt

Another critical concern is road salt, an unavoidable contaminant. Salt has been a major conundrum for science and governments to solve, with little effect.

All research points to the potential value of biochar in addressing the chloride issue in the following manner:

1. Salt amendment products.

2. Roadside soil engineering to buffer and filter the runoff at critical points.

3. Soil desalination at critical runoff points.

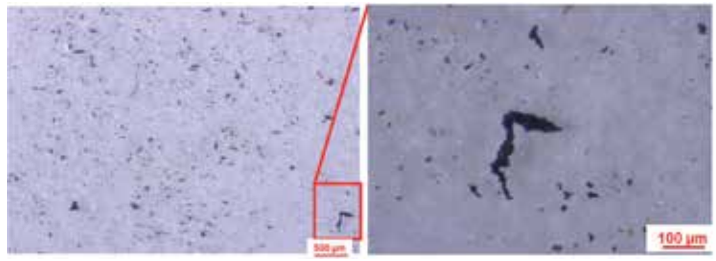
4. Increasing salt tolerance of plants.

The science of road salt mitigation will benefit from DOT rollout of biochar. Our program includes engagement with chloride mitigation groups in local government to prove these lab scale solutions.

4.4 Tire particles field study

Field Evaluation of Rice Husk Biochar and Pine Tree Woodchips for Removal of Tire Wear Particles from Urban Stormwater Runoff in Oxford, Mississippi (USA)

University of MS



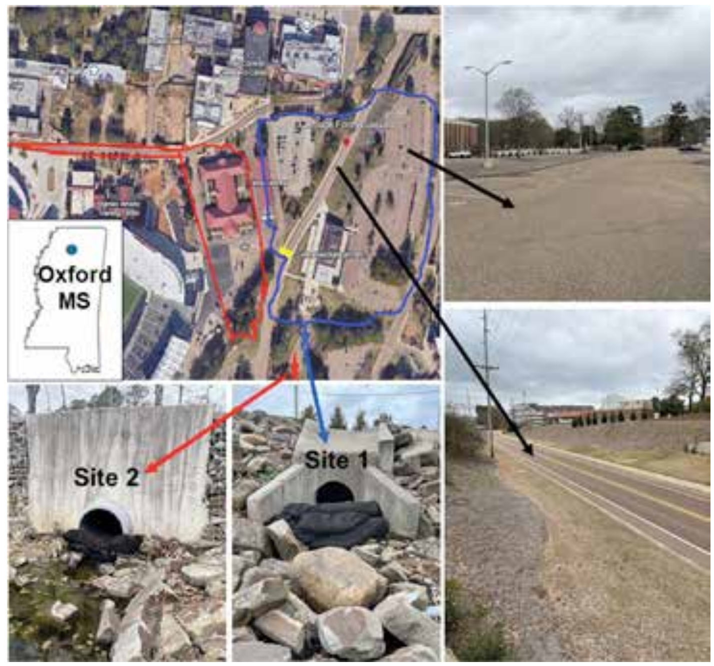
Contact us for more details.

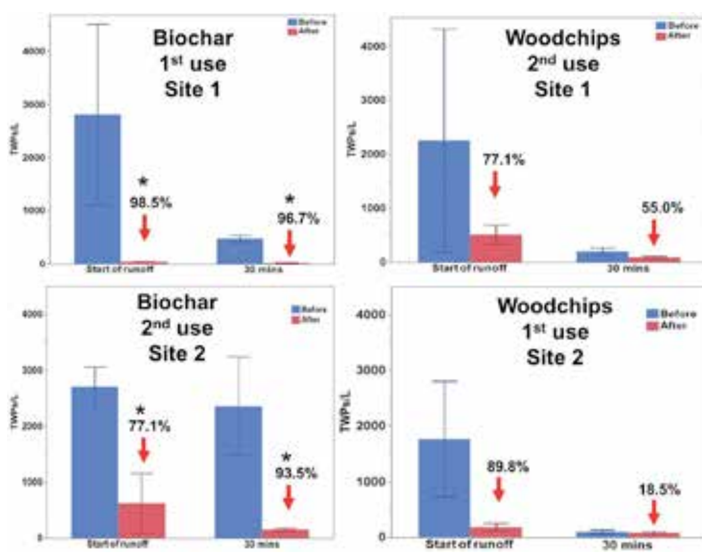
Abstract

We investigated the effectiveness of stormwater filter socks filled with rice husk biochar or pine tree woodchips in reducing TWP pollution in urban runoff in Oxford, Mississippi. Triplicate runoff samples were collected upstream and downstream of the biofilters at two sites during two storm events at peak flow within minutes of the start of the storm and after 30 min.

Biochar was more effective than woodchips ($p < 0.05$) at removing TWPs, reducing concentrations by an average of 97.6% (first use) and 85.3% (second use) compared to 66.2% and 54.2% for woodchips, respectively. Biochar was particularly effective at removing smaller TWPs (<100 µm).

Both materials became less effective with use, suggesting fewer available trapping sites and the need for removal and replacement of the material with time. Overall, this study suggests that biochar and woodchips, alone or in combination, deserve further scrutiny as a potential cost-effective and sustainable method to mitigate the transfer of TWPs to aquatic ecosystems and associated biota.

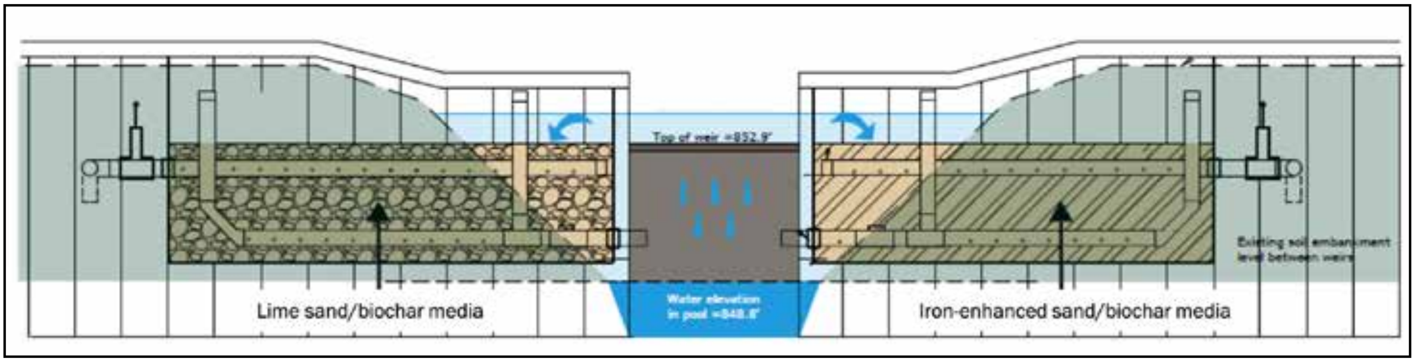


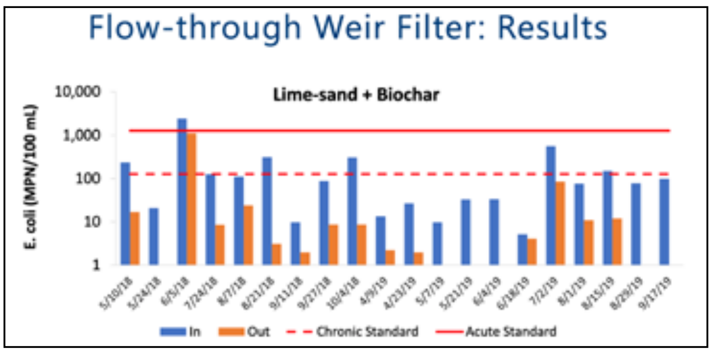


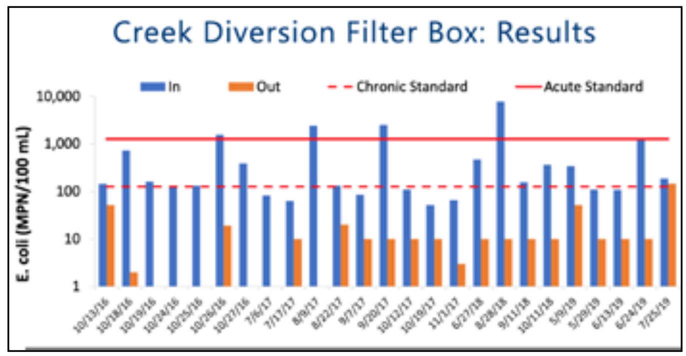
4.6 E. Coli

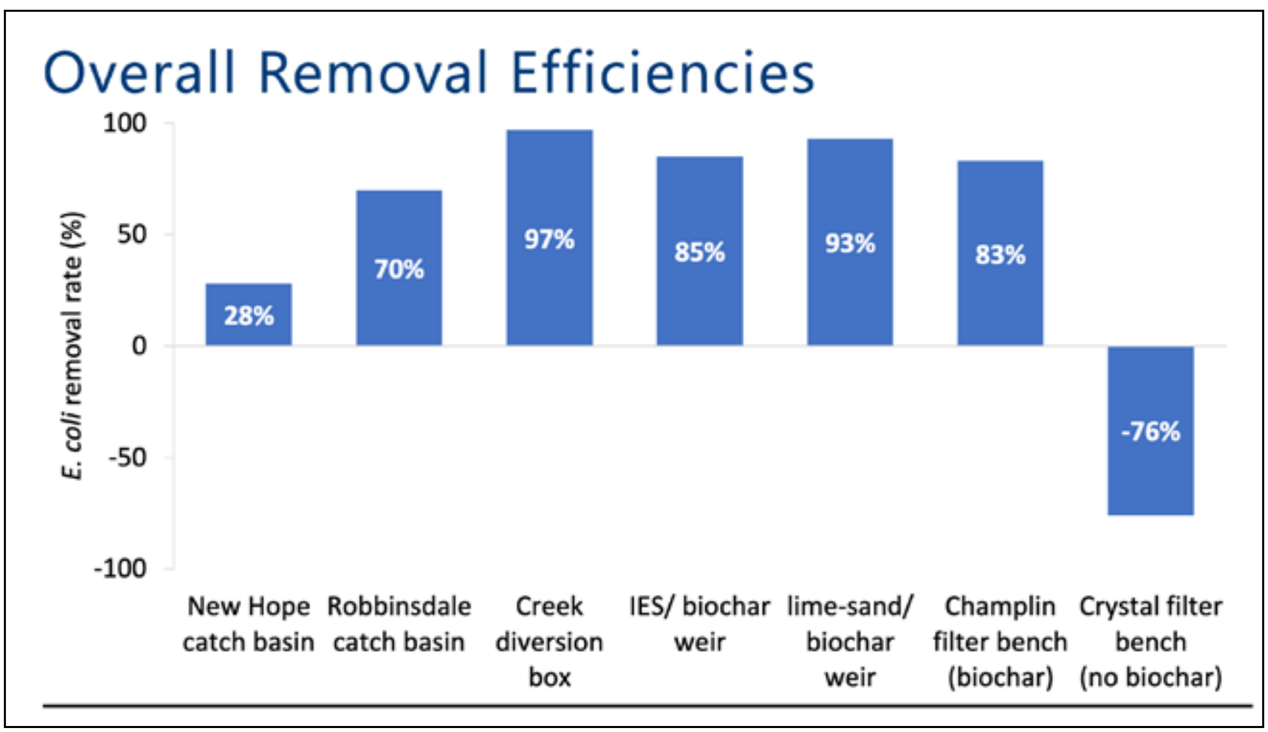
Biochar-enhanced weir filter in Minnesota.

Contact us for more details.









5.1 Community engagement

A New Era of Public Responsibility

Immense value can be gained by partnering with community groups seeking to engage volunteers, with options to learn skills that can be applied as a career.

Considering that roads intersect all of our lives, we can work with DOT to civic groups who are already involved with Support a Highway programs, water activist groups and existing programs at schools, connecting K-12 and research universities.

One example is the Billion Oyster Project in NYC is successfully restoring marine habitats with support of hundreds of volunteers.

Increased participation is required among community members to improve conditions. Landscape companies, homeowners, industry groups and famers can be persuaded with a carefully-planned promotional campaign, which may require funding.

New York City is a leader in developing collaborations with community members to resolve major environmental issues.

The Billion Oyster Project, a volunteer program producing excellent results at restoring marine habitats, with oysters providing a foundation environment that starts with thousands of tons of processed shells donated by restaurants. Like biochar, the shells provide abundant microbial surface area.

Across the US, Riverkeeper groups are among the most committed and effective partners that can help monitor bridges and culvert locations, reducing costs and improving outcomes.

NYC Clean Soil Bank is a municipal clean soil exchange that recovers clean, native soil from deep excavations at construction sites and redirects it to where it's needed.