Samuel P. Burton
Editor

Emerging Technologies in Wastewater Treatment

Water Resource Planning, Development and Management

NOVA

WATER RESOURCE PLANNING, DEVELOPMENT AND MANAGEMENT

EMERGING TECHNOLOGIES IN WASTEWATER TREATMENT

SAMUEL P. BURTON
EDITOR

Nova Science Publishers, Inc.
New York

For permission to use material from this book please contact us:
Telephone 631-231-7269; Fax 631-231-8175
Web Site: http://www.novapublishers.com

Library of Congress Cataloging-in-Publication Data

Emerging technologies in wastewater treatment / editor, Samuel P. Burton.
p. cm.
Includes index.
ISBN 978-1-61470-786-8 (hardcover)
1. Sewage--Purification. I. Burton, Samuel P.
TD745.E48 2011
628.3--dc23

2011026366

Published by Nova Science Publishers, Inc. † New York

WATER RESOURCE PLANNING, DEVELOPMENT AND MANAGEMENT

EMERGING TECHNOLOGIES IN WASTEWATER TREATMENT

WATER RESOURCE PLANNING, DEVELOPMENT AND MANAGEMENT

Additional books in this series can be found on Nova's website under the Series tab.

Additional E-books in this series can be found on Nova's website under the E-books tab.

ENVIRONMENTAL SCIENCE, ENGINEERING AND TECHNOLOGY

Additional books in this series can be found on Nova's website under the Series tab.

Additional E-books in this series can be found on Nova's website under the E-books tab.

PREFACE

Waste discharges from municipal sewage treatment plants into rivers, streams, lakes, estuaries and coastal waters are a significant source of water quality problems throughout the country. States report that municipal discharges are the second leading source of water quality impairment in all of the nation's waters. This book provides information on the emerging technologies in wastewater treatment in order to meet the challenge of keeping progress in wastewater pollution abatement ahead of population growth, changes in industrial processes and technological developments.

Chapter 1- In 2004, there were 16,583 municipal wastewater treatment plants operating in the United States. These plants ranged in size from a few hundred gallons per day (GPD) to more than 800 million gallons per day (MGD). Early efforts in water pollution control began in the late 1800s with construction of facilities to prevent human waste from reaching drinking water supplies. Since the passage of the 1972 Amendments to the Federal Water Pollution Control Act (Clean Water Act [CWA]), municipal wastewater treatment facilities have been designed and built or upgraded to abate an ever-increasing volume and diversity of pollutants. The CWA requires that municipal wastewater treatment plant discharges meet a minimum of secondary treatment. However, in 2004, nearly 30 percent of the municipal facilities produced and discharged effluent at higher levels of treatment than the minimum federal standards for secondary treatment.

Chapter 2- The Clean Water Act prescribes performance levels to be attained by municipal sewage treatment plants in order to prevent the discharge of harmful wastes into surface waters. The act also provides financial assistance so that cities can construct treatment facilities in compliance with the law. The availability of funding for this purpose continues to be a major concern of cities and states. This report provides background on municipal wastewater treatment issues, federal treatment requirements and funding, and recent legislative activity. Meeting the nation's wastewater infrastructure needs efficiently and effectively is likely to remain an issue of considerable interest.

CONTENTS

In: Emerging Technologies in Wastewater Treatment
Editor: Samuel P. Burton
ISBN: 978-1-61470-786-8

Chapter 1

EMERGING TECHNOLOGIES FOR WASTEWATER TREATMENT AND IN-PLANT WET WEATHER MANAGEMENT*

United States Environmental Protection Agency

Prepared for:
Office of Wastewater Management
U.S. Environmental Protection Agency
Washington, D.C.
EPA 832-R-06-006
Under Contract 68-C-02-111
Prepared by: Parsons Corporation
Fairfax, Virginia

Produced under U.S. EPA Contract No. 68-C-02-111
Prepared by the Parsons Corporation Fairfax, Virginia
Technical review was provided by professionals with experience in wastewater treatment.
Technical reviewers of this document were:
Dr. Charles Bott, Assistant Professor, Virginia Military Institute (VMI)
Dr. Sudhir Murthy, Manager, Process Development, Washington, D.C. Water and Sewer Authority (WASA)
Dr. Krishna Pagilla, Professor, Illinois Institute of Technology (IIT)
Tyler Richards, Deputy Director of Operations and Environmental Services, Gwinnett County, GA
Tom Sadick, CH2M HILL
Terry Krause, CH2M HILL
Mark Bishop, Hazen and Sawyer

* This is an edited, reformatted and augmented version of the United States Environmental Protection Agency publication, EPA 832-R-06-006dated February 2008.

PREFACE

The U.S. Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of environmental laws, the Agency strives to formulate and implement actions leading to a balance between human activities and the ability of natural systems to support and sustain life. To meet this mandate, the Office of Wastewater Management (OWM) provides information and technical support to solve environmental problems today and to build a knowledge base necessary to protect public health and the environment well into the future.

This publication has been produced, under contract to the U.S. EPA, by the Parsons Corporation, and it provides current state of development as of the publication date. It is expected that this document will be revised periodically to reflect advances in this rapidly evolving area. Except as noted, information, interviews, and data development were conducted by the contractor. Some of the information, especially related to embryonic technologies, was provided by the manufacturer or vendor of the equipment or technology, and could not be verified or supported by full-scale case study. In some cases, cost data were based on estimated savings without actual field data. When evaluating technologies, estimated costs, and stated performance, efforts should be made to collect current and more up-to-date information.

The mention of trade names, specific vendors, or products does not represent an actual or presumed endorsement, preference, or acceptance by the U.S. EPA or Federal Government. Stated results, conclusions, usage, or practices do not necessarily represent the views or policies of the U.S. EPA.

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym/ Abbreviation	Definition
A/O	Anaerobic/Oxic (Phoredox)
A2/O	Anaerobic/Anoxic/Oxic
AACE	American Association of Cost Engineers International
ABW®	Automatic Backwash Filters
AEBR	Anaerobic Expanded Bed Reactor
AGAR®	Attached Growth Airlift Reactor
AGRS	Advanced Grit Removal System
AGSP	Aerobic Granular Sludge Process
AIZ	Air Intercept Zone
AMBR®	Anaerobic Migrating Blanket Reactor
ANFLOW	Anaerobic Fluidized Bed Reactor
AN-MBR	Anaerobic Membrane BioReactor
AOP	Advanced Oxidation Process
ASBR®	Anaerobic Sequencing Batch Reactor
ASCE	American Society of Civil Engineers
atm	Atmosphere
AT3	Aeration Tank 3
AWTP	Advanced Wastewater Treatment Plant
AWWA	American Water Works Association

BABE	Bio-Augmentation Batch Enhanced
BAF	Biological Aerated Filters
BAR	Bio Augmentation Regeneration and/or Reaeration
BCFS	Biological-Chemical Phosphorus and Nitrogen Removal
BCDMH	1-Bromo-3 Chloro-5,5 DiMethylHydantoin
BHRC	Ballasted High Rate Clarification
BioMEMS	Biological Micro-Electro Machine System
BNR	Biological Nutrient Removal
BOD	Biological/Biochemical Oxygen Demand
BOD/N	Biochemical Oxygen Demand Ratio to Nitrogen
BOD/P	Biochemical Oxygen Demand Ratio to Phosphorus
CASS™	Cyclic Activated Sludge System
CCAS™	CounterCurrent Aeration System
CDS	Continuous Deflection Separator
cfu	Colony forming unit
CMAS	Complete Mix-Activated Sludge
CMF®	Compressed Media Filter (WWETCO CMF®)
CMOM	Capacity, Management, Operations, and Maintenance
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
CWA	Clean Water Act
DAF	Dissolved Air Flotation
DEMON	DEamMONification
DEPHANOX	DE-nitrification and PHosphate accumulation in ANOXic
DF	Disc Filter
DO	Dissolved Oxygen
EBPR	Enhanced Biological Phosphorus Removal
EDC	Endocrine Disrupting Compound
ELISA	Enzyme-Linked ImmunoSorbent Assay
EMS	Environmental Management Systems
FBBR	Fluidized Bed BioReactor
FISH	Fluorescence In Situ Hybridization
GAC	Granular-Activated Carbon
GPD	Gallons per day
gpm/ft^2	Gallons per minute per square foot
HANAA	Handheld Advanced Nucleic Acid Analyzer
HFMBfR	Hydrogen-based hollow-Fiber Membrane Biofilm Reactor
HFO	Hydrous Ferric Oxide
HPO	High-Purity Oxygen
HRC	High-Rate Clarification
HRT	Hydraulic Retention Time
ICAAS	Immobilized Cell-Augmented Activated Sludge
ICEAS™	Intermittent Cycle Extended Aeration System
IFAS	Integrated Fixed-film Activated Sludge
IIT	Illinois Institute of Technology

ISE	Ion Selective Electrode
LOT	Limit Of Technology
IWA	International Water Association
MAB	Multi-stage Activated Biological
MABR	Membrane-Activated BioReactor
MAUREEN	Main-stream AUtotrophic Recycle Enabling Enhanced N-removal
MBR	Membrane BioReactor
MBRT	Mobile-Bed Reactor Technology
MFC	Microbial Fuel Cell
MGD	Million Gallons per Day
mg/L	Milligram per Liter
MISS	Moderate Isotope Separation System
MLE	Modified Ludzack-Ettinger
MLSS	Mixed Liquor Suspended Solids
mph	Miles per hour
MSABP™	Multi-Stage Activated Biological Process
MUCT	Modified University of Cape Town
NACWA	National Association of Clean Water Agencies
NADH	Nicotinamide Adenine Dinucleotide
NF	NanoFiltration
NOB	Nitrite Oxidizing Bacteria
ntu	Nephelometric turbidity unit
O&M	Operation and Maintenance
ORP	Oxidation Reduction Potential
OWM	Office of Wastewater Management (U.S. EPA)
PAC	Powdered Activated Carbon
PAO	Phosphorus Accumulating Organisms
PBDE	PolyBrominated Diphenyl Ether
PCR	Polymerase Chain Reaction
PeCOD™	Photo-electro Chemical Oxygen Demand
PhACs	Pharmaceutically Active Compounds
POTW	Publicly Owned Treatment Works
PPCP	Pharmaceutical and Personal Care Products
ppm	Parts per million
PVC	Poly Vinyl Chloride
psig	Pounds per square inch (gauge)
RAS	Returned Activated Sludge
RBC	Rotating Biological Contactor
R-DN	Regeneration DeNitrification
rDON	Refractory Dissolved Organic Nitrogen
SBR	Sequencing Batch Reactor
SCFM	Standard Cubic Feet per Minute
SHARON	Single reactor High-activity Ammonia Removal Over Nitrite
SHARON – ANAMMOX	Single reactor High-activity Ammonia Removal Over Nitrite – ANaerobic AMMonia OXidation

SNdN	Simultaneous Nitrification deNitrification
SRBC	Submerged Rotating Biological Contactor
SRT	Sludge Retention Time; Solids Retention Time
SSO	Sanitary Sewer Overflow
STRASS	Similar to SHARON named after Strass, Austria
SVI	Sludge Volume Index
TDH	Total Dynamic Head
TDS	Total Dissolved Solids
TF	Trickling Filter
TF/PAS	Trickling Filter and Pushed Activated Sludge
TF/SC	Trickling Filter and Solid Contactor
TMP	Trans Membrane Pressure
TOC	Total Organic Carbon
TSS	Total Suspended Solids
U.S. EPA	United States Environmental Protection Agency
UASB	Upflow Anaerobic Sludge Blanket
UCT	University of Cape Town
UV	UltraViolet
VIP	Virginia Initiative Plant
VIS	Visibility
VMI	Virginia Military Institute
VRM®	Vacuum Rotation Membrane
WAS	Waste Activated Sludge
WASA	Water and Sewer Authority
WEF	Water Environment Federation
WEFTEC	Water Environment Federation's Annual Technical Exhibition and Conference
WERF	Water Environment Research Foundation
WPAP	Water Pollution Abatement Program
WPCF	Water Pollution Control Facility
WRF	Water Reuse Facility
WWEMA	Water and Wastewater Equipment Manufacturers Association
WWPF	WasteWater Production Flow
WWTF	WasteWater Treatment Facility
WWTP	WasteWater Treatment Plant

OVERVIEW

In 2004, there were 16,583 municipal wastewater treatment plants operating in the United States. These plants ranged in size from a few hundred gallons per day (GPD) to more than 800 million gallons per day (MGD). Early efforts in water pollution control began in the late 1800s with construction of facilities to prevent human waste from reaching drinking water supplies. Since the passage of the 1972 Amendments to the Federal Water Pollution Control Act (Clean Water Act [CWA]), municipal wastewater treatment facilities have been designed and built or upgraded to abate an ever-increasing volume and diversity of pollutants. The CWA requires that municipal wastewater treatment plant discharges meet a minimum of secondary treatment. However, in 2004, nearly 30 percent of the municipal facilities produced and discharged effluent at higher levels of treatment than the minimum federal standards for secondary treatment.

This document provides information regarding emerging wastewater treatment and in-plant wet weather management technologies organized into four categories of development:

1) **Embryonic** – Technologies in the development stage and/or have been tested at a laboratory or bench scale only.
2) **Innovative** – Technologies that have been tested at a demonstration scale, have been available and implemented in the United States for less than five years, or have some degree of initial use (i.e., implemented in less than 1 percent of treatment facilities).
3) **Established** – Technologies that have been used at more than 1 percent of treatment facilities throughout the United States or have been available and implemented in the United States for more than five years.
4) **Innovative Uses of Established** – Some wastewater treatment processes have been established for years, but they are not static. In some cases, an established technology may have been modified or adapted resulting in an emerging technology. In other cases, a process that was developed to achieve one treatment objective is now being applied in different ways or to achieve additional treatment objectives. During the operation of treatment systems using these established technologies, engineers, and operators have altered and improved their efficiency and performance. This document includes established technologies that have undergone recent modifications or are used in new applications.

This document also provides information on each technology, its objective, its description, its state of development, available cost information, associated contact names, and related data sources. For each innovative technology, this document further evaluates technologies against various criteria, although it does not rank or recommend any one technology over another. Research needs are also identified to guide development of innovative and embryonic technologies and improve established ones.

1. Introduction and Approach

1.1. Introduction

In 2004, there were 16,583 municipal wastewater treatment plants operating in the United States. These plants ranged in size from a few hundred gallons per day (GPD) to more than 800 million gallons per day (MGD). Early efforts in water pollution control began in the late 1800s with construction of facilities to prevent human waste from reaching drinking water supplies. Since the passage of the 1972 Amendments to the Federal Water Pollution Control Act (Clean Water Act [CWA]), municipal wastewater treatment facilities have been designed and built or upgraded to abate an ever-increasing volume and diversity of pollutants. The

CWA requires that municipal wastewater treatment plant discharges meet a minimum of secondary treatment. However, in 2004, nearly 30 percent of the municipal facilities produced and discharged effluent at higher levels of treatment than the minimum federal standards for secondary treatment.

To meet the challenge of keeping progress in wastewater pollution abatement ahead of population growth, changes in industrial processes, and technological developments, EPA is providing this document to make information available on recent advances and innovative techniques.

> The goal of this document is straight forward—to provide a guide for persons seeking information on innovative and emerging wastewater treatment technologies. The guide lists new technologies, assesses their merits and costs, and provides sources for further technological investigation. This document is intended to serve as a tool for wastewater facility owners and operators.

Emerging technologies typically follow a development process that leads from laboratory and bench-scale investigations to pilot studies and to initiate use or "full-scale demonstrations" before the technology is considered established. Not all technologies survive the entire development process. Some fail in the laboratory or at pilot stages; others see limited application in the field, but poor performance, complications, or unexpected costs may cause them to lose favor. Even technologies that become established may lose favor in time, as technological advances lead to obsolescence. In short, technologies are subject to the same evolutionary forces present in nature; those that cannot meet the demands of their environment fail, while those that adapt to changing technological, economic and regulatory climates can achieve long-standing success and survival in the market.

Some wastewater treatment processes have been established for many years, but that does not mean that they are static. During the operation of treatment systems using these established technologies, engineers and operators have altered and improved efficiency and performance. In other cases, established technologies applied to one aspect of treatment have been modified so that they can perform different objectives. Often, better performance can be achieved by linking established processes in innovative ways. This document includes established technologies that have undergone recent modifications or are used in new applications. These technologies are evaluated in the chapters alongside the innovative and embryonic technologies.

1.2. Approach

To develop this guide, the investigators sought information from a variety of sources, identified new technologies, prepared cost summaries, where information was available, for all technologies, and evaluated technologies deemed to be innovative. This method is described below and in Figure 1-1.

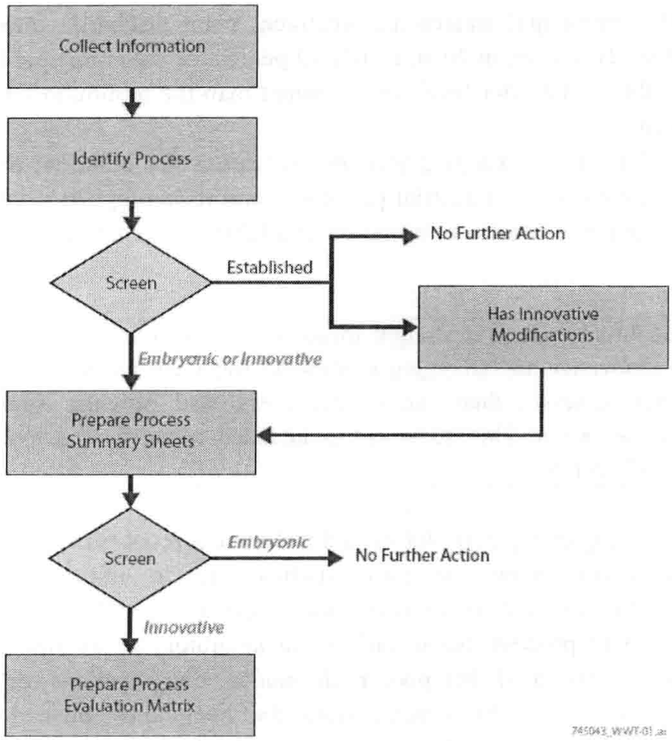

Figure 1.1.Flow Schematic for Guide Development.

1.2.1. Information Collection and New Process Identification

The collection of information and identification of new technology provided the foundation for subsequent work. To identify new treatment process technologies, investigators gathered information and focused on relevant Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE) conference proceedings, as well as monthly publications from these and other organizations such as International Water Association (IWA).

"Gray" Literature – Vendor-supplied information, Internet research, and consultants' technical reports comprise the information collected in this category.

Technical Associations – Investigators contacted a variety of professional and technical associations in the United States to identify emerging wastewater treatment technologies.

Interviews and Correspondence – Individuals known to the project investigation team, including consultants, academics, and municipal wastewater treatment plant owners and operators, were consulted.

Technologies identified through search of the above sources were screened to determine their classification as described below.

1.2.2. Initial Screened Technologies

This project focuses on emerging technologies that appear to be viable, but have not yet been accepted as established processes in the United States. Specific screening criteria used to define the state of development for processes are described in the following paragraphs. This screening resulted in:

- 23 embryonic technologies
- 52 innovative technologies
- 8 established technologies with innovative modifications

Embryonic – These technologies are in the development stage and/or have been tested at laboratory or bench scale. New technologies that have reached the demonstration stage overseas, but cannot yet be considered to be established there, are also considered to be embryonic with respect to North American applications.

Innovative – Technologies that meet one of the following criteria were classified as innovative:

- They have been tested as a full-scale demonstration.
- They have been available and implemented in the United States for less than five years.
- They have some degree of initial use (i.e., implemented in less than 1 percent of municipalities throughout the United States).
- They are established technologies from overseas.

Established – In most cases, these processes are used at more than 1 percent of full-scale facilities in North America; but there are some exceptions based upon specific considerations. The established category may include technologies that are widely used although introduced more recently in North America. Due to the extensive number of established technologies and variations in each technology, only established technologies are listed. None are described in depth in this document and Technology Summary sheets are not provided for established technologies.

Innovative Uses of Established – In some cases, an established technology such as the UCT (University of Cape Town) process may have been modified or adapted, resulting in an emerging technology such as the Modified UCT. In other cases, a process like Actiflo® was developed to remove solids from wet weather flows but is now also being used to polish final effluent.

The focus of this document is on Innovative Technologies along with preliminary information of Embryonic Technologies. Early in the development process (the laboratory stage), data was usually insufficient to prove or disprove technology viability at full scale. Available information on these embryonic technologies is presented in this document. Technologies on the other end of the developmental scale, those defined as established in North America, are excluded from the detailed assessments on the assumption that they are proven, although still relatively new.

The differentiation between technologies established in Europe or Asia and those that have reached similar status in the United States can be critical since technologies that have been applied successfully in other countries have not always flourished here in the United States. Because the viability of imported technologies is not guaranteed, established processes from overseas are classified as innovative technologies for this project, unless they are proven in North American applications.

Some technologies fall into a "gray area" between the embryonic and innovative categories. Technologies that fall into this category are incorporated into the innovative category. The screening assessment is summarized by chapter in Tables 1.1 through 1.4.

- Table 1.1 summarizes the treatment technologies for Chapter 2 – Physical/Chemical Treatment Processes.
- Table 1.2 summarizes the treatment technologies for Chapter 3 – Biological Treatment Processes.
- Table 1.3 summarizes the treatment technologies for Chapter 4 – In-Plant Wet Weather Management Processes.
- Table 1.4 summarizes the treatment technologies for Chapter 5 – Process Monitoring Technologies.

All the cost estimates provided in this document contain a certain degree of expert judgment or educated guesswork concerning the various cost elements that comprise the estimates. This is true when cost estimates are based on limited or no information where in some cases little more than process type, location, and plant capacity are known. Therefore, cost estimates are at best order-of-magnitude level per American Association of Cost Engineers (AACE) International classification. However, numerous peripheral factors that could also interfere with the accuracy of the order-of-magnitude level cost estimates. Considering these facts, the reader should keep in mind that site-specific applications and local requirements should be considered to increase the accuracy of cost estimates provided in this document.

1.2.3. Development of Technology Summary Sheets

Technologies defined as embryonic or innovative are each summarized on an individual Technology Summary sheet. Each process includes the following information:

- Objective – Description of the goal of the technology.
- State of Development – Where and how the technology has been applied (i.e., laboratory study, demonstration scale, full scale, etc.).
- Description – A brief overview of the technology.
- Comparison to Established Technologies – Advantages and disadvantages of innovative and embryonic technologies are compared to more commonly used technologies.
- Available Cost Information – Approximate range of capital and operations and maintenance costs, and assumptions made in developing them (when reliable information was available).
- Vendors Name(s) – Name, address, telephone numbers, web address, and other contact information for equipment manufacturers and suppliers.
- Installation(s) – Name, address, telephone numbers, and other contact information for utilities and facilities where the technology has been used (full or pilot scale).
- Key Words for Internet Search – Because this document is not intended to provide a comprehensive list of vendors for these technologies, key words have been added to aid the reader in finding additional vendors and current product information on the Internet.
- Data Sources – References used to compile the technology summary.