Next Generation
Environmental Technologies

Benefits and Barriers

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Preface

Next Generation Environmental Technologies (NGETs) focus on the redesign, at the molecular level, of manufacturing processes and products so as to reduce or eliminate the use of hazardous materials. The potential for such technologies suggests that they may play an important role in a new approach to environmental protection. NGETs thus raise important policy questions, including the range of benefits such technologies have already provided and may in the future provide and the types of actions commensurate with these benefits that policymakers might take to encourage their development and adoption. This report examines 25 case studies of such Next Generation Environmental Technologies to begin to address such questions.

For readers unfamiliar with NGETs, this study will provide a survey of their promise and weaknesses. For researchers and practitioners creating new NGETs, this study aims to provide a broader context for their efforts. For policymakers, this study aims to provide the raw materials for a systematic assessment of the range of potential benefits of NGETs and the portfolio of policies needed to move them forward.

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Summary

Next Generation Environmental Technologies (NGETs) represent a set of advanced manufacturing technologies that have the potential to produce environmentally benign products and processes. These technologies offer a new approach to environmental protection: Rather than focusing on the cleanup and control of waste and hazardous materials, they involve the redesign of industrial products and processes to reduce the quantity of material inputs required and to eliminate broad classes of environmentally detrimental outputs. When successfully implemented, NGETs offer the promise of substantial new advances in environmental protection often at low cost and even with a net economic benefit. They also raise important policy issues related to the magnitude and importance of the benefits that can be realized and the types of actions that might be taken to encourage their development and diffusion.

This report examines 25 existing NGETs to begin to address these issues. The technologies considered span the range of development from early research to full deployment in profitable businesses. Those that have been commercialized are offering benefits in a variety of areas, including the environment, national security, occupational safety and health, and the economy. Others that are still in various developmental stages offer similar promise.

Most of the technologies reviewed here draw on applications of the emerging science of green chemistry, an important source for NGETs. For each case study, we describe the underlying chemistry, the commercializing firm(s), the incentives that caused those firms to adopt the technology, and the role played by government support. Particular attention is paid to the identification of both near- and long-term benefits as well as to any barriers to technology adoption.

These case studies provide a review of the benefits and problems associated with NGETs. Taken together, they demonstrate the following:

1. NGETs can provide significant benefits to society in all the areas considered in our study: the environment, national security, occupational safety and health, and the economy.

2. NGETs can in some cases eliminate the use and generation of hazardous substances at little or no additional cost.
3. NGETs can be adopted by businesses for a variety of different reasons: to meet environmental regulations in a cost-effective way; to provide environmentally benign products economically; or to develop profitable new products in new and environmentally beneficent ways. NGETs provide new approaches to competitive advantage.

4. The barriers to the widespread use of NGETs can be technical, economic, and/or societal in nature.

This report represents a first step toward assessing the potential benefits of NGETs, reviewing the barriers to their successful deployment and pointing out where government actions have supported their successful adoption. Our case studies indicate that although green chemistry can be a powerful source of environmentally and economically beneficial technologies, its development is still in its infancy. Substantial work is needed both to create new NGETs and to encourage demand for their use. Much also remains to be learned about the basic science and practical application of green chemistry principles.
The authors are especially grateful to the many individuals who provided details or background on specific case studies, including Ruben Carbonell, North Carolina State University; Michael Stern and James Bashkin, Monsanto; Uma Chowdhry, Leo Manzer, Mas Subramanian, and Vasantha Nagarajan, DuPont; Akazu Takahashi, Ube Industries; Eric Beckman, University of Pittsburgh; Jeff Gendler and Ray Ballee, Hydrocarbon Technologies, Inc.; John Cooper, BASF; Nicholas Ashford, Massachusetts Institute of Technology; James Frank, Argonne National Laboratory; Robin Rogers, University of Alabama; David Berkowitz, Global Cooling; Vitaly Pecharsky, Ames Laboratory; Thomas Asmus, DaimlerChrysler; Michael Frenklach, University of California, Berkeley; Fred Cannon, Penn State; Mary Kirchhoff, Green Chemistry Institute; Richard Engler, U.S. Environmental Protection Agency (EPA); Ray Garant, American Chemical Society; Egils Milbergs and Jeff Keuter, National Coalition for Advanced Manufacturing; and Jack Cook, Integrated Manufacturing Technology Initiative.

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The statements and conclusions contained in this report are still the sole responsibility of the authors.
**Acronyms**

ABS  Aqueous biphasic systems
ACQ  Alkaline copper quaternary
ADPA Aminodiphenylamine
AND  Adiponitrile
AO   Advanced oxidation
AOX  Absorbable organic halides
API  Active pharmaceutical ingredient
BAC  Benzyl ammonium chloride
Btu  British thermal unit
CCA  Chromated copper arsenate
CDI  Capacitive Deionization
CFC  Chlorofluorocarbon
Cl₂  Elemental chlorine
CO₂  Carbon dioxide
CPA  Chloropropionic acid
DDAC Dodecyl dimethyl ammonium chloride
DMC  Dimethyl carbonate
DME  Dimethyl ether
DOE  U.S. Department of Energy
DSIDA Disodium diimindociacetate
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ECF</td>
<td>Elemental chlorine free</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>EPCRA</td>
<td>Emergency Planning and Community Right-to-Know Act</td>
</tr>
<tr>
<td>FDA</td>
<td>U.S. Food and Drug Administration</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross domestic product</td>
</tr>
<tr>
<td>GI</td>
<td>Glyphosate intermediate</td>
</tr>
<tr>
<td>GSC</td>
<td>Green and Sustainable Chemistry Network</td>
</tr>
<tr>
<td>GSK</td>
<td>GlaxoSmithKline</td>
</tr>
<tr>
<td>GWP</td>
<td>Global warming potential</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>Hydrogen peroxide</td>
</tr>
<tr>
<td>HCF</td>
<td>Hydrofluorocarbon</td>
</tr>
<tr>
<td>HF</td>
<td>Hydrofluoric acid</td>
</tr>
<tr>
<td>HTI</td>
<td>Hydrocarbon Technologies, Inc.</td>
</tr>
<tr>
<td>IBB</td>
<td>Iso-butyl benzene</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>lbs</td>
<td>Pounds</td>
</tr>
<tr>
<td>MCF</td>
<td>Methyl chloroform</td>
</tr>
<tr>
<td>Mpa</td>
<td>Megapascals</td>
</tr>
<tr>
<td>MTBE</td>
<td>Methyl tert-butyl ether</td>
</tr>
<tr>
<td>N₂</td>
<td>Elemental nitrogen</td>
</tr>
<tr>
<td>NASH</td>
<td>Nucleophilic aromatic substitution for hydrogen</td>
</tr>
<tr>
<td>NESHAP</td>
<td>National Emission Standards for Hazardous Air Pollutants</td>
</tr>
<tr>
<td>NGET</td>
<td>Next Generation Environmental Technology</td>
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</table>
NIH  National Institutes of Health
NO₂  Nitrogen oxides
NSF  National Science Foundation
O₂   Elemental oxygen
OECD Organisation for Economic Cooperation and Development
PAA  Polyaspartic acid
PCE  Perchloroethylene
PDC  Polycrystalline diamond compact
PEG  Polyethylene glycol
PET  Polyethylene terephthalate
PLA  Polylactic acid
PMN  Premanufacture notices
PO   Propylene oxide
psi  Pounds per square inch
R&D  Research and development
RCRA Resource Conservation and Recovery Act
SCF  Supercritical fluid
SCI  Chemical Specialties, Inc.
SIC  Standard Industrial Classification
SO₂  Sulfur dioxide
TCF  Totally Chlorine Free
TRI  Toxics Release Inventory
VOC  Volatile organic compounds