Inspired by Biology: From Molecules to Materials to Machines (Free Executive Summary) http://www.nap.edu/catalog/12159.html

Free Executive Summary

Inspired by Biology: From Molecules to Materials to Machines



Committee on Biomolecular Materials and Processes, National Research Council ISBN: 978-0-309-11704-3, 152 pages, 7 x 10, paperback (2008)

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389	Executive Summary
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391	The ability of biological systems to carry out extremely complex functions in a vast array of
392	environments has long inspired scientists to create synthetic systems that function with similar precision
393	and efficiency. A lack of understanding of how biological systems function has hampered the ability to
394	make such materials and devices. Scientists are using an expanding toolbox of new ways to measure.
395	manipulate, and compute properties of matter, living and nonliving. These efforts are beginning to
396	uncover the principles that govern how biological systems work. Application of the principles uncovered
397	by these investigations will allow scientists to create synthetic materials, processes, and devices that can
398	carry out tasks with the precision of biological systems. As demonstrated by the opportunities and
399	examples presented in this report, now is a very exciting time for research at the intersection of the
400	biological and materials sciences.
401	Practical design of biologically inspired materials has the potential to improve the well-being of
402	U.S. citizens and the nation's economic competitiveness by addressing some of the most urgent national
403	challenges. Biomolecular materials and processes may improve medical therapeutics, allow the creation
404	of reliable sensors to detect biological and chemical threats, and facilitate the path to energy
405	independence. To realize these opportunities and fully harness the potential of biology to inform the
406	development of materials and processes, further advances in fundamental physics, chemistry, and material
407	science will be required. Three closely related strategies for the creation of new materials and systems
408	may help realize the potential of biomolecular materials and processes:
409	
410	Biomimicry . This strategy relies on first learning the mechanistic principle used by a living system to
411	achieve a particular function. Then one attempts to copy the same scheme to achieve similar function in a
412	synthetic material. One example is the design of materials where the building blocks themselves encode
413	information during their synthesis. One can also try to create materials that mimic whole cells in
414	responding to external stimuli. Such materials could be used in devices for detecting nazardous biological
415	and chemical agents.
410	Biging piration Merely knowing that a task can be achieved by a living system can inspire scientists to
417	develop a synthetic system that performs the same function, even if the synthetic system uses a scheme
419	quite different from that employed by the biological system. Nature provides examples of functional
420	systems with exceptional materials properties and performance that would be useful to replicate for
421	technological applications. Examples include the adhesive gecko's foot self-cleaning lotus leaf and
422	fracture-resistant mollusk shell, which have fueled recent interest in "smart" biological materials. Yet
423	attempts to create synthetic analogs have largely been unsuccessful, in part because the fundamental
424	understanding of the biological systems is often limited.
425	
426	Bioderivation. This strategy involves using an existing biomaterial in concert with artificial materials to
427	create a hybrid. A prominent example is the incorporation of biologically derived proteins into polymeric
428	assemblies for targeted drug delivery.
429	
430	Progress in these areas will be facilitated by a number of actions and investment by research
431	agencies, the scientific community, and other stakeholders. In particular, the following steps will help
432	confront the scientific challenges associated with these strategies and to translate the resulting knowledge
433	into societal and economic value:
434	
435	• The synergistic application of approaches traditionally confined to distinct disciplines will be
436	imperative. While such concerted efforts are already emerging in individual circumstances,

substantial interagency cooperation in support of such interdisciplinary research and

development efforts will be needed.

439	
440	Recommendation 1: DOE, NIH, NSF, and other relevant agencies should develop jointly
441	sponsored multidisciplinary programs of innovative research at the crossroads of
442	disciplines. New initiatives of this type will provide incentives for universities to break down
443	and work across traditional departmental boundaries. OSTP should take the lead in
444	coordinating this effort.
445	
446	• Fundamental physical chemical and biological scientists need to work together with engineers
447	to create new biomaterials and technologies. <i>Education of scientists and engineers that can work</i>
448	at the intersection of these fields is crucial
449	at the intersection of these fields is crucial.
450	Recommendation 2: University physics, chemistry, biology, materials science, mathematics,
451	and engineering departments and medical schools should cooperatively examine their
452	curricula to identify ways to prepare scientists and engineers for research at the intersection
453	of the physical sciences engineering and the life sciences. These educational programs
454	should also be evaluated incornorating a wide range of viewnoints including input from
455	leaders in industry and national laboratories
456	Raders in industry and national laboratories.
457	Communication between scientists and engineers from different disciplines is hampered by
457	difficulties in understanding methods, concents, and jargon. Machanisms for facilitating
450	communication across and between disciplines are essential
459	communication across and between disciplines are essential.
461	Recommendation 3: DOF NIH NSF and other relevant agencies should support the
467	development of one- or two-week summer courses to train physical scientists and engineers
463	in the tools and concents of biology and medicine and conversely to train biologists in the
40J 161	tools and concepts of the physical sciences. Special attention should be given to developing
465	ways of communicating fundamental physica-chemical concents to biologists while using
466	mathematical knowledge common to that community. Summer courses focused on these
467	areas would help bridge the physical and life sciences communities to evploit research
468	anonstunities at the intersection of the fields
469	opportunities at the intersection of the netus.
470	• Fundamental research is necessary to realize the applications envisaged in this report and could
471	lead to vet-unimagined technological applications, but translation of new discoveries into useful
472	products is also crucial. Thus, both fundamental and translational research should be
473	omnhasizod
474	emphasizea.
475	Recommendation 4: DOF NIH NSF and other relevant agencies should collaborate to
476	huild bridges from the most fundamental research to commercial applications. While it is
477	imperative to recognize and exploit the connections between fundamental advances and
478	onnortunities to translate the advances into practice curiosity-driven fundamental research
479	on outstanding unsolved questions should be encouraged as it could lead to currently
480	unforeseen technological advances
481	unforescen teenhological auvances.
482	• It is difficult for a single laboratory to house the diverse instrumentation and expertise required
483	for interdisciplinary research in biomolecular materials and processes. Standard equipment in
484	hiology laboratories for example is usually not found in engineering laboratories and vice versa
485	Further many researchers do not have access to shared or private facilities containing such
486	equinment and instrumentation National facilities that house clusters of small to mid-range
487	instrumentation and associated expertise are important for fostering interdisciplinary research in
488	hiomolecular materials and processes

489	
490	Recommendation 5: DOE should continue to evaluate the effectiveness of recently created
491	facilities to provide access to mid-range instrumentation and computational facilities for the
492	advancement of interdisciplinary research in nanoscience and technology. Analogous, but
493	distinct, centers could be created to facilitate research in biomolecular materials and
494	processes.

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- 44 THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001 45 46 NOTICE: The project that is the subject of this report was approved by the Governing Board of the 47 National Research Council, whose members are drawn from the councils of the National Academy of 48 Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the 49 committee responsible for the report were chosen for their special competences and with regard for 50 appropriate balance. 51 52 This study is based on work supported by Contract No. DE-FG02-05ER46197 between the National 53 Academy of Sciences and the Department of Energy and Grant No. DMR-0426181 between the National 54 Academy of Sciences and the National Science Foundation. Any opinions, findings, conclusions, or 55 recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the 56 views of the agency that provided support for the project. 57 58 International Standard Book Number 0-309-XXXXX-X 59 60 Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., 61 Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington 62 metropolitan area); Internet, http://www.nap.edu; and the Board on Physics and Astronomy, National 63 Research Council, 500 Fifth Street, N.W., Washington, DC 20001; Internet, http://www.national-64 academies.org/bpa. 65 66 Copyright 2008 by the National Academy of Sciences. All rights reserved. 67
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- result is a scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.
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91

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- 97 the public, and the scientific and engineering communities. The Council is administered jointly by both
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- 99 vice chair, respectively, of the National Research Council.
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227	Preface
228	
229	The National Research Council of the National Academies convened the Committee on
230	Biomolecular Materials and Processes (BMAP) to assess current work and future promise at the
231	intersection of biology and materials science. The Solid State Sciences Committee of the Board on
232	Physics and Astronomy developed the charge for this study in consultation with the study's sponsors at
233	the Department of Energy and National Science Foundation. The Committee on BMAP was charged to
234	identify the most compelling questions and the emerging scientific opportunities at the interface between
235	biology and condensed matter and materials research, suggest strategies to best meet the identified
236	opportunities, and consider connections to national priorities including healthcare, security, workforce,
237	economic, and other societal needs. The committee did not address tissue engineering in this report as it
238	has been reviewed elsewhere ¹ and was considered outside the scope of the committee's charge. The
239	complete charge is reproduced in Appendix A.
240	The Committee on BMAP is composed of experts from many different areas of biomolecular
241	materials research (see Appendix C for biographical sketches of committee members). The full committee
242	met in person three times (see Appendix B) to address its charge. The committee formed subgroups to
243	study areas in further detail and to develop the text of the final report. At its meetings, the committee
244	heard from experts in the field and from the federal agencies that support BMAP research. Conference
245	calls and email were used to coordinate the work of the committee between meetings. This final report
246	reflects the committee's enthusiasm and excitement for the research opportunities in BMAP.
247	This report is the product of input from many people. On behalf of the committee, I extend my
248	thanks and appreciation to all who participated in this endeavor. I also thank the speakers who made
249	formal presentations at the committee meetings (Appendix B); those presentations and the ensuing
250	discussions strongly informed the committee's deliberations. In addition, the committee would like to
251	thank the following people for their insight: Ian Anderson, James R. Baker, Jr., Sergey Bezrukov, Mark S.
252	Humayun, Nicholas A. Kotov, Ronald G. Larson, John Miao, Dean A. Myles, Kevin Plaxco, Rudi
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Finally, I also thank the NRC staff (Natalia Melcer, Adam Fagen, Don Shapero, Frances
 Sharples, Phillip Long, and Caryn Knutsen) for their guidance and assistance throughout the development
 of the report.

As chair, I am grateful to the committee members for their wisdom, cooperation, and commitment to ensuring the development of a comprehensive report.

261

262 Arup Chakraborty, *Chair*

263 Committee on BMAP

¹ National Research Council, *Capturing the Full Power of Biomaterials for Military Medicine*, Washington, D.C.: The National Academies Press, (2004).

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

- 273
- 274 Robert H. Austin, Princeton University,
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- 282 David A. Tirrell, California Institute of Technology.
- 283

264

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Peter B. Moore, Yale University. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring

290 committee and the institution.

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