

## SYSTEMS BIOLOGY

# Systems Biology

International Research and Development

by

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## WTEC Panel on Systems Biology

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### Abstract

The current textbook image of biological processes is that of a static model of loosely linked, highly detailed, molecular devices. However, every biologist knows that dynamic processes drive biology. Systems biology is defined for the purpose of this study as the understanding of biological network behaviors, and in particular their dynamic aspects, which requires the utilization of mathematical modeling tightly linked to experiment. This involves a variety of approaches, such as the identification and validation of networks, the creation of appropriate datasets, the development of tools for data acquisition and software development, and the use of modeling and simulation software in close linkage with experiment. All of these are discussed in this report. Of course, the definition becomes ambiguous at the margins. But at the core is the focus on networks, which makes it clear that the goal is to understand the operation of the systems, rather than the component parts. The panel concluded that the U.S. is currently ahead of the rest of the world in systems biology, largely because of earlier investment over the past five to seven years by funding organizations and research institutions. This is reflected in a large number of active research groups, and educational programs, and a diverse and growing funding base. However, there is evidence of rapid development outside the U.S., much of it begun in the last two to three years. It must be stressed that the attempt to incorporate the details of molecular events obtained over the past half century into a dynamic picture of network behavior in biological systems is only just beginning, in the U.S. and elsewhere. In particular, progress in the core activity of systems biology—modeling tied to experiment—is still limited. Progress would be facilitated by strong international collaborations in training, research, and infrastructure. Overall, however, the picture is of an active field in the early stages of explosive growth.

## WTEC Mission

WTEC provides assessments of foreign research and development in selected technologies under awards from the National Science Foundation, the Office of Naval Research, and other agencies. Formerly part of Loyola College's International Technology Research Institute, WTEC is now a separate nonprofit research institute. Michael Reischman, Deputy Assistant Director for Engineering, is NSF Program Director for WTEC. Sponsors interested in international technology assessments and related studies can provide support for the program through NSF or directly through separate grants to WTEC.

WTEC's mission is to inform U.S. scientists, engineers, and policymakers of global trends in science and technology. WTEC assessments cover basic research, advanced development, and applications. Panels of typically six technical experts conduct WTEC assessments. Panelists are leading authorities in their field, technically active, and knowledgeable about U.S. and foreign research programs. As part of the assessment process, panels visit and carry out extensive discussions with foreign scientists and engineers in their labs.

The WTEC staff helps select topics, recruits expert panelists, arranges study visits to foreign laboratories, organizes workshop presentations, and finally, edits and disseminates the final reports.

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## Foreword

We have come to know that our ability to survive and grow as a nation to a very large degree depends upon our scientific progress. Moreover, it is not enough simply to keep abreast of the rest of the world in scientific matters. We must maintain our leadership.<sup>1</sup>

President Harry Truman spoke those words in 1950, in the aftermath of World War II and in the midst of the Cold War. Indeed, the scientific and engineering leadership of the United States and its allies in the twentieth century played key roles in the successful outcomes of both World War II and the Cold War, sparing the world the twin horrors of fascism and totalitarian communism, and fueling the economic prosperity that followed. Today, as the United States and its allies once again find themselves at war, President Truman's words ring as true as they did a half-century ago. The goal set out in the Truman Administration of maintaining leadership in science has remained the policy of the U.S. Government to this day: Dr. John Marburger, the Director of the Office of Science and Technology (OSTP) in the Executive Office of the President made remarks to that effect during his confirmation hearings in October 2001.<sup>2</sup>

The United States needs metrics for measuring its success in meeting this goal of maintaining leadership in science and technology. That is one of the reasons that the National Science Foundation (NSF) and many other agencies of the U.S. Government have supported the World Technology Evaluation Center (WTEC) and its predecessor programs for the past 20 years. While other programs have attempted to measure the international competitiveness of U.S. research by comparing funding amounts, publication statistics, or patent activity, WTEC has been the most significant public domain effort in the U.S. Government to use peer review to evaluate the status of U.S. efforts in comparison to those abroad. Since 1983, WTEC has conducted over 60 such assessments in a wide variety of fields, from advanced computing, to nanoscience and technology, to biotechnology.

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<sup>1</sup> Remarks by the President on May 10, 1950, on the occasion of the signing of the law that created the National Science Foundation. *Public Papers of the Presidents* 120: p. 338.

<sup>2</sup> [http://www.ostp.gov/html/01\\_1012.html](http://www.ostp.gov/html/01_1012.html).

The results have been extremely useful to NSF and other agencies in evaluating ongoing research programs, and in setting objectives for the future. WTEC studies also have been important in establishing new lines of communication and identifying opportunities for cooperation between U.S. researchers and their colleagues abroad, thus helping to accelerate the progress of science and technology generally within the international community. WTEC is an excellent example of cooperation and coordination among the many agencies of the U.S. Government that are involved in funding research and development: almost every WTEC study has been supported by a coalition of agencies with interests related to the particular subject at hand.

As President Truman said over 50 years ago, our very survival depends upon continued leadership in science and technology. WTEC plays a key role in determining whether the United States is meeting that challenge, and in promoting that leadership.

Michael Reischman  
Deputy Assistant Director for Engineering  
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## Preface

This report was prepared by the World Technology Evaluation Center (WTEC), a nonprofit research institute funded by grants and other awards from most of the Federal research agencies. Among other studies, WTEC has provided peer reviews by panels of U.S. experts of international research and development (R&D) in more than 55 fields since 1989. In 2004, WTEC was asked by several agencies to assess international R&D in systems biology. This report is the final product of that study.

We would like to thank our distinguished panel of experts, who are the authors of this report, for all of their efforts to bring this study to a successful conclusion. We also are very grateful to our foreign hosts for their generous hospitality, and to the participants in our preliminary workshop on U.S. Systems Biology R&D. Of course, this study would not have been possible without encouragement from our sponsor representatives: Bruce Hamilton, Frederick Heineken, Carol Lucas, and Maryanna Henkart (NSF); Sri Kumar (DARPA); Marvin Frazier (DOE); Richard Wiggins (EPA); Stephen Davison (NASA); Dan Gallahan and Peter Lyster (NIH); and Angela Hight-Walker (NIST).

This report covers a broad spectrum of material on the subject, so it may be useful to give a preview here. The Executive Summary was prepared by the chair, Marvin Cassman, with input from all the panelists. The chapters in the body of this report present the panel's findings in an analytical organization by subdiscipline. Appendix A provides the biographies of the panelists. Appendices B and C contain the panel's individual reports on each site visited in Europe and Japan, which form a chronological or geographic organization of much of the material. To establish a baseline for comparison, a workshop to report on U.S. research was held. A summary of the workshop is at Appendix D. Finally, a glossary is provided as Appendix E.

All the products of this project are available at <http://www.wtec.org>. The full-color electronic version of this report is particularly useful for viewing some of the figures.

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WTEC, Inc.