Reinventing the Automobile

Personal Urban Mobility for the 21st Century

William J. Mitchell, Christopher E. Borroni-Bird, and Lawrence D. Burns

The MIT Press Cambridge, Massachusetts London, England

MIT Press books may be purchased at special quantity discounts for business or sales promotional use. For information, please email special_sales@mitpress.mit.edu or write to Special Sales Department, The MIT Press, 55 Hayward Street, Cambridge, MA 02142.

This book was set in Helvetica Neue LT Pro and Adobe Garamond Pro by the MIT Press. Printed and bound in the United States of America.

The views expressed in this book are those of the authors, and are not necessarily those of General Motors or the MIT Media Laboratory.

Library of Congress Cataloging-in-Publication Data

Mitchell, William J. (William John), 1944–.
Reinventing the automobile : personal urban mobility for the 21st century/William J. Mitchell, Christopher E. Borroni-Bird, and Lawrence D. Burns.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-262-01382-6 (hardcover : alk. paper)
1. Electric automobiles—Technological innovations. 2. Intelligent transportation systems. 3. Transportation, Automotive. 4. Urban transportation. I. Borroni-Bird, Chris. II. Burns, Lawrence D. III. Title.
TL220.M58 2010
629.2—dc22

2009024970

10 9 8 7 6 5 4 3 2 1

1

Introduction

For a century, the automobile has offered affordable freedom of movement within cities—the places where most of the world's people now live, work, play, and pursue their social and cultural lives. It provides access to all of the benefits that cities have to offer; it is an object of desire; and it plays a crucial role in the U.S. and other economies. But it now requires radical reinvention.

Through a complex coevolutionary process—involving interdependencies among vehicle engineering and design solutions, energy supply systems, street and road infrastructures, urban land use patterns, economic incentives, and government policies—the automobile has become part of the urgent problem that cities now face. Cities currently consume too much of the Earth's nonrenewable resources to remain viable and livable in the long term. Their supply lines are insecure and vulnerable to disruption. They are too congested with parked and moving vehicles to be safe, convenient, and pleasant. And they produce more waste—including the greenhouse gases associated with global warming—than the Earth's natural systems can absorb without undergoing unacceptable levels of damage.

This book argues that a reinvented automobile can become a powerful part of the solution to these problems. While maintaining and even enhancing current levels of personal mobility within cities, the new kinds of automobiles and personal urban mobility systems that we'll describe promise to reduce

the overall energy and materials requirements of mobility systems; facilitate a significant shift from nonrenewable energy sources to clean, renewable ones; eliminate tailpipe emissions; enhance energy security; and generally improve the quality of urban life.

These automobiles are also designed to have high consumer appeal—to be fun, fashionable, and affordable. This is crucial: It is only through very high-volume consumer acceptance that reinvented automobiles and mobility systems will make the large-scale contributions to urban sustainability that we need, create exciting new opportunities for the automobile industry, and help to establish a clean, green economy for the coming decades.

The Need for Sustainable Personal Mobility

Automobiles respond to our desire to move about and interact. Ever since our ancestors walked out of Africa, personal mobility has been recognized as a basic human need. The transportation of people and objects and the creation of systems for moving freely from one place to another have been a part of the human story from prehistory.

From clans to cities, caves to skyscrapers, walking to riding, and sandals to cars, we have a rich history of finding ways to grow our population and wealth by increasing our mobility and our access to various resources. The invention of the wheel enabled hand-pulled and animal-drawn carts, and the domestication of horses extended the range of travelers. Horses remained a leading source of transportation power until they were supplanted, a hundred years ago, by mass-produced automobiles.

While automobile transportation has dramatically enhanced our personal mobility and helped us realize our aspirations for growth and prosperity, it has also created troublesome side effects. The freedom and prosperity benefits have been substantial, including greater access to jobs, goods, and services, convenient and safer personal travel, and the ability to go where we want, when we want, while carrying the things that we need. At the same time, however, the side effects have also been significant and growing. In our pursuit of personal mobility, we have damaged our environment, consumed our natural resources, wasted our time in traffic, harmed each other in collisions, and created disparities between the haves and have-nots. The extrapolation of these side effects raises increasingly pressing questions about the sustainability of today's automobile transportation system. Fortunately, rapidly maturing and converging technologies promise to reduce, and in some cases eliminate, these negative effects while further enhancing our freedoms. This book provides a comprehensive vision for the future of automobiles and personal urban mobility based on this promise.

The numbers are staggering. Over 6.7 billion people reside on Earth, with more than half of us now living in urban areas. This includes 26 cities with populations exceeding ten million people.[1] We own 850 million cars and trucks, nearly all powered by internal combustion engines and energized with petroleum. Parked end to end, these vehicles would

circle our planet nearly one hundred times—yet this represents a motor vehicle for just one out of every eight of us.

In the United States, 85 percent of personal travel today is by automobile. Americans drive three trillion miles a year, on four million miles of roads, consuming 180 billion gallons of fuel each year dispensed from 170,000 service stations.[2] Furthermore, we can expect significant increases in the number of cars being sold in emerging markets. With a sales growth rate of 3 percent per year, China's vehicle population is projected to surpass that of the United States by about 2030.[3] And as India's economy expands, it is poised to follow in China's footsteps.

Worldwide, we consume 18 million barrels of oil each day driving cars. Our vehicles emit 2.7 billion tons of carbon dioxide each year.[4] Roadway collisions claim 1.2 million lives each year.[5] And, in dense city centers, average urban speeds today can be well under 10 miles per hour.[6]

Have we reached the point where we now must seriously consider trading off the personal mobility and economic prosperity enabled by automobile transportation to mitigate its negative side effects? Or can we take advantage of converging twenty-first-century technologies and fresh design approaches to diminish these side effects sufficiently while preserving and enhancing our freedom to move about and interact? This book concludes the latter. It weaves together four big ideas that, when combined, hold the promise of sustainable automobility, even for dense megacities. Though some of the elements of these ideas are not new, we believe that it is now necessary—and entirely feasible—to develop and combine them in a radically new way.

Four Ideas: A Summary

The first idea, detailed in chapter 2, is to adopt a new automotive DNA that transforms the design principles that currently underlie automobiles. As summarized in figure 1.1, today's cars and trucks are primarily mechanically driven, powered by internal combustion engines, energized by petroleum, controlled mechanically, and operated as stand-alone devices. In fact, they have essentially the same "genetic

Current DNA	New DNA
Mechanically driven	Electrically driven
Powered by internal combustion engine	Powered by electric motors
Energized by petroleum	Energized by electricity and hydrogen
Mechanically controlled	Electronically controlled
Stand-alone operation	Intelligent and interconnected

Figure 1.1
The new automotive DNA.

makeup" as automobiles pioneered by Karl Benz, Ransom Olds, and Henry Ford over a century ago.

The new automotive DNA is created through the marriage of electric-drive and "connected" vehicle technologies. It is based purely on electric-drive, using electric motors for power, electricity (and its close cousin, hydrogen) for fuel, and electronics for controls. Electric-drive vehicles include battery electrics, extended-range electrics, and fuel-cell electrics. All three of these vehicle types have important roles to play in our future and differ from now-familiar hybrid electric vehicles, which add batteries and electric motors to improve the efficiency of today's mechanically driven cars.

The new automotive DNA also allows vehicles to communicate wirelessly with each other and with roadway infrastructure and roadside activities. When combined with GPS (Global Positioning System) technology and information-rich digital maps, "smart" cars will know precisely where they are relative to everything around them. Even with today's technology, vehicle-to-vehicle (V2V) communications and GPS can allow us to determine the proximity of two vehicles to within a meter and predict where these vehicles will be during the next twenty milliseconds. Taking advantage of such capabilities, connected vehicle technology will enable cars that can drive themselves and avoid crashes. The resulting reduction in crash protection requirements means that cars can become lighter, making them more conducive to electric drive, and thereby encouraging the use of renewable sources of energy for personal transportation. It also means that cars can be even more fun to drive and can provide more freedom of expression and personalization.

The second idea, the Mobility Internet, is discussed in chapter 3. The Mobility Internet will do for vehicles what the Internet has done for computers. It will enable vehicles to share enormous amounts of real-time, location-specific data so that traffic can be managed optimally and travel times can be reduced and made more predictable. Just as today's Internet servers manage extraordinary amounts of e-mail traffic, the Mobility Internet servers will manage vast amounts of vehicle traffic. This will integrate vehicles into the emerging "Internet of things."[7] Automobiles will become nodes in mobile networks.

The Mobility Internet will also permit drivers to share information and remain seamlessly connected to their personal, social, and business networks. Nondriving passengers will be able to do this soon. And, when automobiles begin to drive autonomously, even those in charge of automobiles will be able to safely use their travel time as they please, because there will no longer be the "distraction of driving."

The combination of the automobile's new DNA and the Mobility Internet, when applied within cities and towns, will enable us to reinvent personal urban mobility systems for the twenty-first century. Vehicles designed for city use will have dramatically smaller spatial and carbon footprints and will be considerably less expensive to own and operate. Later, we will introduce two new personal mobility concepts based on the new automotive DNA. These

concepts stem from work done at MIT and General Motors and illustrate just a couple of the many design and styling opportunities made possible when electric-drive vehicles are connected and enabled to avoid crashes and drive autonomously. They are extremely mass, space, and energy efficient. They provide all-weather protection, are comfortable, and allow their occupants to socialize, both physically and virtually. They are works in progress rather than fully designed and engineered products, but they clearly demonstrate the design directions that are possible. They are discussed in chapter 4.

The third idea is smart, clean energy, discussed in chapters 5 through 7. This results from combining electric-drive vehicles with energy-efficient buildings and smart utility grids to create distributed, responsive energy systems. These systems will support the utilization of diverse and renewable (but intermittent) sources of electricity. In addition, because electricity and hydrogen are interchangeable and hydrogen can store energy more densely than batteries, smart energy systems will enable the optimal mix of batteries and fuel cells to facilitate both stationary and vehicle uses of electricity. This includes the potential to efficiently distribute small amounts of energy precisely when and where they are needed.

The final idea is to develop electronically managed, dynamically priced markets (discussed in chapter 8) for electricity, roads, parking, and vehicles. These markets are underdeveloped today, but stationary and mobile connectivity can help realize their potential. They will depend on ubiquitous metering and sensing, make use of powerful computational back-ends, provide price signals and incentives that regulate supply and demand, and motivate sustainable activity patterns within cities.

The Combination of Transformative Ideas

Taken individually, each of these four ideas offers significant individual and societal benefits. Each can be implemented more or less separately. When pursued together, though, they will have their greatest impact. They have the potential to radically transform personal mobility in cities. To illustrate their power in combination, chapter 9 explores their combined effect on cities, where we can expect most of the world's population, together with 80 percent of the world's wealth, to be concentrated by 2030 (according to the United Nations). Cities will continue to attract population because they provide the greatest access to resources and opportunities. However, they are also the places where the energy, environment, safety, congestion, and access-inequality side effects of today's automobiles are most strongly amplified.

When effectively combined, the ideas behind this reinvention promise to enhance our freedoms and stimulate economic growth and prosperity while eliminating many, if not all, of the negative side effects of today's automobile transportation system. Figure 1.2 summarizes this opportunity.

The enabling technologies underlying these ideas have only recently matured and begun to converge, and this has fulfilled a necessary condition for large-scale, comprehensive application. Feasibility now

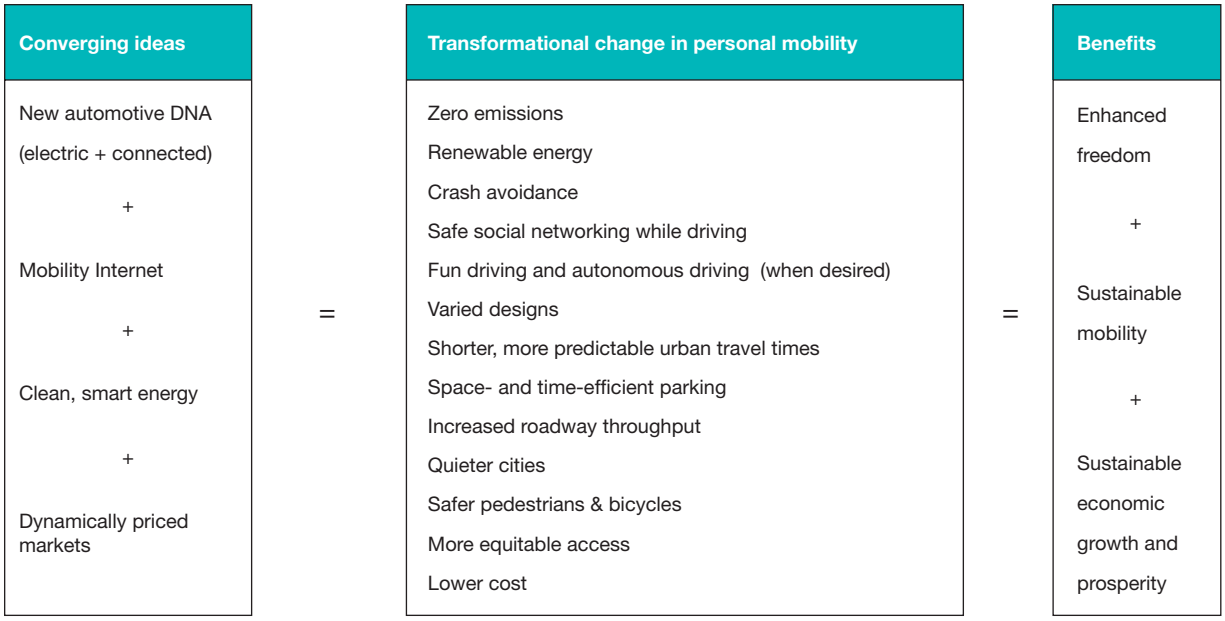

Figure 1.2
The whole is greater than the sum of its parts.

meets need. We have before us an emerging opportunity to reinvent the automobile and personal mobility systems fundamentally, not just improve them incrementally, and in doing so to meet the pressing sustainability challenges we face.

Implementation

We close in chapter 10 by discussing what must be done to realize this vision. The successful development of the Internet has demonstrated that large-scale networks and the necessary integration among diverse products and businesses can be realized. And there are many useful lessons to be learned from this example.

Several of the necessary technology enablers have already been tested in market "footholds." Others need foothold tests, and all need to mature to reach market "tipping points." Because of the codependencies among automobiles, energy infrastructure, communications infrastructure, and governments, it will be necessary to align incentives, form coalitions of stakeholders, and build a broad consensus around a common vision of the future of personal urban mobility. This common vision must be constructed around a "system-of-systems" framework, with widely accepted standards enabling interfaces among systems, and the increase in value of a system for every user as it grows (sometimes known as its "positive network externalities") motivating investment and powering rapid system growth. New forms of public–private partnership, as well as new business models, will be needed to realize the public and private value embedded in the vision and to share its risks and rewards. Finally, we must engage the imaginations of citizens, vividly demonstrate what is at stake and what is possible, and stimulate political support and consumer demand.

Among the first steps will be the development of imaginative, carefully conceived pilot projects. These must be at sufficient scale, and at sufficient levels of investment, to enable the integration of the key ideas. These projects will demonstrate the feasibility of reinvented automobiles and personal urban mobility systems, illustrate the daily operational and experiential realities, provide opportunities for necessary experimentation and testing, enable large-scale data collection and analysis, and provide the experience and learning needed to move to larger scales.

The Road Ahead

Getting to where we need to be will require a lengthy and difficult journey. (Remember, the initiation of what became the Internet took place back in the late 1960s.) But the outcomes can include much more livable and sustainable cities, economic growth based on clean, green technologies, and prosperity and freedom for future generations.