Planning Report 05-2

IPv6 Economic Impact Assessment

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for

National Institute of
Standards & Technology

October 2005

U.S Department of Commerce
Technology Administration

October 2005

IPv6 Economic Impact Assessment

Final Report

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RTI Project Number 008236.003

As a part of this report by RTI International, NIST requested estimates of transition and other costs associated with the Internet Protocol. The quantitative information contained in the RTI report is based on an extremely limited number of participants, including interested stakeholders. Further, because of the early phase of transition to the new Protocol, all estimates obtained are preliminary in nature and subject to significant revision. The results presented, therefore, are not to be regarded as statistically significant, but rather as rough indications of how industry and government costs may unfold under different transition strategies. Thus, the quantitative information contained in this report is meant to be used only as an illustration, not as a definitive assessment.

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Executive Summary

Internet users incur approximately 90 percent of IPv6 transition costs. Vendors and ISPs account for the remaining costs.

This report presents estimates of the costs and benefits associated with transitioning from Internet Protocol Version 4 (IPv4) to Internet Protocol Version 6 (IPv6). Cost estimates are based on likely development and deployment scenarios provided by stakeholders during interviews conducted by RTI International (RTI). Based on interviews, RTI estimates the present value of incremental costs associated with IPv6 deployment over a 25-year period to be approximately $25 billion ($2003),[1] primarily reflecting the increased labor costs associated with the transition. Although these cost estimates seem large, they are actually small relative to the overall expected expenditures on IT hardware and software and even smaller relative to the expected value of potential market applications.

Because major applications for IPv6 have yet to emerge, it is more difficult to quantify their potential benefits. Stakeholders participating in this study identified several major categories of IPv6 applications that, in total, are estimated to have potential annual benefits in excess of $10 billion[2]. These categories include Voice Over IP (VoIP), remote access products and services, and improved network operating efficiencies. However, benefits estimates included in this report are more subjective than cost estimates because they are based on Internet applications that are yet to be well defined. In addition, benefit estimates are potentially conservative because they do not reflect future, next generation applications that may be enabled by IPv6.

[1] All cost and benefit estimates are presented in 2003 dollars.
[2] This statement represents a synthesis of the information gathered by RTI through extensive literature reviews, RTI's informal discussions with stakeholders, commenters to the Department of Commerce (DoC) Request for Comment (RFC), participants in the DoC public meeting in July 2004, and stakeholder interviews conducted by RTI. See section ES-1 for a more detailed description of RTI's research activities.

ES.1 INDUSTRY RESEARCH

The cost and benefits estimates are informed by a series of 30 interviews with stakeholders. Stakeholders included infrastructure vendors, application vendors, Internet service providers (ISPs), and a variety of Internet users (e.g., infrastructure, corporate, government, institutional, and independent/home). In these interviews, RTI asked questions related to the timing of available IPv6 infrastructure components and applications and the likely adoption rates and costs for each stakeholder group. As shown in Table ES-1, interview findings were combined with other information provided through informal discussions and the Department of Commerce (DoC) IPv6 Task Force's Request for Comment (RFC).

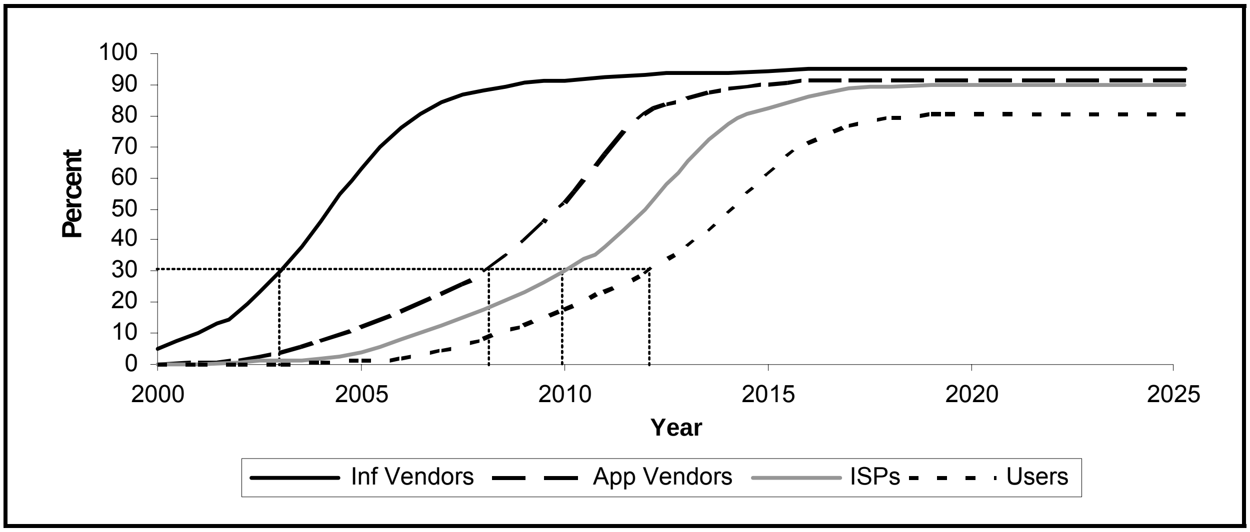
Table ES-1. Informal Discussions, RFC Commenters, and Interviews

Stakeholder Group	Informal Discussions	RFC Commenters	Interviews
Infrastructure vendors	7	5	5
Application vendors	0	1	6
ISPs	3	5	6
Infrastructure users	1	1	4
Corporate users	2	0	1
Institutional users	3	0	2
Government users	4	1	3
Research consortiums	3	4	2
Industry and academic experts	1	5	1
Total	24	22	30

ES.2 BASELINE PENETRATION ESTIMATES

Based on interviews with stakeholders, the penetration curves in Figure ES-1 were constructed to represent likely deployment/adoption rates for the four major stakeholder groups. The infrastructure (Inf) and applications (App) vendors' curves represent the path over which vendor groups will offer IPv6-capable products to customers. For example, based on information provided in interviews, RTI estimates that 30 percent of infrastructure products offered by vendors will be IPv6-capable by 2003, and 30 percent of Internet applications offered by vendors are projected to IPv6-capable by 2008.

Figure ES-1. Penetration Estimates of IPv6 in the United States



The ISP curve represents the share of ISPs' networks that are expected to be IPv6-enabled.[3] As shown in Figure ES-1, on average, RTI estimates that 30 percent of ISPs' networks will be IPv6-enabled by 2010.[4] Similarly, the users curve represents the share of users' networks (including infrastructure vendors, application vendors, and ISPs' internal network users) that are projected to be IPv6-enabled. For example, on average, 30 percent of users' networks are projected to be IPv6-enable by 2012.

ES.3 COSTS

Based on these penetration projections, RTI estimated that the present value of costs for all stakeholder groups to transition to IPv6 will be approximately $25 billion.[5] These costs will primarily occur over the period from 1997 to 2025.[6] As shown in Table ES-2, RTI estimates that users will incur approximately 92 percent of U.S. transition costs, with ISPs and vendors accounting for 0.5 and 8 percent, respectively.

[3] "Enabled" means that some portion of internal networking infrastructure hardware and software (e.g., routers, servers, and operating systems) is able to send and receive IPv6 messages (as opposed to being IPv6 "capable," which means the functionality is included within the hardware and software but is not "turned on.")

[4] This figure is based on information provided by stakeholders participating in interviews conducted by RTI.

[5] *Id.*

[6] Interview participants indicated that adoption of IPv6 by most stakeholders would be distributed over the next 20 years, and many costs have already been borne, back until at least 1997. Each generation of a major Internet standard, such as IP, has a long life time, as evidenced by the fact that IPv4 has been in use for more than 20 years.

Table ES-2. Summary of Transition Costs from IPv4 to IPv6

	Costs (Present Value [PV] Millions $2003)[a]
Infrastructure vendors	$1,384
Application vendors	$593
ISPs	$136
Users	$23,321
Total	$25,434

[a] Calculated using a 7 percent real social discount rate.

Interviews with stakeholders indicated that hardware and software costs to upgrade to IPv6 will be negligible for the majority of Internet users because IPv6 capabilities will be deployed as part of routine upgrade cycles. Over the next 4 or 5 years, the majority of network hardware, operating systems, and network-enabled software packages (e.g., databases, email) sold will include IPv6 capabilities.

As a result, labor costs will constitute the majority of the cost of upgrading to IPv6 for users, and training will constitute the majority of these additional labor costs. Training on the fundamentals and implementation of the IPv6 protocol will depend on individual staff's relative needs based on past experience with IPv4 and potential future applications.

ES.4 BENEFITS

Increased security is a frequently mentioned benefit associated with IPv6. However, the magnitude of security benefits is conditional on removing deployment barriers for existing infratechnologies, such as PKI, and developing other infratechnologies such as end-to-end (E2E) security models.

A general consensus among participating stakeholders exists that IPv6 is technically superior to IPv4; however, there is wide disagreement over the timing, magnitude, and distribution across stakeholder groups of potential benefits. Many of the benefits that were mentioned in interviews hinge on removing and/or changing the management of middleboxes, such as Network Address Translation (NAT) devices and firewalls, because they currently disrupt certain types of end-to-end (E2E) communications.[7] Additionally, other potential IPv6 benefits, such as improved security and new quality of service (QoS) capabilities, will likely not be realized without major changes to Internet security models being used today and considerable research and testing in other areas.

Because of the speculative nature of future IPv6 benefits, it is difficult to estimate future benefits in dollars. Thus, secondary data were combined

[7] End-to-end (E2E) implies that the transmission can be implemented based solely on the knowledge of the applications at the end points of the communications system.

with stakeholders' hypothesized impacts to provide insights into the potential magnitude of IPv6 benefits. As shown in Table ES-3, benefits are grouped into four general categories. Near-term benefits include increased use of Voice over IP (VoIP) and new mobile data services. Long-term benefits potentially include increased Internet security and efficiency gains from removing NATs.[8]

Table ES-3. Several Benefit/Application Categories

Impact Metric	Application/ Market	General Description: Examples
Cost reductions resulting from improved security	IPSec/E2E security model	• In the future, as security costs continue to rise, movement to the use of an E2E security model could reduce enterprise costs, both in downtime and preventative measures.
Cost reductions resulting from increased efficiency	VoIP	• Movement to VoIP from traditional phone networks could save 20 percent or more on telephony expenditures.
	NAT removal	• Enterprise and application vendors' spending on NAT workarounds accounts for up to 30 percent of IT-related expenditures.
Value of remote access to existing products/services	Increased life expectancy of products	• Automobile and appliance owners could increase the functionality and life expectancy of their products through the use of remote monitoring and support services.
	Service costs	• Automotive and appliance owners could decrease service costs through the use of remote monitoring and support services.
Innovation in communications and online products/services	New mobile data services	• Wireless companies could sell new features through expanded network capabilities. • Wireless companies need IPv6 to increase address capacity for peer-to-peer (P2P) (most mobile) applications.
	Online gaming	• Gaming and game console makers could see expanded functionality and thus opportunities for innovative new products.

[8] In order for many of the potential benefits of IPv6 to be realized, NAT devices will likely need to be removed in a significant portion of the current Internet infrastructure. The cost of removing NATs will be potentially large due to redesigning and restructuring network connecting hosts, changing firewalls and established security procedures, and learning to function without a network component which has been in place in networks for almost a decade.

ES.5 ALTERNATIVE DEPLOYMENT SCENARIOS

Stakeholders indicated that IPv6 penetration could occur much more quickly than the “base case” scenario if, for example, some new application was developed that was highly demanded and required IPv6. Figure ES-2 presents the most likely transition timelines for IPv6 costs (to be borne by all stakeholders) based on interviews conducted by RTI. In general, this “base case” reflects the penetration of IPv6 *capabilities* as part of normal hardware and software upgrades and the *enabling* (turning on) of IPv6 capabilities at a later time as applications become available and demand for IPv6 functionality grows.

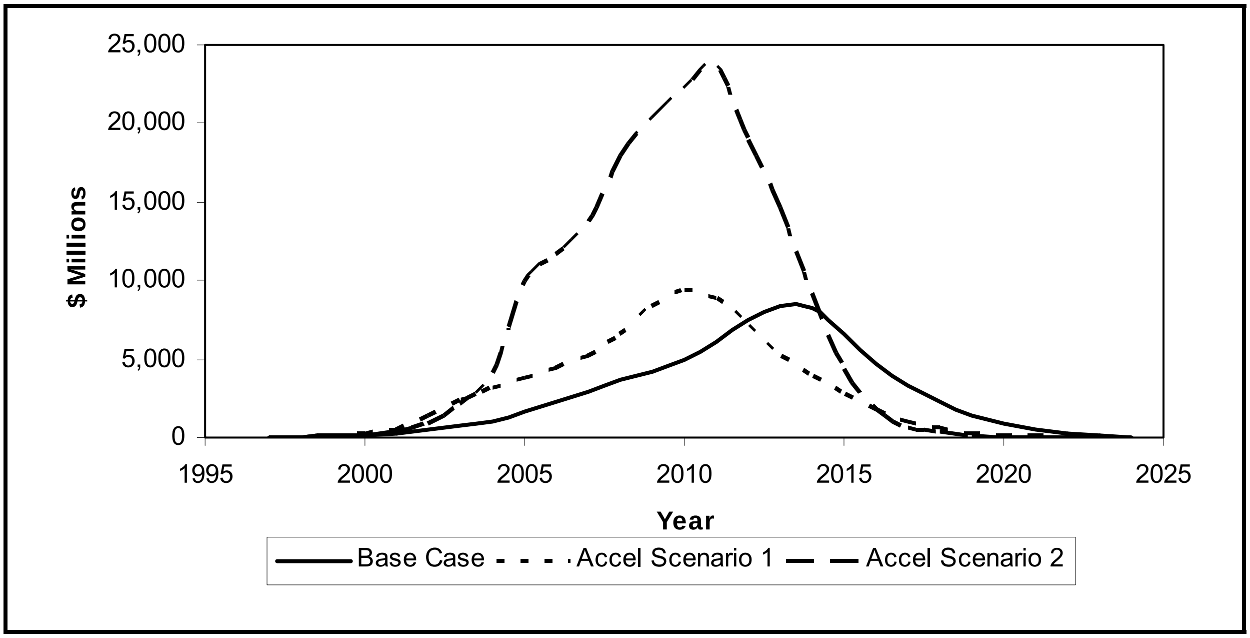
However, participating stakeholders indicated that there is significant uncertainty about the projected timeline for IPv6 deployment. As a result, interview participants were asked to estimate differences in costs under two alternative accelerated deployment scenarios:

1. Scenario 1: IPv6 capabilities are enabled at the same time as capabilities are acquired (i.e., during routine upgrades of hardware and software).
2. Scenario 2: The penetration of IPv6 capabilities is accelerated, as well, leading to the early replacement of some hardware and software. Enabling is therefore further accelerated to match the earlier acquisition of capabilities compared to Scenario 1.

Figure ES-2 illustrates the time series of costs under the base case and two accelerated deployment scenarios in $2003. In Scenario 1, participating stakeholders indicated that the level of effort (labor hours) associated with the transition to IPv6 will increase by approximately 5 percent as activities are compressed as a result of accelerating enablement by 3 years. This 5 percent increase in effort, along with accelerating the time series of costs by 3 years, leads to a 25 percent increase in the present value (PV) of U.S. deployment costs.

In Scenario 2, participating stakeholders indicated that accelerating the replacement of hardware and software by 1 year in addition to a 4-year acceleration of enablement would significantly increase the cost of IPv6 deployment. Scenario 2 represents approximately a 285 percent increase in the PV of U.S. deployment costs. In other words, the degree of acceleration significantly affects the PV of the costs incurred.

Figure ES-2. Timeline of Costs for Base Case and Accelerated Deployment Scenarios



1 Introduction

The Internet Protocol (IP) enables data and other information traffic to traverse the Internet and to arrive at the desired destination. The current generation of IP, version 4 (IPv4), has been in use for more than 20 years and has supported the Internet's growth over the last decade. The transformation of the Internet in the 1990s from a research network to a commercialized network caused some stakeholders to raise concerns about the ability of IPv4 to accommodate emerging demand, particularly the anticipated demand for unique Internet addresses. As a result, the Internet Engineering Task Force (IETF) began work on a new version of IP, and IP version 6 (IPv6) was selected out of several proposals.[1]

IPv6 offers a number of potential advantages over IPv4, most notably a significant increase in the number of Internet addresses.[2] Demand for addresses will likely increase as more of the world's population requests Internet access. The address availability situation may become critical if a market emerges for in-home devices (e.g., "smart appliances," entertainment systems) that need to be accessible from outside the home via the Internet. Based on information from participating stakeholders, RTI observed considerable disagreement about whether,

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[1] For a brief discussion of the reasons for developing a next generation IP and the IETF's activities in that area, see Geoff Huston, "Waiting for IP version 6," at 1-4, *The ISP Column* (Jan. 2003), http://www.potaroo.net/papers/isoc/2003-01/Waiting.html.

[2] The 32-bit address field in the IPv4 packet header provides approximately 4 billion ($4x10^9$) unique Internet addresses (*See* Microsoft Comments at 3 in response to *Request for Comments on Deployment of Internet Protocol, Version 6*, Docket No. 040107006-4006-01, 69 Fed Reg. 2890 (National Institute of Standards and Technology [NIST] and National Telecommunications and Information Administration [NTIA], Jan. 21, 2004). Unless otherwise noted, all subsequent citations to "Comments" refer to comments filed in response to the January 21Request for Comments (RFC). Copies of comments are available at http://www.ntia.doc.gov/ntiahome/ntiageneral/pv6/index.html. *See also* Sprint Corporation (Sprint) Comments at 3). The 128-bit address header in IPv6, in contrast, provides approximately $3.4x10^{38}$ addresses, enough to assign trillions of addresses to each person now on earth or even to every square inch of the earth's surface. (*See* Sprint Comments at 3; Joe St. Sauver, "What's IPv6 . . . and Why Is It Gaining Ground?", http://cc.uoregon.edu/cnews/spring2001/whatsipv6.html, last updated December 28, 2004).

to what extent, and at what pace such demand for addresses will develop, IPv6 would provide the address space to accommodate any level of demand that emerges.

In addition to providing exponentially expanded address space, IPv6 has been designed to accommodate other features and capabilities. These include improved support for header options and extensions, simplified assignment of addresses and configuration options for communications devices, and additional security features.

The objective of this report is to present quantitative cost and benefit estimates associated with the U.S. transition from IPv4 to IPv6. Cost estimates are primarily based on likely development and deployment scenarios provided by stakeholders during interviews conducted by RTI International (RTI). These estimates primarily capture the increased labor costs associated with the transition from IPv4 to IPv6. Benefits estimates are also quantitative, but they are more subjective than the cost estimates because they hinge on the development of, availability of, and demand for new, next generation Internet applications, most of which are yet to be well defined. Thus, RTI analyzed a series of potential applications to provide insights into the future benefits of an IPv6-based U.S. infrastructure.

During the interview phase, RTI talked with a range of stakeholders, including infrastructure vendors, application vendors, Internet service providers (ISPs), and a variety of Internet users (e.g., corporate, government, institutional, and independent/home).[3] In interviews conducted by RTI, discussions surrounded issues such as the timing of available IPv6 infrastructure components and applications and the likely adoption rate and cost for each stakeholder group.

In this report RTI presents numerous informed opinions regarding the costs and benefits of IPv6. These findings are based on extensive literature reviews, RTI's informal discussions with stakeholders, commenters to the DoC RFC, statements given at the DoC Public Meeting in July of 2004, and, and stakeholder interviews conducted by RTI. Many of the statements made represent conclusions drawn by RTI subsequent to the aforementioned research.

[3] Here and throughout the document, the term "user" is used in reference to Internet user organizations, not specific individuals using the Internet. See Appendix A for a list of stakeholders participating in interviews conducted by RTI.

The remainder of this report is divided into the following sections: Section 2 provides an overview of the methodology used to estimate costs and benefits and describes the interview process. The remainder of the section presents findings from interviews with stakeholders. Section 3 presents IPv6 penetration estimates. Cost and benefits estimates are presented in Section 4 and Section 5, respectively. Alternative penetration (acceleration) scenarios are presented in Section 6.

2 Methodology

This section describes the methodology used to estimate the costs and benefits associated with the transition from IPv4 to IPv6. It begins with a description of the affected stakeholder groups that are included in the analysis along with the general cost and benefits categories.

2.1 DESCRIPTION OF STAKEHOLDER GROUPS

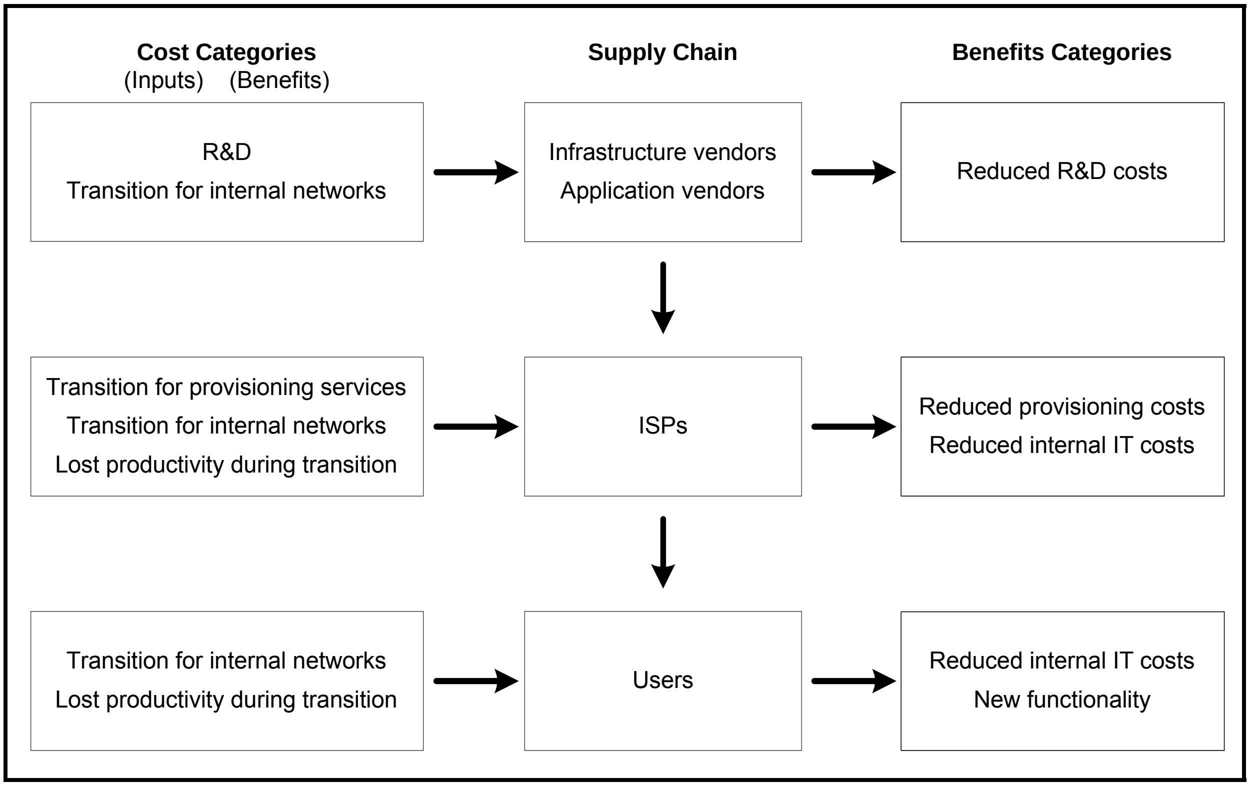
Figure 2-1 provides the general framework used to identify stakeholder groups that will incur costs and realize benefits associated with the transition from IPv4 to IPv6. For the purposes of this study, the supply chain is segmented into four major stakeholder groups:

- infrastructure vendors,
- application vendors,
- ISPs, and
- Internet users.

Infrastructure vendors include manufacturers of computer networking hardware (e.g., routers, firewalls, and servers) and systems software (e.g., operating system) that supply the components of computer networks. Major companies in this category include Microsoft, IBM, Juniper, Cisco, and Hewlett Packard.

Application vendors include suppliers of e-mail, file transfer protocol (FTP) and Web server software, and database software, such as enterprise resource planning (ERP) and product data management (PDM) software. SAP, Oracle, and Peoplesoft are some of the largest companies in this group.

Figure 2-1. Supply Chain Stakeholders, Costs, and Benefits



ISPs are companies that provide Internet connectivity to customers. National backbone ISPs (e.g., MCI, AT&T, and Sprint) provide connectivity to larger companies, some institutional users, and national and regional ISPs (e.g., AOL and Earthlink) that provide Internet connectivity to home and small business users.

Internet users represent a large, diverse group of entities ranging from corporate, institutional, and government organizations to independent users including small businesses and residential households. A subset of this stakeholder group is infrastructure users, companies that use the Internet to provide products and services to customers. Mobile telephone service providers and services such as OnStar are examples of these companies.

2.2 AFFECTED BUSINESS ACTIVITIES

As shown in Figure 2-1, costs and benefits are measured where they are incurred throughout the supply chain. Costs include expenditures on additional labor and training to implement the transition of local networks plus investments such as an increase in R&D for integrating IPv6 into products and services.

Based on the vast information collected as background for this report, RTI believes that the majority of the benefits are likely to accrue to downstream Internet users in the form of new applications made possible by IPv6-enhanced functionality improvements for existing applications.[1] This includes several types of benefits, such as

- new services/products made possible by additional address space (e.g., IP-addressed automobiles, appliances, and mobile phones) and
- new services/products made possible by improvements to the IP infrastructure (not invented/known currently).

In addition, longer-term benefits may be realized from a decrease in IT costs for internal network operations (accruing throughout the supply chain) and from simplified R&D for new products and services developed by vendors.

Table 2-1 identifies the primary business activities of each stakeholder group that will be affected and emphasizes that all stakeholders will bear costs associated with the transition of their own internal networks from IPv4 to IPv6.

Table 2-1. Business Activities Affected by the Transition to IPv6

	Product Development	Provisioning Services[a]	Internal Network Operations
Vendors	●		●
ISPs		●	●
Users			●

[a] "Provisioning Services" indicates the activities necessary to provide connectivity to the Internet to customers.

As shown in Table 2-2, incremental vendor costs associated with the transition to IPv6 primarily involve modifying existing products and services to incorporate IPv6 capabilities and developing new products and services enabled by IPv6 functionality. These costs are largely incurred in the form of labor allocated to standards and protocol activities, research and development, and product testing. In addition, vendors will incur costs associated with the transition of their own internal network because they are also users of the Internet. Internal

[1] For the purposes of this document, "improvements" should be considered as synonymous to "benefits."

Table 2-2. Cost Categories by Business Activity

Business Activity	Product Development	Provisioning Services	Internal Network Operations	Brief Description
Affected stakeholders	Vendors	ISPs	Vendors, ISPs, and users	
Cost categories				
R&D	●			Labor allocated to basic product design and development (e.g., coding or prototyping)
Product testing	●	●		Labor allocated to testing product interoperability, debugging, etc.
R&D staff training	●			Labor and training class expenses for R&D staff
Standards and protocol activities	●	●	●	Labor allocated to developing internal standards for company products
Network management software (upgrade)[a]		●	●	Labor allocated to network-specific management and monitoring software
Network testing		●	●	Labor allocated to testing interoperability between network components with IP capabilities
Installation effort		●	●	Labor allocated to installing IPv6 transition mechanisms
Maintaining network performance		●	●	Labor allocated to maintaining transition mechanisms, such as dual stack, and ensuring high network performance
Training (sales, marketing, and technical staff)	●	●	●	Labor and training class expenses for sales, marketing

[a] This category is intended to include the costs of upgrades to any network management tools, assuming that these costs result from the need to transition to IPv6 network management tools.

network transition costs are also primarily labor resources associated with upgrading network management software and network testing. In contrast, long-term benefits may be realized for vendors through increased efficiency in many of the business activities identified in Table 2-2.

ISPs will incur costs associated with transitioning their Internet provisioning network, used for providing customer connectivity and network care, from IPv4 to IPv6, or more accurately, from IPv4 to a dual network in which IPv4 and IPv6 coexist.[2] These costs will include

[2] This information was received by RTI during an interview in Arlington, VA, on December 11, 2003, with Joe Houle, Technology Consultant of IP Network Architecture at AT&T. Houle indicated that to transition all provisioning networks to IPv6 would cause ISPs to

network testing, installation activities, and maintaining network performance according to participating stakeholders. As with vendors, ISPs also operate internal networks and will bear the costs associated with transitioning any Internet user networks. Participating stakeholders have suggested that all ISP and user networks could see long-term benefits associated with reductions in IT costs following adoption of IPv6.

2.3 PENETRATION METRICS

As part of the interviews (described in Section 2.5), information was collected on the timing of development and deployment of IPv6 products and services. This information included the following:

- when IPv6 capabilities will be integrated into infrastructure hardware and systems software and offered to customers;
- when IPv6-capable applications will be available;
- when IPv6 capabilities will be in place within ISP and users' networks; and
- when IPv6 will be enabled,[3] or turned on, by ISPs and users.

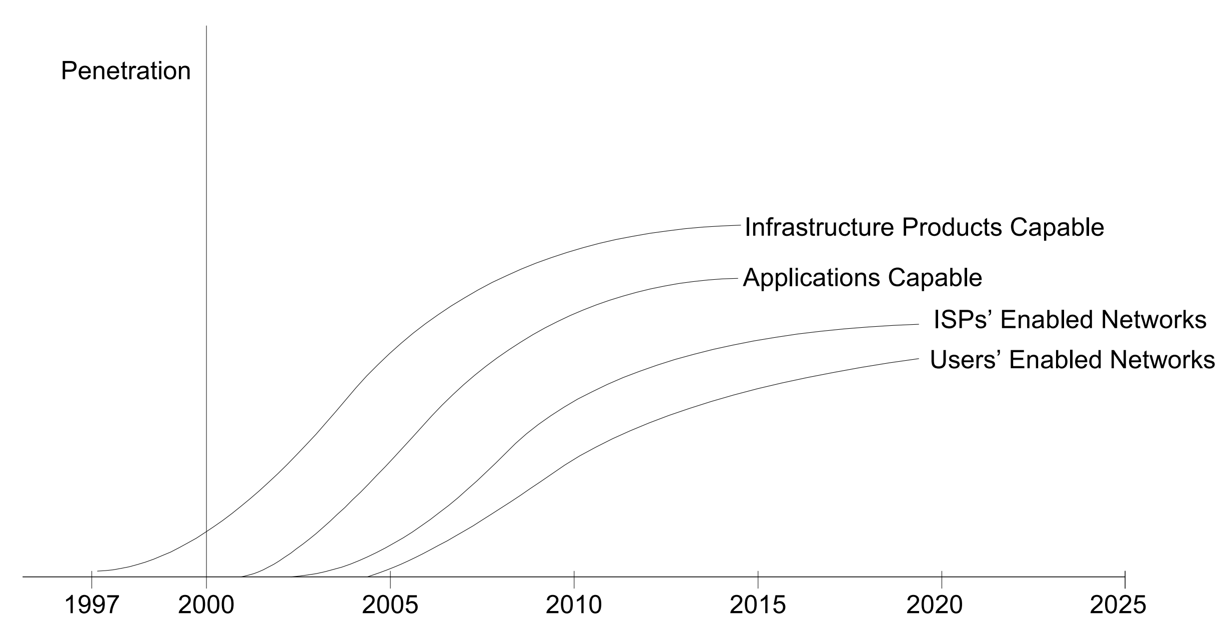
The penetration of IPv6 is likely to be a gradual process and will probably never reach 100 percent of applications or users. Figure 2-2 illustrates the structure by which the cost analysis uses the timing associated with the development (availability) of IPv6 infrastructure products (hardware and software) and applications, as well as the enabling of these products and applications by ISPs and users. Events are generally sequential in that ISPs enabling their network is conditional on the availability of IPv6-capable hardware and software. These four curves are the key penetration metrics for the cost analysis because they capture the timing of expenditures. Section 3 provides estimated penetration curves generated based on the information from the interviews.

For vendors, R&D expenditures to integrate IPv6 into their products are the primary expenditure category associated with the transition from IPv4 to IPv6. The primary expenditures for ISPs and users are labor costs associated with enabling IPv6 capabilities. As a result, these four

incur significant costs. Further, he does not believe that any major North American ISPs have any plans to provide only IPv6 service any time in the near future, rather, Houle suggests, IPv4 service will likely continue to be demanded for many years.

[3] For the purposes of this document, "enabled" is generally defined as the establishment of some form of IPv6 connectivity and, when looking at an overall network's adoption, that some percentage of IP-dependent applications can operate in IPv6. When specific infrastructure components or applications are described as IPv6 enabled, this does not refer to the entire network but merely to that product's ability to function via IPv6 once it has been turned on.

Figure 2-2. Example of Penetration Curves Used for Cost Analysis



penetration curves are used to determine the timing of development and deployment costs associated with IPv6.

Note that the penetration of IPv6 capabilities (i.e., when ISPs and users have IPv6-capable infrastructure components and applications in place, but they are not enabled) is not a key component in determining the timing of costs for these two groups. This is because the incremental variable cost of IPv6 products is negligible compared to IPv4 products—almost all the costs are associated with applications R&D and enabling IPv6 functionality.[4] As a result, the penetration of capabilities is not a factor in determining baseline transition costs. However, the penetration of capabilities is important in assessing the alternative deployment scenarios presented in Section 6. As discussed in that section, the penetration of capabilities provides an upper bound on how much the enabling of IPv6 can be accelerated without adding the costs of early retirement of hardware and software.

[4] RTI has generally assumed, based on information provided by participating stakeholders, that routine upgrades will provide hardware and software upgrades necessary prior to IPv6 enablement for almost all ISPs and user networks and that all interoperability problems have been solved (otherwise, purchasers could incur these latter costs).

2.4 DESCRIPTION OF COST CATEGORIES AND ESTIMATION APPROACH

2.4.1 Cost Categories

Participating stakeholders agree that labor resources will account for the bulk of the transition costs associated with IPv6. Although some additional physical resources may be needed, such as increased memory capacity for routers and other message-forwarding hardware[5], these expenses are treated as negligible in our cost analysis because interview participants indicated that they were quite small compared to the labor resources required.

Labor resources needed for the transition are linked to three general business activities within the Internet supply chain—product development, Internet provisioning services, and internal network operations. Product development activities are conducted by infrastructure and application vendors; service provisioning activities are conducted by ISPs; and internal network operations are conducted by all vendors, ISPs, and users as indicated in Table 2-1.

Table 2-2 shows the underlying transition cost categories included in each of the business activities. As is apparent, ISPs and users will incur costs in the same categories. Additionally, several other cost categories, such as network testing and standards and protocol development, span multiple business activities and thus several stakeholder groups.

2.4.2 Quantitative Estimation Approach

The penetration curves described in Section 2.2 represent the estimated share of infrastructure products and applications that are IPv6 capable and the share of networks that are IPv6 enabled at a given time. This implies that costs will be distributed over time as stakeholders gradually engage in transition activities.

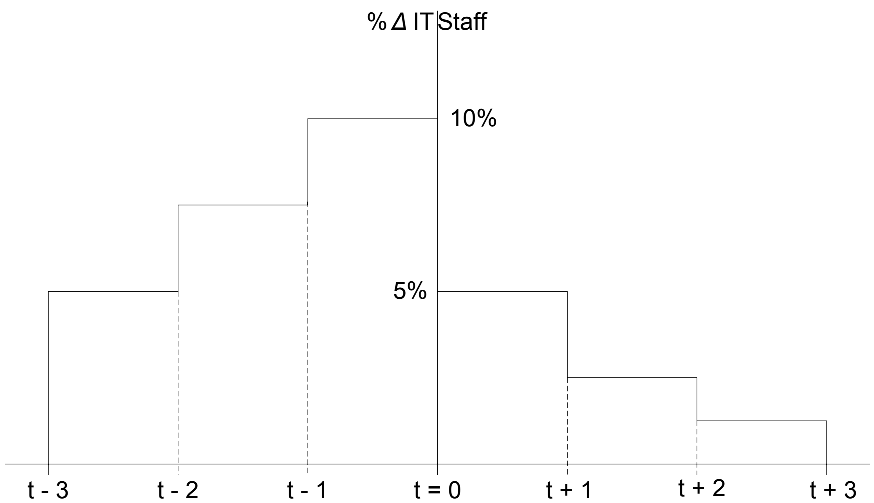
The penetration curves derived from stakeholder interviews in Section 2.2 represent the *point in time* when products and applications become available to customers and networks become enabled. However, activities leading to and supporting these achievements/milestones are

[5] *See* Motorola Comments at 6. Motorola notes that routers would need at least four times their current content addressable memory to operate as efficiently as they do today when accessing both IPv4 and IPv6 addresses in a dual-stake environment. Further expanded buffers and routing tables would need more memory. *Also see* Alcatel Comments at 4.

distributed before and after the point of product roll out or system enabling.

Figure 2-3 provides an *example* of the potential time distribution of labor expenditures surrounding the enablement of a network system;[6] to be clear, this figure represents the likely cost distribution for *one* user, not all U.S. users. In the figure, t = 0 represents the date when the system is enabled. However, the majority of the costs are borne prior to t = 0 as networking staff are trained and the system is reconfigured. Lower costs associated with testing and monitoring are then experienced after the enabling date.

Figure 2-3. Example of the Distribution of IT Staff Resources Needed to Enable IPv6 in a User Network

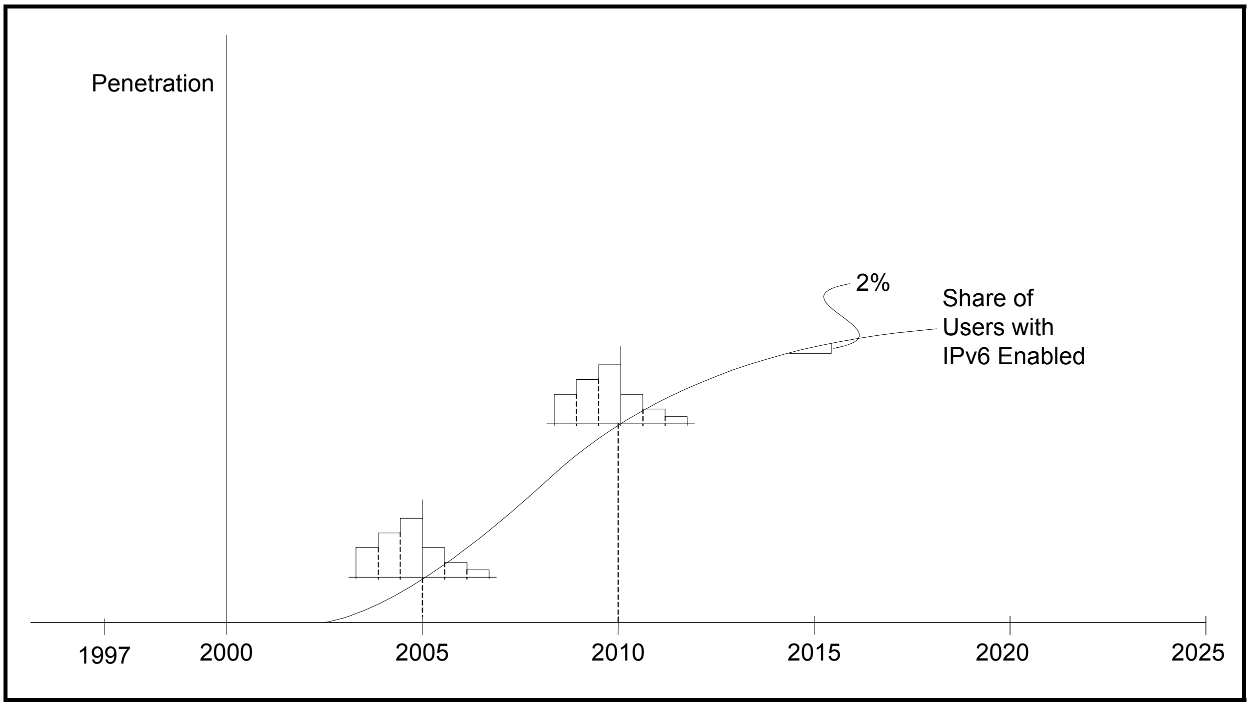


Costs are expressed as the percentage of IT staff's time devoted to IPv6 transition activities. Thus, in this example, 10 percent of a company's IT staff in the year prior to becoming enabled (t – 1) will be devoted to the IPv6 transition. In the year after enabling (t + 1) the share of resources decreases to 5 percent of IT staff time. This number is multiplied by the average IT staff wage rate to obtain the cost per IT staff member associated with the IPv6 transition for each year before and after enabling IPv6 systems.

[6] Figure 2-3 is an example distribution based on RTI's research and interview activities. Stakeholder-specific distributions are presented in Section 4.

Figure 2-4 shows the penetration of IPv6-enabled user systems and determines the timing of the costs. For example, in this hypothetical figure, 2 percent of systems are enabled in the year 2015 (t = 0).[7] This implies that 2 percent of affected U.S. IT staff[8] in 2014 (t – 1) were devoting 10 percent of their time to IPv6 transition activities, and 2 percent of affected U.S. IT staff in 2015 (t = 0) were devoting 5 percent of their time to IPv6 transition activities.

Figure 2-4. Example of U.S. User Enablement Over Time



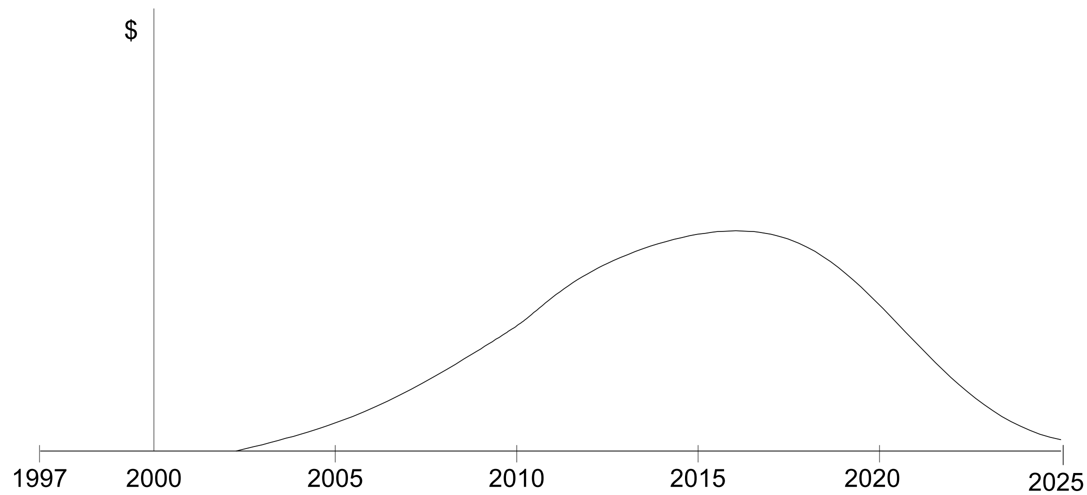
Combining the distribution of costs surrounding enabling (Figure 2-3), and the timing of system enabling (Figure 2-4)[9] yields the cumulative cost curve shown in Figure 2-5. As shown in Section 4, this cost distribution–timing approach is used to calculate the time series of transition costs for

[7] This means that in the year 2015, 2 percent of users enabled or "turned on" IPv6 capabilities. This does not mean that only 2 percent of all users are enabled by this point.

[8] IT staffing figures, including wage rates, were determined using data from the U.S. Bureau of Labor Statistics (BLS). U.S. Department of Labor, BLS, "National Occupational Employment and Wage Estimates," May 2003, available at http://www.bls.gov/oes/2003/may/oes_15Co.htm. Table 4-2 in Section 4 provides more detail on the labor categories used to develop an average IT wage rate.

[9] The main curve in Figure 2-4 is the same as the "Users' Enabled Networks" curve in Figure 2-2.

Figure 2-5. Example of U.S. Users' Transition Costs Over Time



- infrastructure vendors' product development,
- application vendors' product development,
- ISP's provisioning service enabling, and
- users' system enabling.

2.5 DESCRIPTION OF BENEFIT CATEGORIES AND ESTIMATION APPROACH

Participating stakeholders agree that benefits will accrue to organizations and consumers in the long run as IPv6 is adopted and integrated into networks and devices. However, currently no applications are available that require IPv6 or that have shown measurable benefits in conjunction with IPv6 adoption. Mobile phone manufacturers and some mobile service providers are planning to support the use of IPv6 addresses in mobile phones in the next several years, driven mainly as the result of their large need for IP addresses, rather than any technical advantages as compared to IPv4.[10]

[10] This information was received by RTI during a phone interview on August 12, 2004, with Victor Gonzalez, Director of Core Network Development with Nextel. Gonzalez indicated that as more manufacturers integrate IP addresses into their products, the shortage of IPv4 addresses will increase very quickly, particularly given existing allocation policies.

In this analysis, RTI looks at four categories of potential benefits and the most likely affected groups.[11] Most benefits currently appear to depend on the removal and/or restructuring of middleware, such as Network Address Translation (NAT) devices, within network architecture. As indicated in Table 2-3, application vendors and users may benefit from improved security in the long term.[12] In addition, application vendors could benefit from cost reductions as they spend less time developing products that can work around NATs. Organizational Internet users (e.g., corporate, institutional, and government) could benefit from reductions in applications testing expenditures as well as increased network efficiency. Independent Internet users could benefit from improvements to existing products and services as well as new products and services in the future.

Table 2-3. Affected Groups by Benefit Category

Affected Group	Cost Reductions Due to Improved Security	Cost Reductions Due to Increased Efficiency	Improvements to Existing Products and Services	Willingness to Pay for New Products and Services
Application vendors	●	●		
Users—organizations	●	●	●	●
Users—independent (consumers)	●		●	●

Section 5 discusses potential future applications of IPv6 qualitatively and then discusses several case studies that fit into the categories introduced in Table 2-3. However, this analysis is not intended to capture all possible benefits of IPv6 or to attribute the success of certain products and services to IPv6.

2.6 STAKEHOLDER INTERVIEWS, REQUEST FOR COMMENTS, AND PUBLIC MEETING

Several activities helped to inform our analysis, as described in this document. After performing extensive literature reviews in the early

[11] Infrastructure vendors, application vendors, and ISPs are gradually incorporating IPv6 into their services/products as consumer demand appears and competitors integrate IPv6 into their products. However, according to participating stakeholders, neither vendors nor ISPs expect to gain significant additional revenue from IPv6. Thus, our main focus will be on the benefit categories indicated in Table 2-3.

[12] *See* discussion in Final Report for an expanded analysis of the potential security benefits of IPv6.

stages of the project, RTI held 24 informal discussions with stakeholders throughout the Internet supply chain. The objective of these discussions was to gain an understanding of current and future development of IPv6 products and services and of adoption rates by users, potential costs and benefits of IPv6, and any roadblocks and/or research barriers that exist today. In January 2004, the Department of Commerce (DoC) released a public Request for Comments (RFC) to which 22 organizations responded.[13] In July 2004, the DoC held a public meeting in Washington, DC, at which several panel discussions solicited academic, government, and industry participation.[14] Finally, RTI conducted an interview phase in which more than 60 stakeholders were contacted, resulting in 30 interviews across nine stakeholder groups. Table 2-4 lists the number of organizations responding to each information collection exercise.

Table 2-4. Informal Discussions, RFC Commenters, and Interviews

Stakeholder Group	Informal Discussions	RFC Commenters	Interviews
Infrastructure vendors	7	5	5
Application vendors	0	1	6
ISPs	3	5	6
Infrastructure users	1	1	4
Corporate users	2	0	1
Institutional users	3	0	2
Government users	4	1	3
Research consortiums	3	4	2
Industry and academic experts	1	5	1
Total	24	22	30

The estimates provided in this document were largely based on stakeholder interviews conducted by RTI. RTI identified potential interviewees by reviewing lists of participants from the informal discussions, RFC commenters, and stakeholders participating in the

[13] For a complete list of the commenters and comments received in response to the RFC, see NTIA's Web site, "IPv6 Notice of Inquiry—Comments Received" at http://www.ntia.doc.gov/ntiahome/ntiageneral/ipv6/commentsindex.html.

[14] *Id. See* Transcript of the August 8, 2004, IPv6 Public Meeting and a copy of the presentation by RTI at http://www.ntia.doc.gov/ntiahome/ntiageneral/ipv6/webcast.html. Unless otherwise noted, all subsequent citations to "Public Meeting" refer to the IPv6 Public Meeting held on August 8, 2004.

public meeting. In several instances, stakeholders that were interviewed approached RTI and asked to be included in the study.

3 Baseline Penetration Estimates

Based on information from interview participants, RTI estimated IPv6 penetration curves for the four major stakeholder groups. The penetration curves were used to develop the base case cost estimates, by year, presented in Section 4.

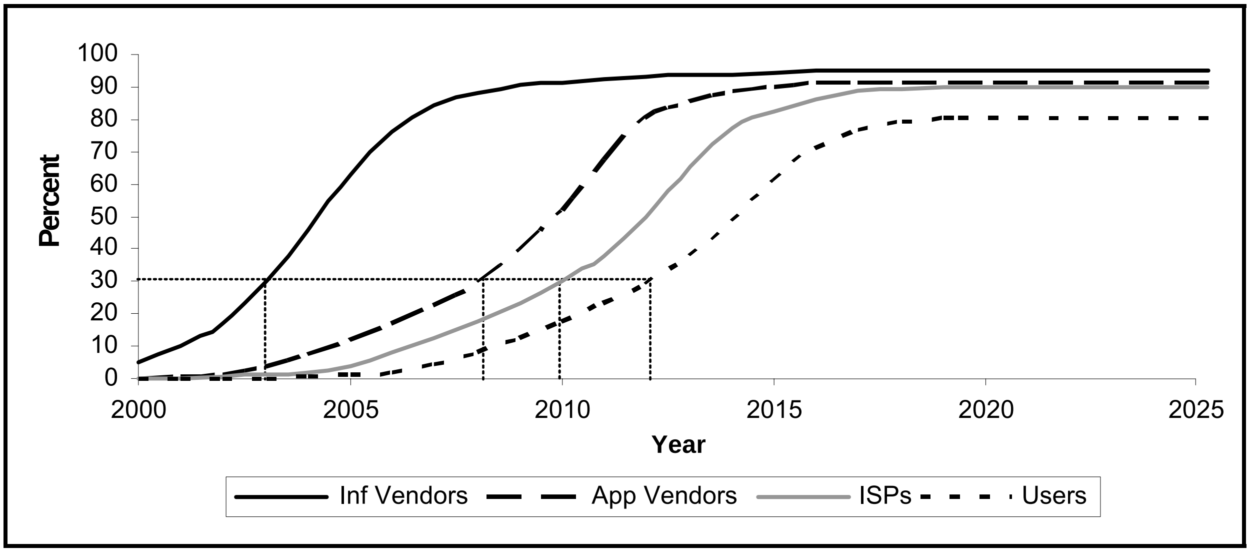
3.1 STAKEHOLDER PENETRATION CURVES

The penetration curves presented in Figure 3-1 reflect cumulative IPv6 transition activities over time. The curves are dependent on each other in that hardware and software must be available prior to ISPs transitioning networks to support IPv6 users. The four curves in Figure 3-1 also represent different adoption activities for each of the four major industry stakeholder groups. The first two curves represent when IPv6 products and services will be *capable*, and the final two curves represent when components of the system will be *enabled*.[1] For example, the four curves can be interpreted as follows

- By 2003, the average **infrastructure (Inf) vendor** will have integrated IPv6 capabilities into 30 percent of the routers and network products it offers.
- By 2008, the average **application (App) vendor** will have integrated IPv6 capabilities into 30 percent of the Internet software it offers.

[1] Hardware and software become capable when the IPv6 functionality is integrated into products and purchased by organizations. According to Nortel Networks, IPv6-capable products were sold as early as 1997 (see "IPv6: FAQs" at Nortel Networks Web site, available at http://www.nortel.com/corporate/technology/ipv6/faqs.html). However, even after the necessary networking components are IPv6 capable, they will need to be enabled (turned on) to support IPv6 communications.

Figure 3-1. Penetration Estimates of IPv6 in the United States



- By 2010, the average **ISP** will have enabled 30 percent of its network to manage IPv6 transmissions.
- By 2012, the average **user** will have enabled 30 percent of its local network to handle IPv6 communications.

The penetration curves were developed to reflect the distribution of IPv6 transition activity and hence provide the basis for estimating the time line of costs. Vendors were asked when they would have IPv6 products available, which provided information on the timing of their R&D activities. ISPs were asked when they expected to offer IPv6 services, indicating the timing of their enabling activities. Similarly users were asked when they would enable parts of their system, also indicating enabling activities.

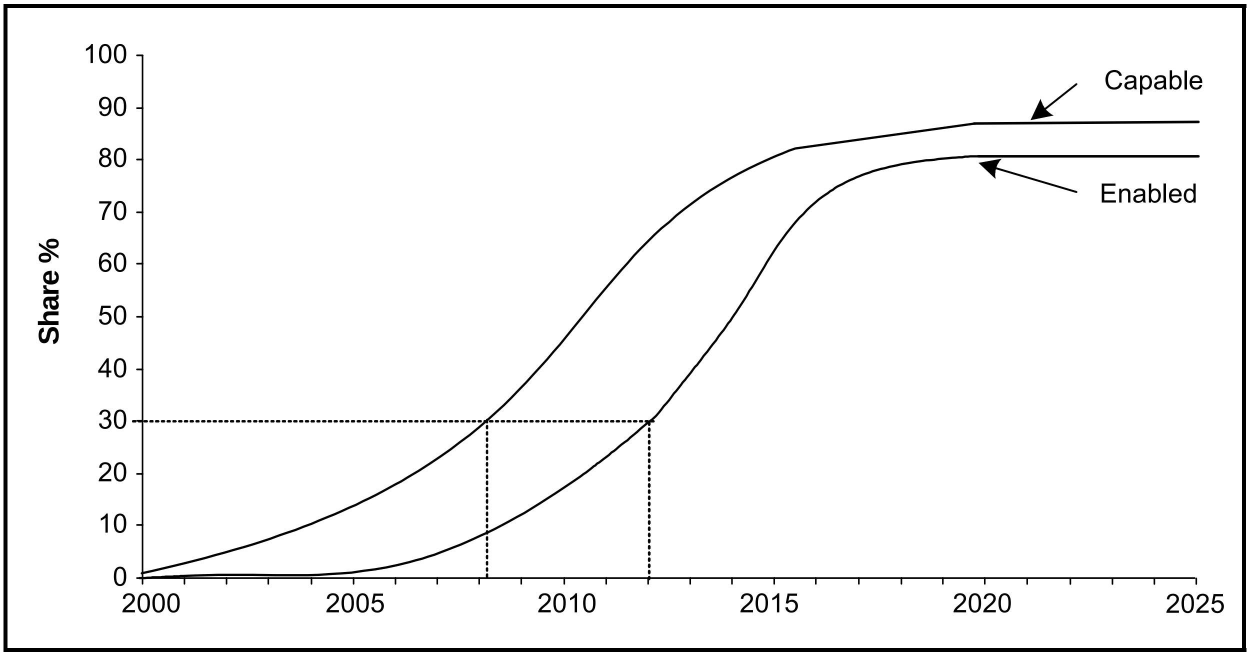
Participating stakeholders agree that IPv6 adoption rates will differ significantly across and within individual companies. For example, users in the financial, telecommunications, or defense sectors will likely be more aggressive in transitioning to IPv6 compared to other sectors that manage less-sensitive information. Also, within a company, certain divisions or business operations will transition before others.

The average penetration estimates presented in the curves in Figure 3-1 capture both differences in adoption rates across companies and the gradual adoption process within companies.[2]

3.2 USERS' CAPABILITIES AND ENABLING CURVES

RTI asked stakeholders participating in interviews to identify the time by which users will have IPv6 capabilities. Figure 3-2 presents users' capable and enabled penetration curves and illustrates the lag between when users obtain IPv6 capabilities through product replacement/upgrades and the time at which they decide to enable these products. The enabled curve in Figure 3-2 is the same as the users' enabled curve in Figure 3-1.

Figure 3-2. IPv6-Capable and IPv6-Enabled U.S. User Networks



Users will acquire IPv6 capabilities primarily as part of routine hardware and software upgrades. For example, based on information provided by interview participants, RTI projects that 30 percent of users' systems will

[2] Note that the penetration curves should neither be interpreted as the percentage of companies that have transitioned to IPv6, nor as the volume of IPv6 traffic. For example, RTI projects, based on information from participating stakeholders, that most ISPs will be offering some level of IPv6 service in the near future by enabling a limited portion of their network; however, it could take several more years for all internal or provisioning networks to be completely IPv6 enabled.

be IPv6 compatible by 2008. Nearly all edge routers[3] being sold today are IPv6 capable, either in hardware or software according to participating stakeholders. Large organizations, which routinely upgrade their networking components, should have IPv6 capabilities in the next 5 to 7 years. However, medium and small businesses and independent users will likely not upgrade in significant numbers for several more years.

On average, IPv6 hardware and software enablement will lag the time by which users receive capabilities by approximately 5 years. For example, using information from interview participants, RTI projects that users will have enabled 30 percent of their systems by 2012. As initial operating systems and routers become enabled and early adopters provide “lessons learned,” IPv6 adoption activities will likely accelerate as users begin to transition a significant share of their applications.

[3] By edge routers, we mean the majority of routers used by enterprise users. This does not include larger backbone routers used by ISPs and large enterprises.

4 Baseline Development and Deployment Costs

In this section we describe the IPv6 transition costs that are projected to be incurred by the four major stakeholder groups—infrastructure vendors, application vendors, ISPs, and other Internet users (including corporate, institutional, government, and independent users). RTI undertook an extensive information collection effort in August and September 2004, involving individual experts and organizations representing the major stakeholder groups and gathered estimates of both past and future IPv6-related costs (see Section 2.5). The methodology described in Section 2 was used to develop cost impact estimates by stakeholder group.

RTI estimates that expenditures for U.S. stakeholder groups to transition to IPv6 will be approximately $73 billion over the period 1997 to 2025.[1] These transition costs over this period equate to a present value (PV), discounted to 1997, of $25 billion ($2003). The year 1997 is used as the base year because it is the year in which IPv6 costs were first incurred. From this point forward, all costs are in $2003 and are discussed in PV terms, referenced to 1997.[2]

Table 4-1 provides estimated annual transition costs broken down by stakeholder group. Government and nongovernment users account for approximately $23 billion of total U.S. IPv6 development and deployment

[1] These years were selected because RTI analyses used "adoption" rates beginning with some infrastructure vendors in 2000, continuing until 2020. Thus, RTI estimated costs both before and after enablement/integration of IPv6.

[2] As discussed in the methodology, the primary factor determining stakeholder transition costs is the average share of IT staff and R&D resources required before and after the transition to IPv6. The estimated average percentage of IT resources is based on a relatively small number of in-depth interviews. The 95 percent confidence intervals for transition costs are $73 ± $65 billion over the period 1997 to 2025 and $25 ± $22 billion for present value discounted to 1997.

Table 4-1. Estimated U.S. IPv6 Adoption Cost Totals, Broken Out by Each Stakeholder Group ($ Millions)

	Infrastructure Vendors		Application Vendors		Total Vendors	ISPs		Total ISPs	Government Users	Non-government Users[a]	Grand Total
	R&D	Internal	R&D	Internal		Provision	Internal				
1997	17.7	0.0	0.0	0.0	***17.7***	0.0	0.0	***0.0***	0.0	0.0	**17.7**
1998	47.3	0.0	0.5	0.0	***47.8***	0.0	0.0	***0.0***	0.0	0.0	**47.8**
1999	88.6	0.0	2.1	0.0	***90.7***	0.1	0.0	***0.1***	0.0	0.0	**90.8**
2000	160.9	0.0	9.1	0.0	***170.1***	0.6	0.0	***0.6***	0.3	3.7	**174.7**
2001	234.8	0.2	21.9	0.0	***256.9***	1.5	0.0	***1.5***	3.5	45.5	**307.5**
2002	302.7	0.7	35.3	0.2	***338.9***	2.4	0.1	***2.5***	12.6	162.3	**516.4**
2003	329.3	1.5	49.1	0.3	***380.2***	4.7	0.2	***5.0***	25.7	330.5	**741.4**
2004	295.3	2.8	58.4	0.6	***357.2***	8.3	0.4	***8.7***	47.6	610.9	**1,024.3**
2005	223.0	5.5	71.3	1.2	***301.0***	12.5	0.8	***13.3***	92.6	1,189.4	**1,596.2**
2006	143.2	8.8	87.4	1.9	***241.3***	14.9	1.3	***16.2***	148.3	1,905.2	**2,311.0**
2007	79.7	11.7	100.4	2.6	***194.5***	17.5	1.7	***19.2***	198.9	2,554.6	**2,967.1**
2008	44.3	14.4	142.6	3.2	***204.6***	20.3	2.1	***22.4***	244.8	3,145.1	**3,616.9**
2009	25.8	16.8	169.6	3.7	***216.0***	25.1	2.5	***27.6***	284.8	3,659.7	**4,188.1**
2010	19.2	19.9	203.1	4.4	***246.6***	31.8	3.0	***34.7***	337.6	4,338.2	**4,957.1**
2011	16.2	25.0	171.2	5.5	***218.0***	40.7	3.8	***44.4***	423.8	5,446.4	**6,132.6**
2012	14.0	31.1	86.3	6.9	***138.3***	43.0	4.7	***47.7***	527.9	6,783.9	**7,497.8**
2013	10.3	35.1	48.0	7.8	***101.2***	34.1	5.3	***39.4***	595.4	7,651.2	**8,387.3**
2014	5.2	34.5	23.1	7.6	***70.3***	22.1	5.3	***27.3***	584.5	7,512.0	**8,194.2**
2015	2.2	27.8	4.5	6.1	***40.6***	15.1	4.4	***19.5***	471.6	6,063.1	**6,594.9**
2016	0.0	20.0	1.0	4.4	***25.4***	9.3	3.3	***12.6***	339.6	4,367.8	**4,745.4**
2017	0.0	14.1	0.0	3.1	***17.2***	5.1	2.5	***7.6***	239.3	3,081.1	**3,345.2**
2018	0.0	9.5	0.0	2.1	***11.6***	2.6	1.8	***4.4***	162.4	2,092.3	**2,270.7**
2019	0.0	5.9	0.0	1.3	***7.2***	0.9	1.2	***2.2***	100.4	1,294.7	**1,404.4**
2020	0.0	3.6	0.0	0.8	***4.4***	0.4	0.8	***1.2***	61.6	795.6	**862.8**
2021	0.0	2.0	0.0	0.4	***2.5***	0.1	0.5	***0.6***	34.5	446.3	**483.9**
2022	0.0	0.9	0.0	0.2	***1.1***	0.0	0.2	***0.3***	15.8	204.1	**221.3**
2023	0.0	0.4	0.0	0.1	***0.5***	0.0	0.1	***0.1***	6.7	86.5	**93.7**
2024	0.0	0.2	0.0	0.0	***0.2***	0.0	0.0	***0.0***	2.9	37.0	**40.1**
2025	0.0	0.0	0.0	0.0	***0.0***	0.0	0.0	***0.0***	0.7	8.8	**9.5**
TOTAL	2,059.8	292.6	1,284.8	64.7	***3,701.9***	313.0	46.1	***359.1***	***4,963.8***	***63,816.0***	***72,840.7***
Present Value ($2003)	**1,284.8**	**99.3**	**571.0**	**21.9**	**1,977.0**	**120.7**	**15.3**	**136.0**	**1,683.4**	**21,637.9**	**25,434.3**

[a] This does not include vendors' and ISPs' internal network transition costs. See separate columns.

costs, or about 91 percent, with nongovernment uses representing the large majority, $22 billion of the U.S. total or 85 percent.[1] The remaining costs are associated with total vendors, $2 billion or 7 percent, and total ISPs, $136 million or 0.5 percent.

For infrastructure and application vendors, Table 4-1 breaks out costs into additional R&D costs necessary to integrate IPv6 into products ($1,855 million in PV 2003 dollars) and additional IT costs to transition internal company networks to IPv6 ($121 million). For ISPs, costs are broken into additional IT costs to transition service provisioning networks[2] to IPv6 ($121 million) and additional IT costs to transition internal company networks to IPv6 ($15 million).

4.1 COST CATEGORIES AND WAGE DATA

The cost analysis focuses on valuing the labor activities associated with the transition from IPv4 to IPv6. Over the next 4 or 5 years the vast majority of network hardware, operating systems, and network-enabled software packages (e.g., databases, e-mail) are likely to be sold with IPv6 capabilities. Based on information provided by participating stakeholders, RTI predicts that IPv6 capabilities will penetrate the hardware and systems software markets and become integrated into ISP and user networks in an additional 2 to 3 years as part of routine upgrade cycles with little to no increase in product price (marginal cost) to ISPs and users.[3] Thus, our analysis assumes that hardware and software costs to upgrade to IPv6 will be negligible for most of Internet users (i.e., the upgrade costs will be no different than routine annual upgrade costs without IPv6) and that labor costs will constitute the majority of the cost of upgrading to IPv6 for users.

Labor costs for ISPs and users are estimated by determining the share of IT staff resources needed to facilitate the transition to IPv6 and

[1] All stakeholder cost estimates were calculated by RTI based on aggregated data provided by stakeholders in the interview phase. As such, RTI estimates government user costs will be approximately $1.7 billion, and nongovernment user costs will be approximately $21.6 billion. The sum is $23.2 billion. This amount is 92 percent of the estimated total cost to all stakeholders.

[2] “Provisioning networks," as discussed in this document, are defined as ISP subnetworks responsible for providing connectivity to the Internet to customers. These networks are always separate from internal networks used by employees.

[3] The exception is that for ISPs and large enterprises the transition of some networking pieces to IPv6 may require additional hardware and software costs. For example, additional memory will be needed in forwarding hardware pieces to continue current network performance given the larger size (128 bits vs. 32 bits in IPv4) of IPv6 addresses. Additionally, mainframes and billing systems might need hardware or software upgrades ahead of routine upgrades, which occur very infrequently for these devices, depending on the specific needs of a network. *See* Motorola Comments at 6; Alcatel Comments at 4.

applying this share to the total population of IT staff involved in Internet activities. As discussed in Section 2, RTI asked interview participants to estimate the percentage of staff time required for enabling IPv6 (see Figure 2-3). U.S. Bureau of Labor Statistics (BLS) employment figures were used to determine the number of ISP and user IT staff supporting Internet activities. Table 4-2 identifies the BLS staffing categories likely to be affected by a transition to IPv6.

Table 4-2. Affected Staff (BLS Occupational Categories) by Stakeholder Group

Occupational Category[a]	Mean Annual Wage ($2003)	Employment
Computer Programmers	$64,510	431,640
Computer Software Engineers, Applications	$75,750	392,140
Computer Software Engineers, Systems Software	$78,400	285,760
Computer Systems Analysts	$66,180	474,780
Database Administrators	$61,440	100,890
Network and Computer System Administrators	$59,140	237,980
Network Systems and Data Communications Analysts	$62,060	148,030
Weighted Average Salary	**$67,996**	

[a] These categories are all classified under “Computer and Mathematical Science Occupations” (15–0000) by BLS and represent approximately 2,000,000 employees. Computer Support Specialists, who also are IT staff employees, were excluded because stakeholder interviews indicated that these employees would spend a very small amount of time being trained on IPv6 and would not be involved in installing IPv6 products and updating services. Computer Support Specialists, representing approximately 200,000 employees in the United States, were used when training costs were incorporated into the total cost to ISPs and users.

Wage data for each occupational category were also obtained from BLS. A single aggregate IT staff wage rate was calculated by weighting the category wage by the number of employees in each category. The average IT staff wage ($2003) is estimated to be approximately $68 per hour.

BLS occupational categories are not available for infrastructure and application vendors staff engaged in product research and development (R&D), even though R&D expenditures are predominately labor costs. Thus, for infrastructure and application vendors, IPv6 transition costs were calculated as a share of R&D expenditures. The share and timing of R&D expenditures were estimated based on the interviews. Annual

R&D expenditures for Internet infrastructure and application venders were obtained from the National Science Foundation (NSF).[4]

Training costs for technical staff (direct costs and labor time) could constitute a significant portion of transition costs;[5] however, the magnitude of training costs for specific staff will depend on their relative needs based on past experience with IPv4 and potential future need, with costs ranging from $195 for a CD or $100 per person for a 1-day group training session of 50 or so people up to $2,600 per person for a 5-day seminar, in addition to the opportunity labor cost of time away from work. Table 4-3 provides typical company-level training costs based on interviews[6] for significantly affected staff in several stakeholder groups and company size categories. Because of economies of scale, the average cost per employee for large Internet users is significantly lower than the average cost per employee for medium-size users and the other stakeholder groups with relatively small IT support staff.

Table 4-3. Representative Training Costs by Stakeholder Group ($2003)

	Number of Affected Staff	IPv6 Training Expenditure	Labor Costs	Total IPv6 Costs	Average Cost per Employee
Medium Internet user	10	$11,600	$5,280	$16,880	$1,688
Large Internet user	1,500	$171,200	$263,081	$434,281	$290
ISP	30	$41,600	$19,015	$60,615	$2,021
Vendor	10	$19,600	$9,457	$29,057	$2,906

The following sections provide more detail on costs to specific stakeholder groups. All data and figures described therein were calculated by RTI based on information provided during interviews

4 NSF Report entitled "Research and Development in Industry: 2000," Table E-2. To proxy for R&D expenditures for Internet infrastructure and application vendors, RTI used a combination of R&D figures for Software Publishing (NAICS 5112), Computer and Peripheral Equipment (NAICS 3342), and Other Computer and Electronic Products (NAICS 334). Available at http://www.nsf.gov/sbe/srs/srs02403/.

5 *See* BellSouth Comments at 6; Dillon Comments at 2; Hain Comments at 11. Cisco additionally indicated that these costs can be amortized over a gradual development cycle. Cisco Comments at 11.

6 This information was received by RTI during a phone interview on September 2, 2004 with Yurie Rich, President of Native6. Rich provided training cost estimates and the basis for the allocation methodology used in these cost calculations. These costs should not be used to determine the level of training needed for a specific organization. They are merely examples of potential impacts for several potentially affected organization types.

conducted by RTI. For each stakeholder group, three figures represent the cost analysis:[7]

- **Spending Distribution**—These graphs provide the likely distribution over time of IT resources needed to support transition to IPv6. This includes the time before and after the enablement or integration of IPv6 occurs (t = 0). These data were calculated by aggregating information from interview participants.
- **Adoption Rate**—These graphs suggest likely adoption rates covering the period from 2000 to 2020. This information was provided by interview participants and commenters to the DoC RFC.[8]
- **Total Spending**—These graphs illustrate the potential time series of costs that each stakeholder group will incur in the United States over the period from 1997 to 2025; these years were selected because using adoption rates from 2000 to 2020 resulted in estimated costs both before and after enablement/integration of IPv6. These figures were calculated by combining the spending distribution, adoption rate, and BLS wage data.

Additionally, in each section, costs are broken out by various activities, summing to 100 percent. Assumptions are given to help provide a basis for interpreting the results and the limitations of the analysis.

4.2 INFRASTRUCTURE VENDORS

To transition to IPv6, including integrating IPv6 into products and services and transitioning internal networks, RTI estimates that infrastructure vendors will spend approximately $1.38 billion between 1997 and 2025 (see Table 4-1 for annual breakdowns). Further, RTI estimates that cost increases related specifically to R&D activities involving IPv6 and those necessary to transition internal networks to IPv6 will equal $1.28 billion and $99.3 million, respectively[9].

Figures 4-1 and 4-2 provide the basis for the time series of costs shown in Figure 4-3 for infrastructure vendors. As shown in Figure 4-1, the majority of expenditures occur in the 3 years prior to rolling out products with IPv6 capabilities; the data underlying this figure represent the aggregated information provided by stakeholders participating in interviews. Combining these data with the penetration curve in Figure

[7] Section 2 provides more information on RTI's methodology.

[8] The official public Request for Comment (RFC), released by the Department of Commerce (DoC) in January 2004, and the comments received can be found at http://www.ntia.doc.gov/ntiahome/ntiageneral/ipv6/index.html.

[9] These figures are based on information provided by stakeholders participating in interviews conducted by RTI.

Figure 4-1. Percentage of R&D Staff Dedicated to IPv6 Transition for Infrastructure Vendors

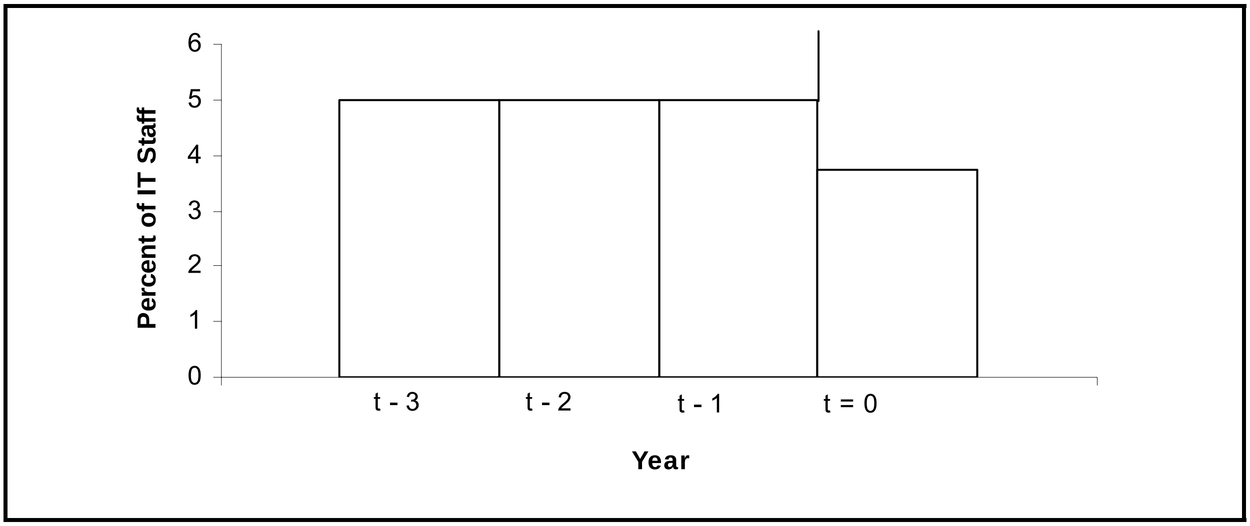


Figure 4-2. Percentage of U.S. Infrastructure Vendors' Products with IPv6 Capabilities

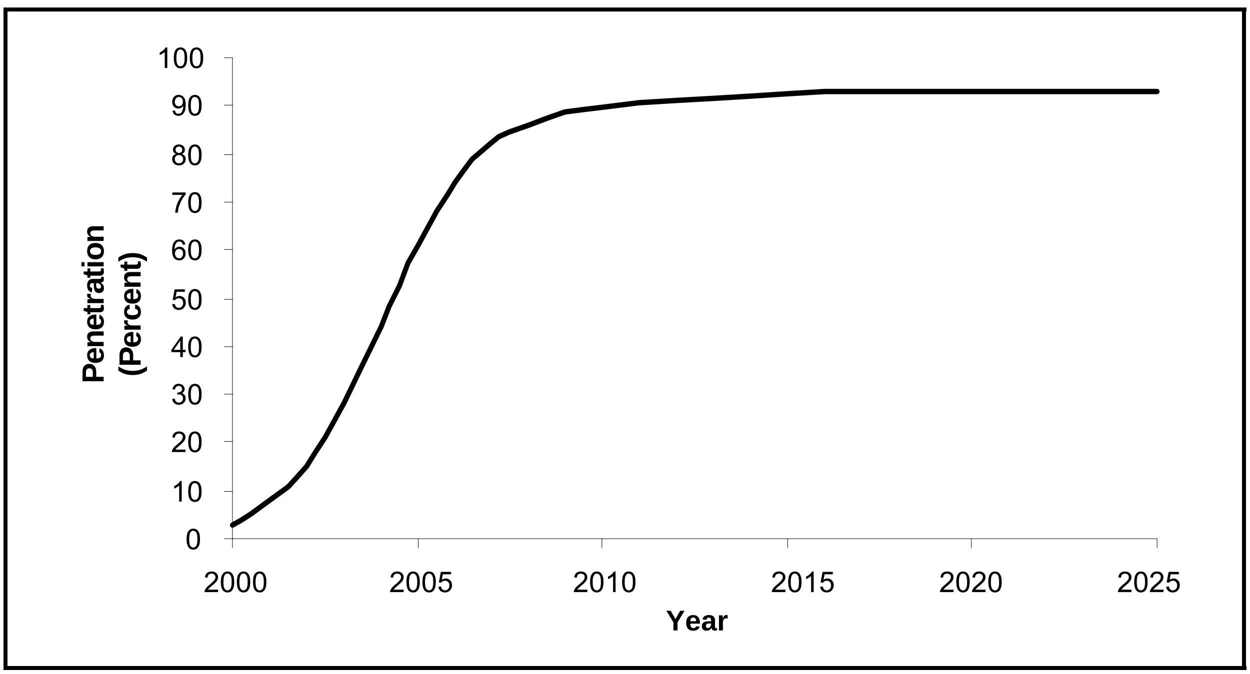
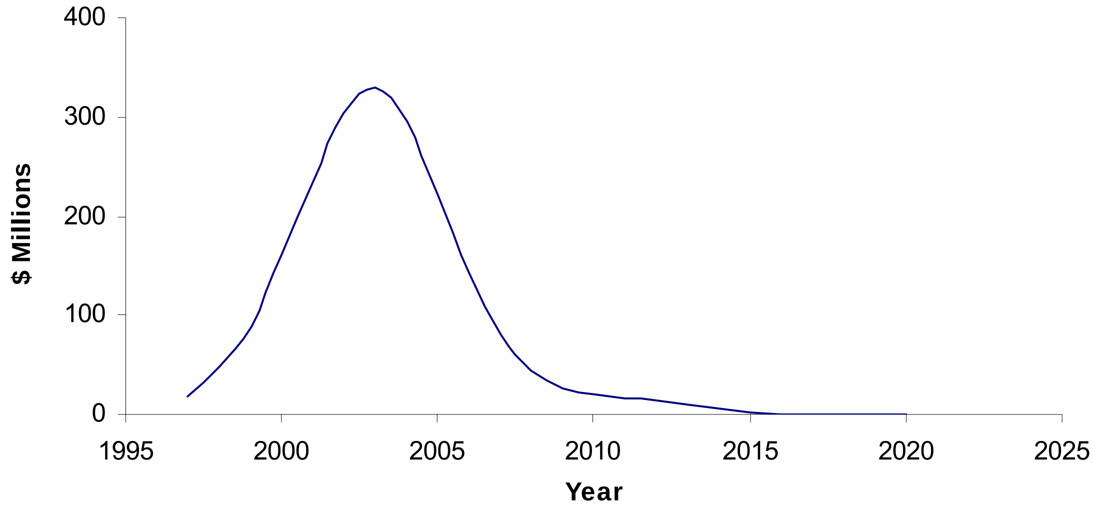


Figure 4-3. Annual Spending by U.S. Infrastructure Vendors on IPv6-Related R&D



4-2 (and using the methodology described in Section 2) results in the time-series cost curve in Figure 4-3.

The data supporting Figure 4-3 were further used to generate the annual costs for infrastructure vendors' R&D shown in Table 4-2, which suggests that infrastructure vendors' product redesign costs related to IPv6 peaked around 2003. The information supporting these figures does not include the costs (and timing) for infrastructure vendors to move internal networks to IPv6, only to integrate IPv6 into their products and services. Infrastructure vendors' internal network transition costs are captured in the Internet users stakeholder group (see Section 4.5).

4.2.1 Assumptions and Underlying Data

Networking infrastructure vendors are currently integrating IPv6 into their products. These vendors, who design and manufacture routers, firewalls, operating systems, and other core networking hardware and software products, have reacted to IPv6 demand abroad and are anticipating growth in U.S. markets.

However, there is wide variation in the level and timing of costs that vendors are anticipating. Some companies have already incorporated IPv6 into their products, some are currently testing and/or integrating IPv6 into their product lines, and others are expending no resources on IPv6 and do not plan to do so anytime in the near future.

Table 4-4 shows that product development costs are significantly greater than internal network costs for infrastructure vendors. Four major labor costs are likely to be incurred related to companies integrating IPv6 capabilities into their products (see the costs listed under "Product Development Costs"). The percentages in Table 4-4 are based on aggregated information provided by the interview participants and represent the likely level of effort, as a percentage of total R&D labor expenditures, required for the transition to IPv6.

Table 4-4. Distribution of IPv6-Related Transition Costs for Infrastructure Vendors[a]

Category	Distribution of Total Transition Costs	
	Product Development Costs	**Internal Network Costs**
Network management software (upgrade)		1.5%
Network testing		1.5%
Installation effort		2.0%
Maintaining network performance		1.4%
Training (internal IT staff)		2.1%
Training (R&D staff)	19.3%	
Standards and protocol development	20.3%	
Research and development	4.8%	
Product testing	47.1%	

[a] The percentages in this table all sum up to 100 percent, comprising the distribution of all costs necessary for infrastructure vendors to move to IPv6.

Although significantly less than product development costs, vendors will also bear costs associated with moving their internal networks to IPv6. These costs are described by the first five cost categories (quantified under internal network costs in Table 4-4). Like all Internet users, vendors' intranetwork operators will have to decide whether to adopt IPv6 (separate from their decision to integrate IPv6 into their products), and if so, they must determine the appropriate timing. As such, these data identify the likely costs they will incur.[10]

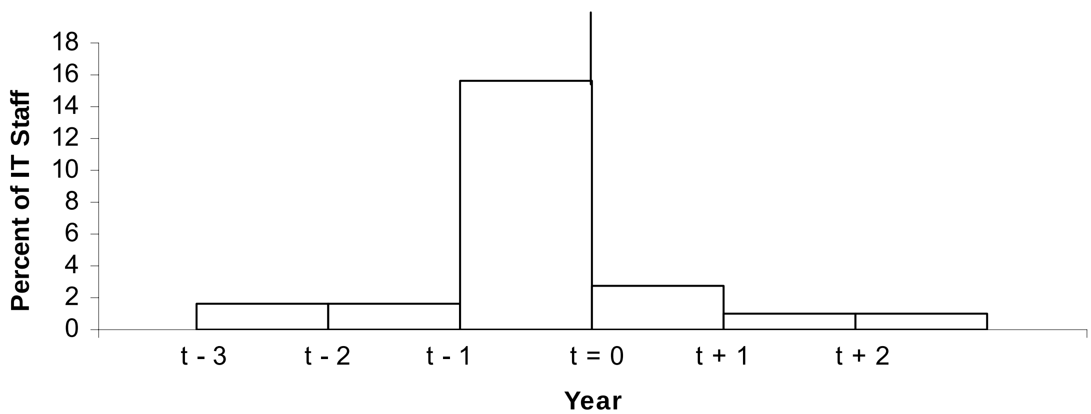
[10] Based on information provided by stakeholders, RTI assumed that all users, including ISP and vendor intranetworks, would transition at approximately the same time and that their costs would be spread over the same number of years. See Section 4.4 for curves describing these time shifts.

4.3 APPLICATION VENDORS

To transition to IPv6, including integrating IPv6 into products and services and transitioning internal networks, RTI estimates that application vendor costs will be approximately $593 million between 1997 and 2025 (see Table 4-1 for annual breakdowns). Of this total, RTI estimates that increased expenditures related specifically to R&D activities involving IPv6 and those necessary to transition internal networks to IPv6 will equal $571 million and $21.9 million, respectively[11].

Figures 4-4 and 4-5 are used to develop the time series of costs shown in Figure 4-6 for application vendors. Figure 4-4 indicates that most of the costs are borne the year prior to introducing products with IPv6 capabilities; the information underlying this figure represents an aggregate of information provided in interviews conducted by RTI.

Figure 4-4. Percentage of R&D Staff Dedicated to IPv6 Transition for Application Vendors



[11] These figures are based on information provided by stakeholders participating in interviews conducted by RTI.

Figure 4-5. Percentage of U.S. Application Vendors' Products with IPv6 Capabilities

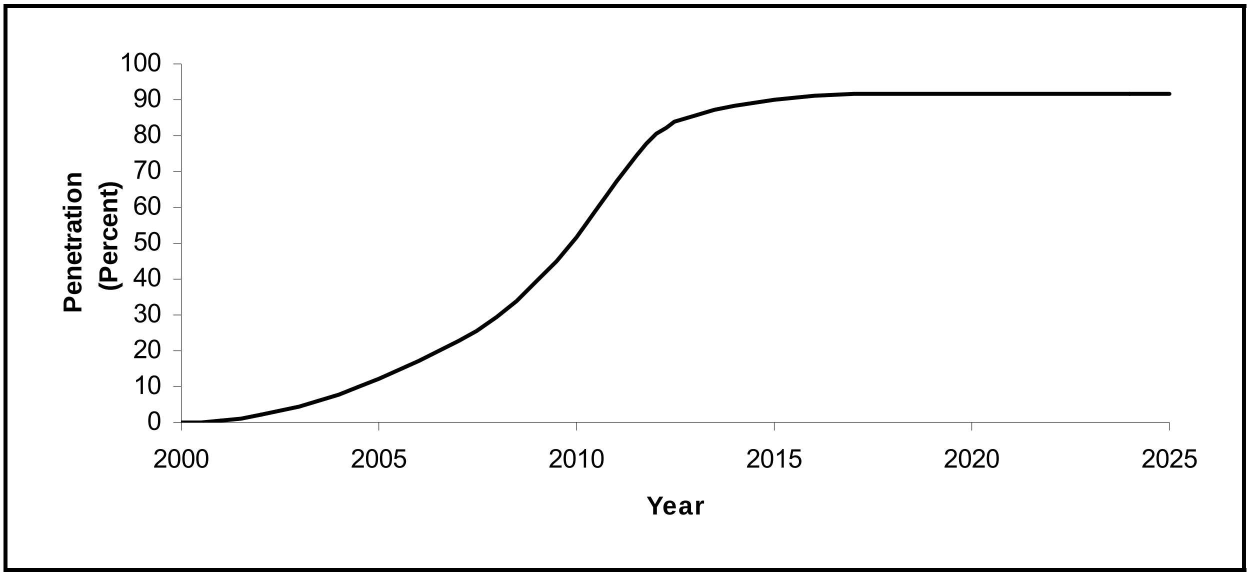
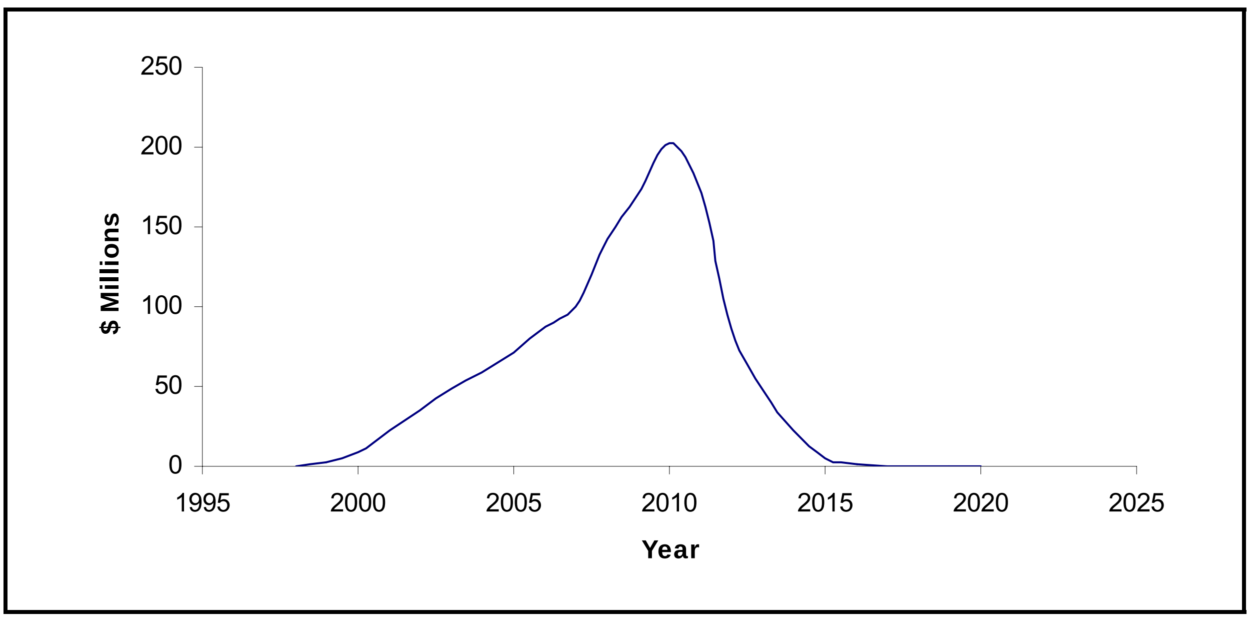


Figure 4-6. Estimated Annual Spending by U.S. Application Vendors on IPv6-Related R&D



Combining these data with the penetration curve in Figure 4-5 (and using the methodology described in Section 2) results in the time-series cost curve in Figure 4-6.

Figure 4-6 is a graphical representation of the annual costs for application vendors' R&D shown in Table 4-1. RTI projects that application vendors' annual R&D costs will peak around 2010.[12] The information supporting these figures does not include the costs for application vendors to move internal networks to IPv6, only to integrate IPv6 into their products and services. Application vendors' internal network transition costs are captured in the Internet users stakeholder group (see Section 4.5).

4.3.1 Assumptions and Underlying Data

Application vendors are moving towards IPv6 at a much slower pace than infrastructure vendors, as indicated by comparing Figures 4-2 and 4-5. Many have been testing IPv6 and planning to integrate IPv6 into their products; however, very few have actually begun selling IPv6-capable products. Although infrastructure vendors have seen increased demand, particularly abroad and from the U.S. Department of Defense, the demand for application vendors related to IPv6 has emerged more recently. Many of these vendors are indicating that they plan to release IPv6-capable products as early as 2007.

Application vendors' costs include both product development and internal network costs. As shown in Table 4-5, the product development cost distribution differs slightly from that of infrastructure vendors' (see Table 4-4). Of particular note is that costs are more equally distributed between training and product testing and development for application vendors than it is for infrastructure vendors, who need to focus more effort on product testing and development. The distribution of internal network costs is the same as it is for all users' networks.

4.4 INTERNET SERVICE PROVIDERS (ISPS)

To transition to IPv6, RTI estimates that ISPs will spend approximately $136 million between 1997 and 2025 (see Table 4-1 for annual breakdowns). This includes transitioning Internet provisioning networks, used solely to provide service to ISPs' customers, and internal networks used by ISPs. Increases related specifically to transitioning provisioning networks and those necessary to transition internal networks to IPv6 could reach $120.7 million and $15.3 million, respectively.[13]

[12] *Id.*
[13] *Id.*

Table 4-5. Distribution of IPv6-Related Transition Costs for Application Vendors[a]

Category	Distribution of Total Transition Costs: Product Development Costs	Distribution of Total Transition Costs: Internal Network Costs
Network management software (upgrade)		1.5%
Network testing		1.5%
Installation effort		2.0%
Maintaining network performance		1.4%
Training (internal IT staff)		2.1%
Training (R&D IT staff)	28.9%	
Standards and protocol development	17.7%	
Research and development	8.6%	
Product testing	36.3%	

[a] The percentages in this table all sum up to 100 percent, comprising the distribution of all costs necessary for application vendors to move to IPv6.

Figures 4-7 and 4-8 provide the inputs to Figure 4-9, which describes the likely time series of costs for ISPs. As shown in Figure 4-7, the majority of the costs are borne the year leading up to transition (t = 0), with some costs trailing up to 5 years after transition; the data underlying this figure represent the aggregated response provided by stakeholders participating in interviews conducted by RTI. Combining these data with the penetration curve in Figure 4-8 (and using the methodology described in Section 2) results in the time-series cost curve in Figure 4-9.

The data supporting these figures do not include costs for ISPs to move internal networks to IPv6, only to transition Internet provisioning networks.

4.4.1 Assumptions and Underlying Data

For ISPs, the decision to move product development and service provisioning to IPv6 is tied to customer demand and future service support. At this point, there is very little demand in the United States for IPv6; therefore, many ISPs are not currently offering IPv6 connectivity because they do not want to incur costs without a clear return on investment (ROI).

Figure 4-7. Percentage of IT Staff Dedicated to IPv6 Transition for ISPs

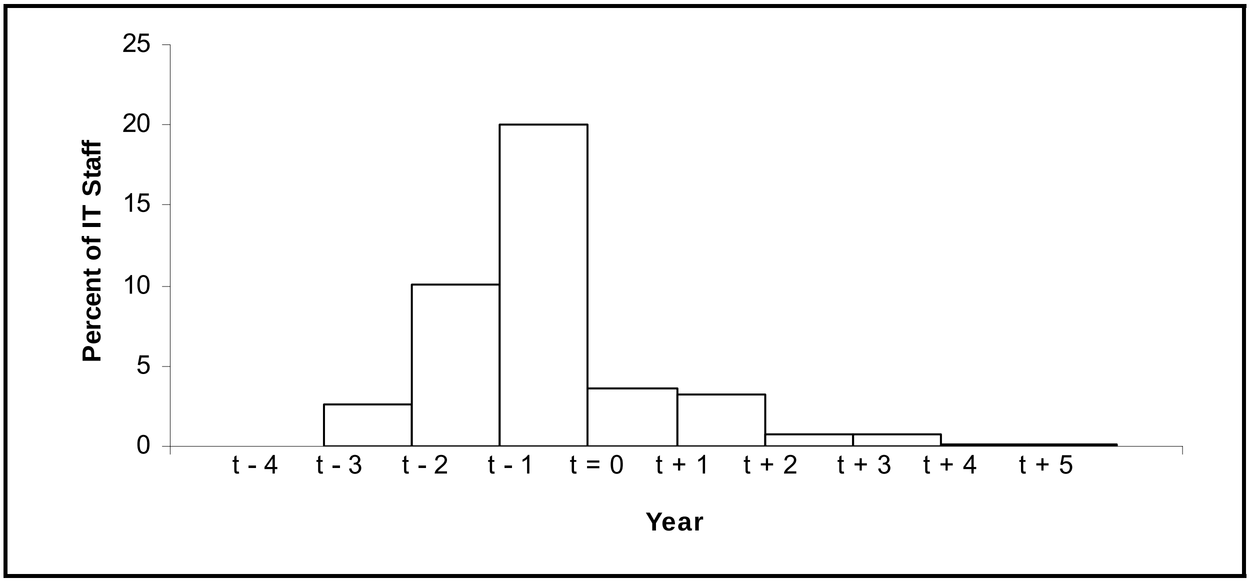


Figure 4-8. Percentage of U.S. ISP Networks Enabled to Provide IPv6 Service

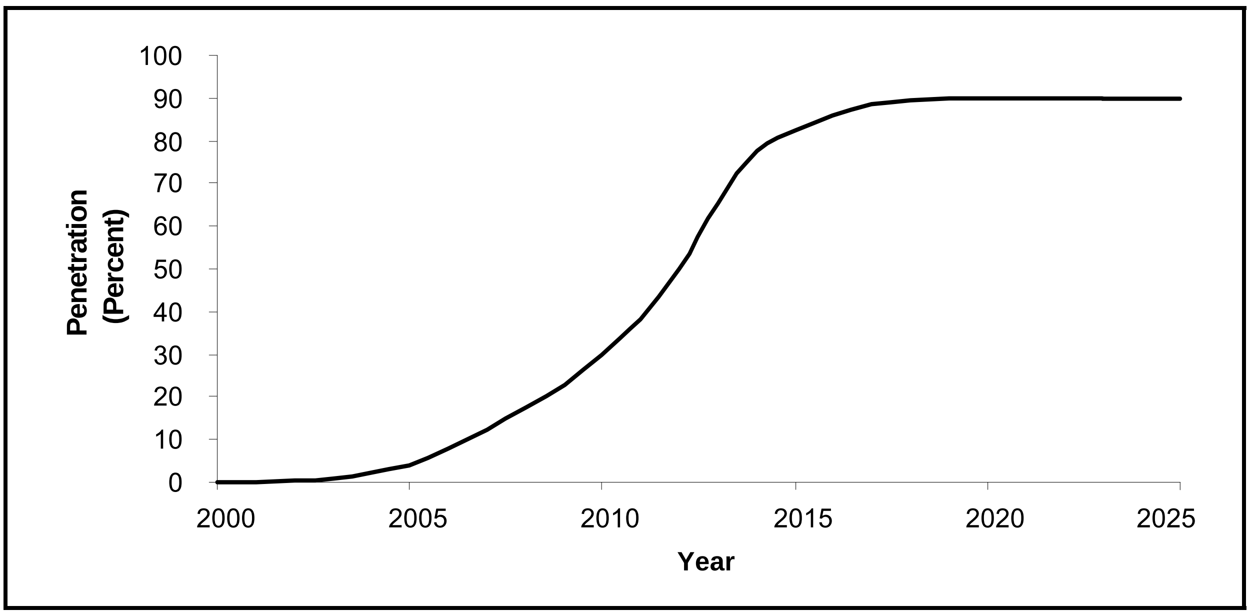
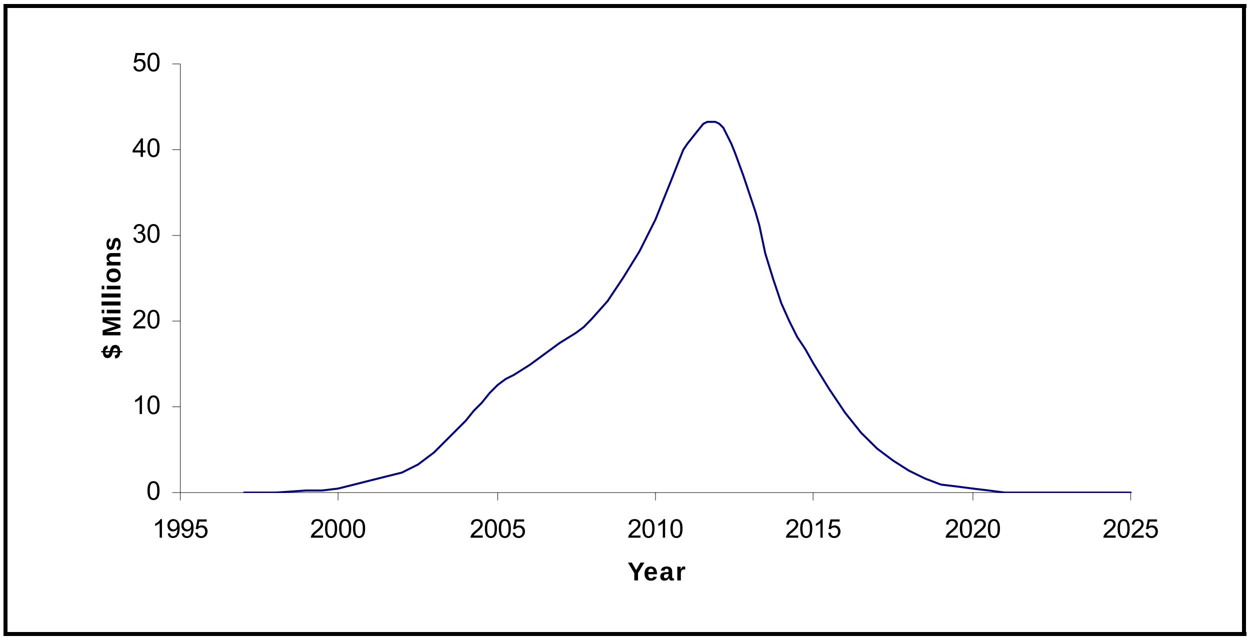


Figure 4-9. Annual Spending by U.S. ISPs on Transitioning Provisioning Networks



Many ISPs are currently engaged in testing activities and plan to offer limited IPv6 services. As soon as a significant number of mainstream customers require IPv6 connectivity, they will be prepared to provide service in 6 months to 1 year. However, similar to users, ISPs do not intend to offer IPv6 service until major hardware and software network components are in place.

Table 4-6 lists the labor costs that will likely be incurred by ISPs, broken down by Internet provisioning costs and internal network costs. The same activity categories are relevant for both transition activities for ISPs; however, as indicated in Table 4-6, transition costs to support provisioning dominate internal network costs.

If an ISP decides to move its Internet provisioning network to IPv6, it will undergo a variety of costs, but stakeholders participating in interviews indicated that the major costs for ISPs would be spent on training and network testing. IPv6 training would be a large cost because both technical staff and customer support staff would need to be involved; this would be particularly burdensome for small ISPs. Further, network testing would require significant resources. Although there were widely differing opinions among participating stakeholders on the effort needed to upgrade network management software, the aggregated figure implies a significant cost.

Table 4-6. Distribution of IPv6-Related Transition Costs for ISPs[a]

Category	Distribution of Total Transition Costs	
	Internet Provisioning Costs	Internal Network Costs
Network management software (upgrade)	19.3%	1.2%
Network testing	18.3%	1.2%
Installation effort	10.7%	1.6%
Maintaining network performance	12.0%	1.1%
Training (sales, marketing, and technical staff)	33.0%	1.6%

[a] The percentages in this table all sum to 100 percent, comprising the distribution of all costs necessary for ISPs to move to IPv6.

Again, similar to vendors, ISPs will bear costs associated with moving their internal networks to IPv6, as shown by internal network costs in Table 4-6. ISPs will make the decisions for their intra-network and Internet provisioning network separately, when appropriate, based on internal demand and intra-network needs.

4.5 INTERNET USERS

To transition to IPv6, RTI estimates that users will spend approximately $23.3 billion between 1997 and 2025 (see Table 4-1 for annual breakdowns). This number includes both government- and nongovernment costs totaling $1.7 billion and $21.6 billion, respectively.[14]

Figures 4-10 and 4-11 were used to develop the time series of costs shown in Figure 4-12 for Internet users. As shown in Figure 4-10, most user costs occur in the 2-year period prior to enabling IPv6 capabilities, with follow-up transition activities ongoing for an additional 5 years; the information underlying this figure represents the aggregated response provided by stakeholders participating in interviews conducted by RTI. Combining these data with the penetration curve in Figure 4-11 results in the time-series cost curve in Figure 4-12. Annual costs for users are projected to peak around 2013.

[14] These figures are based on information provided by stakeholders participating in interviews conducted by RTI.

Figure 4-10. Percentage of IT Staff Dedicated to IPv6 Transition for Internet Users

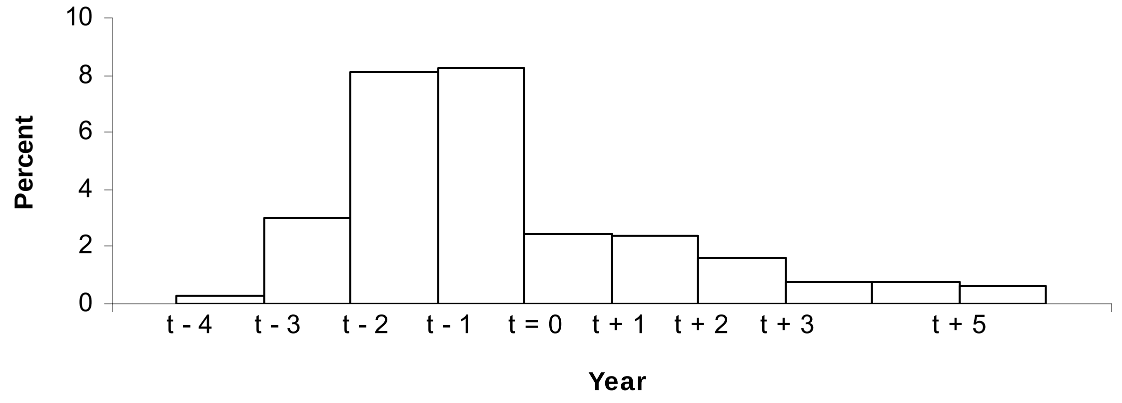


Figure 4-11. Percentage of U.S. User Networks IPv6 Enabled

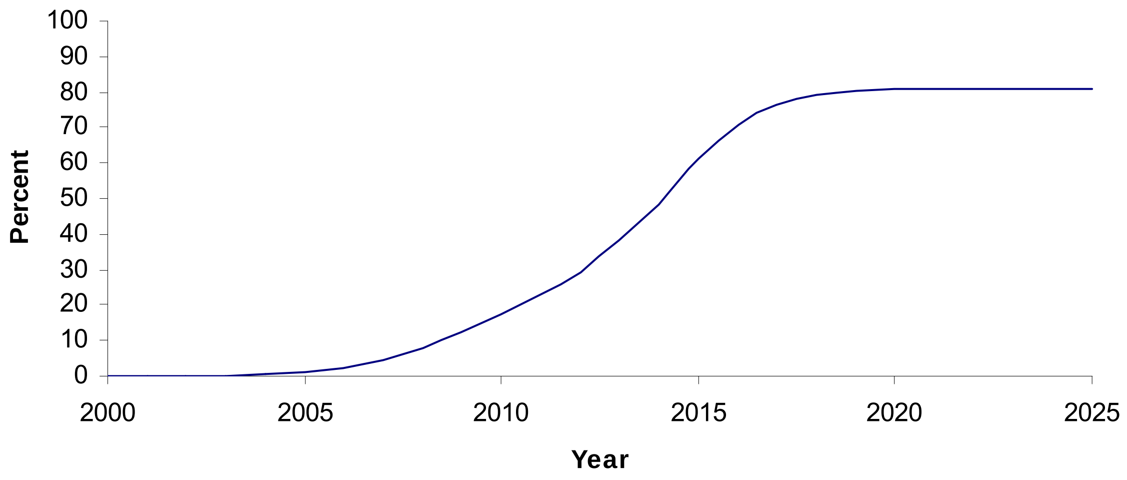
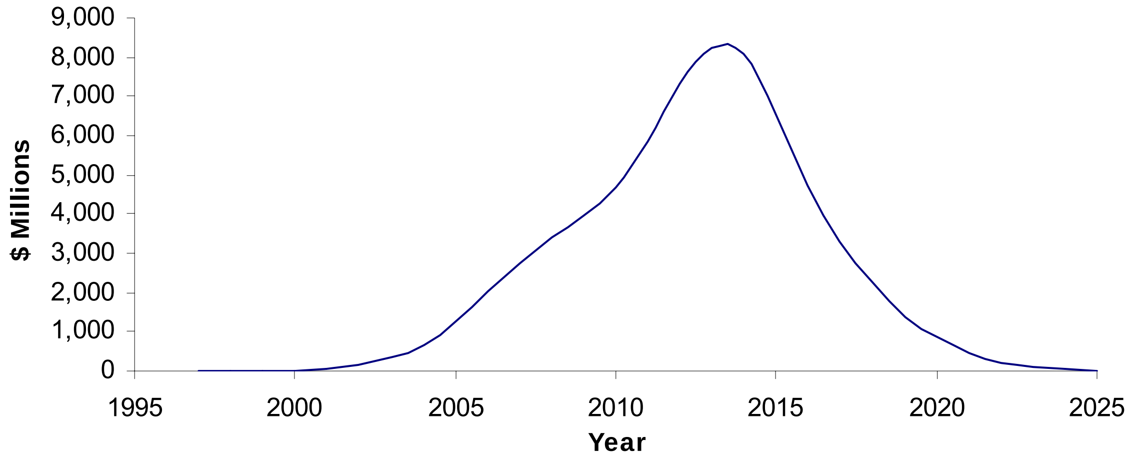


Figure 4-12. Annual Spending by U.S. Users to Become IPv6 Enabled



4.5.1 Assumptions and Underlying Data

Internet users form the largest stakeholder group with approximately 2,200,000 IT staff directly affected by the transition to IPv6.[15] In Table 4-7, the relative cost distribution is broken down for users into activity categories. However, the costs will vary widely for individual organizations within each user group—corporate, institutional, government, and independent users. For example, based on information provided by stakeholders, RTI believes that independent users, comprising home users and small businesses, will incur virtually no cost to move to IPv6 because they would gain IPv6 enablement over time without additional testing and installation costs.[16]

Medium-sized businesses, on the other hand, will likely incur the largest relative increase in IT spending to transition to IPv6. The majority of these costs will be related to the core networking operations and staff training, the size of which does not increase proportionally to the size of an organization. As a result, the cost per IT staff for medium-sized businesses will be larger than for larger businesses (see Table 4-3).

[15] This figure represents RTI's estimate based on BLS data and stakeholder interviews (see Table 4-2). IT staffing figures, including wage rates, were determined using data from the U.S. Bureau of Labor Statistics (BLS). U.S. Department of Labor, BLS, "National Occupational Employment and Wage Estimates," May 2003, available at http://www.bls.gov/oes/2003/may/oes_15Co.htm.

[16] These users do not have network management software or major networking hardware which would need to be enabled. Routing upgrades would provide equipment and software that would be IPv6 enabled several years into the future, but no additional cost should be seen.

Table 4-7. Distribution of IPv6-Related Transition Costs for Users[a]

Category	Distribution of Total Transition Costs
	Internal Network Costs
Network management software (upgrade)	18%
Network testing	17.6%
Installation effort	24%
Maintaining network performance	16%
Training (sales, marketing, and tech staff)	24.4%

[a] The percentages in this table sum to 100 percent, comprising the distribution of all costs necessary for users to move to IPv6.

Regardless of cost differences, which are nonlinear in relation to organizational size, in general users' costs will depend heavily on several common factors:

- existing organizational network infrastructure, including servers, routers, firewalls, billing systems, and standard and customized software programs;
- the type of organization (i.e., some types of services could be interrupted/damaged during a transition);
- the future needs/desires of the organizational network; and
- the level of security required during the transition.

As an example, the Defense Research and Engineering Network (DREN), the Department of Defense's recognized research and engineering network, recently completed an IPv6 pilot project in which IPv6 was deployed in infrastructure components in the core network and at 12 High Performance Computer Centers (HPCs). This process included upgrading networks, DNS software, other IP infrastructure, computer server operating systems, and desktop operating systems at each HPC.

Costs for transitioning each site included approximately $500 to $2,000 per router to expand the memory[17] and train staff members at between $30 and $2,500 each in addition to time[18] and approximately 400 hours

[17] This information was received by RTI during a phone interview on September 17, 2004, with John M Baird, IPv6 Pilot Implementation Manager with the DoD High Performance Computing Modernization Program (HPCMP). According to Baird, assuming a router runs at 40 percent of capacity regularly, if IPv6 addresses are used, the same routers would regularly be running at 80 percent of capacity. Therefore, routers will need approximately double the memory to ensure spikes do not crash the systems.

[18] Several sites purchased commercial training at a cost of between $600 and $2,250 per person; DREN provided a half-day on-site orientation, training, and planning seminars; and staff used numerous books, CDs, and video to help them understand the implications of IPv6.

of labor to transition numerous high-capacity networking components.[19] This process took a period of approximately 6 to 9 months to complete. Because DREN had previous experience both testing IPv6 and working with operational IPv6 networks, transition costs are likely to be low compared to many other organizations.[20]

[19] Each site had several computers, massive file servers, a few high-speed networks, and an average of approximately 45 desktop/laptop computers and visualization workstations.

[20] This information was received by RTI during a phone interview on September 17, 2004, with John M Baird, IPv6 Pilot Implementation Manager with the DoD High Performance Computing Modernization Program (HPCMP).

5 Baseline Benefits

Several common themes exist regarding potential IPv6 benefits. There is a general consensus by stakeholders participating in this study that IPv6 is technically superior to IPv4;[1] however, there is great uncertainty concerning the timing, magnitude, and distribution across stakeholder groups of potential benefits. Many potential benefits hinge on removing and/or changing the management of middleboxes, such as NAT devices and firewalls, because they currently disrupt certain types of host-to-host connections. Additionally, other potential IPv6 benefits, such as improved security and new quality of service (QoS) capabilities, will likely not be seen without major changes to Internet security models being used today and considerable research and testing in other areas.

Despite these caveats, stakeholders participating in this study indicated that widespread adoption of IPv6 could lead to a world of connected devices. In a "virtual home" individuals could manage their heating and cooling systems, take stock of their refrigerator or access files from their home computer while from another country. Companies could offer constant monitoring services to automobile and appliance owners to determine the best possible time to get certain services performed.

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[1] Although longer IPv6 addresses will require more memory in many network components than in IPv4-based networks to retain current transmission speeds, participating stakeholders indicate that in most cases this memory will be included in IPv6-capable products. Recent tests by Internet2 have indicated that transmission speeds are not affected by moving to IPv6 networks. *See* slide 19 of presentation entitled "IPv6 and Internet2 Update" by Bill Cerveny, Internet Engineer at Internet2, presented at the IPv6 Summit in Reston, VA, on December 10, 2004, available at http://usipv6.unixprogram.com/usipv6_reston_2004/fri/Cerveny.pdf. The explanation for this result (no change in transmission speeds as reported by Internet2) is that although IPv6 has twice the header size of IPv4, it has faster route calculation by design, assuming hierarchical addressing is enforced. Further, IPv4 and IPv6 must be natively supported, and there must be hardware-supported processing between the two network implementations. This information was received by RTI during a phone interview on November 14, 2004, with John Streck, Director of CENTAUR Labs at NC State University.

Meteorologists could use sensors with IP addresses on cars to more accurately predict and report current and future weather.[2]

Currently, major mobile phone service providers are planning to move to IPv6 because of the need for large numbers of IP addresses for new products and services and concerns about potential shortages of IPv4 addresses.[3] However, it is less clear if other near-term IPv6-dependent applications will emerge. For example, teleconferencing quality and implementation simplicity could improve[4] (through the use of IPv6, the removal of NATs, and network restructuring) and potentially decrease the need for companies to incur large travel expenses. However, it is unclear to what extent improved teleconferencing will replace in-person interactions in the near future due to quality enhancements.[5]

The intent of the following discussion is to provide examples of benefit categories along with the relative magnitudes of the potential effects. The effects discussed are not intended to be a comprehensive list of benefit categories, and an assessment has not been performed to determine the likelihood that a certain benefit will materialize.

Because of the speculative nature of future IPv6 benefits, stakeholders participating in this study were hesitant to provide empirical data. Thus, we leverage secondary data when possible to provide insight into the potential magnitude of the impacts. Benefits have been grouped into four general categories:

- **Cost reduction due to improved security**—savings in both time loss resulting from security intrusions and preventative and repair costs
- **Cost reduction due to increased efficiency**—operations improvements, holding the quality and functionality of products and services constant
- **Improvements to existing products and services**—including traditionally non-Internet-related products and services
- **Innovations leading to new products and services**—primarily information/communication services with significant increased functionality

[2] *See* Public Meeting Transcript at 48-49 (Paul Liao Panasonic USA, and Stan Barber, NTT/Verio) (IPv6-addresses taxicabs in Tokyo can inform meteorologists when the cabs' windshield wipers are on, providing the weathermen with more detailed information about rainfall patterns in the city).

[3] This information was received by RTI during a phone interview on August 12, 2004, with Victor Gonzalez, Director of Core Network Development with Nextel.

[4] *See* Microsoft Comments at 5.

[5] This information was received by RTI during an interview in Research Triangle Park, NC, on March 16, 2004, with John Streck, Director of CENTAUR Labs at NC State University.

Table 5-1 lists several benefit/application categories along with the associated measurement approach used to quantify the benefits of IPv6. These categories represent potential benefits that could be realized conditional on IPv6 adoption and significant network restructuring, such as removal of NATs. Although speculative in nature, the annual benefit estimates provided in this section give valuable insights into the magnitude of potential impacts resulting from IPv6 adoption.

Table 5-1. Several Benefit/Application Categories

Impact Metrics	Application/ Market	General Description: Examples
Cost reductions resulting from improved security	IPSec/E2E security model	• In the future, as security costs continue to rise, movement to the use of an E2E security model could help save major enterprise costs, both in downtime and preventative measures. IPSec, an IP-based security protocol that is more common in IPv6 systems, would likely be part of this movement.
Cost reductions resulting from increased efficiency	VoIP	• If enterprises move to VoIP from traditional phone networks, current studies suggest they could save 20 percent or more on telephony expenditures. IPv6 could drive and/or facilitate the move to VoIP.
	NAT removal	• Enterprise spending on NAT workarounds is quite significant according to estimates from participating stakeholders that range up to 30 percent of IT-related expenditures. • Application vendors' spending on NAT workarounds is also large, according to industry stakeholders; estimates range up to 20 percent of IT-related expenditures.
Value of remote access to existing products/services	Increased life expectancy of products	• Automobile and appliance owners could increase the functionality and life expectancy of their products by using remote monitoring and support services.
	Service costs	• Automotive and appliance owners could decrease service costs by using remote monitoring and support services.
Innovation in communications	New mobile data services	• Wireless companies could sell new features through expanded network capabilities (e.g., IP-addressed phones). • Wireless companies need IPv6 to increase address capacity for P2P (most mobile) applications.
Innovation in online products/services	Online gaming	• Gaming and game console makers could see expanded functionality and thus opportunities for innovative new products.

5.1 COST REDUCTIONS RESULTING FROM IMPROVED SECURITY

IPv6 adoption could be a significant driver (and potentially a necessary step) for networks to move to a more secure networked environment.[6] To the extent that deployment of IPv6 can enhance network security, the potential benefits to organizations and individuals can be significant. However, empirical estimates of the cost of cybersecurity breaches vary widely because of differences in what is included in the cost estimates and disincentives for companies to publicly disclose the number of breaches or level of damage. For example, studies that focus on IT costs, such as the "2004 Computer Security Institute/FBI Computer Crime and Security Survey," have reported total losses from cybersecurity breaches of approximately $142 million in 2004.[7] Similarly, a 2003 briefing by Richard Clarke, then-White House security chief, indicated that private companies were spending approximately $500 million on IT security, including both preventative and repair activities.[8] In contrast other studies that include a broader range of impacts estimate costs in the billions. Computer Economics, Inc., a research firm, put the damages of cybersecurity breaches at nearly $12.3 billion worldwide for 2001,[9] and other worldwide cyber crime estimates have been cited as high as $200 billion per year.[10]

As security costs have continued to plague enterprises and home users, many experts have been discussing the need to move to a new security model, which is more responsive and customizable. Several experts have suggested that new E2E security models and/or major

[6] *See* Public Meeting Transcript at 95-96 (Stan Barber, NTT/Verio), 146-148 (Marilyn Kraus, DoD IPv6 Transition Office).

[7] "2004 CSI/FBI Computer Crime and Security Survey" by Lawrence A. Gordon, Martin P. Loeb, William Lucyshyn, and Robert Richardson. Available at http://www.gocsi.com. Additionally, 50 percent of the CSI/FBI survey respondents reported spending 3 percent or more of their IT budget on security, and approximately 53 percent reported unauthorized use of computer systems within the last 12 months.

[8] "White House Advisor Richard Clarke Briefs Senate Panel on Cybersecurity" by Jeff Wynne with the U.S. Embassy in Japan, on February 14, 2002. Available at http://japan.usembassy.gov/e/p/tp-se1069.html.

[9] "Guard Up, Hacking Down" by Alix Nyberg with CFO Magazine, published on January 16, 2002. Available at http://www.cfo.com/article.cfm/3002790/c_2984786?f=archives&origin=archive.

[10] "IT Theft Lucrative for Web Crooks" by CBS Evening News, December 7, 2004. Available at http://www.cbsnews.com/stories/2004/12/07/eveningnews/main659641.shtml. Cyber crime includes stolen identifications, credit cards, and bank accounts.

modifications to current models will be necessary to address today's problems.[11] This would include developing "trust models" that would allow hosts to confidently send and receive messages based on a Public Key Infrastructure (PKI) system.[12]

5.2 COST REDUCTIONS RESULTING FROM INCREASED EFFICIENCY

As introduced in Table 5-1, several categories of increased efficiency could result from a transition to IPv6. In this section, we discuss the removal of NATs (and the restructuring of additional network components) within networks and the potential savings accruing to vendors and Internet users as the result of increased use of VoIP.

5.2.1 NAT Removal Leading to Increased Efficiency

IPv6 has the potential to lower costs associated with application development for software vendors and to reduce the costs of network management and the installation and testing of new applications for all enterprises. These represent long-term efficiency gains (net cost reductions) after the transition from IPv4 to IPv6 is complete; however, they are contingent on the removal of NAT devices and the restructuring of organizational networks, including the evolution of firewalls to be more versatile to allow seamless connectivity.

According to stakeholders participating in interviews, application vendors on average allocate 8.8 percent of their labor for product design and testing activities to address NAT transversal issues. NAT transversal typically involves designing products so that they will work through NAT boxes. In addition, this work can stifle innovation by diverting time away from R&D activities and increasing the complexity of new applications.

[11] *See* Public Meeting Transcript at 93-95 (Henry Kafka, BellSouth) and 59-60 (Dr. Latif Ladid, IPv6 Forum), 95-96 (Stan Barber, NTT/Verio) 139 (Dr. Doug Maughan, Department of Homeland Security), 149-150,156, 160, 178, 179 (Preston Marshall, DARPA).

[12] Simply, the sending host would encode his message with a "key" given to him/her by the PKI management organization, and the receiving host would decode the message with a different key given to him/her to the same organization, but only if the sending host gives permission.

Based on stakeholder interviews, RTI estimates that NAT transversal expenditures account for as much as $500 million per year for application vendors (see Table 5-2).[13]

Table 5-2. Potential Annual Cost Reductions Associated with NAT Removal

Description	Value	Source
Application Vendors—R&D and Training Costs		
R&D expenditures	$6.28 billion[a]	NSF
Reduction in level of effort	x 8.8%	RTI Interviews
Annual cost reduction	***$552.6 million***	***RTI calculations***
User Networks—Application Installation and Testing Costs		
IT staff (FTEs) involved	241,495[b]	BLS
Average fully loaded salary	$85,280[c]	BLS
Reduction in level of effort	x 6.7%	RTI Interviews
Annual cost reduction	***$1.38 billion***	***RTI calculations***

[a] As an estimate of applications vendors' R&D and training costs, RTI used 50 percent of R&D spent by software manufacturers in 2000. The original data are from an NSF report entitled "Research and Development in Industry: 2000," Table E-2. See R&D figures for Software Publishing (North American Industry Classification System [NAICS] 5112). The report is available at http://www.nsf.gov/sbe/srs/srs02403/tables/e1.xls.

[b] As an estimate of IT staff involved in applications installation and testing, RTI used 50 percent of Computer Support Specialists (Standard Occupational Classification Systems (SOC) 15-1041) in the United States as reported by the Bureau of Labor Statistics (BLS). Available at http://www.bls.gov/oes/2003/may/oes151041.htm.

[c] For IT staff involved in applications installation and testing, RTI used the BLS wage rate for Computer Support Specialists (SOC 15-1041) as of 2003, with a multiplier of two to incorporate overhead expenses incurred by employers.

Similarly, RTI estimates that Internet users spend 6.7 percent of IT labor resources on managing NATs (and other middleware) and ensuring the interoperability of applications (including the installation, testing, and monitoring of applications) with NATs. Combining this estimate with data from the Bureau of Labor Statistics (BLS), RTI estimates a potential annual reduction of over $1 billion in IT (primarily labor) expenditures.[14]

NATs are network hardware components that allow a group of hosts on a private network to share a relative small number of public IP addresses used to send and receive messages over the Internet.

[13] The estimated 8.8 percent of application vendor R&D effort was based on a relatively small sample size, with respondents' estimated savings ranging between 0 and 30 percent of annual costs. Based on the individual responses, the 95 percent confidence interval for savings costs is 8.8 percent ± 9.3 percent of R&D effort, or $552 ± $585 million.

[14] The estimated 6.7 percent of users' IT efforts was also based on a relatively small sample size, with respondents' estimated savings ranging between 0 and 35 percent of annual costs. The 95 percent confidence interval for users' IT effort is 6.7 percent ± 4.6 percent, or $1.38 ± 0.93 billion in annual savings from NAT removal for users.

Along with the benefits of NAT *removal*, many participating stakeholders indicated that over time NATs have evolved to serve several functions and potentially significant costs could be associated with removing NATs from user networks. Although not designed for security, many networks today use NATs to provide hosts with some level of obscurity from potential intruders.[15] In most networks that use NATs, hosts are assigned external addresses only for the duration of each Internet session, and even during that period, the internal host cannot receive communications originated from the outside. Thus, NATs can help block some common viruses and worms that scour the Internet for exposed hosts. At issue is that this function can impede IPv6 applications that require or perform better when direct E2E connectivity is possible.

For many of the potential benefits of IPv6 to be realized, NAT devices will likely need to be removed in a significant portion of the current Internet infrastructure. The level of NAT removal and network restructuring depends on the type of benefit. For example, if one network removes its NATs and moves to VoIP, it could see productivity improvements and decreased internal communications costs, but external calls would have to travel through NAT boxes, leading to potential problems.

In addition, the cost of removing NATs could be significant. Although likely to be an order of magnitude less than total IPv6 transition costs,[16] to remove NATs a network would redesign and restructure the network-connecting hosts, change firewall and established security procedures, and learn to function without a network component that has been in place in many networks for almost a decade. Thus, many stakeholders expressed concern that if NATs disappear in their current form, firewalls alone could result in many of the same problems.[17]

5.2.2 VoIP Potential Savings

VoIP represents an increasing share of the telecommunications market, and IPv6 could allow companies to move to VoIP more easily and enable more extensive use of VoIP capabilities. According to a survey of 250 U.S. executives performed by the Economist Intelligence Unit (EIU) in

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[15] *See* Alcatel Comments at 4; NTT/Verio Comments at 13-14.

[16] This information was received by RTI during a phone interview on November 14, 2004, with John Streck, Director of CENTAUR Labs at NC State University. Streck stated that costs associated with NAT removal would likely be much compared to IPv6 transition. This is because NAT impact fewer components of the system compared to IP standards.

[17] *See* Public Meeting Transcript at 15 (remarks of Vint Cerf, MCI), 58 (remarks of Paul Francis, Cornell University), 178 (remarks of Preston Marshall, DARPA).

association with AT&T, 43 percent are using or plan to use VoIP in the next 2 years.[18] Without middleware (e.g., NATs), applications such as VoIP and real-time videoconferencing could be implemented much more simply, at a lower cost, and with more features. A direct connection (i.e., IP address to IP address) could be established and maintained without the need to establish additional protocols and procedures to traverse one or more NAT devices.

In a recent study, SouthTrust Bank indicated that installation of VoIP resulted in a 30 percent reduction in annual communications costs.[19] Other studies by Forrester Research suggest a savings from VoIP of 20 percent compared to traditional network telecommunications spending.[20] A 20 percent reduction in traditional network spending represents approximately $7.8 billion in potential annual savings for U.S. businesses (see Table 5-3).

Table 5-3. Potential Annual VoIP Savings

Description	Value	Source
Annual U.S. Fixed Telecom Market Retail Voice Connection Revenue	$39.1 billion	Gartner[a]
Reduction in phone network/ management enterprise spending	x 20%	Forrester Research[b]
Annual cost reduction	***$7.8 billion***	***RTI calculations***

[a] Based on Total Business Connection Retail Service Revenue in 2003. Table 1-3 in Gartner report entitled “Forecast: Fixed Public Network Services, United States, 2002–2008” by Alex Winogradoff, April 2004.

[b] Forrester Research prediction as reported by News.com at http://news.com.com/2001-7352_3-0.html?tag=ne.map.

5.3 REMOTE ACCESS TO EXISTING PRODUCTS/SERVICES

Devices that are globally addressable so that they can be remotely accessed and controlled via the Internet represent a potential application of IPv6 addresses. Automobile components or subsystems, refrigerators, cameras, home computers, and other home appliances could be assigned IP addresses, linked together on home networks, and

[18] “Survey: VoIP to become new standard for voice traffic” by Matthew Friedman with CommsDesign, published on September 23, 2004. Available at http://www.commsdesign.com/news/market_news/showArticle.jhtml?articleID=47902339.

[19] “VoIP gaining ground, despite cost concerns” by Matt Hamblan with ComputerWorld, published on August 13, 2004. Available at https://www.computerworld.com/printthis/2004/0,4814,95248,00.html.

[20] “Get up to Speed: VoIP” by News.com, last accessed on December 7, 2004. Available at http://news.com.com/2001-7352_3-0.html?tag=ne.map.

connected to the Internet. Home owners could control such devices remotely, and automobile and appliance manufacturers, for example, could offer remote service and support packages. Existing products, such as OnStar, imply there is already demand for this type of service.

OnStar has 2 million subscribers currently, and monthly charges vary from $16.95 to $69.95.[21] OnStar can provide directions and emergency assistance. In the event of airbag deployment, the OnStar Center is automatically contacted by the car's OnStar system to report the accident and location. The OnStar operator then contacts the nearest emergency-services dispatcher. Currently OnStar uses a combination of global positioning system (GPS) and cellular technologies; however, according to several stakeholders, a service similar to OnStar could be enhanced and operated much more efficiently using IPv6 addressing.[22]

Although it is difficult to predict whether or when products and services will develop that offer mobile monitoring, access, and support through IP, participating stakeholders indicated that IPv6 offers opportunities for wireless sensor networks and for machine-to-machine communications, potentially leading to a large proliferation of devices that will connect to the Internet. Currently, several Japanese companies offer IP-addressed products (e.g., cameras, printers),[23] and other U.S. companies are involved in development and testing activities.

Among the many benefits of remote access are the potential increased life expectancy of large-ticket items such as automobiles and appliances (durable goods) and an associated decrease in service/repair costs. Table 5-4 provides hypothetical benefit estimates based on a 1 percent increase in life expectancy and 1 percent decrease in service costs for automobiles and appliances. Whereas single directional communications (i.e., from the appliance to the service provider) are readily implemented using IPv4, the introduction of IPv6 and the removal of NATs greatly increases capabilities of mobility two-way communications.

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[21] "OnStar enters 6th generation" by Earle Eldridge on March 22, 2004, USA Today. Available at http://www.usatoday.com/tech/news/2004-03-22-onstar_x.htm.

[22] This information was received by RTI during an interview in Research Triangle Park, NC, on March 16, 2004, with John Streck, Director of CENTAUR Labs at NC State University.

[23] *See* "IPv6 Ready Logo: Phase 1" for a list of products that the IPv6 Ready Logo program, operated by the IPv6 Forum, has approved. See list at http://www.usatoday.com/tech/news/2004-03-22-onstar_x.htm. Most of the companies with products listed are based in Asia.

Table 5-4. Potential Annual Benefits of Remote Access to Automobiles and Appliances

Description	Automobiles	Appliances	Source
Product life expectancy			
Annual U.S. expenditures	$222.0 billion[a]	$108.4 billion[b]	Census data
Increase	x 1%	x 1%	Example impact
Benefits	***$2.22 billion***	***$1.08 billion***	***RTI calculations***
Expenditures on services			
Annual U.S. expenditures	$65.5 billion[c]	$5.0 billion[d]	Census data
Reduction	x 1%	x 1%	Example impact
Benefits	***$655 million***	***$50.0 million***	***RTI calculations***

[a] Includes NAICS 33611 Automobile & Light Duty Motor Vehicle Manufacturing. Source: 2002 Economic Census. Available at http://www.census.gov/prod/ec02/ec0231i336111.pdf and http://www.census.gov/prod/ec02/ec0231i336112t.pdf.

[b] Includes NAICS 3352 Household Appliance Manufacturing, 33421 Telephone Apparatus Manufacturing, 33422 Radio & TV Broadcasting and Wireless Communications Equipment Manufacturing, 3343 Audio & Video Equipment Manufacturing. Source: 1997 Economic Census. Available at http://www.census.gov/epcd/ec97/industry/E3352.HTM, http://www.census.gov/epcd/ec97/industry/E3342.HTM, http://www.census.gov/epcd/ec97/industry/E3342.HTM, and http://www.census.gov/epcd/ec97/industry/E334.HTM.

[c] Includes U.S. Standard Industrial Classification (SIC) codes 753 Automotive Repair Shops and 754 Automotive Services, Except Repair. Source: 1997 Economic Census. Available at http://www.census.gov/epcd/ec97brdg/E97B2_75.HTM.

[d] Includes NAICS 811211 Consumer Electronic Repair and Maintenance and 811412 Appliance Repair and Maintenance. Source: 2002 Economic Census. Available at http://www.census.gov/prod/ec02/ec0281i01t.pdf and http://www.census.gov/prod/ec02/ec0281i01t.pdf.

5.4 INNOVATIONS LEADING TO NEW PRODUCTS AND SERVICES

Participating stakeholders indicated that certain promoted features of IPv6—connectivity through a wider array of channels and transmission modes,[24] the ability to maintain multiple simultaneous access paths for multiple networks/hosts without manual involvement,[25] improved speed,[26] and improved quality of connections[27]—could spur the deployment of new P2P or E2E networking applications. Without interference from middleware, such as NAT devices, the increased address space available from IPv6 use could simplify the provision of plug-and-play,[28] “always-on,”[29] and other E2E applications.[30].

[24] *See* Sprint Comments at 11.
[25] *See* Hain Comments at 4.
[26] *See* Microsoft Comments at 5.
[27] *Id.*
[28] Plug-and-play applications are those that after being installed (or “plugged in”) can immediately be used (or “played”) without configuration requirements (e.g., a laptop on a new network).

In addition, participating stakeholders suggested that the recent emergence of mobile data services such as sending photos and text messages could drive the adoption of IPv6 so that more advanced services, such as remote data management and transmission, could be offered.[31] The recent growth in mobile phone subscribers shown in Table 5-5, in addition to their constant desire for more features, and the looming potential shortage of available IPv4 addresses has already provided enough incentive for several mobile phone service providers to move to IPv6 addressing.[32]

Table 5-5. Growth in U.S. Mobile Phone Subscribers

Year	Subscribers[a]	U.S. Population[b]	Penetration Rate
1984	91,600	236,789,000	0.04%
1987	883,778	243,291,000	0.36%
1991	6,390,053	255,419,000	2.50%
1995	28,154,415	263,909,000	10.67%
1999	76,284,753	273,828,000	27.86%
2002	141,477,000[c]	289,717,000	48.83%

[a] Source (other than where noted): "Trends in Telephone Service" by the Industry Analysis Division of the Common Carrier Bureau at the Federal Communications Commission, released in March 2000, page 2-3, Table 2.1. Available at ftp://www.fcc.gov/pub/Bureaus/Common_Carrier/Reports/FCC-State_Link/IAD/trend100.pdf.

[b] Sources: "Monthly Estimates of the United State Population: April 1, 1980 to July 1, 1999" released on January 2, 2001 by the Population Estimates Program, Population Division, U.S. Census Bureau, Resident Population estimates in this report were used for 1984-1999 figures. Available at http://www.census.gov/popest/archives/1990s/nat-total.txt. For 2002, "Monthly National Population Estimates (in thousands): April 1, 2000 to September 1, 2003" last revised August 6, 2004. Released by Population Estimates Program, Population Division, U.S. Census Bureau, Resident Population estimates in this report. Available at http://www.census.gov/popest/archives/2000s/vintage_2002/NA-EST2002-06.html.

[c] Source: Gartner report entitled "Mobile and Wireless Services and Service Providers in the United States" by Carol Skvarla and Brian Dooley, January 2004, page 2, Table 1.

The North America mobile data market, including text messaging (often referred to as short message service or SMS) and other data services,

[29] Always-on applications require constant reachability from the Internet to be used fully (e.g., video conferencing, voice telephony).
[30] E2E applications use a direct connection between two hosts both of which accept connection requests from the other (e.g., computer gaming or video conferencing).
[31] *See* Sprint Comments at 11.
[32] This information was received by RTI during a phone interview on September 16, 2004, with Victor Gonzalez, Director of Core Network Development at Nextel.

such as Internet and e-mail access over Wireless WANs (Wide Area Networks), reached approximately 22.67 million connections in 2002 (see Table 5-6), and Gartner predicts this market will grow approximately 80 percent in the next 3 to 4 years.[33] There were 18.7 million wireless Internet users in North America at the end of 2002, and that number is expected to grow to 95.6 million by 2007.[34] Additionally, 14.5 percent of U.S. cell phone subscribers were using SMS messaging at the end of 2003;[35] however, penetration is much higher in Asia[36] and Western Europe,[37] an indicator of the future (or future loss of) potential in the United States.

Table 5-6. Growth in U.S. Wireless Data Revenue and Connections

	1999	2000	2001	2002
Wireless data connections	1,833,600	6,260,210	14,930,489	22,671,000
U.S wireless data revenue ($ millions)	$419	$697	$1,401	$1,972

Source: Gartner report entitled "Mobile and Wireless Services and Service Providers in the United States" by Carol Skvarla and Brian Dooley, January 19, 2004, page 3, Table 2.

Historical data imply that consumers will be willing to pay for improved communication and information services. As shown in Table 5-7, household computer and Internet use continues to grow. This implies that the infrastructure capable of supporting always-on connectivity to the home, through DSL and cable modem broadband Internet, must become more robust. Further, with the emergence and rapid penetration of mobile telephones and the development of broadband Internet connectivity, telecommunications spending has significantly increased

[33] Gartner report entitled "Mobile and Wireless Services and Service Providers in the United States" by Carol Skvarla and Brian Dooley, January 19, 2004, page 3, Table 2.

[34] Gartner report entitled "Mobile Data Communications Services: North America, 1999–2007 (Executive Summary)" by Tole Hart, March 4, 2004, page 4.

[35] Gartner report entitled "Market Trends: Mobile Wireless, North America, 2004 (Executive Summary)" by Tole J. Hart, Tuong Huy Nguyen, Hugues J. De La Vergue, and Michael J. King, June 30, 2004, page 1.

[36] China Mobile (Hong Kong), which combined with its parent company China Mobile controls approximately 65 percent of the mobile service market in China, reported that 70 percent of their subscribers were mobile data users. See Gartner report entitled "Mobile and Wireless Services and Service Providers in China" by Jayashri Dasgupta, April 8, 2004, page 2-3.

[37] Approximately 70 percent of the 749 users surveyed by Gartner in France, Germany, Italy, Spain, Sweden, and the United Kingdom indicated that they use their mobile phones for text messaging. See Gartner report entitled "User Survey: Mobile Phones and Services, Western Europe, 2004 (Executive Summary)" by Stéphanie Pittet , November 15, 2004, page 1.

Table 5-7. Percentage of U.S. Households with Computers and Internet Access

	1994[a]	1997[b]	2001[b]	2003[b]
Computer	24.1%	36.6%	56.2%	61.8%
Internet use		18.6%	50.3%	54.6%

[a] Source: "Trends in Telephone Service" by the Industry Analysis Division of the Common Carrier Bureau at the Federal Communications Commission, released in March 2000. Available at ftp://www.fcc.gov/pub/Bureaus/Common_Carrier/Reports/FCC-State_Link/IAD/trend100.pdf.

[b] Source: "A Nation Online: Entering the Broadband Age" by the National Telecommunications and Information Administration (NTIA) and the Economics and Statistics Administration at the Department of Commerce, released in September 2004. Available at http://www.ntia.doc.gov/reports/anol/NationOnlineBroadband04.pdf.

over the past 10 years. As such, consumers have shown a willingness to pay as new Internet applications are identified and brought to market.

However, for new E2E applications to succeed in the household market, applications developers must determine how to work with ISPs, for example, to develop an infrastructure and applications that can use the benefits of IPv6 and E2E connectivity. Today, many houses still lack broadband connections. According to a DoC report released in September 2004 entitled "A Nation Online: Entering the Broadband Age," although 58.7 percent of the U.S. population uses the Internet, only 33.9 percent of these users have broadband at home.[38] Further, many of those people who have always-on Internet access also have small routers that operate as NAT devices and would inhibit many E2E services (or make them more complex).

Whereas based on all information available,[39] RTI concludes that consumers could benefit from new (next generation) IPv6-enabled products and services (given the proper infrastructure support), no specific new features of such applications, timing of availability, or willingness to pay for enhanced functionality enabled by IPv6 could be determined at the time of this report. Although currently several Asian companies are selling IPv6-addressed devices (and U.S. and European companies are designing and producing these), with NAT devices and/or

[38] "A Nation Online: Entering the Broadband Age" by the National Telecommunications and Information Administration (NTIA) and the Economics and Statistics Administration at the DoC, released in September 2004, page 7. Available at http://www.ntia.doc.gov/reports/anol/NationOnlineBroadband04.pdf.

[39] This statement represents a synthesis of the information gathered by RTI through extensive literature reviews, RTI's informal discussions with stakeholders, commenters to the Department of Commerce (DoC) Request for Comment (RFC), participants in the DoC public meeting in July 2004, and stakeholder interviews conducted by RTI.

current firewall structures and associated procedures in the majority of homes and businesses, customers cannot take advantage of IP-addressed devices in most situations. No “IPv6-required” applications had been discovered (or disclosed) as of December 2004.

6 Costs Under Alternative Deployment Scenarios

Section 3 presents the likely transition timeline for IPv6 based on the information provided during stakeholder interviews conducted by RTI. This study emphasizes that there is significant uncertainty over this projected timeline, in that it depends on future market and technology developments. For example, cost-sensitive design requirements (for each organization and individual) that are necessary to achieve security benefits from IPv6 have not been developed; therefore, the timing of such benefits cannot be projected easily. However, based on extensive information collection exercises, RTI believes that advances in the development of PKI or new E2E security models could potentially accelerate the development of and demand for IPv6 products and services.[1]

Conceptually, stakeholders participating in this study were not in agreement over an adoption path that would be in the best interest of the United States. Some stakeholders indicated that IPv6 deployment should be accelerated so that benefits can be realized earlier and that the United States does potentially lose its technological advantage by lagging other parts of the world in deployment. In contrast, other stakeholders believe that IPv6 deployment should be delayed until the magnitude and timing of potential benefits are more certain.[2]

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[1] *See* BellSouth Comments at 8-9.

[2] This statement represents a synthesis of the information gathered by RTI through extensive literature reviews, RTI's informal discussions with stakeholders, commenters to the Department of Commerce (DoC) Request for Comment (RFC), participants in the DoC public meeting in July 2004, and stakeholder interviews conducted by RTI.

This section investigates the costs of accelerating the deployment of IPv6 in the United States. We focus on acceleration scenarios because participants in interviews indicated that the cost implications associated with *delaying* the deployment of IPv6 are negligible (e.g., the magnitude of the costs will not change), although a delay in adoption could affect the timing of benefits. However, participating stakeholders indicated that efforts to accelerate the deployment of IPv6 capabilities or the enabling of IPv6 capabilities could result in increased costs[3]. This section investigates the cost implications of two acceleration scenarios, one that accelerates user enabling of IPv6 (keeping the penetration of IPv6 capabilities unchanged) and a second that accelerates both the penetration of user capabilities and the enabling of IPv6.

Users are the focus of the acceleration cost scenarios because interview participants indicated that acceleration costs for vendors and ISPs were negligible (within a reasonable time frame of several years) and that their products and services would be available when demand/applications materialized. Several participating stakeholders indicated that users would be capacity constrained (by limited IT staff) and would bear costs associated with accelerated training and enabling. In addition, if early retirement of hardware or software were required to facilitate acceleration of IPv6 adoption, interview participants suggested that this could potentially be extremely costly.

The cost impact of both scenarios is measured relative to the baseline penetration of IPv6 user capabilities and enabling activities shown in Figure 3-2. The acceleration scenarios and the procedure for estimating costs are described below.

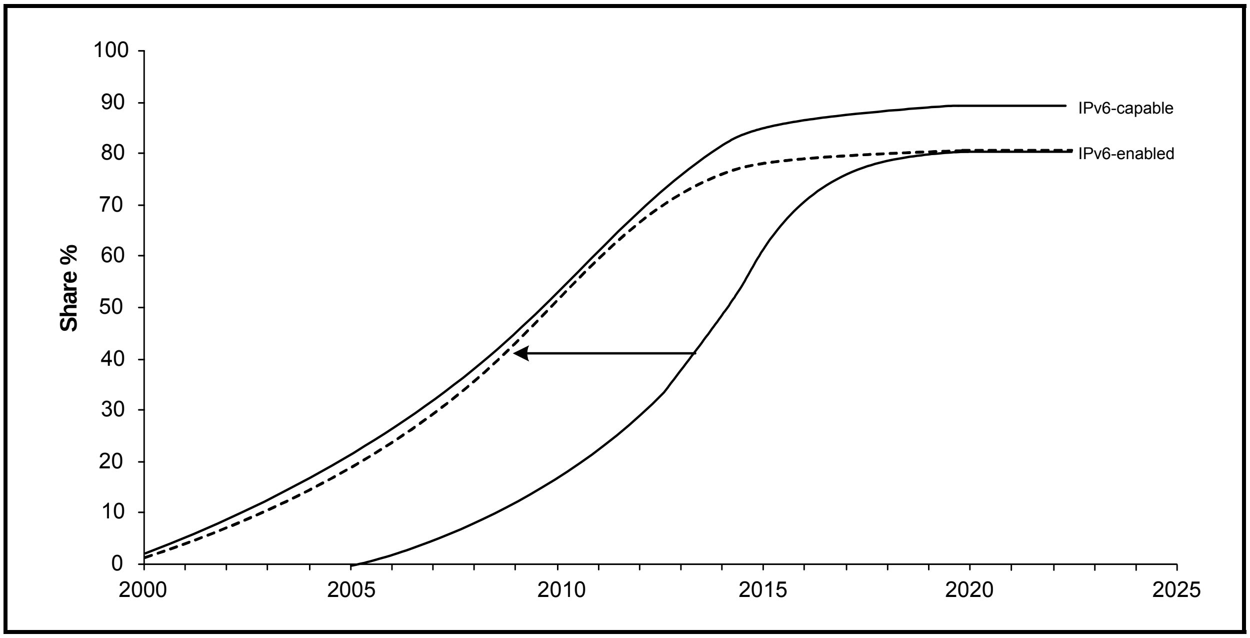
6.1 SCENARIO 1: ACCELERATING ENABLEMENT BY USERS

Scenario 1 involves accelerating the enablement of IPv6 by users to the time when users become IPv6 capable. Based on interviews, RTI calculates that this represents approximately a 3-year acceleration of enabling activities. As shown in Figure 6-1, this represents a shift in the user-enabled curve presented earlier in Section 3 (see Figure 3-2).

Accelerating the user-enabled curve has two cost implications. The first is that because of limited resources, an accelerated deployment of IPv6 could increase the average enabling cost for users. The degree to which

[3] *See* BellSouth Comments at 6.

Figure 6-1. Acceleration Scenario 1



acceleration would affect users' transition costs is uncertain; however, it would likely lead to incremental cost increases. These cost increases reflect overtime for IT staff, potential outsourcing of some transitioning activities, and a decrease in companies' ability to benefit from "lessons learned" over time. For example, less experience and time with IPv6 could lead to more problems and issues that would need to be addressed during a transition. Based on information provided in interviews, RTI applied a 5 percent increase in users' transition costs (maintaining the same relative cost distribution around t = 0) for Scenario 1.

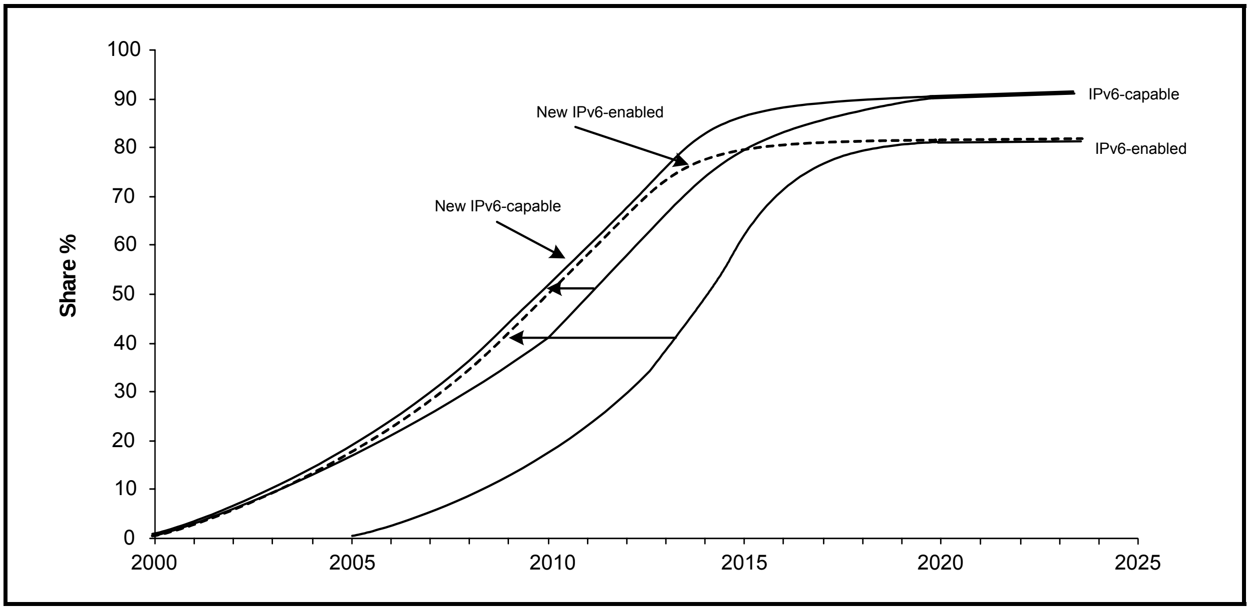
The second acceleration factor affecting deployment cost is that expenditures are incurred sooner than later. Accelerating expenditures increase the PV of the time series of costs.

For this scenario, acceleration is bounded by the penetration of IPv6 capabilities. Capabilities are still assumed to be deployed as part of routine hardware and software upgrades. Therefore, RTI assumes that incremental capital costs are negligible in Scenario 1. This assumption is relaxed in Scenario 2.

6.2 SCENARIO 2: ACCELERATING CAPABILITIES BY USERS

Scenario 2 accelerates both the penetration of IPv6 capabilities and enabling of IPv6 by users. RTI projected the impact of a 1-year acceleration of capabilities. In addition, enablement still occurs at the time that capabilities become available, resulting in a 4-year acceleration of IPv6 enabling. Figure 6-2 provides a visual representation by adjusting the U.S. user-capable and enabled curves from Figure 3-2.

Figure 6-2. Acceleration Scenario 2



Similar to Scenario 1, costs increase in Scenario 2 due to a 5 percent increase in the cost of enabling activities and users incurring costs sooner than later. However the main incremental cost component in Scenario 2 is the early replacement of hardware and software needed to accelerate the penetration of user IPv6 capabilities.

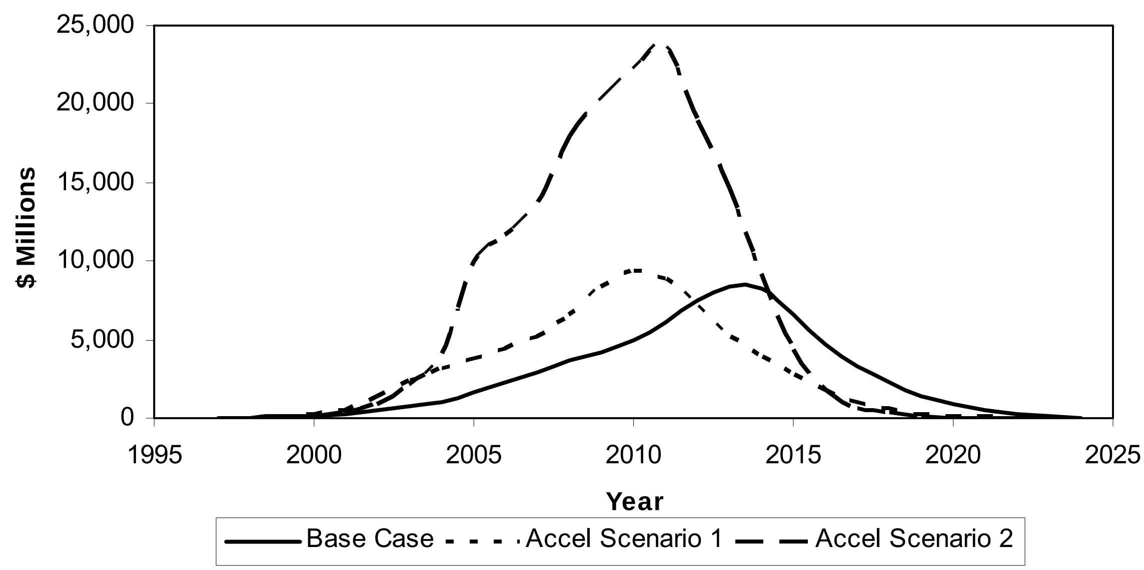
If users are to accelerate the penetration of IPv6 capabilities on average 1 year earlier than would occur during normal upgrades and replacement, this implies a 1-year decrease in the average life expectancy of existing hardware and software.

To capture this opportunity cost of early hardware and software retirement, RTI added to our cost model 1 year's annual spending on affected hardware and software components. To approximate the 1-year opportunity cost of the existing stock of Internet hardware and software, we used annual expenditures in 2003. Based on estimates provided in the "Gartner 2004 IT Spending and Staffing Survey Results" report[4] and Census data,[5] annual expenditures on Internet hardware and software in the United States in 2003 totaled approximately $123 billion. This cost is distributed over time based on the accelerated (new) penetration rate of user capabilities shown in Figure 6-2.

6.3 INCREMENTAL SCENARIO COSTS

The time series of costs associated with acceleration Scenario 1 and Scenario 2 are compared to the base case in Figure 6-3. PV cost differences are shown in Table 6-1. Scenario 1 yields a PV increase of approximately $6.4 billion over the time period of this analysis.

Figure 6-3. Acceleration Scenarios 1 and 2



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[4] Gartner report entitled "Gartner 2004 IT Spending and Staffing Survey Results" by Barbara Gomolski, October 29, 2004. In this report, Gartner provides summary data based on a survey of approximately 400 organizations. RTI used data in Table 15 (pages 15-17) concerning capital spending on client computing and storage hardware, servers, total capital software spending, in-building data networking (LANs), and external data communications (Internet/WAN/VPN/remote access).

[5] "2002 Economic Census: Table 1. Advance Summary Statistics for the United States—2002 NAICS Basis" by the U.S. Census Bureau. RTI summed "Sales, receipts, revenue, or shipments" estimates to determine total U.S. revenue. Available at http://www.census.gov/econ/census02/advance/TABLE1.HTM.

Table 6-1. Acceleration Costs ($ Millions)

	Peak Annual Cost ($M), Year	Incremental Maximum Annual Cost ($M)	Present Value in 2003 Dollars ($M)	Incremental Costs over Base Case ($M)
Base case	$8,387 (2013)		$25,434	
Acceleration Scenario 1	$9,361 (2010)	$974	$31,879	$6,445
Acceleration Scenario 2	$23,601 (2011)	$15,214	$71,963	$46,529

Scenario 2 becomes significantly more costly because of the early replacement of hardware and software 1 year ahead of schedule. The PV cost of the transition in Scenario 2 increases $46 billion over the base case to more than $70 billion.

Table 6-1 also indicates the year in which annual IPv6 transition costs peak. In the base case, costs peak in 2013 at $8.3 billion. Scenario 1’s annual costs peak at $9.4 billion in 2010, and Scenario 2’s annual costs peak in 2011 at $23.6 billion. Scenario 1’s costs peak a year earlier than Scenario 2’s because Scenario 1’s costs are driven by enabling activities that can occur 1 to 3 years prior to early replacement of hardware and software.

Appendix A: Interview Participants

The following is a list of organizations and individuals who participated in the interviews conducted by RTI.

Infrastructure Vendors

- Boeing Integrated Defense Systems
- Hewlett-Packard Company
- Microsoft
- Native6
- Nortel Networks

Application Vendors

- Arkivio
- Hexago
- Level7
- Mentat
- OnStor, Inc.
- Red Storm Entertainment Inc.

Internet Service Providers (ISPs)

- AT&T
- Earthlink
- Qwest
- Sprint
- Teleglobe
- Verio

Infrastructure Users

- Motorola
- Nextel
- Nokia
- Panasonic

Internet Users

- The Boeing Company
- CENTAUR/NC State University
- Defense Research Engineering Network (DREN)
- ESNet
- Internet2
- U.S. Army

Other Interested Parties

- IPv6 Forum
- North American IPv6 Task Force (NAv6TF)
- Paul Francis