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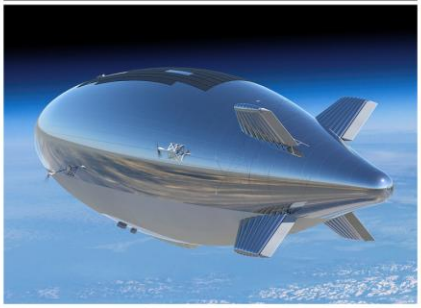
COLORADO



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LAUNCH!

TAKING COLORADO'S SPACE ECONOMY TO THE NEXT LEVEL

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BROOKINGS ADVANCED INDUSTRIES SERIES

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THE BROOKINGS INSTITUTION | METROPOLITAN POLICY PROGRAM | 2013

STATE OF COLORADO

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John W. Hickenlooper
Governor

February 5, 2013

Greetings:

Colorado has long been a hub for innovation. Since our state's founding, entrepreneurs have employed Colorado's resources to access new markets and direct new technologies that have contributed greatly to our economic successes.

Today, this spirit maintains Colorado's reputation as a great place to work, live and play. With one of the most educated workforces in the country and an unparalleled quality of life that provides a great place to raise a family, there is no question why Colorado is an attractive place for companies to expand and relocate.

We are grateful that the Brookings Institution, supported by the Rockefeller Foundation, partnered with the Colorado Office of Economic Development and International Trade to craft a forward thinking business strategy to support the Aerospace Industry in Colorado. This report affords us the opportunity to capitalize on the strengths of Colorado's Aerospace sector and develop strategies to collaboratively address the challenges facing the industry.

Building on the Colorado Blueprint, a bottom-up economic development strategy, this joint effort has created a platform for communicating directly with industry to develop a strategic plan that demonstrates how Colorado is positioned to confront the challenges we face as a state. The effort will also ensure that Colorado is at the forefront of cultivating a relentlessly pro-business environment in which advanced industries will thrive.

We are optimistic that Colorado, in close collaboration with our partners, can strengthen its competitive standing in the Aerospace Industry and utilize the momentum to build upon our continued efforts to support other important industry networks.

Together, we will make Colorado the best state in the nation for business, while maintaining the highest quality of life.

Sincerely,

John W. Hickenlooper
Governor

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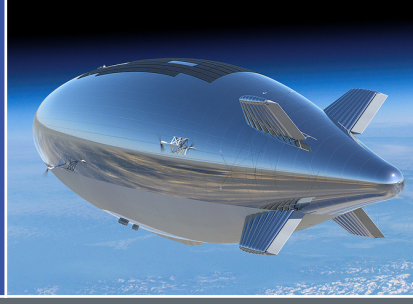


LAUNCH!

TAKING COLORADO'S SPACE ECONOMY TO THE NEXT LEVEL

EXECUTIVE SUMMARY

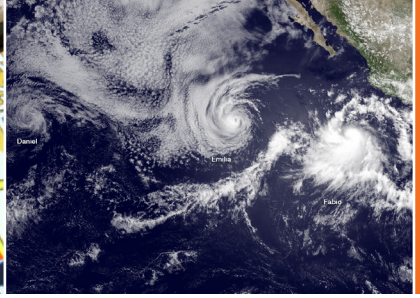
Anchored by critical military installations, glistening clean rooms, and iconic defense and aerospace contractors, the Colorado space industry has been a source of pride and prosperity for Colorado residents for decades.

Now, at a time of testing, interest is rising again.

With the Great Recession receding but disruptive change in the air, the state—like many others—has been moving to reassess its economic positioning and identify the most reliable sources of long-term growth and competitiveness.

Most notably, the administration of Gov. John Hickenlooper—alert to calls that the U.S. must reorient its drifting economy away from consumption activities and imports and more toward high-value innovation, production, and exports—has been carrying out a major economic planning initiative aimed at engaging the state's key industries and regions in a "bottom-up" effort to explore and seize on the best opportunities for economic expansion.

Through this Colorado Blueprint process, the state has come to focus—with support from the Brookings Institution Metropolitan Policy Program—on its extraordinary space / aerospace cluster, which it quickly recognized was a classic "advanced industry."



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As defined by Brookings, advanced industries (AIs) like the space industry are the high-value engineering- and R&D-intensive industrial concerns that are the prime movers of regional and national prosperity in the U.S.

AIs matter because large and small companies in the sector—ranging from Lockheed Martin, Ball Aerospace, and DigitalGlobe in space to Ford, Nissan, Siemens, GE, Intel, and Medtronic in other industries—generate 10 percent of the nation's output, 46.5 percent of U.S. goods exports, and over 8 million skilled jobs. Likewise, AIs like aerospace and defense, advanced electronics, automotive design and assembly, semiconductors, and medical devices matter because they encompass a huge piece of the national R&D enterprise that has enabled a steady stream of life-transforming innovations ranging from air flight and GPS to LASIK, MRIs, and clean energy.

Yet like the Colorado space industry AIs are not inevitable. And so—at a moment of economic and policy uncertainty at the national level and disruptive change in the space industry—a confluence of state economic development interest and industry self-reflection has created a juncture of some urgency in Colorado.

Focused by change and the state Blueprint process, the state's space sector finds itself residing at a point of tremendous opportunity and peril as it considers how to navigate massive uncertainties and capture further advantage in the years ahead.

On the one hand, Colorado space activities and space technologies appear well positioned to enable and profit from major expansions of the nation's most critical military, civil, and commercial enterprises. Military actors in the state provide capabilities increasingly important to monitoring potential threats, managing forces, and carrying out combat operations while civil and commercial players remain deeply enmeshed in hot growth industries ranging from earth observation and weather forecasting to GIS and satellite communications.

On the other hand, though, the state's space cluster faces the next five years concerned about threats ranging from its continued dependence on increasingly uncertain government budgets to the rise of new competitors, new business models, and new questions about its competitive underpinnings.

In short, one of the nation's leading space states (and clusters)—aware of both its substantial strengths and disruptive change—is gearing up to defend and expand its long-term competitiveness.

Hence this report: Reflecting extensive consultation with space industry stakeholders convened by the Colorado Blueprint's Key Industry Networks Process and delivered as part of the Brookings Advanced Industries Series, **"Launch! Taking Colorado's Space Economy to the Next Level"** assesses the current competitive position of the Colorado space cluster and suggests private-sector and state government strategies for advancing it.

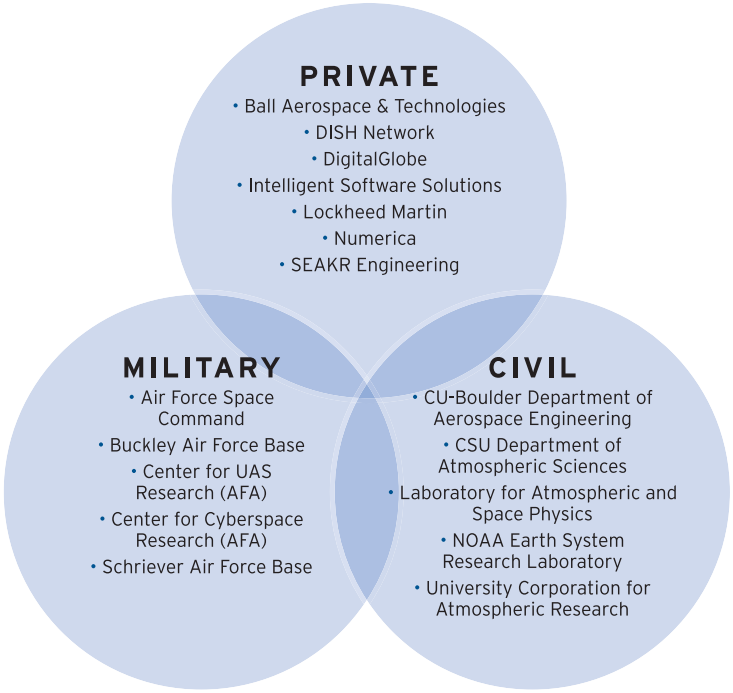
In that vein, the pages that follow advance three major findings about the Colorado space economy:

1. COLORADO POSSESSES ONE OF THE MOST DIVERSIFIED, MULTIDIMENSIONAL, AND HIGH-POTENTIAL SPACE ECONOMIES IN THE NATION

In this respect, a detailed, establishment-level analysis of the state's space cluster furnishes encouraging new intelligence about the cluster's depth, diversity, and growth dynamics. Specifically, the new analysis concludes that:

- **THE SPACE ECONOMY IS AN OUTSIZED DRIVER OF COLORADO'S ECONOMY.** According to the new analysis, space activities, applications, and services pervade the state's industry base—cutting across the public and private sectors and spilling over into telecoms, software, advanced materials, and more. In total, the Colorado space economy directly employs over 66,000 workers across the military, civil, and private domains. Furthermore, the cluster contributes inordinately to the state's overall economic enterprise. In this fashion, the value-added output generated by the private space economy's 2.6 percent of the workforce reached $8.7 billion in 2011, or 3.8 percent of Colorado's private-sector gross domestic product (GDP). All told, space firms generated around $16 billion in sales in 2011. Moreover, space economy firms and establishments have been steady contributors to job growth in the state. From 2008 to 2011, as the national economy fell into and began its climb out of recession, small space establishments added nearly 2,000 jobs and large establishments nearly 1,500 jobs, thereby helping mitigate the effects of the economic downturn on the Colorado economy. Nor are space jobs average jobs. Private sector space economy employees earned an average annual income of $92,500 in 2011, compared to the state private-sector average of just $49,000. Thanks to these high wages, the space economy paid 4.9 percent of all private wage earnings in the state despite employing just a little more than half that share of the private workforce

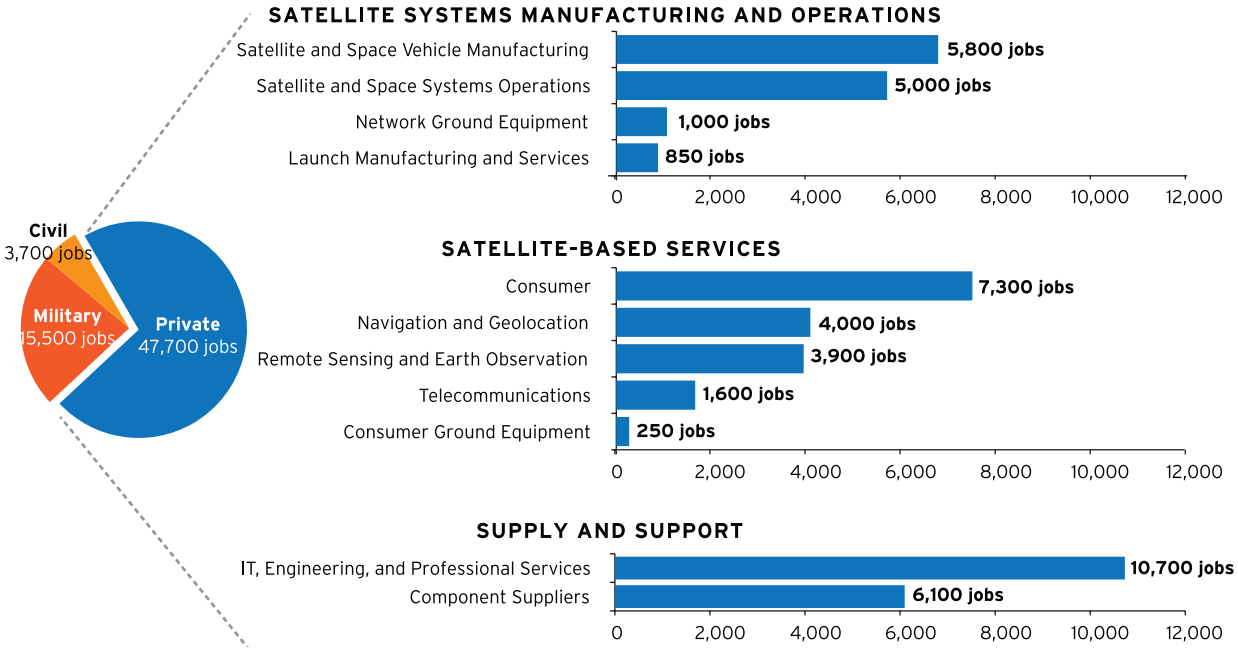
The Colorado space economy comprises three sectors



Source: Brookings analysis

- **COLORADO'S PRIVATE SPACE ECONOMY IS MULTIDIMENSIONAL AND POLYCENTRIC.** The sizable private-sector side of the state's space economy is relatively evenly distributed across three broad categories of space activity: space system manufacturing and operations; satellite-based services; and supply and support. As such, the private space enterprise in Colorado stretches across the full spectrum of space-related activities to comprise a cluster that is diverse, multi-centered, and technology-intensive. The three large categories of activity can be further divided into 11 narrower segments. The traditional core of the industry—*space systems manufacturing and operations*—is the smallest of the three categories, accounting for just under 30 percent of the state's space economy jobs (13,900 in 2011) but a disproportionate share of revenues. This category includes satellite and space systems operations and satellite and space vehicle manufacturing as well as launch manufacturing and services and network ground equipment—and it has been relatively slow growing. Much faster growing has been the *satellite-based services* category which encompasses those segments that use satellites to deliver a service back on earth. This set of industries has been growing by nearly 8 percent a year and now employs 17,000 Coloradans or 35.7 percent of the state's private space economy jobs. Satellite-based services is now the largest category of space economy activity in Colorado in terms of both jobs and revenues. Ranging from consumer services to navigation and geolocation, remote sensing and earth observation to telecommunications, these industry segments generate $6.3 billion in annual revenue—a disproportionate 37.8 percent of the revenue produced by the space economy as a whole. Finally, over one-third of space economy jobs—35.3 percent, or 16,825 positions—fall into the *supply and support* category, which supplies and supports the space manufacturing and services complex with myriad products and services. This category, which encompasses both components and IT, engineering, and professional services, punches slightly below its weight in terms of revenue and output, generating just of 30 percent of net sales and GDP.
  In sum, Colorado's space economy consists of a wide and deep assemblage of activities united by a common platform: space-based technology. Taken together, these activities generate exceptionally well-paying jobs and significant sales and growth all unified by increasingly high-tech platforms and content

Within the private sector, the number of space economy jobs varies by category and segment



- **COLORADO'S SPACE ECONOMY IS INCREASINGLY SERVICES-ORIENTED.** The new analysis further reveals that the space enterprise in Colorado is changing. Specifically, the space economy—notwithstanding the size and importance of its manufacturing and operations sector—is increasingly services-oriented as that is where the growth is. This is on balance good news for the Colorado space economy as a whole as these dynamic, often commercial, industry areas play to some of the state cluster's strengths. What is more, demand for services such as direct-to-home satellite television, satellite telecommunications, and satellite-based precision-navigation-timing capabilities helps drive the upstream space systems manufacturing complex. The state now specializes in both activities. Nor is the trend towards services restricted to end-user markets for space-derived capabilities. At the other end of the value chain, IT and engineering services represent an increasingly significant input into the ever-more complex technology systems that enable the space economy in the first place. This strength in advanced services also bolsters manufacturing, which still represents a critical element of the state's space economy. In this respect, the co-location of advanced manufacturing and services constitutes a competitive advantage of increasing importance and positions Colorado for continued growth and innovation in both areas

- **COLORADO'S SPACE ECONOMY SPANS FOUR METRO AREAS AND AT LEAST EIGHT RURAL COUNTIES BUT IS HEAVILY CLUSTERED ALONG THE FRONT RANGE.** Finally, the establishment level analysis concludes that fully 99 percent of jobs in Colorado's private space economy are concentrated in the four metropolitan areas along the Front Range, the megapolitan area that stretches from Fort Collins in the north to Colorado Springs in the south. The remaining space economy jobs are spread across three smaller metropolitan areas—Pueblo, Durango, and Grand Junction—in addition to at least seven further rural counties. In this sense, the Colorado space industry represents a classic innovation and industry cluster, highly concentrated in a single region. Even still, important geographic distinctions emerge at the sub-regional and segment level. Boulder specializes in civilian-oriented space activity with an emphasis on high-value science and engineering, Colorado Springs specializes in military-oriented space activity, and Denver boasts the most diversified segment portfolio in the state and dominates in the satellite-based services category.

The sum-total of these findings: Colorado has amassed a formidable, layered, and diverse space economy that contributes heavily to the state's economic well-being. To be sure, future growth will likely occur outside of the industry's traditional core, representing an important shift from years past. But fortunately, promising growth opportunities exist in a wide variety of industry segments already clustered up and down the Front Range.

2. HOWEVER, WHILE SIGNIFICANT OPPORTUNITIES ARE EMERGING, A SET OF DISRUPTIVE FORCES AT WORK IN THE GLOBAL SPACE MARKET HAVE EXPOSED A NUMBER OF COMPETITIVE CHALLENGES FOR THE COLORADO INDUSTRY

To be sure, numerous trends point to continued growth in Colorado's space economy—especially in promising "adjacent" markets that hold out compelling commercial opportunities. Some in the venture capital community, for example, speak of a coming "Netscape moment" for the industry when major capital market investments set off a wave of fundings of so-called "new space" startups. Likewise, while projections indicate modest top-line global growth for private-sector space revenues, they suggest the cybersecurity / intelligence and unmanned aerial vehicle (UAV) markets will double in next five and 10 years respectively. In short, the global space economy presents a sizable, growing, and attractive opportunity for Colorado. And yet, fundamental changes in the space marketplace are challenging participants to innovate by developing new technologies and business models. At least three mega-trends are redefining the very nature of competition in the U.S. space sector:

- **THE CUSTOMER BASE IS CHANGING.** To begin with, global demand is shifting away from its historic, relatively simple, concentration in space infrastructure for a few governments (particularly America's). Federal government spending is flatlining, on the one hand, while growing international demand is difficult to access—and contested. More fundamentally, the space industry has shifted from one dominated by the manufacture and build-out of space infrastructure (satellites, launch systems, and ground-based control systems) to one driven primarily by the provision of space-based services—including communications such as fixed and mobile satellite services and entertainment such as direct-to-home television and satellite radio. Service-provision often to commercial customers is the new reality

- **CUSTOMERS ARE DRIVING A NEW INDUSTRY EMPHASIS ON VALUE, SERVICE, AND CAPABILITY.** At the same time, changes in the customer base are requiring space actors to change how they operate to improve their responsiveness. Changing government preferences and the growth of commercial space-based services markets are amplifying the need for the adoption of more commercial business models—i.e., fixed-price, product-based, and customer-focused approaches. These dynamics are forcing both business and technological change in the industry. Companies deeply rooted in big-government or military-oriented cultures are being forced to become more entrepreneurial and collaborative. And meanwhile firms must seek out new sources of research and development (R&D) to develop and commercialize new technologies, which in turn will require new financing mechanisms to fund the critical space economy innovation process

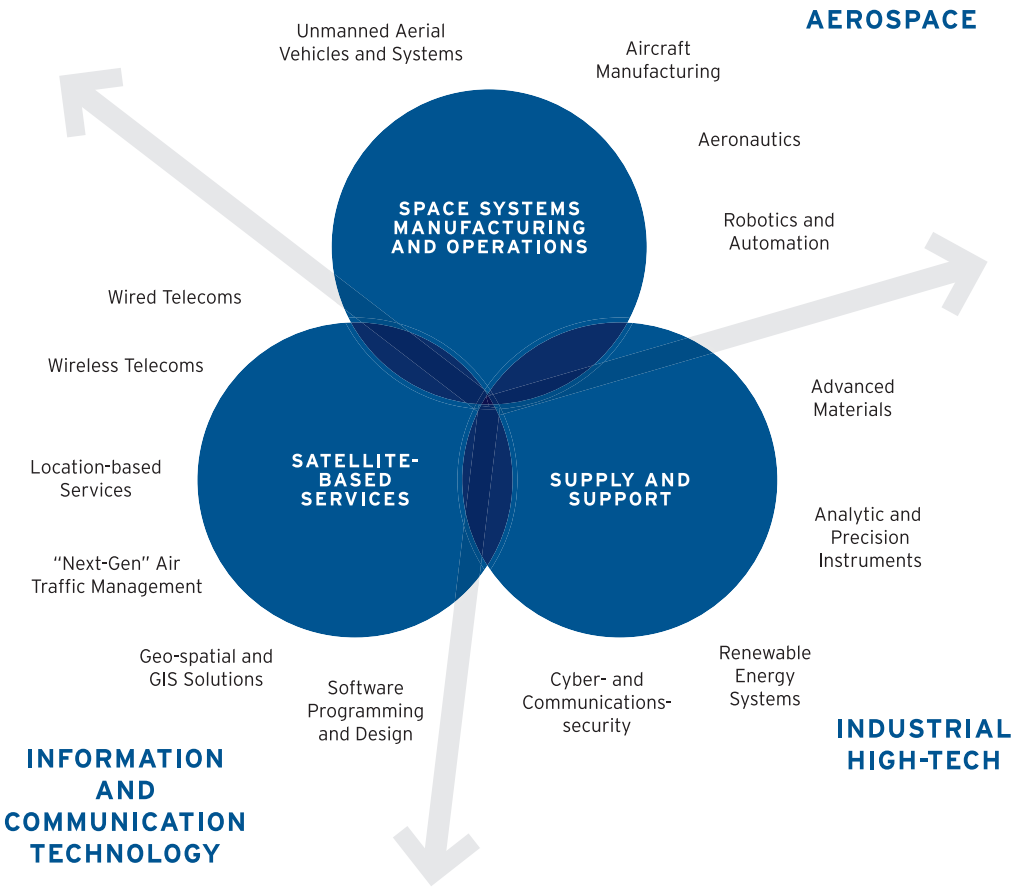
- **THE INDUSTRY'S COMPETITIVE UNDERPINNINGS ARE UNDER STRESS.** Finally, a looming skills gap due to an aging workforce and a growing imperative to innovate are challenging the very origins of the space industry's competitive standing. On the skills front, a potential wave of retirements in the next five years will severely test the ability of the space industry to maintain a high-quality technical workforce. As to technological advancement, the imperative to maintain competitiveness in a world with more players, shorter product lifecycles, and more complex products is ratcheting up the need to strengthen the space economy innovation system and the collaborations that make it work best. Along these lines, space companies are increasingly finding that they need to reshape themselves to maintain world-class technical staffs and innovate at the needed rates

In light of these trends, a systematic SWOT (strengths, weaknesses, opportunities, and threats) assessment reveals that Colorado's space economy approaches the future with tremendous assets but also a number of vulnerabilities. In terms of its assets, Colorado seems well situated to flourish. A strong entrepreneurial bent, low to moderate costs of doing business, a strong innovation system, and a large base of skilled STEM talent provide the prerequisites for success. Yet the state's strengths go far beyond business basics to encompass more specialized sector-specific attributes. An enviable complex of military and civil institutions anchors the cluster. A dense assemblage of organizations and networks such as the Colorado Space Coalition (CSC), the Space Foundation, eSpace: The Center for Space Entrepreneurship, and the Space Business Roundtable provide intellectual infrastructure for a well-organized, geographically concentrated space ecosystem. And of course, the state enjoys a strong position in government space, secured in large part by its proven ability to win federal contracts.

At the same time, ongoing trends expose a number of deficiencies that could imperil the ability of the Colorado space economy to maintain its momentum. In this respect, at least six challenges raise questions about the near- to medium-term competitive position of this "crown jewel" industry:

- **A HEAVY DEPENDENCE ON GOVERNMENT SPACE MAKES THE COLORADO SPACE ECONOMY VULNERABLE TO FEDERAL FUNDING PULLBACKS.** Ironically, what makes the state strong also makes it vulnerable. The predominance of military and intelligence activities in the space sector and the state's heavy reliance on federal government contracting make the state susceptible to federal budget drawdowns and fiscal uncertainties

The future shape of Colorado's space economy will be defined by both familiar segments and new opportunities in emerging and adjacent ones



Source: Brookings analysis in consultation with McKinsey & Co.

- **THE STATE HAS YET TO GAIN A SIGNIFICANT TOEHOLD IN NEW SPACE, ADJACENT, AND GLOBAL MARKETS.** Although Colorado firms badly need to pivot into emerging new markets that are less dependent on federal support, the state space industry has not moved aggressively in this direction as yet and actually lags on some indices of competitiveness when compared to its peer states

- **THE STATE'S INNOVATION SYSTEM IS STRUGGLING WITH THE CHALLENGES INHERENT IN TECHNOLOGY TRANSFER AND COMMERCIALIZATION WITHIN THE AEROSPACE AND SPACE SECTORS.** Very little matters for the future competitiveness of the Colorado space economy as much as the efficiency and speed of the state's innovation ecosystem, which will increasingly depend on effective collaboration, especially between the state's universities and industry. And yet here, too, shortcomings in the state's space-related innovation activities—particularly with regard to university-industry collaboration and technology transfer—raise questions about Colorado's ability to achieve and defend global leadership in this industry

- **INSUFFICIENT ACCESS TO RISK CAPITAL STYMIES STARTUPS.** Innovation and commercialization in the space economy also require adequate flows of patient, risk-tolerant capital. And yet, investment capital has remained scarce in the aerospace and space sector. With venture capital (VC) funding in the state heavily skewed toward the energy, software, IT services, and biotech sectors, Colorado's space economy entrepreneurs find themselves at a disadvantage when compared to competitors in other states. Furthermore, because VC funds typically prefer to invest in local companies, fewer Colorado-based VC funds effectively translates into less VC for Colorado startups

- **AN AGING SCIENCE AND ENGINEERING WORKFORCE AND OTHER WORKFORCE-RELATED CHALLENGES COULD ADVERSELY IMPACT THE INDUSTRY'S FUTURE GROWTH.** The national STEM workforce challenge appears especially acute for Colorado. In this regard, three workforce-related challenges must be addressed in order to ensure the future growth of Colorado's space sector: an aging science and engineering workforce; a looming shortage of STEM graduates in the next five to 10 years paired with increasing demand for skilled workers; and very low state spending for higher education as a proportion of GDP

- **SUBOPTIMAL CLUSTER DYNAMICS—ESPECIALLY THOSE INVOLVING COLLABORATION—MAY BE HINDERING GROWTH.** With collaboration increasingly central to the innovation and growth process, the state's complicated cluster dynamics may not be functioning at optimal levels. Qualitative analysis suggests that a number of institutional, geographical, sectoral, and cultural challenges may well be depressing the collaborative vibrancy of the state's extraordinary assemblage of space actors

3. GIVEN THESE CHALLENGES AS WELL AS ITS MANY STRENGTHS, COLORADO SHOULD COMMIT ITSELF TO PREEMINENCE IN SPACE THROUGH A COLLABORATIVE PARTNERSHIP OF INDUSTRY AND GOVERNMENT ALONG SIX DIMENSIONS

In this respect, Colorado's strong overall competitive standing amid disruptive megatrends licenses an ambitious vision of the state's future in the space economy. Colorado's goal over the next five to 10 years should therefore be simple and bold: **"Colorado becomes the center of innovation for the global space economy."** As to how to get there, Colorado's industry leaders and government should embrace a new, more aggressive, creative, and collaborative mindset focused on addressing specific cluster deficiencies in the light of global dynamics by creating a supportive environment in which competitive and innovative space firms can flourish. Implied by the six major challenges the state faces, six strategies for advancing the Colorado space economy suggest themselves:

- **CONSOLIDATE AND MAXIMIZE THE STATE'S POSITION IN THE SPACE ECONOMY EVEN AS GOVERNMENT SPACE CONTRACTS.** As federal funding declines, big projects are dwindling, government customers are moving toward lower-priced solutions, and commercial contracting methods are on the rise. Colorado and its space firms will need at once to "defend the base" of its present civilian and military activity even as they adapt to the changing landscape of government space

- **SEIZE COMMERCIAL OPPORTUNITIES IN EMERGING NEW SPACE, ADJACENT, AND GLOBAL MARKETS.** With growth prospects modest in conventional government space, a strong and strategic pivot to embrace emerging opportunities in new commercial, adjacent, and global markets is the most important thing that Colorado and its space firms can do to assure continued preeminence in the future space economy. Pivoting in this way will require all parties to master new technologies and new ways of doing business

- **COMMIT TO INNOVATION AND OWNING THE NEXT GREAT SPACE TECHNOLOGIES.** Amid disruptive change Colorado's space competitiveness will hinge on how well its innovation ecosystem functions. The state should put a new emphasis on R&D; collaboration among companies and between industry and research institutions; and the commercialization of innovation. Innovation is not everything, but it is almost everything

- **IMPROVE THE AVAILABILITY OF RISK CAPITAL.** Colorado companies—working with the state—will need to adopt more of an investment mindset and seek out and experiment with broader sources of finance to scale up their products

- **BOLSTER THE WORKFORCE PIPELINE TO SECURE COLORADO'S HUMAN CAPITAL ADVANTAGE.** A long-term commitment to and strategy for developing, attracting, and retaining a skilled, flexible, and technically competent workforce will be critical in the coming half-decade

- **INTENSIFY CLUSTER DYNAMICS.** A strong cluster-based development strategy that emphasizes breaking down silos and increasing collaboration among the state's myriad industry stakeholders and cluster organizations will help to diversify and increase the competitiveness of Colorado's space economy. In this respect, the centrality of collaboration to innovation makes it imperative to foster the collaborative exchanges of the state's rich cluster

* * *

In terms of moving forward, both industry and government should organize an array of actions along the lines of these six strategies. In this vein, this report recommends the following division of labor among industry and government actors to take the Colorado space economy to the next level:

- **THE PRIVATE SECTOR MUST LEAD THE WAY IN MAKING COLORADO THE UNDISPUTED CENTER OF INNOVATION FOR THE GLOBAL SPACE ECONOMY.** In this respect, though military and civil sector organizations will continue to anchor the state's space cluster, the private sector alone possesses both the self-interest and ability to grow its share of current markets and pursue new growth opportunities. To that end, Colorado space firms should embrace the six growth strategy themes to simultaneously improve their individual performance and advance the collaborative power of the cluster.

  To consolidate and maximize their position in space, firms should (among other things): **Focus on affordability to secure competitive positions in core government markets,** which will increase an individual contractor's probability of winning and help ensure that programs remain fully funded. To achieve greater affordability, companies will need to drive a step change in efficiency and productivity and institutionalize a more commercial approach to business. In addition, firms should aggressively develop, seek out, or acquire distinctive capabilities

  To seize commercial opportunities in new markets, firms should: **Build on product and technology knowledge in R&D to develop new products or take products to new markets.** Likewise, companies can leverage existing customer relationships to expand their offerings or expand into new areas of the value chain

  To commit to innovation, firms should: **Increase internal R&D investment in next-generation technologies.** Companies should set a goal of "owning" the technologies that will enable the next generation of space-based systems and space-enabled services. In addition, industry should actively **support the development of a Colorado AI innovation hub**, which will strengthen the state's innovation ecosystem, foster collaboration, and help build the industrial commons that will nurture Colorado's advanced industries for its next growth period

  To improve the availability of risk capital larger, companies should: **Reinvigorate corporate venture capital** efforts, which will afford larger firms improved access to cutting-edge capabilities while also helping small companies break into established space markets. Such a way of identifying, scaling, and bringing to market innovative new products and capabilities will benefit both large and small companies in the state

  To bolster the workforce pipeline, all firms should: **Better model future skill requirements,** which will enhance both how industry attracts and retains new talent as well as how it develops its existing workforce. Sharpening the process

THE FEDERAL GOVERNMENT MUST DO ITS PART

The state of Colorado is rededicating itself to a collaborative partnership with industry and other governments to advance the state's extraordinary space cluster. So should the state's congressional delegation. Members should organize their work around the six strategy agendas this report has identified along the lines of the actions presented below:

- To consolidate and maximize Colorado's position in the space economy, the federal government must **circumvent sequestration** and provide a more predictable path to budgetary and programmatic stability in the near- and long-terms. The federal government should also **recommit itself to the nation's space program** and endow it with a clear vision and mission.

- To help Colorado's space economy seize commercial opportunities in new markets, the federal government should **implement export control reform** as quickly as possible and **set the regulatory parameters for integrating UAVs / UASs into national air space.**

- To commit to innovation, the federal government should **invest in R&D, make the research and experimentation tax credit permanent** and move to **create and scale up a national network of AI innovation hubs**, beginning with the proposed National Network for Manufacturing Innovation.

- To improve access to capital, the federal government should **maintain its commitment to the SBIR / STTR grant program** and consider tax incentives for startup operating capital.

- To bolster the workforce pipeline, the federal government should **create and fund portable manufacturing skills certifications, reinvigorate the workforce development system** with a "Race to the Shop" competition, and reform the immigration system for growth.

- Finally, to intensify cluster dynamics, the federal government should **support and expand existing cluster grant programs** and, in addition, **seek ways to boost federal laboratories' involvement in economic development.**

by which firms and industry identify and fill critical skills gaps will be essential. **In addition, stronger partnerships with educational and training institutions** will help ensure that workers are well prepared for current and projected job opportunities

To intensify cluster dynamics, the private sector should: **Encourage and engage with state efforts to improve how the space cluster functions.** Advocacy for and active engagement with a new state space cluster champion, support for state-led marketing initiatives, and contributions to the state's industry mapping efforts will help improve coordination and collaboration within the state's space cluster

- **MEANWHILE, THE PUBLIC SECTOR MUST CREATE A SUPPORTIVE ENVIRONMENT IN WHICH COMPETITIVE AND INNOVATIVE SPACE FIRMS CAN FLOURISH.** For its part, the state—in collaboration with industry and in close partnership with Colorado's congressional delegation—should work in focused, strategic ways to ameliorate the sorts of governance, institutional, and market challenges this report has identified. In this respect, the state should lead on a number of fronts while at the same time maintaining a supportive and collaborative stance in dealings with industry, the delegation, and the state's critical cluster organizations.

To consolidate and maximize the state's position, the governor should: **Take the lead in convening both Colorado's congressional delegation and other aerospace states** so that together they can defend and advocate for growth in the space economy. The state government should also **brand and relentlessly market Colorado's space economy** in order to raise awareness of the many space-economy strengths that Colorado offers. **A dedicated "sector champion"** can further these marking efforts while at the same time spearheading space cluster development and ensuring regular dialogue with stakeholders

To seize commercial opportunities in new markets, the state should: **Position the state to lead on next-generation system platforms** such as UAV/UASs. In addition, **establishing a governor's prize for new space business plans** would direct attention toward new commercial opportunities, build buzz, and open the door to follow-on investment, and encourage further innovation

To commit to innovation, state government should: **Create a targeted matching grants program** similar to the Bioscience Discovery Evaluation Grant Program that would help researchers and companies bridge the AI technology development gap more efficiently and effectively. The state should also **establish a statewide AI innovation hub**, which would further bolster Colorado's innovation capacity by taking on the cross-cutting technology challenges that are most critical to the state's advanced industries. **A state-run innovation vouchers program** for smaller firms seeking innovation expertise would encourage industry-university collaboration on pressing concerns, and **a SWAT team of innovation "site miners"** would expedite technology transfer by helping participating universities actively seek out commercial opportunities

To improve the availability of risk capital, the state should: **Establish an annual space economy investor's conference** at which top-quality opportunities could be presented, deals discussed, and networking accelerated. In addition, **matching grants to SBIR/STTR award recipients and a Phase 0 Fund for prospective SBIR/STTR applicants** would help maximize Colorado firms' access to federal resources. Meanwhile, as the state takes steps to **improve its existing state-run venture capital fund**, it should also consider working to **create university-based venture capital funds**, which would greatly expand the availability of risk capital

To bolster the workforce pipeline, state government should: **Create a dedicated STEM education initiative or entity** in order to ensure that the many great STEM education resources and programs already in place become more than the sum of their parts. **An "Intern in Colorado" initiative**, meanwhile, would better connect students to various AI internship opportunities across the state. And a push to **create industry skills panels** (including in aerospace) would foster a robust workforce and economic development ecosystem by bringing together representatives from the private sector, labor, and the state's educational and training system to devise solutions to common workforce and skills challenges in the space industry and elsewhere

To intensify cluster dynamics, it should: **Leverage existing cluster partnerships** to increase the levels of collaboration, inclusivity, and exchange within the cluster. **A state-run competitive grant program** would reinforce such efforts by building the networking capacity of the state's cluster organizations. And **a collaborative R&D tax credit** would reward collaboration between industry and academia

* * *

In the end, the aspirations and actions for industry development urged here are bold—but only as bold as is required given the potential for decline posed by the disruptive forces at work. In that sense, the potential for success seems high—and the opportunity for gains large—should industry and government together focus together now: and execute. ■

INDUSTRY AGENDA

$** = Little to no cost | **$$** = Low cost | **$$$** = Moderate cost | **$$$$ = High cost

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Focus on affordability to secure competitive positions in core government markets	**$-$$$**

Seize commercial opportunities in emerging new space, adjacent, and global markets

Build on product and technology knowledge in R&D to develop new products or take products to new markets	**$$-$$$**
Leverage existing customer relationships and familiarity with customers' requirements to expand offerings	**$**

Commit to innovation and owning the next great space technologies

Increase internal R&D investment in next generation technologies	**$$$$**
Actively support and help shape the state's efforts to establish a statewide advanced industries innovation hub	**$$-$$$**

Facilitate the availability of risk capital for small and medium-sized entrepreneurial firms

Reinvigorate corporate venture capital	**$$$$**

Bolster the workforce pipeline to secure Colorado's human capital advantage

Model future skill requirements	**$**
Develop a greater number of leaders conversant in commercial and international markets	**$**
Develop stronger partnerships with educational and training institutions	**$-$$**

Intensify cluster dynamics

Advocate for and actively engage with a new state space cluster champion	**$**
Support state-led marketing and industry mapping efforts	**$$**
Foster more effective collaboration	**$**

STATE AGENDA

$** = Little to no cost | **$$** = Low cost | **$$$** = Moderate cost | **$$$$ = High cost

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Produce and annually or biannually update a sophisticated strategy for bolstering Colorado's space economy preeminence	**$**
Lead in convening Colorado's congressional delegation to defend and advocate for the expansion of the state's space economy	**$**
Lead in convening the leading aerospace states	**$**
Brand Colorado's unique space economy and market it relentlessly	**$$**
Name a dedicated "sector champion" to spearhead cluster development	**$$**
Ensure that Colorado remains a business and military friendly state by engaging in regular dialogue with stakeholders	**$**

Seize commercial opportunities in emerging new space, adjacent, and global markets

Survey the competitive landscape in additional detail	**$**
Promote the new opportunities and celebrate the companies seizing them	**$**
Position the state for leadership in next-generation aerospace / space platforms	**$$-$$$**
Offer modest "deal closers" or small relocation incentives for innovative small firms	**$$$**
Launch a governor's prize for new space business plans	**$-$$$**
Facilitate the convening of technology "boot camps" around opportunities for innovation	**$**
Spearhead a space and new space trade mission	**$$**
Solicit foreign direct investment	**$**

Commit to innovation and owning the next great space technologies

Create a program that bridges the advanced industries technology development gap	**$$$$**
Establish a statewide advanced industries innovation hub	**$$$$**
Bolster the Colorado Higher Education Competitive Research Authority	**$$$**
Create an innovation vouchers program	**$$$**
Launch a matching grants program for collaborative R&D projects	**$$$**
Appoint a SWAT team of innovation "site miners"	**$$**
Develop more industry-friendly university-to-business technology licensing agreements	**$**

Improve the availability of risk capital

Establish an annual space economy investor's conference	$
Provide matching grants to SBIR / STTR award recipients	$$-$$$
Create a "Phase 0" Fund	$$
Improve the existing state-run venture capital fund	$
Create university-based venture capital funds	$$$$
Create an advanced industries fund of funds	$$$$

Bolster the workforce pipeline to secure Colorado's human capital advantage

Create a dedicated statewide STEM education entity or initiative	$-$$
Create a set of focused high school advanced industries career academies	$$-$$$$
Expand and strengthen advanced industries apprenticeship opportunities	$$
Provide far more opportunities for work-based learning including cooperative education	$
Launch an "Intern in Colorado" initiative	$$
Launch an advanced industries fellows program	$$
Create industry skills panels	$

Intensify cluster dynamics

Leverage existing cluster partnerships	$
Build the capacity of the state's cluster organizations through a competitive grant program	$-$$$
Launch a multi-sectoral, multidisciplinary road-mapping and collaboration forum	$-$$
Create a collaborative R&D tax credit	$$$
Prioritize or provide incentives for multi-actor applications to state funding programs	$
Sponsor or provide matching grants for an "entrepreneurial leave" program	$$-$$$

FEDERAL AGENDA

$ = Little to no cost	**$$** = Low cost	**$$$** = Moderate cost	**$$$$** = High cost

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Circumvent sequestration	**$**
Maintain commitment to the nation's civil space program	**$-$$**
Support the National Space Policy's priorities	**$$**
Move to reduce recent uncertainty in budgeting and programming	**$**

Seize commercial opportunities in emerging new space, adjacent, and global markets

Implement export control reform	**$**
Accelerate spectrum sharing initiatives	**$-$$**
Accelerate the integration of UAV / UASs into national air space	**$-$$**
Assure and expand commercial access to space	**$-$$$**
Embrace the spirit of frugal innovation throughout the procurement process	**$**
Pursue multilateral trade agreements	**$**

Commit to innovation and owning the next great space technologies

Boost investment in advanced R&D	**$$$$**
Move to create and scale up a national network of advanced industries innovation hubs	**$$$$**
Expand and make permanent the research and experimentation tax credit	**$$$**
Institute a collaborative R&D tax credit	**$$$**
Scale up mission-oriented, outside-the-box innovation initiatives	**$$-$$$$**
Expand the focus of the nation's research enterprise	**$**

Improve the availability of risk capital

Support continued or expanded funding of SBIR and STTR programs	**$-$$$**
Leverage the Export-Import Bank of the United States	**$**
Create tax incentives for startup operating capital	**$$$**

Bolster the workforce pipeline to secure Colorado's human capital advantage

Create and fund a nationwide manufacturing skills standards initiative	**$$**
Promote the creation of STEM-focused elementary, middle, and high schools	**$$$**
Create a "Race to the Shop" competition	**$$$$**
Reform the immigration regime for growth	**$**

Intensify cluster dynamics

Support maintenance or expansion of bottom-up competitive grant programs	**$-$$$**
Explore avenues for intensifying federal laboratories' engagement in regional economic development	**$$**

I. INTRODUCTION

Anchored by critical military installations, glistening clean rooms, and iconic defense and aerospace contractors, the Colorado space industry has been a source of pride and prosperity for Colorado residents for decades.

Generations of Coloradans have celebrated the presence of what may be the nation's largest complex of space-oriented military bases and university space exploration and earth-observation centers.

For years residents have watched the industry's steady stream of technological innovations, ranging from early rocket designs and the first weather satellites to the explosive growth of GPS technologies, space-enabled telecommunications, and meteorology.

And all along the state has appreciated the industry for its solid base of good-paying scientific, technical, and managerial jobs.

Now interest is rising again—but with new urgency.

With the Great Recession receding but disruptive change in the air, the state—like many others—has been moving to reassess its economic positioning and identify the most promising sources of long-term growth and competitiveness.

Most notably, the administration of Gov. John Hickenlooper—alert to calls that the United States must reorient its drifting economy away from consumption activities and imports and more toward high-value innovation, production, and exports—has been carrying out a major economic planning initiative aimed at engaging the state's key industries and regions in a "bottom-up" effort to explore and seize on the best opportunities for economic expansion.

Through this Colorado Blueprint process, the state has come to focus—with support from the Brookings Institution Metropolitan Policy Program—on its extraordinary space / aerospace cluster, which it quickly recognized stands as a classic "advanced industry."

As defined by Brookings, advanced industries (AIs) like the space industry are the high-value engineering- and R&D-intensive industrial concerns that are the prime movers of regional and national prosperity in the United States.[1]

AIs matter because large and small companies in the sector—ranging from Lockheed Martin, Ball Aerospace, and DigitalGlobe, Inc. in space to Ford, Nissan, Siemens, GE, Intel, and Medtronic in other industries—generate 10 percent of the nation's output, 46.5 percent of U.S. goods exports, and over 8 million skilled jobs. Likewise, AIs like aerospace and defense, advanced electronics, automotive design and assembly, semiconductors, and medical devices matter because they

encompass a huge piece of the national R&D enterprise that has enabled a steady stream of life-transforming innovations ranging from air flight and GPS to LASIK, MRIs, and clean energy.

Yet like the Colorado space industry AIs are not inevitable. And so—at a moment of economic and policy uncertainty at the national level and disruptive change in the space industry—a confluence of state economic development interest and industry self-reflection has created a juncture of some urgency in Colorado.

Focused by change and the state Blueprint process, Colorado's world-class space sector finds itself standing at a point of tremendous opportunity and peril as it considers how to navigate massive uncertainties and capture further advantage in the years ahead.

On the one hand, Colorado space activities and space technologies appear superbly well positioned to enable and profit from major expansions of the nation's most critical military, civil, and commercial enterprises. Military actors in the state provide capabilities increasingly important to monitoring potential threats, managing forces, and carrying out combat operations while civil and commercial players remain deeply enmeshed in hot growth industries ranging from earth observation and weather forecasting to GIS and satellite telecommunications.

On the other hand, though, the state's space cluster faces the next five years concerned about threats ranging from its continued dependence on increasingly uncertain government budgets to the rise of new competitors, new business models, and new questions about its competitive underpinnings.

In short, one of the nation's leading space states (and clusters)—aware of both its substantial strengths and disruptive change—is gearing up in order to defend and expand its long-term competitiveness.

All of which sets the moment for this report: Reflecting extensive consultation with space industry stakeholders convened by the Colorado Blueprint's Key Industry Networks Process and delivered as part of the Brookings Advanced Industries Project, **"Launch! Taking Colorado's Space Economy to the Next Level"** assesses the current competitive position of the Colorado space cluster and suggests private-sector and state government strategies for advancing it. In doing that, the report addresses the competitive situation of one quintessential advanced industry while suggesting the sort of strategies needed to advance other AIs.

Along these lines, the report that follows draws together significant new economic analysis of the Colorado space cluster; provides a new assessment of the state's competitive positioning amid global trends and domestic competition; and sets out a vision and action steps for enhancing that positioning.

The section immediately following this one frames the present moment of strategy seeking in the space sector and describes how Brookings worked to support, and glean input from, the state's convening of the Colorado space / aerospace industry through its Key Industry Networks Process.

Following that, Chapters III and IV furnish a new, detailed profile of the state industry and its growth trends and then a "big picture" scan of key forces at work in the global space market. These forces represent dynamic, challenging features of the current competitive environment.

Chapter V assesses the strengths and weaknesses of the state's asset base in space against the backdrop of the key forces at work identified in Chapter IV and calls out six crucial themes for industry and government action to improve the state's competitiveness.

The rest of the report then looks ahead to opportunity and action.

Chapter VI—entitled "Colorado's Space Economy Future: A Vision and Strategies for Getting There"—articulates an ambitious but justifiable and achievable mission for the state's space economy, calling on the cluster to insist that "Colorado becomes the center of innovation for the global space economy."

Chapters VII and VIII lay out a set of action steps for the private sector and government, respectively, to deliver on the vision of making Colorado's space economy globally preeminent for space-sector innovation. The public policy section, Chapter VIII, focuses on state policy moves, though a sidebar in the section briefly reviews top needed federal policy actions. A brief final section concludes.

In the end, the aspirations and actions for industry development urged here are bold—but only as bold as is required given the potential for decline posed by the many disruptive forces now at work. In that sense, the potential for success seems high—and the opportunity for gains large—should industry and government focus together now and execute.

To be sure, pursuing the present moment's new opportunities for growth will require a wholly different mindset among all concerned than has been required by the passing era of conventional "government space."

But even so, achievable actions of the sort detailed here are at once practical and warranted, while the urgency of industry and government leaders to compete and win is palpable.

And who, at any rate, would dare to bet against Colorado? The Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado, Boulder (CU-Boulder) remains the only research institution in the world to have sent analytic instruments to all eight planets and Pluto. Sierra Nevada Corporation is one of the three companies developing an innovative commercial space transportation vehicle—the Dream Chaser—that resides at the forefront of modernization plans at the National Aeronautics and Space Administration (NASA). And it is Colorado's DigitalGlobe that provides millions of square kilometers of the high-resolution satellite data that Google Earth, Google Maps, Apple Maps, and Bing Maps deliver to billions of the world's computers, mobile phones, and tablets every day.

Believe it: The objective can be achieved.

II. COLORADO PREPARES FOR LAUNCH

Coloradans and their leaders have taken a special interest in the state's strong space economy for more than 25 years.

In the 1990s under Gov. Roy Romer the state piloted an Office of Space Advocacy to serve as a voice for the industry's interests statewide and beyond. The office lacked a clear mandate, however, and was soon spun off as an independent networking entity.[1]

By 2000, momentum again built around a concerted state-level effort to grow the space industry.

In response, Gov. Bill Owens launched the Colorado Space Strategy Initiative, which commissioned a strategic plan from the Space Foundation.[2] The final report, "Colorado's Strategic Plan for Space," astutely described the position of Colorado's space economy at the turn of the century and proposed a number of strategies to advance it.

Implementation of this plan was slow to get off the ground, however, and the initiative eventually faltered over the establishment of a new "space advocate" position in the governor's office. The position disappeared within two years of its creation due to insufficient funding, unclear objectives, and poor institutional design, and soon the state shifted its focus to biotech and clean energy.

Today, the state again appears poised to launch into preeminence in the increasingly dynamic space economy, a classic advanced industry, and signs suggest that the follow-through may be more substantial now than in previous years.

For the past five years the Colorado Space Coalition (CSC)—supported by the Denver Metro Chamber and Metro Denver Economic Development Corporation (Metro Denver EDC)—has been asserting itself as a formidable marketing and lobbying voice for the industry. Meanwhile, the Metro Denver EDC itself has emerged as an important networking center for the industry and since 2005 has produced its invaluable annual aerospace industry cluster profile, which tracks developments in the state's aerospace industry year by year and provides an important information base for the industry.[3]

This year, moreover, has brought new activity.

With the state still searching for the next powerful source of high-value near- and longer-term growth, Colorado under the leadership of Gov. Hickenlooper is again taking a special interest in consulting, rallying, and seeking to partner with and advance the state's diverse space industry for the state's larger benefit.

Mindful of the rising national interest in so-called advanced industries that are also increasingly a focus of leading regions,

the state has moved in the last year to ensure its statewide bottom-up economic development initiative entitled the Colorado Blueprint advances the aerospace industry, a quintessential AI.[4]

Specifically, in the spring of 2012 the state availed itself of an offer from the Metropolitan Policy Program at Brookings to help Colorado business and government leaders assess and advance the space sector as an exemplary advanced industry.

At that time, Brookings—by way of its own Advanced Industries Series—was seeking to work intensively with two emblematic state AI clusters to highlight their value to national policymakers and develop actionable economic development strategies to advance the clusters and so further national competitiveness. For its part, Colorado saw an opportunity to work with Brookings to bring increased research and analytic firepower to the aerospace component of the governor's Key Industry Networks Process, a portion of the Blueprint process in which the state works industry by industry to convene and facilitate a stakeholder-led dialogue aimed at co-developing a detailed economic development action and implementation plan.[5]

What are advanced industries?

Advanced industries (AIs) are defined by the Metropolitan Policy Program at Brookings as the nation's engineering- and R&D-intensive industrial sector.

As such, the AI sector extends from the aerospace, space, and defense industries (as are discussed in this report) to auto assembly and industrial machinery and energy equipment manufacturing to semiconductor and medical device production.

In effect, then, the AI sector encompasses a broad and diverse swath of "high-tech" and research-driven industries that anchor the U.S. innovation enterprise and generate inordinate shares of the nation's and regions' output and goods exports.

Source: "Defining Advanced Industries," (Brookings Institution, forthcoming) and "How Can the U.S. Advanced Industries Sector Maintain its Competitiveness?" (McKinsey & Company).

And so in March 2012 the state Office of Economic Development and International Trade (OEDIT) invited Brookings to work with the Lt. Governor's Office, the CSC, the Metro Denver EDC, and industry stakeholders to assess the Colorado space industry's position and develop action agendas for public- and private-sector industry development.

As to the mechanics of the strategy development, work on the project began in April 2012 and proceeded through the rest of the year.

This analysis was developed through an intensely collaborative process. While this report is the work of Brookings alone, its content reflects the input and contributions of numerous external partners in Colorado and nationally at multiple phases of ideation and development.

Likewise, the team embedded itself in the state's aerospace Key Industry Networks Process—itself an inherently collaborative endeavor. As part of the process the Lt. Governor's Office and OEDIT convened a Steering Committee of senior business leaders and a Tactical Team of industry stakeholders to develop jointly the industry strategic plan. At meetings and listening sessions with both the Steering Committee and Tactical Team, Brookings heard from well over 100 Coloradans who have deeply informed this report.

Finally, close collaboration with the Metro Denver EDC and the CSC enabled Brookings to access the knowledge and perspectives embedded in the strong networks already in place in the state.

In developing this report, Brookings employed a three-part process.

The initial **diagnostic** phase, which ran from spring 2012 into the summer, set out to describe the industry, define key trends, and identify the issues facing the industry locally but within a global context. To those ends Brookings conducted one-on-one interviews with key stakeholders in the state and organized, along with the state and the Metro Denver EDC, an early listening session with select leaders from industry, the workforce training system, academia, economic development, and government.

Parallel to this consultative fact-gathering, the team engaged in an unprecedented effort to measure Colorado's space economy from the bottom-up, establishment by establishment. This exercise required identifying every business establishment in Colorado engaged in space-related activity and constructing a detailed dataset of their characteristics. The team also conducted its own research inquiry into the national and global forces affecting the industry with which Colorado's space economy must contend in order to remain competitive.

Brookings' "bottom-up" methodology

In order to size Colorado's space economy, Brookings first needed to define it. To do that, Brookings conducted an extensive literature review, multiple conversations in-state, and an in-depth analysis of the space ecosystem in Colorado in order to arrive at an expansive definition of the industry that encompasses not only the manufacture and operation of space-based platforms, but also the capabilities that these platforms enable.

With this definition in hand, Brookings then engaged in an unusually detailed **bottom-up identification** of business establishments in companies identifying space as a primary activity.[6] In this effort Brookings consciously rejected using standard industry classification codes to identify establishments because the space economy itself defies the bounds of conventional industry codes. Encompassing activities that range from the manufacture, launch, and operation of space-based assets to the downstream provision of services via those assets, the business lines of the Colorado space economy cut across standard industry definitions and thus require special analytic strategies.

In view of that, Brookings set out to identify the full universe of space establishments in Colorado by consulting a range of in-state and national sources, including: CSC membership lists and directories; the Metro Denver EDC aerospace industry cluster profile; membership directories of national industry organizations such as the Satellite Industry Association and Aerospace Industries Association; NASA, National Oceanic and Atmospheric Administration (NOAA), and Department of Defense (DoD) contract, grant, and award records; and news reports. The Brookings team visited the website of every firm captured in the scan to ensure that space-related activities were self-reported as a core focus of the firm.

To complete the dataset, Brookings pulled **establishment records** from Dun & Bradstreet and joined them with the National Establishment Time-Series (NETS) database containing each establishment's history.

The result is a uniquely high-resolution view of Colorado's space economy, its structure, and current dynamics, built from the bottom up.

It should be noted, meanwhile, that this new Brookings analysis complements but does not replace other high-quality analyses, such as the Metro Denver EDC aerospace cluster profile, that use more conventional methodologies.

For further detail on methodology, see Appendix A.

In the second phase, **ideation**, Brookings developed policy problem statements and actionable recommendations through

stakeholder interviews and policy analysis. The July Aerospace Key Industry Networks Process Steering Committee and Tactical Team Meetings convened by OEDIT kicked off this phase. This brainstorming and strategy-setting forum provided critical input into the development of the report straight from the industry's key players. These meetings laid the foundation for another round of one-on-one interviews with firm leaders, military representatives, and others that further honed the recommendations. Desk research complemented these efforts and exposed another layer of strengths, weaknesses, gaps, and opportunities.

In the **finalization** phase Brookings developed public documents—including this report and related presentations—to frame the issue and detail actionable recommendations to the state and space industry leaders. This project will culminate with a high-level release event summarizing the report's findings and unveiling the public- and private-sector agendas. The Brookings project team will then turn to advising decision-makers on implementation.

A second stage of the finalization phase will take the form of a national framing paper highlighting the importance and distinctive needs of AIs. This will be released at a Washington, DC forum later in 2013.

Along these lines the space economy strategy that has emerged from the state's Key Industry Networks Process includes the following components:

- An establishment-level analysis of the size, shape, and dynamics of Colorado's space economy
- A review of the forces at work shaping (and disrupting) the market in which Colorado's space economy competes
- A SWOT assessment of the competitive position of Colorado's space economy and a proposed set of strategies to advance that position
- Agendas and strategies for the state and the private sector to move Colorado's space economy forward

Colorado's space economy stands at a critical juncture, with rapid change threatening to disrupt the status quo even as it offers exciting new opportunities for growth. This report aims to empower Colorado to position itself for success in this new competitive environment.

Defining the space economy

Brookings has adopted a fresh and inclusive definition to capture the full range of actors that make, operate, and use space systems in the state. That is because over the past half-century space systems have increasingly come to constitute infrastructure that has enabled or been adopted by entire industries. Any definition of the space industry must therefore capture both infrastructure and capabilities. Along these lines, Brookings believes that the term "the space economy" best represents the true depth and range of space-related activities occurring in Colorado.

The **space economy** is defined as the manufacture and operation of space systems and the range of capabilities enabled by them.[7]

Several other important terms with subtle differences in meaning appear throughout this report. They are:

Aerospace—the manufacture of aircraft, missiles, rockets, and space vehicles; aerospace engines and propulsion units; aerospace products and parts; and aeronautical instruments

Adjacency—a market or industry with significant technology or knowledge relatedness to one or more space economy segments; a market to which space-related capabilities are readily adaptable; e.g., alternative aerospace platforms such as unmanned aerospace vehicles (UAVs), unmanned aircraft systems (UASs), and aircraft; wired and wireless telecommunications; robotics and automation; and advanced materials

New space—a generation of disruptive entrepreneurial firms typically financed by private investors pioneering new business models to radically increase access to space and lower the cost of spaceflight

III. MEASURING COLORADO'S SPACE ECONOMY

Coloradans know that the space economy comprises a critical component of the state's advanced industry base. However, the exact size and dimensions of the state's changing space enterprise remain obscure in part because so many industries and disciplines—including some in apparently unrelated markets—increasingly utilize space-based platforms, services, or content.

Space-related activities, in short, are not as limited as they used to be and increasingly pervade the Colorado economy. Which is why the following pages provide a new, detailed profile of the Colorado space economy that aims to convey the sector's true size and shape with sufficient detail to inform strategy and policy. The resulting profile yields a series of key takeaways.

The space economy is an outsized driver of Colorado's economy

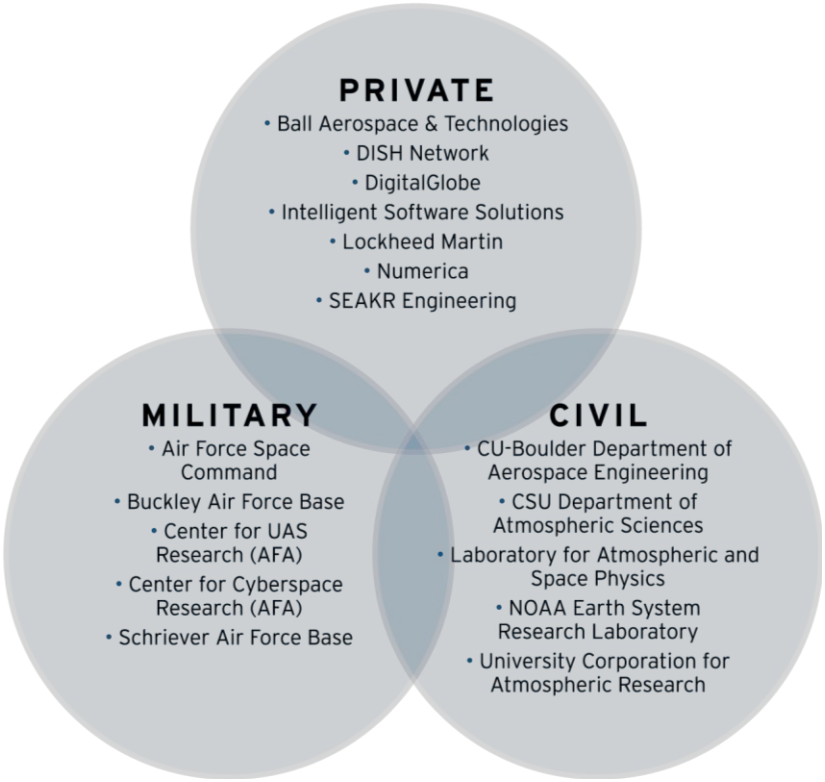
Colorado is home to one of the deepest and broadest concentrations of space-related activity in the country. This set of activities, moreover, suffuses the state's broader industry base, cutting across the public and private sectors and spilling over into telecoms, software, advanced materials, and beyond. In total, the Colorado space economy directly employs over 66,000 workers across the civil, military, and private domains.

The **civil space** sector includes all universities, laboratories, and federal government (non-military) entities engaged in space-related activity in the state. Representative organizations include NOAA's Earth System Research Laboratory and Space Weather Prediction Center; CU-Boulder's Laboratory for Atmospheric and Space Physics, Department of Aerospace Engineering Sciences, and Center for Astrophysical and Space Astronomy; and the Department of Atmospheric Sciences and Cooperative Institute for Research in the Atmosphere at the Colorado State University (CSU).

This sector plays a critically important role in the space economy's ecosystem. The civil sector houses the bulk of the state's expertise in space exploration and planetary, earth, and atmospheric sciences. It leads in the application of space-enabled capabilities like remote sensing and in the development of technologies and instruments that advance human understanding of the universe. It serves as an important source of knowledge and technological spillovers, it attracts the bulk of space-related research dollars coming into the state, and it both trains and concentrates a formidable pool of talent.

Altogether, civil space remains the smallest of the space economy's major subsectors, accounting for 5.5 percent of employment in the Colorado space economy and directly providing 3,700 jobs.

The Colorado space economy comprises three sectors



The **U.S. military**, for its part, forms a cornerstone of Colorado's space economy by both anchoring a large supplier and service provider network and by being a major employer in its own right. The military operates six major installations in the state, four of which—Buckley, Peterson, and Schriever Air Force Bases and Fort Carson—house critical space-related national assets. In addition to training the next-generation of space technology leaders, the Air Force Academy, for its part, conducts some of the world's most advanced space-related research at six of its research centers of excellence. More generally, the exacting specifications of the U.S. military induce the innovation system into action—with helpful boosts from contracts and grants. Retired service members and erstwhile contractors, meanwhile, carry knowledge and skills sharpened on base into the private sector. Finally, and importantly, the military is the source of innumerable technological advances and spillovers that the private sector ultimately commercializes—GPS being an obvious and pertinent example.

Altogether, the military directly employs an estimated 15,500 active duty servicemen and women and civilian government employees in space-related activities.

Finally, the **private sector** encompasses all private business establishments producing space-related goods and services.

Thanks to its subjection to market forces, it is the most dynamic of the space economy sectors: Businesses of all sizes compete intensely with each other to provide innovative products and services at the lowest cost to civilian, military, and commercial markets.

The private sector accounts for the lion's share of space activity in the state, encompassing nearly three-quarters of all Colorado space economy jobs. In this respect, Colorado has built a formidable private-sector space industry that represents an outsized economic force in the state. In 2011, nearly 48,000 individuals worked across 370 companies and 520 private business establishments in Colorado's space economy.

While these companies and establishments vary in size and specialty, together they represent the entire spectrum of the global space economy—from space and launch system manufacturing to the provision of space-based services such as broadcasting, communications, and remote sensing—all in an advanced industry cluster at the base of the Rockies.

Homegrown primes power the Colorado space economy, past, present, and future: Lockheed Martin

Colorado's large prime government contractors helped give birth to the state's space industry almost sixty years ago. Today, firms like Lockheed Martin continue to deliver the technologies that drive the U.S. government's space programs, even while they position themselves for growth as the market evolves.

In 1955, the Glenn L. Martin Company—now known as Lockheed Martin Space Systems Company (LMSSC)—established a plant in Waterton Canyon just southwest of Denver in order to build the Titan intercontinental ballistic missile. Over the course of the 50 years that followed, the Titan family of rockets formed a central pillar of the U.S. space program, launching over 150 successful missions into space, including the first American spacewalk, Voyager missions to the outer reaches of our galaxy, the Mars Viking landers, and numerous national security missions.

The LMSSC Waterton facility now produces technology that lies at the leading edge of today's global space economy—including the next-generation Global Positioning System (GPS III) satellites and the GOES-R weather satellites that will enable, in course, the next generation of navigation, geolocation, and earth observation services, and the Orion Multi-Purpose Crew Vehicle, designed for the next era of human deep space exploration. LMSSC shipped the propulsion core for the GPS III Space Vehicle 1 to the recently completed GPS Processing Facility on the Waterton campus in September 2012, and the U.S. Air Force plans to buy up to 32 GPS III satellites in the coming decades.

Lockheed Martin is also positioning itself for growth in emerging adjacent markets. For example, the company's Information Systems and Global Solutions business segment is developing smart grid solutions for electric utilities. Working from its Colorado Springs location, the company is leveraging its systems integration, command and control, cybersecurity, and engineering prowess to help public utilities deploy, operate, and protect smart grid technology.

Regardless of federal budget uncertainties in the years ahead, Lockheed Martin and other prime government contractors in Colorado will continue to play a vital role in developing state-of-the-art, innovative solutions needed to meet the nation's growing desire for more advanced space capabilities, including deep space exploration. In so doing, these companies will further the growth of Colorado's space economy, inspiring and employing the next generation of scientists, engineers, and explorers now and for years to come.

Source: Lockheed Martin Space Systems Company, The Denver Post.

Nor are space jobs average jobs. Private-sector space economy employees earned an average annual income of $92,500 in 2011, compared to the state private-sector average of just $49,000. Thanks to these high wages, the space economy paid 4.9 percent of all private wage earnings in the state to the 2.6 percent of the private workforce it employs.

Likewise, the space economy contributes inordinately to the state's overall economic enterprise. The value-added output generated by that same 2.6 percent of the workforce reached $8.7 billion in 2011, representing 3.8 percent of Colorado's private non-farm gross domestic product (GDP). All told, space firms generated around $16 billion in sales in 2011.[1]

Over the past decade, space economy firms and establishments have been steady contributors to job growth in the state. Private space economy employment grew at an average rate of 3.1 percent a year between 2002 and 2011—a rate that trailed statewide job growth but still represents an important expansion of available jobs.[2] Against the backdrop of a national recession and slow return to recovery, from 2008 to 2011 employment in Colorado's private space economy expanded by an annual average rate of 2.4 percent.

Both large and small companies have contributed to employment growth in the Colorado space industry since 2002. Companies with fewer than 100 employees in the state—over 85 percent of the nearly 375 individual companies in the space economy—grew at a swift 6.5 percent on average annually and added more than 2,700 jobs in total over the decade. Large companies, defined as those with 100 employees or more across all of their Colorado establishments, grew more slowly, by 2.6 percent per year, but added 8,600 jobs. From 2008 to 2011, as the national economy fell into and began its climb out of recession, small space companies added 1,000 jobs and large companies added nearly 2,300 jobs, thereby helping mitigate the effects of the economic downturn on the Colorado economy.

The big role of small companies in Colorado's space economy: Braxton Technologies

The big companies that anchor Colorado's space economy also tend to be the most visible. Lockheed Martin, DISH Network, Ball Aerospace, and others have globally recognized brands in the space industry and are among the largest employers in the state. At the same time, though, small companies with fewer than 100 employees make up the vast majority—over 85 percent—of the firms active in Colorado's space economy.* These firms play a vital role in sustaining the space cluster's competitiveness and delivering growth. They develop the innovative technologies that reside at the core of the state's space activities and help anchor jobs and capabilities firmly in the state.

Braxton Technologies is one such company, with just 50 Colorado-based employees as of 2011. Braxton develops software used to operate space and weapons systems, including mission planning, command and control, and simulation products and systems. They also provide a suite of related services including system installation, training, and staff augmentation and support. The Global Positioning System (GPS) Program's launch, early-orbit, operations, and disposal command and control functions are currently performed using Braxton's ACE Premier product and the company's entire suite of products is in use on the U.S. Air Force's GPS satellite operations floor.

Like many small and medium-sized firms, Braxton is firmly entrenched in the Colorado community. When the O'Neil Group purchased Braxton Technologies in 2008, it moved its headquarters from Livermore, California to Colorado Springs. The O'Neil Group's founder, Kevin O'Neil, is a longtime Colorado Springs resident and the company often references its strong commitment to helping revitalize the business climate of southern Colorado. The Braxton move is part of the parent company's strategy to acquire defense oriented companies, bring them to Colorado to streamline costs, and incubate growth.

Small firms like Braxton house the expertise that will help drive innovation in the global space industry. As these firms continue to evolve, they will bolster the competitive position of Colorado's space economy in the process.

Source: Braxton Technologies, O'Neil Group
*Note that this metric refers to *total company employment* in Colorado, not individual establishments.

Colorado's private space economy is multidimensional and polycentric

Colorado's space expertise stretches across the full spectrum of space-related activities. Private-sector jobs are distributed rather evenly across three broad categories, which can be further subdivided into 11 narrower segments, revealing a wide and deep assemblage of activities that is multidimensional, polycentric, and technology-intensive.

Along these lines, 29 percent of Colorado space economy workers build, place, and maintain space-based assets in the space systems manufacturing and operations category. A further 36 percent of workers provide services rendered by satellite in a number of consumer markets. Finally, 35 percent of space economy jobs support the wider space complex with components and generic instrumentation, on one end, and information technology (IT), engineering, and professional services on the other.

Colorado's private space economy can be divided into categories and segments of activity

Brookings has divided the private space economy into three broad categories—the manufacture and operations of space systems, the services enabled by these systems, and the supply and support chain for both—within which 11 distinct segments of activity are organized:

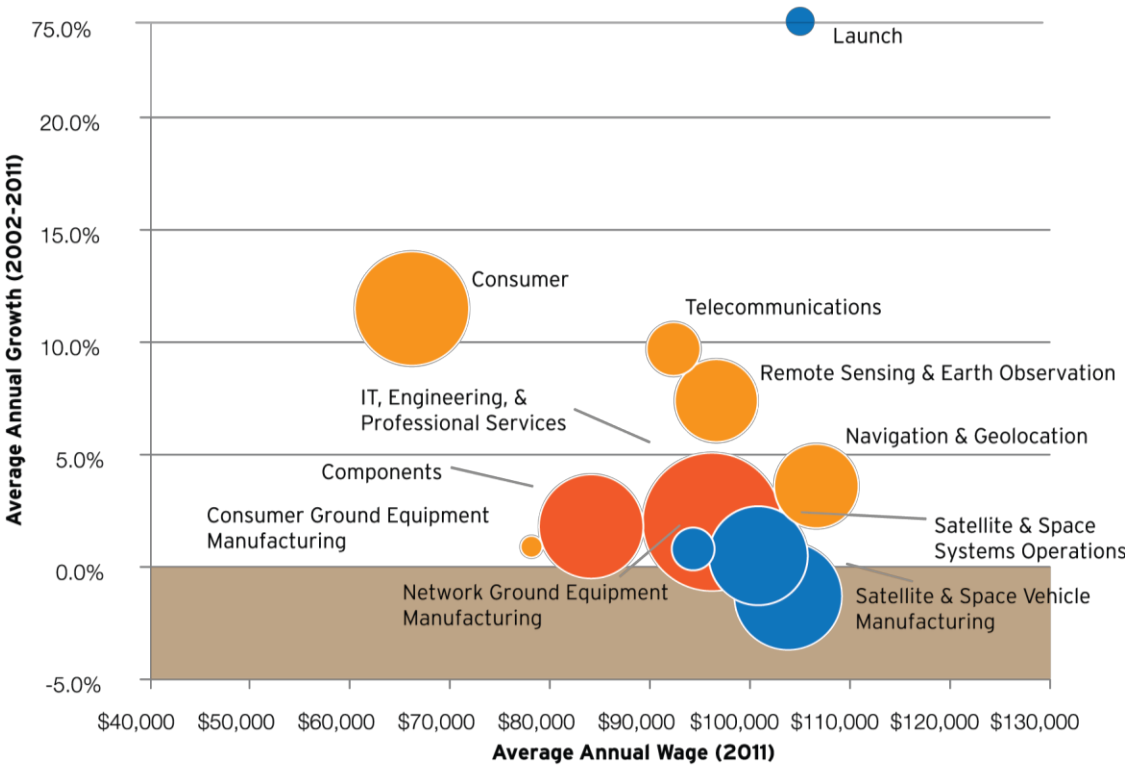
Space systems manufacturing and operations	**Satellite and space vehicle manufacturing**—the development and manufacture of satellites, space vehicles, rockets, and missiles
	Satellite and space systems operations—the management and operation of in-space systems from earth
	Network ground equipment—the manufacture of the terrestrial infrastructure that communicates with satellites
	Launch manufacturing and services—the development and manufacture of launch systems, including propulsion; the provision of launch services
Satellite-based services	**Consumer ground equipment**—the manufacture of terrestrial devices to transmit information relayed via satellites to end-users (e.g., satellite dishes)
	Remote sensing and earth observation—the use of optics, sensing, and imaging technologies to capture and relay information about the earth from space; commonly used for intelligence and surveillance, weather, earth sciences, and GIS purposes
	Telecommunications—point-to-point communication services transmitted via satellite
	Consumer—broadcasting of consumer services such as television or internet broadband via satellite
	Navigation and geolocation—GPS and positioning, navigation, and timing (PNT) services
Supply and support	**Component suppliers**—the manufacture of materials, composites, and components for satellite and space vehicle systems, and of generic satellite-based instrumentation
	IT, engineering, and professional services suppliers—the application of specialized IT and software engineering services, systems engineering services, and technical or consulting services in the space economy

Within these three categories, segments vary considerably in terms of size, revenues, growth, and wages.

The traditional core of the industry, **space systems manufacturing and operations**, is the smallest of the three categories and accounts for fewer than one-third of the state's space economy jobs—13,900 in 2011—even as it accounts for a greater share of revenues. Average wages are the highest in the space economy, at over $102,000 annually, and revenues per employee approached an impressive $390,000 in 2011. Net job growth over the decade was negligible, however. Even then, annual average job growth did accelerate to 3.1 percent from 2008 to 2011 and surpassed the rate of expansion in the other two categories.

Performance across these metrics varies significantly within the category. Satellite and space systems operations—represented by companies such as Northrop Grumman and Raytheon—and satellite and space vehicle manufacturing—represented by companies such as Ball Aerospace & Technologies, Lockheed Martin, and Sierra Nevada Corporation—each employ over 5,000 Coloradans. Launch manufacturing and services, for its part, grew at explosive rates over the decade, primarily due to the advent of United Launch Alliance and displaced many of the jobs lost in the satellite and space vehicle manufacturing segment. All three of these segments pay annual average wages of over $100,000, in line with high revenues per employee.

The segments of the Colorado space economy vary in terms of size, growth, and wages



Source: Brookings analysis of NETS data

Satellite-based services, which encompasses those segments that use satellites to deliver a service back on earth, employs 17,000 Coloradans and accounts for 35.7 percent of the state's space economy jobs. These industry segments generate $6.3 billion in annual revenue—a disproportionate 37.8 percent of the revenue produced by the Colorado space economy as a whole. With an average annual job growth rate of 7.9 percent, this category has seen extremely rapid expansion over the past decade and includes the fastest growing space segments in Colorado outside of launch. Despite its productivity and growth, however, satellite-based services have an average annual salary of $85,227, the lowest among the three categories in the space economy.

Consumer services—led by companies such as DISH Network and Liberty Global—is the largest segment in the satellite-based services category and clocked the space economy's fastest annual average job growth rate outside of launch over the decade—11.5 percent—even as employment contracted during the recession. It generated the second-highest revenues per job in the space economy but offered relatively low wages in an otherwise very high-paying category.

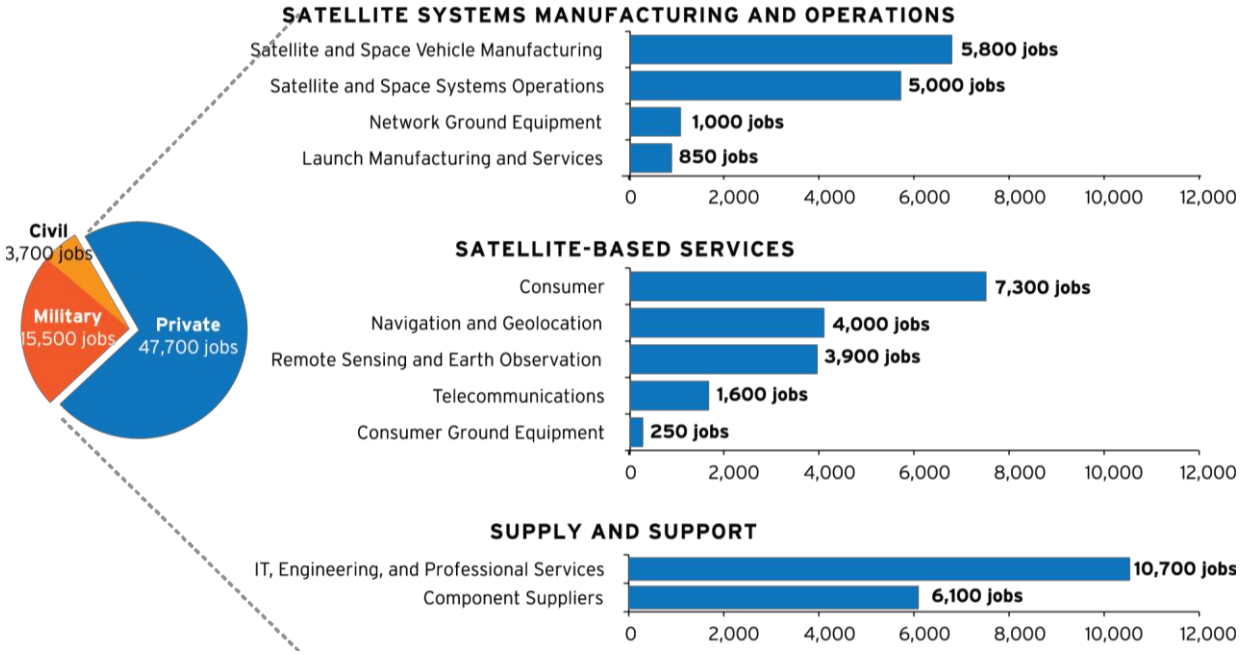
The navigation and geolocation segment—represented by firms such as Trimble Navigation, Jeppesen, and NavSys Corporation—paid average wages upwards of $106,000 annually to its nearly 4,000-strong workforce. The similarly-sized remote sensing and earth observation segment—led by firms such as DigitalGlobe, i-Cubed, and Vaisala—paid lower wages but grew by 7.4 percent annually over the decade and by 8.0 percent annually since the recession. Together, both segments' lucrative services offerings generate revenues of around $350,000 per employee. Telecommunications, meanwhile, combines wages in line with the space economy average with nearly 10 percent average annual job growth over the decade in large and small firms such as Harris CapRock, L-3 Communications, and WildBlue Communications.

Finally, over one-third of space economy jobs—35.3 percent, or 16,800 positions—fall into the **supply and support** category which predictably supplies and supports the space manufacturing and services complex with myriad products and services.[3] This category generates a smaller share of revenues and output—just shy of 30 percent of the total—signaling lower productivity (or less pricing power) than the rest of the space economy. Nevertheless, supply and support constitutes a major employment base that generates a reliable stream of new jobs, with a steady 1.9 percent annual average growth rate from 2002 to 2011 and a faster 2.4 percent growth rate since the recession.

The IT, engineering, and professional services segment employs more Coloradans than any other space economy segment, underscoring the fundamental link between technology and the space enterprise. This segment includes companies such as Analytical Graphics, IHS Global, Intelligent Software Solutions, Red Canyon Software, and Tech-X Corporation. The components segment, meanwhile, is represented by Barber-Nichols, Coorstek, Fiberforge, and SEAKR Engineering and substantially smaller than its technical services peer, with approximately 6,100 jobs compared to 10,700 jobs. It offers lower wages—$84,000 per year compared to $96,000—but job growth rates are comparable, suggesting that broad industry dynamics may affect these two supplier segments similarly.

In sum, Colorado's space economy consists of a wide and deep assemblage of activities united by a common platform: space-based technology. Taken together, these activities generate exceptionally well-paying jobs and significant sales and growth unified by increasingly high-tech platforms and content. This interaction between upstream systems and downstream services has yielded an industry in Colorado that is increasingly diversified and sprawling. For example, while the traditional space manufacturing complex remains a large and stable source of employment, its growth appears to have plateaued. By contrast, technologically enabled supply and support industries as well as satellite-based services providers now employ more workers than the manufacturing complex and—based on performance since 2002 and market projections—hold out superior promise for future growth.

Within the private sector, the number of space economy jobs varies by category and segment



Source: Brookings analysis of NETS data

Colorado's space economy is increasingly services-oriented

This analysis reveals, further, that the space enterprise in Colorado is changing. Specifically, the space economy—notwithstanding the size and importance of its manufacturing and operations sector—is increasingly services-oriented. This is on balance good news for the whole of Colorado's space economy. Demand for services such as direct-to-home satellite television, satellite telecommunications, and satellite precision-navigation-timing capabilities helps drive the upstream space systems manufacturing complex, with the result that the state has begun to specialize in the entire and growing spectrum of space activities.[4]

Over one-third of private-sector space economy jobs in Colorado now provide advanced services via space, and these segments are growing rapidly. Over the course of the past decade, average services segment growth rates ranged from an above-average 3.6 percent a year in navigation and geolocation to a torrid 11.5 percent a year in consumer services such as broadcasting and satellite radio. Those rates slowed over the recession, but secular trends suggest that future growth in these young evolving segments is likely as new applications for space-derived data emerge.[5]

Nor is this trend toward services restricted to end-user markets for space-derived capabilities. At the other end of the value chain, IT and engineering services represent an increasingly significant input into the ever-more complex technology

systems that enable the space economy in the first place. What is more, a new generation of IT companies such as Intelligent Software Solutions is beginning to adapt the technologies and capabilities they developed in support of the Colorado space ecosystem to other commercial markets. As would be expected, IT, engineering, and professional services posted steady growth rates over the 2002 to 2011 period and have experienced increased growth in recent years.

This strength in advanced services also bolsters manufacturing, which still represents a critical element of the state's space economy. Indeed, the ability to render ever more advanced high-value services via space remains tied to the manufacture of systems in orbit. The co-location of manufacturing and services positions Colorado for continued growth and innovation in both areas.[6] Across all 11 segments, fully 186 establishments—over one-third of the state's space economy total—are classified as "manufacturing" by the U.S. Census Bureau, with a total of 20,600 workers or 43.1 percent of the space economy workforce working in—or at least on-site with—manufacturing.[7]

Colorado's space economy spans four major metropolitan areas, three smaller ones, and at least seven rural counties but is heavily clustered along the Front Range

Fully 99 percent of jobs in Colorado's private space economy are concentrated in the four large metropolitan areas along the Front Range, the megapolitan area that stretches from Fort Collins in the north through Boulder and Denver to Colorado Springs in the south. By comparison, this region contains only 78.7 percent of total private employment in the state. The remaining space economy jobs are spread across three smaller metropolitan areas—Pueblo, Durango, and Grand Junction—in addition to at least seven further rural counties. In that sense, the geographic concentration of Colorado's space economy signals a classic industry and innovation cluster.[8]

At the subregional and segment levels, important geographic distinctions emerge. Boulder specializes in civilian-oriented space activity, Colorado Springs specializes in military-oriented space activity, and Denver in satellite-based services.

Launching a new global industry from Colorado: DigitalGlobe

The explosive growth of commercial satellite imagery has both transformed how people see the world and opened up advanced new analytic capabilities such as space-based land use assessment. As the birthplace of the U.S. commercial satellite industry, Colorado has directly benefitted from the growth of industry pioneers like DigitalGlobe Inc.

Founded in 1993 in Longmont as WorldView Imaging Corporation, the company now known as DigitalGlobe received the first license from the U.S. Department of Commerce to operate a satellite system to collect high-resolution satellite imagery for commercial sale. Since that time, it has expanded from roughly 20 employees at its founding to 740 worldwide by 2011, 360 of whom are located in Colorado.

DigitalGlobe's work with other Colorado space economy companies has served to reinforce the strength of the state's space cluster. All three current DigitalGlobe satellites were built by Boulder-based Ball Aerospace, which is presently at work on Worldview-3, DigitalGlobe's most advanced imagery satellite yet. And DigitalGlobe continues to dominate innovation and growth in the industry, as evidenced by its nearly-approved merger with a major competitor, GeoEye—itself the successor of Colorado-based Space Imaging. This merger will further consolidate DigitalGlobe's position as the global leader in satellite imagery and geospatial analysis.

The company's innovations have had widespread impacts in multiple markets. DigitalGlobe pioneered wider accessibility

DigitalGlobe (continued)

of global imaging beginning in 2002 through its partnership with Google Earth. The eight-band multispectral capability of DigitalGlobe's Worldview-2 satellite allows precise identification of vegetative cover, land use, and even underwater features in coastal waters from space. Change detection—comparing previous and current imagery of the same location—greatly speeds identification of items of interest for intelligence analysts and helps disaster relief organizations identify damage caused by severe weather.

The impact of innovations advanced by DigitalGlobe extend further, to a partner network of over 90 companies worldwide—20 in the United States—that specialize in a wide variety of geospatial industries and applications enabled by DigitalGlobe's products and services.

As DigitalGlobe's imaging capabilities expand, new business opportunities will emerge for entrepreneurs across industries with the imagination and insight about how to leverage them. Like other companies in Colorado's space economy, DigitalGlobe's efforts to develop the next generation of space-based capabilities will drive innovation and productivity growth—not only within the space economy but across the broader Colorado economy as well.

Source: DigitalGlobe Inc., The Denver Post.

Boulder is home to 7.0 percent of the state's private-sector jobs but 13.4 percent of private space employment and 13.7 percent of total space economy employment. Activities in the metropolitan area revolve around high-value science and engineering in the civil and private sectors. On the civil side, NOAA anchors significant activity around weather and earth sciences while CU-Boulder remains a critical center of space exploration and space sciences. On the private side, remote sensing and earth observation (epitomized by DigitalGlobe, Exelis, and MDA Information Systems) and satellite and space vehicle manufacturing (exemplified by Ball Aerospace & Technologies and Sierra Nevada Corporation) have grown into major enterprises.

Colorado Springs also punches far above its weight, claiming 10.7 percent of total private-sector jobs in the state but 26.5 percent of private space jobs and fully 35.1 percent of total space economy jobs. Unsurprisingly, space in Colorado Springs is oriented toward the military. Two-fifths of private space economy jobs fall into IT, engineering, and professional services, and nearly one-quarter of jobs can be found in satellite systems and operations—jobs primarily supporting nearby military commands in companies such as Braxton Technologies, Infinity Systems Engineering, and Northrop Grumman. High concentrations of telecommunications and navigation and geolocation jobs at companies such as Harris CapRock, Navsys Corporation, and L-3 Communications further bolster the military-space-technology cluster in the Springs.

The space economy itself is not disproportionately concentrated in the Denver area, but the capital region boasts the most diversified segment portfolio in the state and dominates in the satellite-based services category. Home to giants such as DISH Network and sister company EchoStar Corporation, the Denver metro area holds over two-thirds of the state's jobs in satellite-based services. With both United Launch Alliance and Lockheed Martin Space Systems headquarters located in the metro area, the capital is also the dominant player in the traditional launch and satellite and space vehicle manufacturing segments, bringing together space platforms and services. Altogether, Metro Denver hosts a diverse mix of space-related activities and is the locus of many of the space economy's spillovers into wider broadcasting, telecoms, and software and IT clusters.

* * *

As this analysis demonstrates, Colorado has amassed a formidable, layered, and diverse space economy that contributes heavily to the state's economic well-being.

At the same time, this analysis reveals that Colorado's private-sector space industry is at once polycentric and evolving. Future growth will likely occur outside of the industry's traditional core, representing an important shift from years past. Fortunately, promising growth opportunities exist in a wide variety of industry segments already clustered up and down the Front Range.

IV. OPPORTUNITIES AND THREATS: THE SPACE MARKET AND KEY FORCES AT WORK

The global space economy is changing. Powerful forces are reshaping the market for space infrastructure and services and so generating new opportunities as well as significant challenges for the space economy. Industry leaders and policymakers each need to take cognizance of the new dynamics and respond aggressively to put in place winning strategies for competing successfully in tomorrow's marketplace.

Projections of continued growth in the global space market and the development of promising new adjacent markets hold out strong opportunities for the space industry

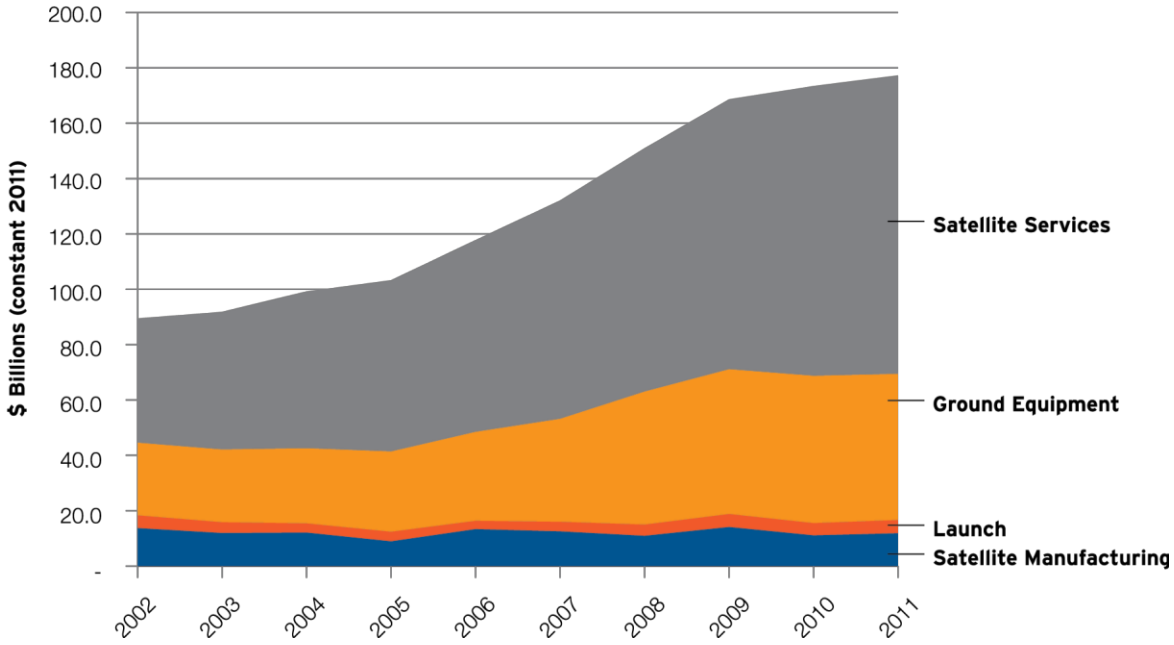
The global space economy in 2011 reached $290 billion according to the Satellite Industry Association, with two broad categories of actors—government space activities (civil and military) and the private-sector space industry.[1]

Globally, governments allocated between $70 billion and $110 billion dollars to their own activities—government employees doing government work such as manufacturing space vehicles, operating space systems, and conducting manned space flight. The United States drove the lion's share, accounting for two-thirds of this total (with over half in military activities).[2]

The private-sector space industry meanwhile earned $180 billion to $220 billion from the manufacture and operation of space infrastructure such as satellites and launch vehicles and the provision of space-based services such as satellite communications, direct-to-home television, and earth observation for government and commercial customers.[3]

Space is an attractive market, with an 8 percent annual average growth rate (in real terms) over the last decade that places it in the top half of industries worldwide.[4] Though smaller than the $2.3 trillion motor vehicle industry, the space economy is 30 to 50 percent larger than the global railroad industry, which totals roughly $140 billion.[5] It also maintained a healthy and consistent 8 percent growth rate through the recent economic downturn (2007–2011) with positive growth each year, thanks to its strategic importance to many countries, the continuing success of space-based services, and the need for recapitalization of satellite fleets.[6]

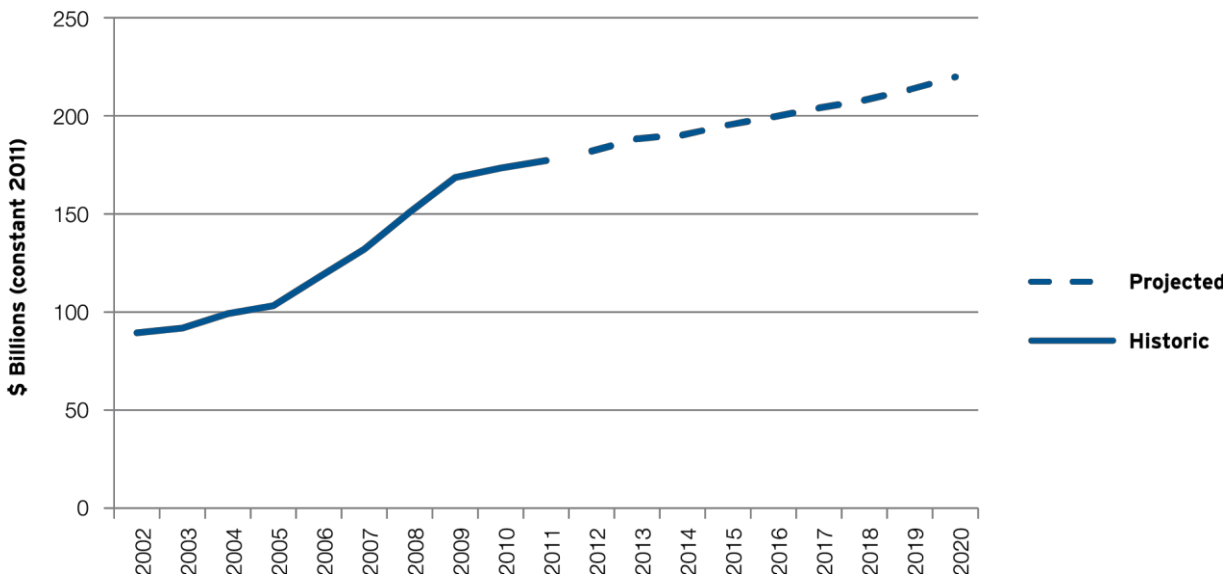
The private-sector space industry has experienced steady revenue growth, particularly in satellite services



Source: Satellite Industry Association, U.S. Bureau of Labor Statistics.

Space economy growth is expected to continue, moreover, though at a slower rate than in previous years. Projections from leading market research firm Euroconsult indicate top-line global revenue growth somewhere near 2.5 percent per year in real terms through 2020, with total revenues rising to approximately $220 billion in annual sales (in constant 2011 dollars). Going forward, these increases will be driven primarily by growth in space-based services.[7]

Revenue growth is projected to continue in the global private-sector space industry



Source: Satellite Industry Association, Euroconsult, US Bureau of Labor Statistics.

Emerging and adjacent markets further enhance this growth potential. A new set of private companies including Virgin Galactic, Blue Origin, XCOR Aerospace, and Armadillo Aerospace—the so-called "new space" companies—are developing suborbital vehicles capable of human spaceflight and a variety of other missions. The Tauri Group, a Washington-based analytic consulting firm, predicts that these companies could earn between $300 million and $1.6 billion in revenue over the next decade.[8] While these numbers are modest in comparison to the global space market, some in the venture capital (VC) community believe they portend a "Netscape moment" for the space industry, when the first major investment from the capital markets such as an initial public offering (IPO) sets off a wave of new commercial ventures.[9]

In adjacent markets, building and operating remote and autonomous vehicles—a hallmark of the space industry—has clear application in current efforts to develop UAVs. Teal Group, an aerospace and defense industry analytics firm, projects that the UAV market for military and civil uses will almost double from $6.6 billion to $11.4 billion between 2012 and 2022.[10] In addition, the space industry's advanced computing, software development, and data processing capabilities, combined with long experience working in secure environments, have ready application in the fast-growing cybersecurity and intelligence arena, a market expected to grow in real terms from $64 billion to $120 billion globally between 2012 and 2017 (roughly 11 percent per year), according to market research firm MarketsandMarkets.[11]

In short, the global space economy presents a sizable, growing, and attractive opportunity for Colorado.

However, an array of disruptive trends makes this a critical moment for the Colorado space industry

And yet, despite the favorable trends, fundamental changes in the space economy are challenging participants to innovate by developing the new technologies and business models that they will need to be successful in the coming years. Most notably, the global space market is transitioning rapidly from a relatively simple structure that was once the exclusive domain of a few governments to one that is increasingly globalized, commercial, and services-based. This transformation has far-reaching implications for all involved in the space economy.

The customer base is changing

The first disruptive trend in the space economy is the changing nature of demand. Global demand continues to shift away from its historic concentration in space infrastructure for a few governments (particularly the United States). Increasingly, demand resides in a growing number of international markets and the ever-expanding space services markets that together are creating a very different customer base.

Government spending is becoming an ever smaller and more contested portion of the market, particularly as U.S. government budgets flatline or contract. The Space Foundation projects increasing program uncertainty across government space activities as nations face persistent budget pressures. This new reality is particularly true in the United States, which remains the primary driver of global government space economy spending. Thus while governments will remain an important source of revenue, the industry must now look to other customer segments for growth.

Government procurement accounted for 68 percent of industry satellite manufacturing revenues in 2010 and in 2011 (the most recent data available), governments accounted for 59 percent of launch revenues, with fully two-thirds coming from U.S. programs.[12] Meanwhile, DoD and NASA—which together represent 95 percent of total U.S. government spending on space—project flat to declining budgets for the foreseeable future.[13] The President's FY2013 DoD budget request, for example, calls for a 20-percent reduction in space modernization funds (i.e., new satellites) over 2012 levels, and future requests are expected to stay flat through at least 2017.[14]

Sequestration and other federal budget contractions could accelerate these trends. If Congress fails to pass a deficit-reduction package by March 1, 2013, automatic across-the-board cuts in government spending could take an additional 9 percent out of current budgets in accordance with the Budget Control Act of 2011.[15] And there could well be additional budget cuts, fluctuations, or uncertainties associated with the nation's likely protracted budget debates.

At the same time, U.S. government space programs are increasingly contested. In 2011 alone, Alaska, Maryland, Texas, and Virginia all published strategies to improve the competitiveness of their space industries that positioned government space programs as a central pillar.[16] Furthermore, according to recent reports from the U.S. Government Accountability Office (GAO), there are fewer contracts for which to compete as DoD and NASA cancel smaller satellite programs due to cost and schedule overruns in major programs.[17]

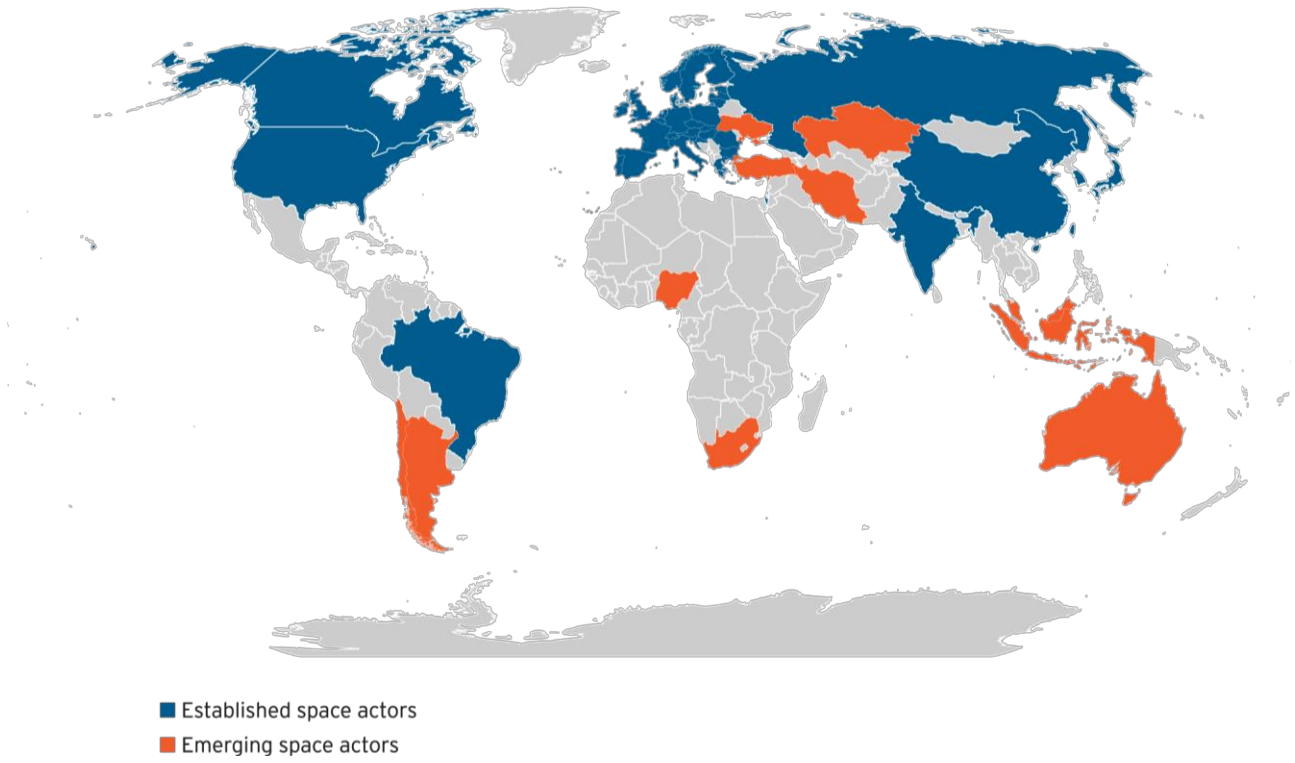
In a word, long-term budget constraints and scale-backs are producing a wide variety of new uncertainties in the traditional mainstay of the space economy.

Meanwhile, growing international demand remains difficult for U.S. firms to access. International demand for space services has continued to grow as globalization increases connectivity, deregulation creates new competitive markets, and improved economic conditions expand the number of consumers worldwide.[18] Likewise, international demand for space infrastructure has also grown as more countries, driven by motivations ranging from national prestige to the societal benefits of improved communications and space-based imagery, enter the spacefaring ranks.[19] However, an aggressive push from overseas competitors and ongoing regulatory hurdles for space infrastructure together make this growing global demand increasingly difficult for U.S. firms to access. As such, U.S. firms looking to capture some of this growth must either focus on the provision of space-based services or seek out new competitive advantages.

The market for space-based services has experienced sizable growth in recent years. In 2011, 60 percent of new subscribers in the direct-to-home television market—by far the largest segment of the global space market—resided in the developing world.[20] Correspondingly, to provide content to these new customers, the largest increase in video feeds through fixed satellite services that year were in the Middle East and North Africa. These regions are also the most promising markets for enterprise satellite communication services for large businesses and governments.[21]

At the same time, more nations are engaging in space enterprises, holding out the potential of added demand for space components and services. Argentina launched its home-built Aquarius SAC-D earth observation satellite aboard a Delta II rocket in 2011 and Brazil published a four-year budget and policy strategy that included a goal to develop two separate space vehicles by 2015. Furthermore, Futron, a leading space market research firm, added five new countries to its annual Space Competitiveness Index report in 2011 and now recognizes Argentina, Australia, Iran, South Africa, and the Ukraine among 15 active spacefaring nations (compared to 10 countries listed in the firm's inaugural 2008 report).[22]

Global competition is increasing as growing numbers of nations enter the space economy



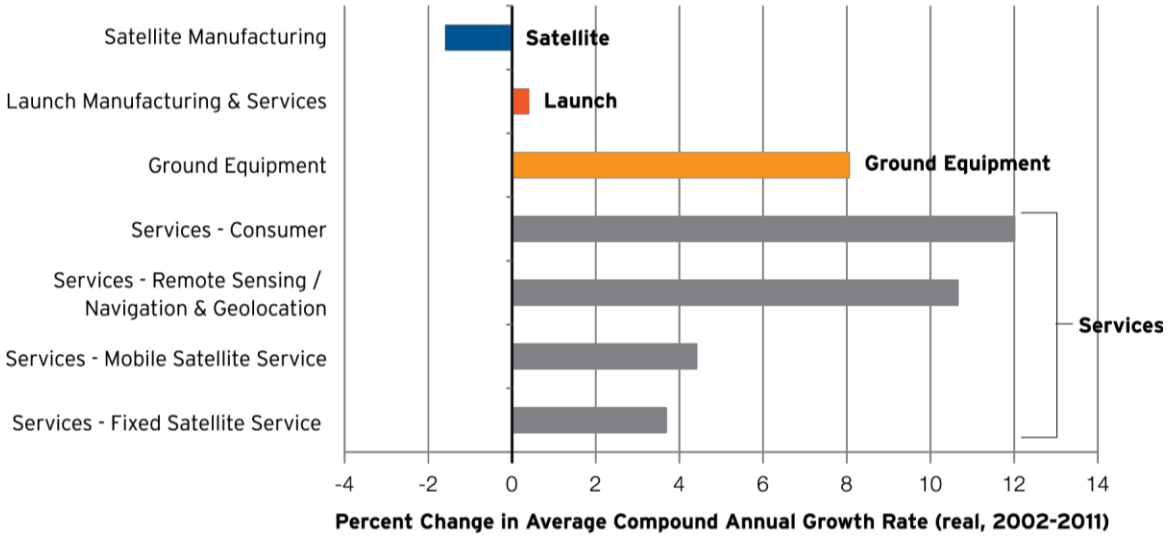
Source: Futron Corporation's "Space Competitiveness Index" and the Space Foundation's "The Space Report"

However, as international demand grows, so too does competition from international suppliers to meet it. Both Russia and China continue to strengthen their market position in infrastructure and services. In 2011, Russia had a world-leading 31 orbital launches—37 percent of the global total—while China surpassed the United States for the first time, with 18 successful launches to the United States' 17.[23] In addition to this growth in launch activities, both countries increasingly package satellite sales with launch and financing, thereby shutting out other competitors.[24]

Regulation also remains a major barrier for U.S. companies hoping to access international markets. Since Congress placed commercial satellites on the United States Munitions List (USML) in 1999, U.S.-built commercial satellites and components remain under export control under International Traffic in Arms Regulations (ITAR) and cannot be shipped to restricted launch providers such as China. Even though legislation enacted in January 2013 contains a long-awaited and hard-won provision opening the door to lifting export restrictions on widely-available communications satellite technologies, much damage to the market position of U.S. manufacturers has already been done. The market is so wary of running afoul of these strict regulations that some non-U.S. satellite manufacturers have begun advertising "ITAR-free" satellites and components to capture market share.[25] Many in the industry feel that ITAR restrictions—which will remain in place until lifted by the president and approved by multiple agencies—have themselves spurred the growth of increasingly formidable international competitors. For example, China has created a number of partnerships with other nations to develop space capabilities due to the fact that they were barred from launching satellites with U.S. components.[26] As such, if and when these restrictions are lifted, U.S. manufacturers will be returning to the game at a disadvantage.

Space has become a services-led (rather than manufacturing-led) industry. More fundamentally, the space industry has shifted from one dominated by the manufacture and build-out of space infrastructure—satellites, launch systems, and ground-based control systems—to one driven primarily by the provision of space-based services—including communications such as fixed and mobile satellite services and entertainment such as direct-to-home television and satellite radio. For that reason, companies seeking growth must work to establish a stronger presence in the services market.

Growth in the global private-sector space industry varies by segment



Source: Satellite Industry Association, "Satellite Industry Statistics," (2001-2004), "State of the Satellite Industry Report," (2005-2011)

In 1996, satellite services accounted for just over 40 percent of industry revenues. By 2011, that number had risen to 60 percent. The rapid expansion of direct-to-home television firms such as DIRECTV and DISH Network in the United States drove much of this growth, with a 12 percent average real annual growth rate that increased sales from $32 billion per year in 2002 to $84 billion in 2011. Likewise, fixed satellite services from companies such as Intelsat, SES Eutelsat, and Telesat as well as mobile satellite services such as Iridium and Globalstar grew at a healthy 4 percent per year in real terms over the same time period.[27]

In stark contrast, revenues from satellite manufacturing and launch have remained flat over the last 10 years. While year-to-year levels vary greatly (e.g., a 50 percent increase between 2005 and 2006), on average, satellite manufacturing revenues shrank by an average 2 percent per year in real terms. The launch industry saw a similar trend, with no growth over the last decade.[28] Moreover, despite a projected one-year bump in 2013, revenue from sales of satellites and launch are expected to remain flat in the years ahead.[29]

Customers and technology are driving a new industry emphasis on value, service, and capability

The second global megatrend in the space economy involves the new bases of competition. Changing government preferences and the predominance of space-based services are amplifying the need for the adoption of more commercial business models—i.e., fixed-price, product-based, and customer-focused approaches—and are forcing industry to seek out new sources of research and development (R&D) to develop and commercialize new technologies.

Government demand for commercial solutions—i.e., fixed-cost, "off-the-shelf" offerings—is giving rise to new, lower-cost competitors. Government space programs frequently produce exquisitely engineered, bespoke solutions at high cost on long timelines using cost-plus development contracts.[30] Government customers drive this trend by setting requirements beyond the capabilities of existing technology at the time of contract and buying in low numbers. In the new era of austerity, government customers—still dominant drivers of the U.S. space infrastructure marketplace—are amplifying their push for simpler, lower-cost commercial solutions to meet their needs. As a result, government suppliers will increasingly need to compete on price using fixed-cost, "off-the-shelf" offerings as new lower-cost providers emerge.

DoD's attempts to leverage commercial offerings to reduce costs go back at least to the origination of the Enhanced Expendable Launch Vehicle (EELV) program in the 1990s. The EELV program attempted to leverage an initial fixed-price investment by the government to develop a new commercial launch capability. Projected high-volume commercial sales were to keep unit costs low, with government benefiting as a secondary buyer.[31] More recently, Gen. William Shelton, Commander of the U.S. Air Force Space Command, indicated that the Air Force will look more to lower-cost, less complex commercial solutions to reduce costs.[32] In FY2010, NASA followed suit creating the Commercial Crew and Cargo Program (C3PO) to spur the development of commercial spaceflight vehicles that move crew and cargo to low-earth orbit more affordably.[33]

Within the context of government contracts, commercial solutions can take a variety of forms. Commercial providers deliver well-defined "off-the-shelf" products or services at fixed prices. In contrast to traditional cost-plus contracting, they generally deliver systems faster and within cost estimates. Using a commercial approach in government contracting can also refer to relying on incremental improvements to mature technologies.[34] For example, each successive model in Apple's popular iPhone line of smartphones adds incremental technology improvements to the previous model, without requiring a complete redesign. Fixed-price government contracts can also push product development risk onto the contractor, thereby providing further incentive for cost reductions.

This heightened emphasis on lower-cost commercial solutions is transforming the government space landscape. For example, SpaceX's successful rendezvous of its Dragon capsule with the International Space Station (ISS) on May 25, 2012 following launch of its Falcon 9 rocket marked the first time that a privately built and operated vehicle accomplished this feat.[35]

Of course, not all government missions will shift to commercial solutions. After all, many DoD and other national security missions do not have commercial applications and many deliberately seek to develop new, leading-edge technology in order to gain an advantage over potential adversaries.[36] Still, stiffer competition for mature services with commercial application—such as launch to low-earth orbit, standard long-haul communications, and earth imaging—will continue to grow as viable, lower-cost commercial providers emerge.

More broadly, a more diverse customer base will require an increased focus on customer service. The fact that the customer base is becoming more diverse as it shifts toward international, space services, emerging new space, and promising adjacent markets means that capturing growth will require a redoubled focus on customer service. Companies seeking growth must anticipate and react to the needs of a more diverse set of customers, emphasizing value and developing the appropriate channels to reach these new market segments.

A quick scan of expected growth areas in the space market affirms this new customer-focus imperative. Fixed-satellite service providers, characterized by companies such as Inmarsat and Eutelsat, focus primarily on business-to-business and consumer sales.[37] The consumer segment, dominated by direct-to-home television companies such as DIRECTV and DISH Network, focuses on individual consumers. The nascent new space industry focuses primarily on selling services to a market of approximately 8,000 wealthy individuals with the interest in and ability to pay for private space travel.[38] And the UAV market will see increased demand from civil and private-sector customers over the next decade (e.g., border patrol, forest service).[39]

In short, all kinds of actors in the space economy will need to be much more attentive and respond much more nimbly to the changing demands of existing and new customers.

Rapid and increasingly demand-driven technology change will both increase the threat of substitution and make new business models possible. As UAV and UAS technologies mature, for example, it is guaranteed that they will expand the market for aerospace products, parts, applications, and services generally, creating new markets and customers. Indeed, demand is already accelerating market development faster than regulation can keep up.[40] At the same time, though, these systems will increasingly compete with satellites as substitute platforms for service delivery in a number of realms. Fully outfitted and redeployable high-altitude surveillance systems can monitor combat zones at a fraction of the cost and with much more flexibility than traditional satellites, for example. The emergence and maturation of such cheaper platforms will create opportunity for fleet and creative service providers even as it threatens slower moving actors.

The conventional satellite market, meanwhile, could also be convulsed from within. As incremental and radical innovations continue to drive the cost of satellite technology lower, the economics of the industry will eventually reach a tipping point at which satellite-enabled capabilities become accessible to a far larger market. Formerly, payloads had to be high-value and long-lasting in order to recover the cost of placing an asset in space. Presently, smaller-value hosted payloads, CubeSats, and smallsats piggyback into space on these larger launches. Already companies such as Skybox, Surrey Satellite, and Colorado's own Sierra Nevada Corporation are pioneering development of the affordable, smaller, durable satellite systems increasingly demanded by the market. Once the cost of launch—at present prohibitively high for many would-be payloads—declines, market evidence suggests that the latent demand for more commoditized space assets could be explosive.[41]

In any event, agile firms will be able to manage these forces and others, adapt their portfolios, and tailor their service offerings. Others more wedded to specific technologies or rigid business models will struggle and may ultimately fold. Technology change will need to be mastered continuously by competitive firms.

To master technology change the industry will need to find new sources of financing to secure the R&D and scale-up funding. In this regard, just as the technology challenge is sharpening, new industry dynamics are disrupting the financial base of the industry's traditional innovation system. As the government's share of the space market declines, so too will the level of R&D activity it supports. For that reason, the space industry must seek out new ways to finance its R&D activities. This funding may come from a number of sources, including greater investment of firms' own capital (e.g., "corporate venture" and internal research and development (IRAD)) and by seeking to educate the broader

investment community about the opportunities in the space economy. But at any rate new finance mechanisms must be found.

This financing issue is a matter of some urgency. By definition, advanced industries are R&D-intensive. Aerospace, in fact, resides among the six industry groups that account for three-quarters of all R&D activities performed in the United States.[42]

Adding to the urgency is the fact that the space economy is highly reliant on government funding for its R&D. To this day, the majority of the aerospace industry's R&D—70 percent in 2008—is funded by the U.S. government, according to the latest data available from the National Science Foundation (NSF).[43] In fact, at a time when government-funded R&D totaled less than 40 percent for the U.S. business sector as a whole, top-10 aerospace and defense contractor BAE Systems reached 84 percent and another top-10 firm, General Dynamics, had 55 percent of its R&D funding supplied by the federal government.[44]

Given these older patterns of dependence on government R&D funding, the new dynamics of the space economy pose a serious challenge to the industry's innovation system. As government funding flatlines or declines, the aerospace industry will need new sources of capital to support these investments. Yet this may prove more challenging for aerospace than other advanced industries. For example, *The Space Review* points out that none of the six major new space companies have launched an IPO, nor have they received major levels of private financing.[45] Meanwhile, venture capital—recognized by the NSF as an important source of capital for technology development—is dominated in the United States by software, biopharmaceuticals, medical devices and equipment, consumer information services, and business support services, which collectively received 60 percent of all VC between 2007–2010.[46]

The bottom line: Changing industry dynamics will require adoption of new financing mechanisms to fund the critical space economy innovation process.

The industry's competitive underpinnings are under stress

Finally, the space industry must respond to two key trends affecting the core of its competitive standing—a looming skills gap due to an aging workforce and a growing imperative to collaborate and innovate.

The core of the American space industry's competitive foundation—its technical workforce—faces an aging stock of workers and a critical skills gap. The first disruptive trend is well-known but no less troublesome. A potential wave of retirements looms and the industry lacks sufficient numbers in the next generation to replace them. Yet, with downsizing expected in response to government cutbacks, the industry's challenge is not one of simple replacement. Rather, the industry must identify and fill critical skills gaps that will open as older workers retire and industry needs evolve. Companies must clearly understand which skill sets they will need to compete in tomorrow's marketplace and then accelerate efforts to find, attract, and develop top science, technology, engineering, and mathematics (STEM) talent with the necessary technical and managerial skills.

The U.S. aerospace workforce is clearly out of balance, in this respect, with a substantially larger proportion of older workers than the overall U.S. workforce. Roughly 55 percent of aerospace workers are between the ages of 40 and 60, compared to 45 percent nationwide. In addition, the industry employs fewer younger workers—just 35 percent of the workforce is between ages 20 and 40, compared to 40 percent nationally.[47] Meanwhile, between 25 and 40 percent of the U.S. aerospace workforce will be eligible to retire by 2014, though many have put off retirement in the wake of the Great Recession. Even still, a potential rush for the door looms in the coming years.[48]

Yet with that said, the challenge for today's space industry is not a simple numbers game. The industry expects some contraction in its workforce given reductions in government spending. *Aviation Week*'s 2012 Workforce Study shows that although the U.S. aerospace and defense sector expected to lose 56,000 workers to attrition and retirement in 2012, firms planned to hire only 28,000 new workers in that same time period. Meanwhile, survey respondents claim that there are floods of applications for any vacant positions they do have.[49]

At any rate, the space industry's top concern at present is finding sufficient numbers of candidates with the requisite high-quality knowledge and experience—particularly in software development and aerospace, mechanical, electrical, and systems engineering. Companies also project shortages in workers with program management and business development experience—precisely the types of expertise that the older generation of workers will take with them as they retire.[50] In short, the aerospace industry must find ways to effectively compete for talent and develop the skill sets it needs to remain competitive.

Innovation matters more and greater collaboration is required to achieve it. Finally, the imperative to maintain competitiveness in a world with more international players, shorter product lifecycles, and more complex products is ratcheting up the need to strengthen the space economy innovation system and the types of collaboration that make it work best.

Innovation, after all—whether of technology or business models—has always been a critical component of U.S. strength in advanced industries. It will now become an even more central determinant of business and industry success in the space economy as the industry faces what is perhaps the most demanding period in its history.[51]

Extensive research of British firms has found that higher innovation, as measured by R&D and patent development, is directly related to a firm's productivity growth. Moreover, firms must continuously innovate—by introducing new products or business processes—and do so at a faster and faster rate or risk losing ground to competitors.[52]

Globalization, moreover, has only amplified this effect, bringing more competitors into the mix. Emerging markets such as China are increasingly becoming hubs of innovation rather than simply production centers. In 2009, for example, the Chinese telecom manufacturer Huawei led the world in patent applications. It is now the world's third largest telecom-equipment manufacturer and increasingly viewed as a global competitor in the industry.[53]

Unfortunately, the aerospace and space economies—although synonymous with breakthrough technology development—must increasingly contend with troubling indications that the industry's ability to innovate at the needed rates may be compromised. R&D costs are frequently far higher than estimated and execution problems on key programs have led to calls for government acquisition reform.[54] Perhaps more fundamentally, numerous observers have concluded that the industry is not always organized to promote innovation effectively.[55] Many observers contend that excessively centralized, mechanistic, stovepiped, or proprietary organizational structures can weaken innovation processes that require much more exchange and coordination than conventionally conceived R&D.[56] Likewise, others suggest that the "command and control" mentality of the aerospace and defense culture may obstruct innovation imperatives such as openness and experimentation.[57]

All of which suggests that as the innovation imperative intensifies, greater collaboration among workers, between firms and academia, and with customers and suppliers will be required to remain competitive in the years ahead. In fact, recent findings by scholars of innovation note a consistent upward trend in the size of inventive teams. This need for collaboration, in turn, points to the critical importance of well-functioning industry networks and clusters to facilitate success. Studies of innovation show that innovation increases with the number and intensity of strategic alliances across organizations and confirm that the presence of dense, vibrant industry clusters enhances innovation.[58]

For the space industry (and all advanced industries), the message is clear: Greater collaboration—mediated through effective industry networks and robust regional industry clusters—will be required if firms hope to remain competitive in the ever-evolving space economy.

* * *

In short, the global space industry is changing rapidly. As the industry becomes increasingly international, services-led, and commercially oriented, industry players must innovate to remain competitive. This is true whether battling it out in the increasingly contested government sector or pursuing growth opportunities in the space services, nascent new space, or adjacent markets. Growth will require more commercial, product-based offerings; a stronger focus on customer service; new ways of funding critical R&D; and a redoubled emphasis on spurring innovation activity. Furthermore, to deliver on this innovation imperative, the space industry must address its looming talent crisis and ramp up the reach and intensity of its collaborations.

V. STRENGTHS AND WEAKNESSES: COLORADO'S COMPETITIVE POSITION

Amid disruptive change, the Colorado space economy approaches the future with tremendous assets and real momentum. The state possesses an extraordinary array of innovative companies, highly respected university research programs, signature military installations, and sophisticated intermediary organizations. No region in the world may be better positioned to seize the coming opportunities for commercial delivery of satellite-based services such as GIS, earth observation, and telecom.

And yet, the state space industry is experiencing sustained pressure from both competitor states and global competition. This pressure, in turn, is exposing a number of shortcomings of the state cluster that raise questions about the medium-term competitive position of this "crown jewel" industry.

From the state's reliance on federal funding flows to weaknesses in its innovation system, access to finance, workforce pipeline, and cluster performance, these challenges must be recognized and addressed if the state is to maintain its competitiveness in the coming decades.

Which is why this chapter assesses the strengths and weaknesses of Colorado's broader economy—and its space economy specifically, where possible—across a variety of critical dimensions by benchmarking the state's performance against that of the nation and of eight states that are considered leaders in the aerospace and defense industry: Alabama, Arizona, California, Florida, Maryland, New Mexico, Texas, and Virginia (see Appendix C for the complete results of this benchmarking exercise). These interstate comparisons are of particular use because Colorado will continue to face strong competition from its peer states amidst an environment of flat or declining government funding.

Overall, the chapter concludes that although Colorado possesses a long list of potent assets, it also faces a number of challenges that could imperil the state space industry's ability to maintain its competitive edge.

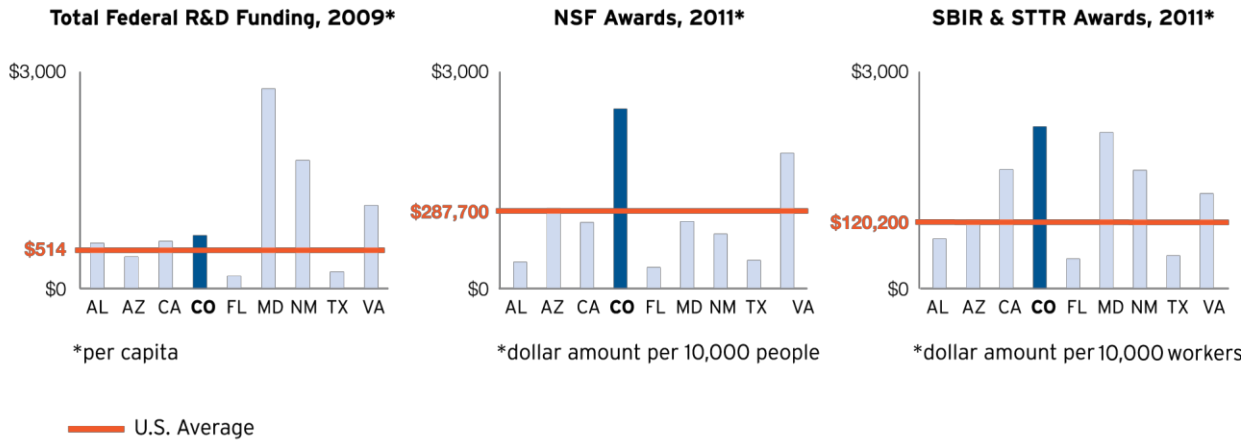
Colorado possesses powerful local assets that support its presence in the global space economy

In many respects, Colorado seems perfectly situated to flourish amid the changing and demanding conditions of today's space market.

To begin with, a strong **entrepreneurial bent** and an array of highly entrepreneurial segments in the space economy position Colorado extremely well to compete in emerging commercial markets. Most notably, Colorado ranks among the top five states in the nation on the "2011 Kauffman Index of Entrepreneurial Activity," with 420 entrepreneurs for every 100,000 people in the state—an incidence 1.3 times higher than the national average.[1] In addition a number of high-impact incubators and accelerators, such as the Rocky Mountain Innosphere and the Innovation Center of the Rockies, exist to support the successful development of entrepreneurial companies in the state. This ambient entrepreneurial bent positions Colorado's space economy to move ahead and potentially seize on new opportunities in the commercial space market. This is especially true given the large and diverse nature of the state's space industry, as revealed in this report, with its array of sophisticated specializations in such dynamic niches as satellite imagery, remote sensing, and space systems manufacturing.

Likewise, the state possesses critical components of a **strong innovation system** that has generated a steady stream of cutting-edge research and advanced solutions, particularly for government clients.[2] Specifically, Colorado performs extremely well nationally and compared to its peer states in attracting federal R&D funding, NSF and Small Business Innovation Research / Small Business Technology Transfer (SBIR / STTR) awards, and university R&D spending. In 2009, Colorado ranked sixth among all states in per capita federal R&D funding flows, securing $737 per person, nearly double the national average of $422 per person.[3] What is more, Colorado's share of all NASA R&D funding has increased steadily, reaching nearly 21 percent of the nation's total in 2009.[4]

When compared to peer states, Colorado performs well in government-supported innovation

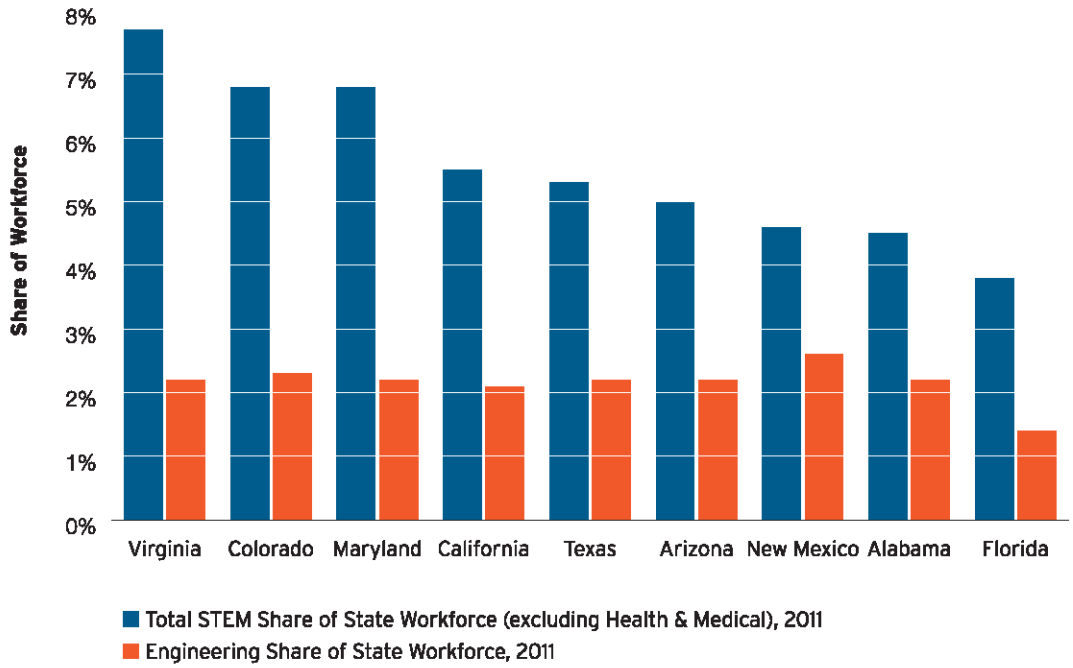


Source: Brookings analysis of National Science Foundation's Survey of Federal Funds for Research and Development, FY 2009 and U.S. Census Bureau Population Estimates, 2009. Brookings analysis of National Science Foundation's Budget Internet Information System Award Summary by State/Institution FY 2011 and U.S. Census Bureau Population Estimates, 2011. Brookings analysis of data from Small Business Innovation Research (SBIR.gov), 2011 and Moody's Analytics, 2012.

Colorado's universities have proven especially successful at securing federal funding, and overall university R&D spending in Colorado ($224 per person) is much higher than the national average ($189 per person). Likewise, Colorado's NSF awards between 2007 and 2011 reflect the state's exceptional research capabilities and are significantly higher than the national average in per capita terms. Colorado also performs exceptionally well when compared to the rest of the nation and leads its peer states in the total dollar value of overall SBIR & STTR grants per 10,000 workers as well as in attracting DoD / NASA / NOAA SBIR & STTR grants, which are more closely related to space activities.[5] In short, at least as measured by metrics of federal research prominence, Colorado would seem to possess the kind of innovation system needed to drive growth in its space economy.

In addition, Colorado's space economy benefits from a large base of **skilled talent,** especially in STEM disciplines.[6] With vibrant aerospace, biotechnology, and technology industries, 6.8 percent of the state's jobs are in STEM, a standing that ranks Colorado second among its space economy peer states and fourth among all states for the depth of its technical orientation. Equally encouraging is the fact that the share of Colorado's workforce in STEM occupations has risen 4.6 percent since 2001. Among its peers Colorado also has the second highest (while ranking fifth nationally) share of its workforce engaged in engineering occupations, which are critical to meeting the changing technological needs of the global knowledge economy.[7] In addition to the larger STEM makeup of Colorado's workforce, the state's institutions of higher education have been producing a higher proportion of STEM graduates than most states, thereby helping to provide a bigger pool of skilled workers from which space firms can hire.[8] (It should be noted, however, that despite exhibiting a high proportion of STEM graduates relative to peers, this share has been trending downward since 2001, which in the future could increase the risk of talent shortfall for high-end knowledge jobs.)

When compared to peer states, Colorado ranks well on its share of workforce in STEM and engineering occupations



Source: Brookings Analysis of BLS May 2011 Occupational Employment and Wage State Cross-Industry Estimates.

Colorado also fares well on rankings of state business climate and global connectivity. With a competitive tax structure and a business-friendly tax climate, Colorado's **low to moderate cost of doing business** stands out among the nation's more economically competitive states.[9] Although the state levies every major tax, the rate of each is among the lowest in the nation, due in large part to the fiscal discipline mandated by the Taxpayer Bill of Rights (TABOR).[10] Furthermore, **strong air transit links** and **surging international trade** are enhancing Colorado's status as a leading space industry destination. The state's growing global business exchanges—soon to be augmented with direct flights to Tokyo—are cultivating a cadre of internationally experienced executives while at the same time boosting exports. In terms of total exports, Colorado has experienced 7.2 percent annual growth from 2003 to 2010 and 9.1 percent annual growth in exports of aircraft products and parts—an adjacent market—putting it second among its peers in both measures.[11]

In short, Colorado provides a sound economic platform for the operations and entrepreneurial culture of its space economy.

Colorado space economy competitiveness SWOT summary

Strengths	Weaknesses
• Entrepreneurial spirit and can-do western attitude • Strong federally funded research base that provides core asset to innovation system • Skilled talent base, especially in STEM • Low to moderate cost of doing business • Robust global engagement and international trade • Strong space ecosystem with a diversity of major business establishments as well as numerous smaller, growing firms • Solid positioning in government space • Proven ability to win federal contracts	• Heavy dependence on federal contracts causes uncertainty due to federal budgetary instability • Insufficient marketing efforts • Relatively junior congressional delegation with limited presence on key committees • Weak presence in new space and adjacent markets • Relatively low performance on some measures of university-to-industry tech transfer • Venture capital funding skews toward energy, software, IT, and biotech sectors • Declining spending on higher education • Suboptimal collaboration between stakeholders
Opportunities	**Threats**
• Consolidate and maximize position in the space economy • Seize commercial opportunities in emerging new space, adjacent, and global markets • Commit to innovation and owning the next great space technologies • Improve the availability of risk capital • Bolster the workforce pipeline to secure Colorado's human capital advantage • Intensify cluster dynamics	• Vulnerability to pullbacks in government space • Stiff competition from peer states in both traditional and emerging, adjacent markets • Complacency about state already doing well • Insufficient access to risk capital • Aging technical-engineering workforce • Large decline in graduates with STEM degrees • Institutional, geographical, sectoral, and cultural challenges stifle collaboration

Yet the state's assets go far beyond business basics to encompass more specialized sector-specific strengths.

Colorado boasts the presence of strong **military and civil institutions** that anchor the state's space economy. The state possesses an unrivaled concentration of military organizations that provide national security functions using space assets and the space infrastructure. These installations act as a magnet for the space industry, encouraging the growth of regional clusters to support military space activities. Furthermore, the military serves a vitally important role as an employer, a source of talent, a source of demand, and an inducer of innovation. In addition to the five major military installations and five strategic commands—including the Air Force Space Command—located in the state, Colorado is home to six space-related research centers at the Air Force Academy.[12]

For its part, the civil sector, which includes universities, research organizations, and federal labs, plays an equally important role in conducting R&D and inspiring and training the next-generation space workforce. The aerospace engineering and other science and engineering programs at Colorado's universities are among the best in the nation.[13] Specialized research centers tailored to emerging fields like unmanned systems or cyberspace abound. And close relationships with laboratories provide students with the opportunity for internships and applied learning.

These laboratories themselves complete one of the nation's most impressive scientific communities along the Front Range. An impressive 24 federally funded research laboratories concentrate in and around Boulder.[14] The National and University Centers for Atmospheric Research, the National Institute of Standards and Technology, the National Renewable Energy Laboratory, and NOAA's Earth System Research Laboratory, to name just three of the labs active in the space economy, have been at the forefront of some of the world's most important discoveries about earth and beyond. These entities leverage space to provide public goods like weather forecasting and environmental data and thus act as a discerning consumer base for space-based capabilities like remote sensing. The recent opening of the U.S. Patent and Trademark Office's satellite office in Denver stands as yet another important testament to the state's robust R&D ecosystem—of which space is only one part.

The state complements its strong institutions with an additional competitive asset: Colorado's geographically concentrated, well-organized **space ecosystem**. A dense assemblage of organizations and networks such as the CSC, the Space Foundation, and the Metro Denver EDC represent important intellectual infrastructure for the state's space economy, providing an array of forums for the exchange of information and knowledge.[15] In addition the eSpace Center for Space Entrepreneurship (eSpace) serves as the state's primary business incubator and workforce development organization for aerospace companies.[16] Taken together these entities play critical roles in promoting Colorado's significant space assets at the national level, advancing federal legislation that is vital to the industry's growth, hosting forums and events that spotlight Colorado as a leading destination for space companies to do business, and helping entrepreneurs establish new space companies.

It is no wonder, then, that Colorado has come to enjoy an increasingly **strong position in government space,** secured in large part by its **proven ability to win federal contracts**.[17] The state's highly regarded R&D capabilities have allowed Colorado to successfully attract a significant flow of federal government contracts, particularly from DoD and NASA.[18] Compared to its peers, Colorado's space companies have a stellar record of winning high-value federal contracts—especially in development of spacecraft and satellites, remote sensing, and navigation and detection instruments—demonstrating not only the state's capacity for innovation but also serving as a foundation for one of the most robust and vibrant 21st-century space economies in the nation.[19]

The main takeaway from all this: Colorado possesses tremendous assets and capabilities upon which it can draw as it contends with the many disruptive forces now at work in the global and national space marketplaces.

Colorado performs well in securing federal (DoD-NASA-NOAA) core space contracts

	Contract Value, 2011 (State Rank)	Average Contract Value, 2011 (State Rank)	Normalized Contract Value, 2011 (State Rank)
Alabama	$1,509,293,184	$679,250	$71,905
	(8)	(3)	(3)
Arizona	$4,342,781,952	$732,712	$99,972
	(4)	(2)	(2)
California	$11,746,821,120	$556,748	$42,426
	(1)	(5)	(6)
Colorado	**$4,673,232,384**	**$1,805,034**	**$151,286**
	(3)	**(1)**	**(1)**
Florida	$1,677,173,504	$197,268	$33,624
	(6)	(8)	(8)
Maryland	$2,075,488,128	$403,321	$41,452
	(5)	(6)	(7)
New Mexico	$114,389,992	$159,986	$4,391
	(9)	(9)	(9)
Texas	$4,944,647,680	$575,494	$52,038
	(2)	(4)	(4)
Virginia	$1,617,728,256	$306,911	$48,653
	(7)	(7)	(5)

Source: Brookings analysis of the General Services Administration's USA Government Spending Database, 2012.

At the same time, Colorado faces a number of deficiencies that could imperil the ability of its space economy to maintain its momentum

In this respect, at least six challenges raise questions about the near- to medium-term competitive position of this "crown jewel" industry. These problems include:

A heavy dependence on government space makes the Colorado space economy vulnerable to federal funding pullbacks. Ironically, the very activities that have made the state strong in government space could endanger its position in the future. Specifically, the predominance of military and intelligence activities in Colorado's space sector and the state's heavy reliance on federal government contracting make the state particularly susceptible to federal budget drawdowns and fiscal uncertainties.

Most notably, Colorado's dependence on federal spending exposes the state's major space actors to high levels of direct and indirect uncertainty—with more in store going forward. Consider, for example, that Colorado's top five aerospace contractors—Lockheed Martin, United Launch Alliance, Ball Aerospace, Raytheon, and Northrop Grumman—derived nearly 60 percent of their total revenues between 2008 and 2010 from government contracts.[20] That means that fluctuating contract awards and related uncertainty are now likely to hit the state's prime aerospace / space contractors even harder as federal budget pullbacks intensify. Even so, the fate of the big aerospace primes is just one part of a larger problem. Scores of other Colorado contracting firms receive on average more than 42 percent of their revenue from the federal government.[21] And the effects of federal scalebacks extend further, rippling through the state's many subcontractors and the supply chain. Thus, federal program reductions and budgetary uncertainty represent a substantial challenge to the Colorado space cluster as a whole.

What this means more broadly is that with more space-industry-intensive states competing for the same limited number of federal contracts, Colorado will need to further hone its competitive edge just to break even. Unfortunately, there is a perception that Colorado needs to up its game in this regard. Various industry stakeholders pointed out during interviews and conversations that Colorado needs to do a better job of promoting itself as a tier-one space state with extraordinary capacities. Likewise, several stakeholders noted that the state's relatively junior congressional delegation has not always been able to speak in one voice in order to elevate Colorado's space-sector concerns at the federal level (though all agree that much progress is being made on this front).[22] At the same time the Colorado spaceport and Orion projects prove that when statewide priorities are conveyed unanimously and urgently, the congressional delegation is effective in advancing that agenda and championing the state space industry. The state's delegation has also been a longstanding advocate for ITAR reforms—especially with Senator Bennet writing export control changes related to commercial communications satellites and components into the Senate version of the 2013 National Defense Authorization Act—indicating that when needed Colorado's entire delegation has provided a unified voice on tough issues affecting the state.

The state has yet to gain a significant toehold in new space, adjacent, and global markets. Shifting federal policy and continued technological developments also point to the need for the Colorado space community to "broaden the aperture" to embrace new market opportunities, including emerging niches in traditional space, new space, and closely related or adjacent market segments that build on the industry's core capabilities. In this respect, while Colorado firms need badly to pivot into emerging new markets that are less dependent on federal support, the state space industry has not moved aggressively in that direction as yet. In fact, the state actually lags on some indices of competitiveness in comparison to its peer states.

To be sure, the state is not inactive in the new niches. On the new space front, the state may still lack a billionaire-financed publicity-maker along the lines of Elon Musk's Space Exploration Technologies Corporation (SpaceX) in California or Jeff Bezos' Blue Origin in Washington State, but a number of companies are rising to the competition—and defining it. Sierra Nevada Corporation's Dream Chaser is a leading contender to provide the next generation of commercial crew and cargo transportation services to NASA.[23] United Launch Alliance itself is preparing to compete with the insurgents head-on by, for example, human-rating its Atlas rocket. Likewise, the space community has rallied around the Spaceport Colorado initiative in an effort to proactively build the infrastructure of the future on the Front Range. And most recently the Golden Spike Company entered the race with a novel business plan, substantial technology, and a vision of forging the "railroad of the future" to the moon.[24]

Much activity is burgeoning in the realm of UAVs and UASs as well—unsurprisingly considering the state's longstanding research strengths in aeronautics. In centers such as the Air Force Academy's Center for Unmanned Aircraft Systems Research and CU-Boulder's Research and Engineering Center for Unmanned Vehicles, Colorado actors are conducting the R&D that will determine how, to what ends, and with what capabilities remotely piloted aircraft will be deployed in both combat and civilian life. In addition, the U.S. Geological Survey's Denver office is conducting R&D into civilian applications of UASs to further its own and other agencies' missions.[25] No longer the domain of engineers tucked away in their laboratories or large primes on secret government contracts, a number of small entrepreneurial Colorado firms are now active in this realm too—Black Swift Technology, Bye Aerospace, CLMax Engineering, DroneMapper.com, SkySentry, and Tigon Enertec, to name only a handful—and a number of others such as Numerica are adapting their instruments and services to operate on these alternative aerospace platforms. Meanwhile the Mesa County Sheriff's Office in western Colorado is one of the

country's three law enforcement organizations testing UAVs in the field.[26]

But beyond that—or in spite of it—Brookings analysis of 2011 DoD, NASA, and NOAA contracting data in selected "adjacent" markets reveals that Colorado ranks behind many of its competitors in terms of the number of its companies winning contracts in UAVs; cybersecurity and electronic communication systems; energy storage, production, and conservation technology; solar energy systems; and high-tech manufacturing.[27] While in no way a definitive metric, this proxy for technical and commercial ability in adjacent markets suggests that too few of the technologies, products, and services being developed in these markets by Colorado companies are being commercialized, and that too many opportunities for diversification by Colorado companies into adjacent markets remain unexplored.

Furthermore it appears that much of the activity in the commercial space industry and in new space is heavily concentrated in California and to some extent Virginia and Texas. The NewSpace Global 100 Index—which ranks private companies in the growing commercial space sector—reports 25 such firms headquartered in California, eight in Texas, and six in Virginia. Only five Colorado companies—UP Aerospace, Altius Space Machines, Escape Dynamics, Sierra Nevada Space Systems, and Special Aerospace Services—made it into the index. Colorado is, in short, "in the mix" but not yet a leading site for emergent commercial activity.

Colorado lags peer states in securing federal (DoD-NASA-NOAA) contracts in adjacent markets

	Contract Value, 2011 (State Rank)	Average Contract Value, 2011 (State Rank)	Normalized Contract Value, 2011 (State Rank)
Alabama	$38,107,696	$396,955	$1,816
	(7)	(6)	(7)
Arizona	$95,534,256	$519,208	$2,199
	(6)	(5)	(6)
California	$1,420,902,400	$1,374,180	$5,132
	(2)	(2)	(4)
Colorado	**$35,250,468**	**$387,368**	**$1,141**
	(8)	**(7)**	**(8)**
Florida	$131,287,144	$280,528	$2,632
	(5)	(9)	(5)
Maryland	$1,119,172,224	$1,216,492	$22,352
	(3)	(3)	(2)
New Mexico	$15,967,368	$354,830	$613
	(9)	(8)	(9)
Texas	$726,692,224	$1,389,469	$7,648
	(4)	(1)	(3)
Virginia	$1,471,590,784	$569,942	$44,258
	(1)	(4)	(1)

Source: Brookings analysis of the General Services Administration's USA Government Spending Database, 2012.

The state's innovation system is struggling with the challenges inherent in technology transfer and commercialization within the aerospace and space sectors. In this connection, very little matters for the future competitiveness of the Colorado space economy as much as the efficiency and speed of the state's innovation ecosystem, which will increasingly depend on effective collaboration, especially between the state's universities and industry. And yet here, too, shortcomings in some measurements of the state's space-related innovation activities raise questions about Colorado's competitiveness.

To be fair, many experts have observed that fundamental market problems impair the nation's ability to translate innovative research discoveries of all sorts into viable commercial products.[28] They note—whether in reference to engineering fields, cleantech, or biotech—that a significant finance gap (the so-called "valley of death") frequently separates potentially valuable research discoveries from commercialization. As a result of this funding gap between basic research and commercial innovations—with the private sector, including venture capital firms, loath to invest money in the intermediate stages—many opportunities to create technology ventures remain undeveloped and un-exploited.

Moreover, a number of challenges inherent in the space industry may especially hinder university-industry collaboration on innovation issues, wherever it is attempted. Most notably, the fact that NASA and DoD are the dominant customers for the aerospace and space industry means that there exists no large commercial market for many space-related technologies. That signal fact clearly represents a major impediment to technology commercialization, whether in Colorado or elsewhere, and may somewhat explain the state's performance.

And yet, a number of general and some aerospace-specific indicators suggest that the state's technology transfer system (just one component of the overall innovation system in the state) may not be functioning as effectively as those of some competitors.[29]

In terms of its all-around effort across all sectors, room would seem to exist for the state to capitalize more extensively on recent improvements in university-based technology development and commercialization over the past few years, especially given its many important university programs, world-class researchers, and substantial federal R&D enterprise. In FY 2011 Colorado's three big universities—CU, CSU, and Colorado School of Mines (CSM)—ranked the state 36th in the nation on university patenting rates and sixth in comparison to its eight space-state peers, with five patents issued per $100 million in research expenditure.[30] Over the past decade patents issued by Colorado's universities grew at a rate of 2.5 percent annually, a rate slower than the national average of 2.7 percent and its peer states' average of 3.2 percent over the same period. Royalty income generated from licensing—another important metric of the commercial use of technologies generated within universities—is also below expected levels. When 2011 license revenue is normalized across top-earning institutions according to the size of the research enterprise, CU ranked 85th, CSU 95th, and CSM 109th out of 153 U.S. universities. Between 2001 and 2011 royalty income generated from licenses grew 4.9 percent annually, falling below the national average of 5.7 percent over the same period.[31] With that said, Colorado universities perform somewhat better on measures of university-inspired entrepreneurship, ranking 13th nationally, although Colorado ranked a middling 5th in comparison to peer-state institutions in 2011, with 1.5 startups created for every $100 million spent on research.[32] More encouraging has been the fact that startups originating from the state's universities grew 16 percent annually between 2001 and 2011, an annual growth rate more than twice that of its peers.

A closer look at the state aerospace and space sectors specifically reveals untapped opportunities in university technology transfer activities.[33] Statistics on space-oriented entrepreneurship based on technologies developed in Colorado universities demonstrate the special challenges of generating startups to exploit university-based intellectual property. Out of the 53 startups created to commercialize CU-developed technologies between 2007 and 2011, only two companies operate in the space industry. Most startups coming out of CU are in either the energy / cleantech or bioscience / biotechnology fields.[34] Similarly, of the 30 CSU-inspired startups formed to date, three can be identified as operating in the space economy. In the case of CSU, almost all entrepreneurial success has been in biotechnology and agriculture.[35] Data from CU and CSU on patent applications and patents issued in the aerospace and space sector reveal a better performance. Between FY2008 and FY2012, for example, the CU-Boulder campus had 375 patent applications and 81 patents issued. Of these, approximately 31 were aerospace and space-related patent applications with approximately 12 patents issued in this sector.[36] During the same period CSU researchers generated 710 patent applications and saw 56 patents issued. Of these 710 applications, aerospace and space sector research yielded 62, with eight patents issued.[37]

What is one to make of these mixed but generally suboptimal numbers? Much likely owes to the inherent challenges in conducting tech transfer in the aerospace industry, particularly given its limited commercial marketplace.[38] In addition, it is important to keep in mind that significant commercial exchanges take place in forms not captured by patenting and firm startup metrics such as cooperative research and development, and through conferences, publications, and networking.

Nevertheless, stakeholders in both industry and academia—while recognizing the value of ongoing interactions—tend to suspect that collaborations between Colorado universities and the private sector on technology innovation and commercialization could be more robust, especially in the aerospace sector. Along these lines they pointed to a number of problems both on the university side and the private-sector side that they felt could be inhibiting such needed collaborative activity. Several stakeholders wondered if Colorado universities' success in attracting federal funding had perversely made commercialization and corporate partnerships less of a priority.[39] Others argued that the small size of university tech transfer office budgets and staffing and the rigid nature of these offices' one-size-fits-all approach to licensing inhibit deal flow. Still others mentioned the difficulty of identifying and marketing cross-cutting space or aerospace technologies within the universities given that their best commercial applications may well lie in adjacent or farther-flung non-space markets (for instance, imaging technology for cancer screening). With regard to the private sector, stakeholders questioned whether Colorado aerospace and space companies are fully oriented toward the sorts of collaborative innovation that will be demanded in the coming years. Several sources noted among large aerospace companies a bias toward keeping R&D and intellectual property (IP) development in-house in order to maintain exclusive rights and control over technologies.[40] Others observed that the culture of the larger aerospace and defense companies has not always been oriented toward external engagement and partnering. Still others suggested that smaller firms may simply lack the wherewithal to engage in extensive innovation exchanges with academia or other actors.

In any event, both quantitative and qualitative evidence suggests that the Colorado space economy's innovation system is not now operating at the optimal pitch needed to achieve and defend global leadership in this industry.

Insufficient access to risk capital stymies startups. Yet innovation and commercialization in the space economy require more than just innovation and technology transfer. They also require adequate flows of risk capital—including angel and venture funding—which is essential to support the commercialization and scale-up of new technologies or business models. And yet, on this front, too, Colorado's space economy entrepreneurs find themselves at a disadvantage when compared to competitors in other states.

To begin with, of course, aerospace and space firms everywhere must contend with the particular difficulties of financing commercialization activity in the sector.

Most notably, investments in innovative pursuits in this sector tend to be expensive and risky, often requiring large upfront R&D investments in projects that extend over long development periods.[41] Political uncertainty over the demand for space products and services—resulting from shifting national security priorities and federal budget impacts on program continuity—only increases the level of risk involved in long-term investments.[42]

What is more, investment capital including angel and VC has remained scarce in the aerospace and space sector for other reasons. Due to its heavy involvement with critical government programs and missions, the space industry has historically employed an approach to product development that differs significantly from that of other sectors. The industry frequently engages in providing technically complex, "one-time-use only" products and services that have been designed to meet the requirements of a specific military or civilian program. Rarely, then, do companies build products that directly address a market need shared by large numbers of commercial customers.[43] This market reality has undermined interest in the space industry among investors seeking sizable returns on investments within relatively short timelines.

Relatedly, the difficulty of predicting revenues for startups operating in the aerospace and space industry has further depressed VC investment. Revenues for space and aerospace companies, after all, tend to be lumpy and hard to manage given that they fluctuate dramatically from year to year due to the vagaries of defense and civilian programs, which can be downgraded or eliminated altogether depending on politics, budget levels, and other factors beyond the industry's control.

Furthermore, since space and aerospace startups typically sell to large prime contractors whose level of demand is often determined by their fortunes in winning government contracts, visibility into the revenue pipeline tends to be limited.

And yet, beyond the difficulties inherent in financing space economy development and commercialization activities in general, Colorado's space companies appear to struggle in this respect even more than many of their counterparts in other states. Most notably, even though Colorado companies generally do well in attracting private capital funding in the form of VC investments, a closer look at the relevant data reveals several problems with significant implications for the ability of the state's space companies to grow and thrive.[44]

To begin with, VC funding in the state remains heavily skewed toward the energy, software, IT services, and biotech sectors, with more than 60 percent of Colorado's total VC funding going to those four sectors in the last five years and almost none going to companies in Colorado's space economy.[45] In 2011, more than 75 percent of Colorado VC investment took place in those four leading sectors and none in aerospace or space.[46] In other words, young companies in Colorado's space sector are receiving virtually no venture capital.

Nor does the availability of VC funding seem to be improving in Colorado. After all, even as aerospace-focused VC investment remains extremely limited, the state's share of total U.S. VC financing for all sectors has remained more or less flat since 2002, clocking in at approximately 2 percent of the national total. In no year in the last decade has the state reached the impressive 4 percent of U.S. VC funding that it secured in the years prior to 2000. Which means that VC funding in Colorado is becoming less available and harder to get. On top of that, more than 90 percent of VC funding in Colorado in 2011 came from out of state.[47] That is risky because VC funds typically prefer to invest in local companies. Fewer Colorado-based VC funds effectively translates into less VC for Colorado startups.

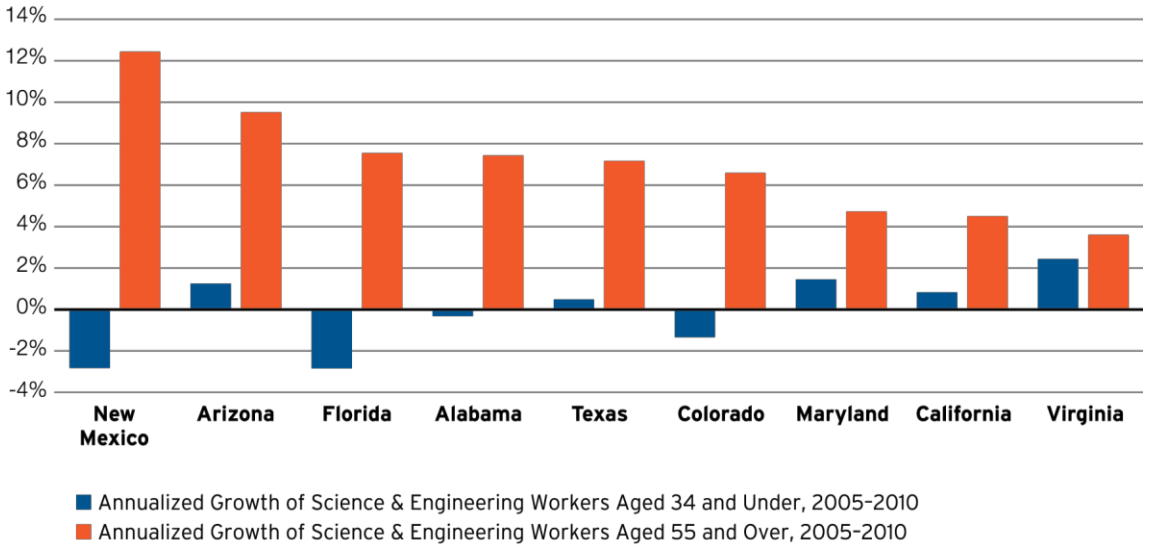
With that said, there is burgeoning interest in the expanding new commercial space market, with a growing number of investors excited about the emergent space technology sector—which includes hardware and infrastructure for getting to space and operating space equipment as well as applications enabled by greater access to satellites and other innovations.[48] However, since much of this still-nascent activity appears to be confined to California, Colorado will need to make a sustained effort to attract venture capitalists to invest in its space-related companies.[49]

An aging science and engineering workforce and other workforce-related challenges could adversely impact the industry's future growth. The national STEM workforce challenge, meanwhile, appears especially acute for Colorado. Given its large existing base of STEM jobs, after all, an especially large number of skilled engineers and scientists are going to be needed to staff the space industry's cubicles, clean rooms, and production lines. In this regard, three workforce-related challenges must be addressed in order to ensure the future growth of Colorado's space sector: an aging science and engineering workforce; a looming shortage of STEM graduates in the next five to 10 years paired with increasing demand for skilled workers; and very low state spending for higher education as a proportion of GDP.

Begin with the aging of the science and engineering workforce. Four years ago, with approximately one-quarter of the nation's aerospace workforce eligible to retire, the Aerospace Industries Association declared the potential skills drain one of the most critical challenges facing the industry.[50] Yet now, it appears that the situation has improved little since that time and may actually be poised to get worse—especially in Colorado.

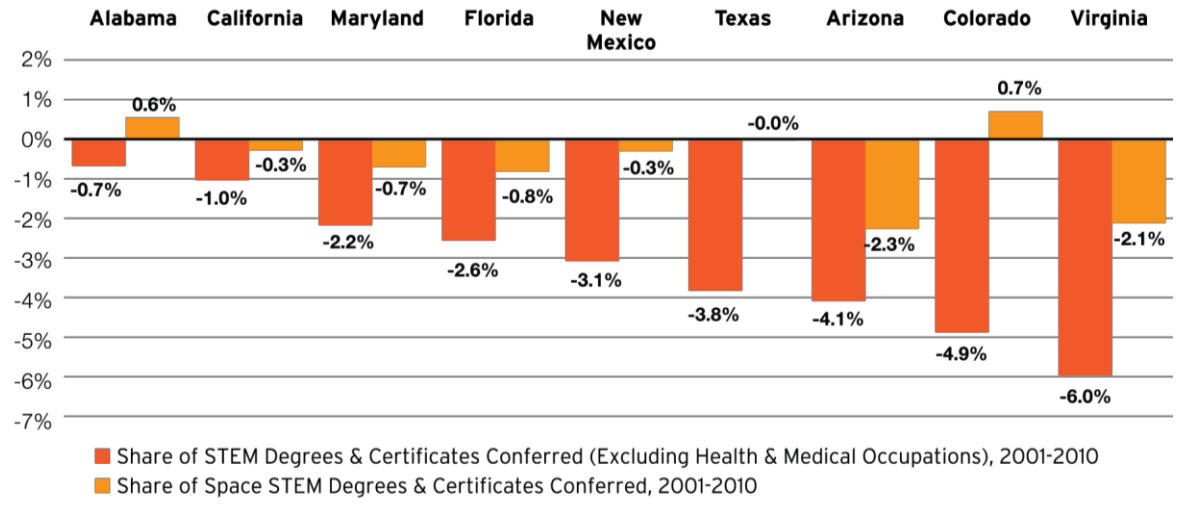
To be sure, the aging of the technical workforce is a secular trend affecting most states.[51] Yet even so, the challenge appears especially stark for Colorado, where between 2005 and 2010 the share of the state's STEM workers younger than age 34 declined by 2.6 percent annually to 55,640 while the share of those older than 55 over the same period increased by 4.5 percent annually to 31,450.[52] The implication: As a sizable portion of the Colorado science and engineering workforce

Between 2005 and 2010, Colorado experienced a decline in the number of younger STEM workers and an increase in the number of older STEM workers



Source: Brookings Analysis of Population Reference Bureau, Trends in Science and Engineering Labor Force Project.

When compared to peer states, Colorado has seen an especially large decline in graduates with STEM degrees, despite a modest increase in space-related degrees



Source: Brookings analysis of National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Centes IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates.

ages and begins to retire—taking with it crucial institutional and technical knowledge—the state faces an urgent need to produce enough trained scientists and engineers to replace the retiring workforce.

And yet, current trends suggest that this may prove difficult. While all of the peer states and the nation as a whole saw a decrease in graduates with STEM degrees, Colorado has seen an especially large decline despite a modest increase in specific space economy STEM degrees.[53] A low share of STEM graduates may well increase the risk of talent shortfall for various high-end knowledge jobs in Colorado.[54]

Nor does a look forward provide reassurance. Ten-year projections of current trends in STEM workforce demographics and STEM degree production are also sobering.[55] If these trends are not reversed, in as soon as six years Colorado's STEM labor force could hit an inflection point where there will be more STEM workers transitioning into retirement than starting their careers.[56] This decline in the share of STEM workers ages 34 and under is highly correlated with the decline in the share of STEM degrees and certificates conferred within Colorado.

Colorado's ability to produce sufficient homegrown talent becomes critical in the face of the growing demand for STEM workers in the state. After all, although Colorado led the nation with net in-migration of 13,000 new residents possessing bachelors' degrees in 2011, such inflows are not likely to play a significant role in replenishing the state's aging STEM-trained workforce going forward.[57] At present rates Colorado will only produce approximately 65,000 space economy-oriented STEM degrees and 155,000 general STEM degrees between 2011 and 2020—a time period over which, on the demand side, at present rates, Colorado's economy will generate between 190,000 and 230,000 new STEM openings.[58]

All of which makes clear the need for strong STEM education and training initiatives to avert a skills shortage, especially since nearly 60 percent of space economy STEM occupations require a bachelor's degree or higher. On this front it does not help that Colorado resides among the lowest tier of states when it comes to state spending for higher education as a share of its GDP. In 2010, Colorado's appropriations for higher education operating expenses as a share of GDP stood at a mere 0.26 percent, just half the national average of 0.52 percent and one of the lowest figures in the country.[59] Even more distressing, the state trend has been toward decreased support for higher education. Between 2000 and 2010, while most states increased appropriations for higher education in terms of current dollars, Colorado decreased its appropriations by 16 percent.[60] On a per student basis, the numbers look even worse. Colorado's public research universities have witnessed a substantial decline in state funding per student over the course of the last decade—at a time of substantial enrollment growth.[61] Per student state funding (in constant 2005 dollars) plunged from $6,617 in 2002 to $3,417 in 2010, reflecting a 48-percent decline over the period that ranked Colorado 50th among states for the trend of its per-student education funding.[62] Such trends raise serious questions about the state's ability to attract the best talent and provide quality education for the next generation of space industry scientists and engineers.

Suboptimal cluster dynamics—especially those involving collaboration—may be hindering growth. Finally, with collaboration increasingly central to the innovation and growth process, the state's complicated cluster dynamics may not be functioning at optimal levels. In this respect, while dynamic regional clusters and cluster organizations are increasingly recognized as vital forums for the collaboration that is itself increasingly critical to innovation, qualitative analysis suggests that a number of institutional, geographical, sectoral, and cultural challenges may well be depressing the collaborative vibrancy of the state's extraordinary assemblage of space actors.[63]

In a way, this conclusion is surprising, given the sheer volume and diversity of space-sector activity concentrated along the Front Range and the good work being done by such cluster organizations as the CSC, the Colorado Space Business Roundtable, eSpace, and the Metro Denver EDC. Few states, after all, possess either so much diverse space economy activity or so many organizations to advance it. And it bears noting that stakeholders across the space economy have demonstrated the ability to come together to advance shared interests like the Colorado Spaceport. For that matter, the Rocky Mountain Center for Innovation and Technology—formerly known as the Aerospace and Clean Energy (ACE) Manufacturing and Innovation Park—in Loveland reflects a recognition that disconnects exist among the state's many strong and successful entities.[64]

And yet, it may be that the special complexity of the Colorado space ecosystem combined with the state's unusual variety of

cluster actors is itself inhibiting cluster dynamics.

To begin with, numerous stakeholders suggest that the disparate helpful activities of the state's multiple space economy cluster organizations do not always get "added up" in ways that maximize the organizations' impact—in part because the organizations are separate entities. These stakeholders note that the proliferation of such organizations often means that the industry more broadly is not able to speak with one voice on strategic direction, outcomes expected, and specific actions to be taken. What is more, notwithstanding the state's abundance of cluster organizations, it appears that these organizations do not now fully represent the entire spectrum of the state's emerging space economy. Specifically, representation in Colorado's main space economy cluster organizations seems far denser in the traditional space systems manufacturing and operations category and its supply chain and in the federal contracting sphere.[65] Representation is much thinner in the satellite-based services segments farther downstream, in the adjacencies, and outside of the federal contracting world—which is precisely where future growth is most likely to occur and where the most productive new collaborations might well take place. In a word, then, the state's networking institutions may be at once disconnected and not fully representative.

And the state's space cluster must contend with other issues as well. For one thing, geographical divides may depress connectedness in the space sector. For example, stakeholder interviews repeatedly remarked on the prominence of the "Palmer divide"—a ridge of land between Denver and Colorado Springs—that separates the Colorado Springs and Denver-Boulder space clusters. This divide stems in large part from the specializations of the two clusters. Colorado Springs remains heavily oriented toward its extraordinary array of military space activities while Denver and Boulder specialize in civilian research and commercial opportunities—and the two sub-clusters do not engage with each other extensively.

Likewise, and relatedly, the remarkable diversity of the Colorado space economy means that the state's space cluster remains fissured by sector. In this respect, it is hard to avoid the impression that three distinct and successful communities—one geared toward the military; one toward scientific and civilian applications; and one toward consumer communications—exist in parallel in Colorado, with too little exchange and cross-fertilization among them. Stakeholders, meanwhile, report that the disconnects are quite fundamental. In fact, the relative thinness of university-government-industry commercial exchanges in Colorado revealed by standard tech-transfer metrics likely reflects basic differences in how Colorado's specific mix of sector actors interact. For example, multiple stakeholders noted that many Colorado university researchers, like those elsewhere, tend to hold to a "discovery" or "science for science's sake" mindset that is oriented more toward securing federal research grants and publishing than working with industry or commercializing discoveries. Military actors, for their part, subscribe to a national security mindset—which extends deep into a supply chain where top secret security clearances are still required of employees—and answer to a command-control culture that may cut against such cluster virtues as openness, exchange, and spontaneity. And for that matter, much has been written about the stovepiped organizational structure and procedural "engineering" culture of the big aerospace prime contractors.[66] These factors, too, may be restricting the dynamism of the Colorado space cluster by inhibiting the prolific exchanges, rich knowledge flows, and partnering that characterizes the most dynamic industry clusters.

* * *

In short, Colorado has a strong competitive position in the space economy but faces sustained pressure from competitors both within and outside the United States. The strengths and weaknesses of Colorado's distinctive positioning in the space industry carry with them a variety of threats and opportunities that at once comprise the state's current strategic positioning and point to the need for a strategic agenda to advance the state's space industry in the decades ahead.

Selected Aerospace/Space Initiatives from Peer States

State	Description
Consolidate Position in Government Space	
Arizona	The **Aerospace and Defense Initiative**, launched in October 2010 by Science Foundation Arizona through a $1.3 million grant from the governor, is meant to develop a coordinated strategy for growth in the aerospace and defense industry and support investments in university-industry partnerships conducting aerospace research.
Florida	**Space Florida**, created in 2006, is the aerospace economic development agency of the State of Florida acting as a one-stop shop for fostering the development of the aerospace and defense industries across the state.
Seize Commercial Opportunities in New Space and Adjacent Markets	
Florida	Advanced in 2011, **Space Florida Vision 2020** is a strategy mapped out by Space Florida to leverage Florida's existing space launch and processing capabilities, current workforce, and infrastructure to seize opportunities in 10 specific commercial markets, including adventure tourism, advanced materials and new products, clean energy, cybersecurity and robotics, and satellite systems and payloads.
Maryland	**Advanced Cybersecurity Experience for Students (ACES)** is the nation's first cybersecurity honors program for undergraduates created by University of Maryland and Northrop Grumman to educate a new generation of advanced cybersecurity professionals. Northrop Grumman has provided a grant of $1.1 million to launch the program.
New Mexico	**Spaceport America** seeks to become a major launch-pad for the commercial spaceflight industry. When complete, both vertical and horizontal takeoff space launch vehicles will be able to use the site. The facility is home to Virgin Galactic, which has signed a 20-year lease as the anchor tenant and will operate its spaceflights from there.
Virginia	The **Virginia Space Liability and Immunity Act**, 2007 requires companies performing commercial space launches to disclose the risks posed to humans aboard commercial space launch vehicles and provides them with liability protection. Virginia was the first state to confront the difficulties that tort law poses to this emerging industry. Similar laws were later passed in California, Florida, and Texas.
Commit to Innovation	
Arizona	The **Aerospace and Defense Research Collaboratory** is an Arizona State University-led statewide initiative created in 2011 to build broad connections between industry and universities to advance and strengthen aerospace and military technologies. Science Foundation Arizona's Aerospace and Defense Initiative created the program with a $1 million grant that was matched by research and industry partners.
Maryland	The **Maryland Innovation Initiative**, created in 2012, facilitates the commercialization of technologies from universities to start-ups by providing funding at three separate points in the process: pre-commercial translational research, commercialization planning, and early-stage product development. One of the initiative's programs, the Innovation Discovery Program, grants funds to universities for hiring "site miners" that work to take full commercial advantage of the universities' research.
Texas	The **Emerging Technology Fund** has awarded $8.9 million as of September 2011 to aerospace projects. Created in 2005, it makes early-stage technology investments to assist companies translate ideas and concepts into viable commercial products. It also provides Research Matching Awards to help university researchers secure additional research funds from outside and Research Superiority Acquisition Awards to help universities recruit the best researchers available.
Virginia	The **Commonwealth Center for Advanced Manufacturing**, created in 2011, focuses on supporting innovation in the aerospace industry while advancing the research efforts of Virginia's university system. It emphasizes the acceleration of basic research into technologies that can be applied in a diverse range of industry sectors including aerospace.
Provide Access to Risk Capital	
Florida	The **Florida Opportunity Fund** is a fund of funds that invests in a diversified, high-quality portfolio of seed and early-stage venture capital funds that are focused on investment opportunities within Florida's targeted industries, including aerospace.
Virginia	The **Virginia SBIR Matching Funds Program** provides matching awards to help commercialize research and technology products from companies in Virginia that have received a Phase I or II SBIR or STTR award. In FY2013, award applicants are eligible for two SBIR Matching Funds awards with a value of up to $50,000 for each.

Selected Aerospace/Space Initiatives from Peer States (continued)

State	Description
Bolster the Workforce Pipeline	
Florida	The **Employ Florida Banner Center for Aviation and Aerospace** is a statewide, industry-driven center that assists with current and future workforce training needs by crafting relevant curricula and providing a one-stop shop for training, certification, and support for the state's aviation and space industries.
Maryland	Established by the Governor's Workforce Investment Board, the **Maryland Aerospace Industry Initiative** is a partnership between industry, government, and educational entities to develop resources for educators, students and job seekers to inform and educate them about the opportunities in the Maryland aerospace industry.
Virginia	The **Aerospace Science and Technology Scholars Program** provides an interactive online learning experience as well as a six-day residential summer academy at NASA Langley Research Center to educate high school juniors about the inner workings of the space industry.
Intensify Cluster Dynamics	
Arizona	The Arizona Commerce Authority was one of 10 grant recipients nationwide to win 1.8 million through the federal government's Advanced Manufacturing Jobs and Innovation Accelerator Challenge. The grant money, awarded in the fall of 2012, will be used to fund the **Growing the Southern Arizona Aerospace and Defense Region**, which will strengthen the state's aerospace sector in a six-county region with focus on developing cluster networks, expansion of aerospace and defense-supplier network through database development, and workforce development.
Virginia	The **Governor's Aerospace Advisory Council**, created in 2007, identifies policy and funding priorities for the Governor relating to aerospace economic development, workforce training, educational programs and curriculums, and space exploration. It comprises legislative representatives and members from academia, industry, and the state.

VI. COLORADO'S SPACE ECONOMY FUTURE: A VISION AND STRATEGIES FOR GETTING THERE

Colorado's strong competitive standing amid a confluence of disruptive megatrends licenses an ambitious vision of the state's future in the space economy.

The state is in fact extremely well positioned. Colorado possesses a unique space-oriented asset base composed of outstanding university and government research institutions; critical military and security operations centers; and leading global aerospace and defense companies and the supply chains that support them.

The strong innovation system that runs through those assets is staffed by a highly educated workforce, surrounded by entrepreneurs, and encouraged by a business-friendly environment rich in advanced industry activity and support in general.

And meanwhile, the state is beginning to build up a diverse, multidimensional cluster of vibrant small and medium-sized entrepreneurial companies that are well positioned to capitalize on exciting opportunities in both familiar segments such as satellite-based communications, earth observation, and GIS and emerging ones such as cybersecurity, autonomous and semi-autonomous systems, and cleantech. These opportunities may position the state cluster uncommonly well for weathering the retrenchment and disruptions of the present moment.

Which is why Colorado can and should declare its aspirations for the space economy in the strongest terms. In short, Colorado's vision over the next five to 10 years should be simple and bold: **Colorado becomes the center of innovation for the global space economy**.

What would attainment of this vision look like? Should it achieve such a goal, the state of Colorado would, as never before, be:

- **Globally branded** as the leading center for space research, manufacturing, services, and entrepreneurship for the most dynamic aspects of the space economy. Colorado has now become the place to which business and government leaders across the United States come when they want to find the smartest thinkers in both commercial and government space. A strong international profile in the space industry has also emerged through the state's increasing international ties and the aggressive leveraging of top-flight international industry events such as the annual Space Symposium. Colorado residents instantly recognize their state as the global leader in

space-related innovation

- **Home to a tightly knit cluster** of interconnected, highly collaborative businesses, networking organizations, and research institutions arrayed across key market segments, major customer sectors, and adjacent industries as well as geographic boundaries. An increasingly strong and cooperative relationship between the space industry's flagship business associations (such as the Colorado Space Coalition and the Colorado Space Business Roundtable), individual firms, the universities, federal research centers, and an industry champion within state government begins to yield dividends. Such "coopetition" gives rise to a burst of new cooperative R&D initiatives, producing new innovations in record time. Established global space businesses, foreign governments, and investors find it simple to learn what capabilities exist within the cluster and are increasingly attracted to it. The state provides quick and easy access to the right companies, suppliers, and niches and proactively facilitates the establishment of new business within the state

- **Headquarters for a solid core of government space activities that are increasingly complemented by surging sales of dynamic space-services companies** such as DISH Network, Trimble, and WildBlue as well as a proliferation of exciting startups and new business units at Colorado-based aerospace / defense contractors—all engaged in commercializing space-derived technologies or new applications for those technologies in adjacent markets such as cybersecurity, UAVs, and more

In short, a Colorado space economy that commits now to preeminence has a great shot at achieving compelling growth for itself and attractive gains for the state's overall economy. Continuing just its historic growth rate of 4 percent per year, the space economy could add more than 10,000 jobs to Colorado's private sector by 2017 and add 1 percent in real terms to the state's GDP. At 5 percent growth per year, the space economy could add 18,000 private-sector jobs and over 2 percent to state GDP. Moreover, a more diversified space economy with outgrowth into commercial and adjacent markets would be more robust than today's still heavily government-oriented industry.

As to how to get there, Colorado's industry leaders and government should embrace a new, more aggressive, more creative and collaborative mindset. Rather than hunkering down to defend the status quo, this new mindset should enact a searching new development strategy focused on bolstering a nationally significant AI innovation cluster through targeted interventions aimed at addressing specific deficiencies in the light of global dynamics, removing documented constraints, and responding to resource shortcomings. Such an approach will strengthen the state's space industry while also fostering an environment in which other advanced industries can cluster, connect, and thrive.

In this fashion, then, industry leaders and government should work together to address the six major challenges identified in the previous chapter, each of which implies an associated positive strategy for increasing the competitiveness of the Colorado space economy.

Along these lines, six major strategies for advancing the Colorado space economy suggest themselves. Working together, the state's private sector and public and non-profit realms should:

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts. The traditional space industry is changing. Even as federal funding declines, government customers are moving toward more commercial solutions, big projects are dwindling, and government regulations are slowly giving way to commercial contracting methods. Colorado and its space firms will need to adapt to the changing landscape of government space if they want to stay competitive.

Seize commercial opportunities in emerging new space, adjacent, and global markets. With growth prospects likely modest in conventional government space, a strong and strategic pivot to seize emerging opportunities in new commercial, adjacent, and global markets is the most important thing that Colorado and its space firms can do to assure continued preeminence in the future space economy. Pivoting in this way will require all parties to master new technologies and new ways of doing business in the next few years.

Commit to innovation and owning the next great space technologies. Amid disruptive change, Colorado's global and national competitiveness in the space economy hinges on how well its innovation ecosystem functions. The state should put a new emphasis on R&D activity, collaboration both among companies and between industry and research institutions, and commercialization of innovation as the drivers of long-term growth, competitiveness, and employment in the Colorado space economy.

Improve the availability of risk capital. The current lack of risk-tolerant scale-up capital available to Colorado space economy startups and growth firms impedes technology deployment in the state. With the new space sector said to be approaching a "Netscape moment" marked by a substantial increase in investment and growth, Colorado companies will need to adopt more of an investment mindset and seek out broader sources of finance to scale up their products.

Bolster the workforce pipeline to secure Colorado's human capital advantage. With additional waves of retirements on the horizon, now is not the time to lose ground in the competition for well-trained workers. A long-term commitment to and strategy for developing, attracting, and retaining a skilled, flexible, and technically competent workforce will be critical in the coming half-decade.

Intensify cluster dynamics. A strong cluster-based development strategy that emphasizes breaking down silos and increasing collaboration among the state's myriad industry stakeholders and cluster organizations will help to diversify and increase the competitiveness of Colorado's space economy.

* * *

In keeping with these strategies, the two chapters that follow suggest how a focused partnership between the private sector and government can help the state's extraordinary space economy master disruptive forces and capitalize on new opportunities.

Chapter VII focuses on steps that private-sector firms can take both individually and through collaboration to foster increased innovation and continued growth in the state space economy. Chapter VIII sets out a series of recommendations for how the state government, working in conjunction with the state's congressional delegation, can work to provide a supportive environment for Colorado's space economy in the years ahead.

With all of these strategies, though government can and should play a role, the private sector must take the lead in mastering disruptive forces and capitalizing on new opportunities.

In many cases, supportive interventions to advance the space economy can be readily adapted to strengthen the entire complex of the state's multiple advanced industries.

Regardless, Colorado should move now to prevail.

VII. THE PRIVATE SECTOR: DRIVING GROWTH THROUGH IMPROVED PERFORMANCE AND GREATER COLLABORATION

The private sector must lead the way in delivering on the vision of making Colorado's space economy—a classic advanced industry—preeminent. The reason is stark: Colorado companies are the actors in the state with the greatest urgency, self-interest, and knowledge to move aggressively to address head-on the coming decline of government spending on space and make the state cluster more capable, competitive, and agile than its competitors.

Yet, individual companies cannot do this alone. The private space firms that will emerge as winners out of the coming down-cycle in government spending will be those that aggressively partner with the public sector, local institutions, supply chain partners, and select competitors to innovate and seek out new markets.

Winning firms, in this respect, will not "hunker down" in isolation to protect the projects they have and wait for budgets to rebound. Instead, winning firms will seek to stay ahead of disruptive trends while also becoming more agile and responsive to near-term opportunities and shocks. To do that, companies will need to embrace new, more collaborative, and sometimes "open" brands of innovation as they hunt for new markets or seek to create disruptive products and new business models for serving their customers and developing talent.

And so the actions recommended here take two general forms. First, companies active in Colorado's space economy must improve their individual performance to strengthen their competitive position in light of global trends. And second, these companies must also recognize the benefit of increased collaboration to speed the innovation required to remain competitive in tomorrow's market.

Along these lines, then, private-sector companies—private contractors, manufacturers, engineering and service companies—should take seriously the six key strategic themes identified by this report as they seek to advance their businesses and, in so doing, Colorado's space economy. They should:

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Government contracts remain the largest driver of Colorado's space economy today, accounting for an estimated half of the sector's combined income in 2010.[1] For that reason, securing this base market is going to be critical to maintaining the health of the state's space economy. And yet, the government market is becoming increasingly challenging as budgets contract, competition for programs increases, and government customers increasingly seek commercial solutions to reduce costs.

Against this backdrop, the private sector must **focus on affordability to secure competitive positions in core government markets**. Affordability will both increase an individual contractor's probability of winning and help ensure that programs remain fully funded. And so, to solidify its current position, Colorado space firms will need to drive a step change in efficiency and productivity in the coming few years. Specifically, companies active in the government sector will need do more than find marginal improvements in cost. Instead, they will need to achieve structural cost changes by reworking product design to emphasize functionality over hyper-engineered solutions, consolidating facilities, and taking a systematic approach to sourcing. Such cost differences are very much within reach, based on the experiences of commercial aerospace and defense players who have engaged in these transformational, rather than incremental, cost efforts.

Key to unlocking this affordability challenge will be urgent moves to systematically review structural costs by taking a rigorous "clean-sheet" approach in the near term. Rather than simply taking out costs where they can, contractors instead will need to develop a clear perspective on a competitive cost envelope based on customer demand and budget realities, and then develop a strategy to achieve that target. This will include looking carefully at all direct, indirect, and material costs.

Over the longer term, companies competing in the government market will need to fundamentally change their capabilities and culture to root out the gold-plated, bespoke solution mentality that pervades the traditional cost-plus world. Instead, contractors should institutionalize a more commercial approach, with an emphasis on affordability. To begin with, players should engage the government to systematically explore cost-feature trade-offs that can provide the customer with the desired capabilities at a lower cost. At the same time, traditional cost-plus contractors will need to change the way they do business. For example, companies must put in place product development processes that take a more incremental, product-line approach to technology development rather than generational leaps. Rather than organizing primarily around large programs, companies should put in place an organizational structure that maintains legacy capabilities while enabling a product-line approach that can deliver capabilities to multiple customers.

Seize commercial opportunities in emerging new space, adjacent, and global markets

Even as Colorado's space cluster solidifies its position in base government markets, it must recognize that government spending will be at best flat, or more likely decline. Similarly, whether serving government or commercial customers, the space infrastructure markets (satellites, launch) are also likely to remain flat for the foreseeable future. All of which means that Colorado's space industry must look aggressively to new space, space-based services, and adjacent or overseas markets for growth. Demand for communications, earth sensing, and geolocation activities, for example, will continue to grow, particularly among commercial customers and consumers and internationally. Meanwhile, Colorado space companies can leverage their technologies and organizational capabilities to pursue promising growth in adjacent markets such as cybersecurity, UASs, wireless communications, geospatial solutions, robotics and automation, or renewable energy systems.

A number of Colorado companies have already begun the push into adjacent markets

Not only is the Colorado space economy extensive and multifaceted. It is also evolving and increasingly moving into new markets within "adjacent" industries—defined as markets or industries with significant technology or knowledge relatedness to one or more space economy segments, or to which space-related capabilities are readily adaptable.

Adjacencies generally fall into three broad technology clusters: aerospace, industrial high tech, and information and communication technology.

In the broader **aerospace technology** cluster, opportunities for space companies abound in aeronautics and aircraft manufacturing, and companies such as Woodward anchor this portion of a deep aerospace cluster in Colorado. Meanwhile new aerospace platforms like unmanned aerial vehicles or systems pose disruptions but also huge opportunities to expand the application of conventionally space- and aerospace-based technologies. Here, insurgent newcomers such as Black Swift Technologies, Tigon Enertec, and Starcor are now competing with larger traditional players such as BAE Systems and Northrop Grumman to seize the lead.

Space economy companies are discovering new applications for their capabilities in the burgeoning **industrial high-tech** cluster too. Cross-cutting technologies such as advanced materials—embodied in firms such as Fiberforge—and robotics and automation are in demand across the production economy. Meanwhile manufacturers of the renewable energy and energy storage systems that have long powered satellites are deploying innovations in the clean economy. And the analytical and precision instrument technologies in which Colorado excels enable an increasingly sophisticated array of high-value activities in measuring, testing, sensing, the sciences, and beyond.

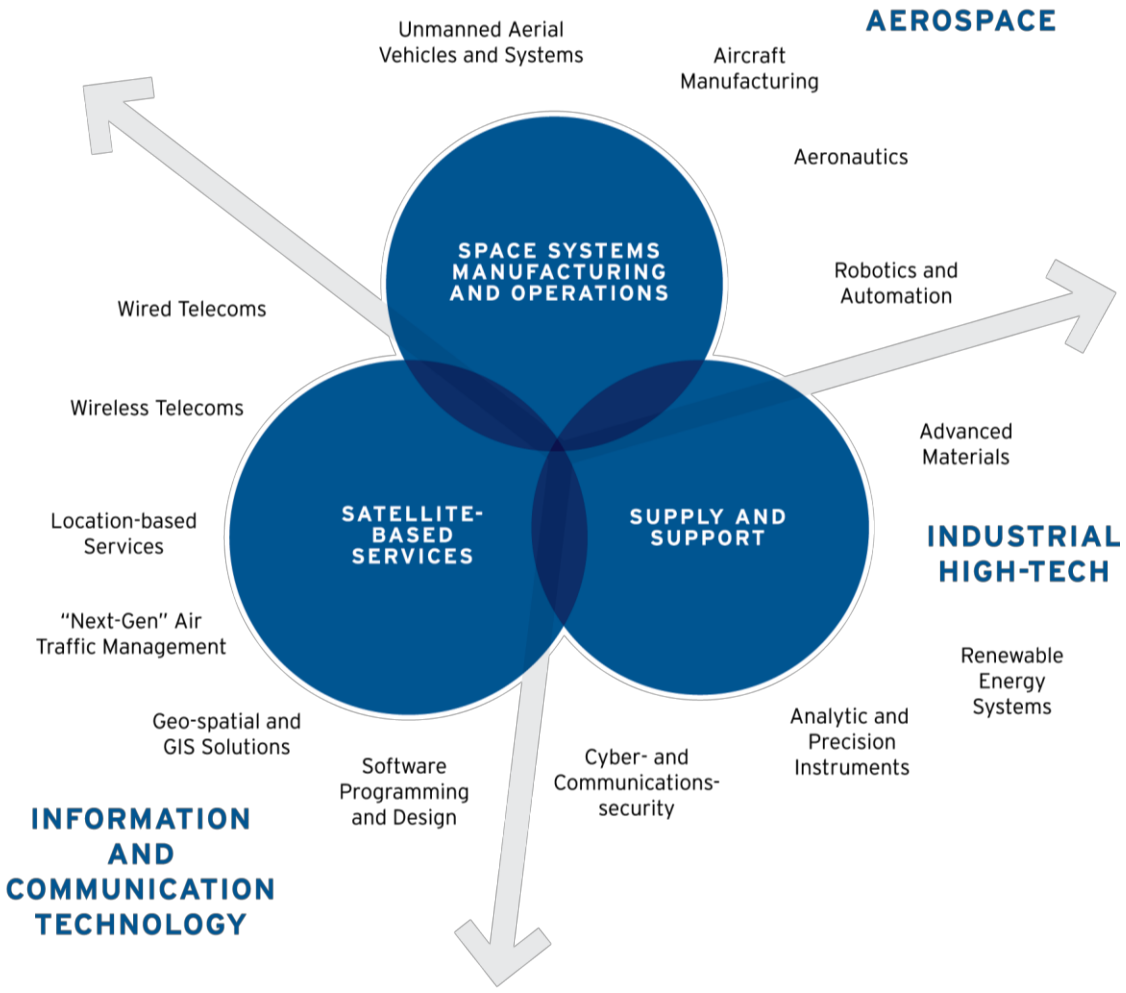
Satellite services providers—companies in the business of relaying information—house massive stocks of knowledge and technology ready to be deployed in the wide and rich **information and communication technology** cluster. Satellite broadcasters and telecoms providers compete directly with alternative wired and wireless telecommunications platforms to deliver similar capabilities to similar markets. Each communications technology has its advantages, and satellite services providers are extremely well-positioned to capture the market for internet broadband services to rural areas. DISH Network, for its part, is leveraging its sophisticated communications know-how to make a shrewd push into the cellular market.

A rich ferment of innovative activity is bubbling at the intersection of IT, earth observation, and precision-navigation-timing capabilities and Colorado companies are not only at its center—they're actively making and shaping the market. Colorado is the GPS capital of the world—home to the system's manufacturing, its operations, and numerous commercial capabilities providers—and it is also the birthplace of the commercial remote sensing and satellite imagery industry. Geospatial and GIS solutions and increasingly location-based services are dominated by Colorado companies such as DigitalGlobe, Exelis, Jeppesen, Sanborn, and Woolpert. Start-up Dronemapper.com is already developing a UAS-based platform for these capabilities. And Colorado companies are logical contenders for owning "next-gen" air traffic control technologies too.

Meanwhile the advanced IT and software programming and design capabilities that underpin the entire space enterprise can be deployed in multiple information-rich sectors such financial services. Companies such as Colorado Springs-based Intelligent Software Solutions are seeing explosive results offering "space to mud" IT services and capitalizing on big data. Cybersecurity and secure communications, for that matter, represents one of the highest potential growth markets and Colorado's providers—many of whom cut their teeth serving the U.S. military's advanced needs—are competitively positioned to succeed.

These adjacent markets, where Colorado is well-positioned, represent significant potential growth opportunities for the state alongside its conventional space cluster—and hold out the possibility of partially offsetting projected contractions in government space budgets and possible saturation in consumer markets like satellite television.

The future shape of Colorado's space economy will be defined by both familiar segments and new opportunities in emerging and adjacent ones



Source: Brookings Institution analysis

Pursuing this growth will require, however, an entirely different management approach than has been required by government programs. Most notably, managing more dynamic commercial ventures will require executives to take on risk, set longer budget horizons, and engage in greater collaboration with external partners. Along these lines, Colorado space companies can choose among a number of viable strategies for pursuing new sorts of opportunity. First, they can **build on product and technology knowledge in R&D to develop new products or take products to new markets**. The software engineering capabilities used to develop autonomous or semi-autonomous operation of space systems can also be used to develop the autonomous or semi-autonomous capabilities that will allow UASs to integrate into the national airspace system as currently proposed by the Federal Aviation Administration (FAA). cybersecurity needs.

Second, industry can **leverage existing customer relationships and familiarity with their customers' requirements to expand offerings**. For example, a firm that operates and maintains a satellite system on behalf of a particular customer may also understand that customer's cybersecurity needs. As such, they could develop or acquire the capability to serve the customer in this new area. Finally, industry can expand into new areas of the value chain such as growing from satellite network operations to providing satellite communications services to firms in their geographic market or even overseas.

Capturing these opportunities, meanwhile, may require companies to form new partnerships with companies established in growth markets. This could be accomplished through acquisition of smaller companies or the establishment of joint ventures or jointly-owned subsidiaries. In any case, it will require considerable focus and meeting several conditions for success to compete in these new markets. Industry must quickly achieve the minimum scale required, ensure that relevant organizational competencies or technologies can be brought to bear, and establish the right business model. However, where the value at stake is large enough, companies should fully engage to capture the new growth platforms.

Commit to innovation and owning the next great space technologies

As the innovation imperative intensifies, Colorado's space economy must keep pace to compete and win. That means that the private sector must commit resolutely to innovation and owning the next great space technologies.

Luckily, the state possesses companies with deep R&D capabilities in both of today's core market segments as well as a tremendous diversity of more far-flung or emergent space market segments, ranging from infrastructure to services. In fact, Colorado has an asset base that is unique among peer space states. For that reason, it appears likely that amplifying R&D activities at individual companies and increasing collaboration across companies will have the desired effect of generating the capabilities and products needed by the growing new space and space-based services markets; creating new opportunities by adapting space-derived technologies to adjacent markets; and establishing Colorado as the innovation hub for the global space market.

Individually, companies should **increase internal R&D investment in next generation technologies** such as advanced materials, communications systems and techniques (e.g., new data modulation algorithms), and energy management and storage. Industry should set a goal of "owning" these technologies that will enable the next generation of space-based systems and space-enabled services. Greater internal investment will be required both to backfill declining government investment and to keep pace with the accelerating rate of innovation across industries. Companies must actively manage a portfolio of technology investments in anticipation of future customer needs and market trends rather than waiting for government to fund the next R&D contract.

Industry can further accelerate the rate of innovation in Colorado through collaborative and applied R&D and so should **actively support and help shape the state's efforts to establish a statewide advanced industries innovation hub**. In this connection, the state has before it a compelling opportunity to secure federal support for the creation of such a hub through the Department of Commerce's proposed National Network for Manufacturing Innovation (NNMI). Both private and public sectors should pursue such a hub for Colorado, as is detailed in the chapter that follows. Space firms large and small should engage in and in many respects lead Colorado's push to stand up a significant applied research innovation hub that would bring together the public and private sectors to work on cutting-edge, industry-defined technological challenges faced by AIs. Through the collaborations facilitated by this hub, companies would develop long-term partnerships with key players as they worked to develop shared infrastructure and applied research agendas for technology development. Firms of all sizes could work together to bring emerging pre-competitive technologies of cross-cutting value to market readiness with the support of relevant academic centers, training organizations, customer groups, and financiers. This will allow companies to deliver new technologies and capabilities faster and at lower cost and lower risk. And so the space industry—working in close collaboration with the state and its research institutions—will need to be a driving force in advancing and designing any such center.

Industry invests in game-changing research facility: Virginia's Commonwealth Center for Advanced Manufacturing

The Commonwealth Center for Advanced Manufacturing (CCAM) is the centerpiece of Virginia's effort to promote advanced industries in the state by focusing on R&D and technology commercialization. Reflecting the increasingly popular "hub" approach to applied innovation, CCAM brings together researchers from both the public and private sectors to bridge the gap from research to product development and commercialization while supporting the skills that workers need in advanced industries. Organizations like CCAM show how the private sector—working in collaboration with academia and governments—can play a lead role in making advanced industries more innovative and competitive.

CCAM is a collaboration between three of the state's leading universities—the University of Virginia, Virginia Tech, and Virginia State University—and manufacturing companies worldwide. Companies join CCAM as members and inform high-tech research with university faculty in two focus areas: surface engineering and manufacturing systems. Research on these two thematic areas has application across a wide array of advanced industries. For instance, research on improving surface coatings technology—used to protect various types of engines and equipments from intense heat or friction—could be useful in the aerospace, automotive, and energy industries.

To date, CCAM has attracted more than a dozen companies, with several, including Rolls-Royce, Siemens, and Canon, already taking advantage of the center's expertise. Member companies can request directed research, the products of which eventually become the company's intellectual property. In addition, the center conducts generic research that could potentially benefit multiple CCAM members facing a common technological challenge. The intellectual property arising from generic research is then made available to all CCAM members.

Rolls-Royce was the driving force behind CCAM's formation, donating 20 acres of land for the construction of the institution. Indeed, the creation of the center was one of the key reasons that the company decided to locate its new aerospace facility in Virginia. CCAM has also received significant state and federal support, including a $2.5 million grant from the Virginia Tobacco Indemnification and Community Revitalization Commission, a $4 million grant from the federal government's Economic Development Administration, and a portion of the $15 million in Recovery Act bonds that the state received.

CCAM illustrates how Virginia's advanced industries seized on an opportunity to collaborate on transformational technological solutions in order to reduce costs and improve product lines. With member companies pooling in their R&D dollars and conducting research at the center instead of in their individual facilities, CCAM appears poised to translate laboratory research into business improvement and commercialization faster and more cost-effectively than before.

Source: Commonwealth Center for Advanced Manufacturing website.

Improve the availability of risk capital

Yet accelerating technology development is only part of the innovation agenda. Also critical is financing new technologies' deployment. With government funding flatlining or declining, firms must seek out new ways to commercialize the innovations that will allow them to remain competitive in base markets and begin to compete in new growth markets.

On this front, in addition to accelerating internally funded R&D (both individual and collaborative efforts) industry should consider moves to **reinvigorate corporate venture capital** as a cost-effective way to identify, scale, and bring to market

innovative new products and capabilities that will put them at a competitive advantage. Corporate VC holds out attractions for both large and small companies. In an era of constrained government budgets and a government push for more commercial approaches, large companies will need to find cost-effective ways to gain the distinctive capabilities that may be resident in smaller companies. These small companies can also provide new growth platforms for large companies seeking to enter new markets. Conversely, access to the capital that large companies possess would meet the longstanding needs of small and entrepreneurial companies in a market that has so far struggled to attract private investment. The market exposure of large companies also provides tremendous value to small companies looking to break into established space markets.

Nor is corporate VC a radical departure for industry's larger players. Businesses such as Siemens and Intel have each operated corporate VC units, and Boeing—a key component of Colorado's space economy—has used VC investments in the past as part of its global R&D efforts. The operating model can vary significantly depending on the needs and risk profile of the companies involved, such as investing through established VC funds or making direct investments. However, in all cases, these investments can provide a cost-effective way for industry to gain insight into new technologies before competitors; develop new markets or market segments for existing or new products; build new businesses; or even import new business practices. In this respect, a corporate VC strategy could well serve larger Colorado companies as a way to launch new commercially oriented entrepreneurial activity in a long established cost-plus government contracting business unit. Large companies should reinvigorate these capabilities with a specific focus on the space industry and the leveraging of space-based technologies to accelerate innovation and growth. While global companies will look globally for opportunities, the strong entrepreneurial spirit and tremendous space capabilities resident in Colorado should provide fertile hunting ground.

Bolster the workforce pipeline to secure Colorado's human capital advantage

As in all industries, a highly skilled workforce is essential to competitiveness. As highlighted earlier, the aerospace industry faces a critical skills gap in the coming years. Industry must take deliberate action now to ensure it maintains a healthy workforce as the foundation for success in an evolving industry.

To accomplish this, space economy companies should revitalize their human capital strategies across the board to identify emerging skills gaps, develop their existing staffs, and upgrade how they attract and retain new talent. There are several sub-elements to this initiative.

First, industry should better **model future skill requirements**. As companies adjust their portfolio of capabilities or grow into new markets, they must understand how that will affect the specific skills sets they will require to compete. For example, will they need more aerospace engineers or more software engineers to compete in the UAS market? This modeling will provide a fact-base to help human resource managers identify the best sources for new talent and shape their recruiting messages.

Second, industry should **develop a greater number of leaders conversant in commercial and international markets**. As the global space industry becomes more commercially oriented, services-based, and internationally focused, leaders must be attuned to the needs of these customers and what it will take to compete successfully for their business. This can be accomplished through both direct hiring of candidates with experience in relevant markets and revamped leadership development programs deliberately designed to provide this exposure.

Finally, industry should **develop stronger partnerships with educational and training institutions**. Industry should proactively seek out opportunities to partner with these institutions to help communicate their future workforce needs both in terms of numbers and relevant skill sets and to help align curriculum to develop the right talent. In addition, industry can work with these institutions to put in place internships or other work-study programs to simultaneously inspire the younger generation and build relevant industry skills. These programs can give students real-world engineering experience while

improving the quality of local workforces and providing employers with a unique source of talent. Germany has had great success with programs like these: for example, employers and schools collaborate in technical apprenticeship programs—three- to five-year certification programs in which students split their time between a job site and the classroom.[2]

Intensify cluster dynamics

Colorado space firms will always compete first and foremost as individual companies. The trends shaping the global space industry in the coming years mean that they will need to innovate at ever-increasing speeds. At the same time, companies in Colorado and around the world must recognize the benefit that greater collaboration can bring to this equation. Intensifying the interaction and exchange of ideas among the critical mass of space companies concentrated in Colorado—through stronger networks, consortia, and other avenues—can accelerate the sharing of ideas, the pace of problem-solving, and the speed of innovations. For that reason, Colorado firms should push aggressively to strengthen the vitality, profile, and information exchange in the state's space economy.

Industry can take three concrete, low-cost actions in this direction. First, firms should **advocate for and actively engage with a new state space cluster champion.** Companies active in Colorado's space cluster today may participate in multiple industry associations such as the CSC or Colorado Space Business Roundtable, or they may not participate at all. As a result, the industry has not been effective in providing a clear articulation of the industry's importance to the state's economy or the support they need from state and federal lawmakers. Actively supporting a state champion can significantly strengthen the overall cluster by helping him or her develop that value proposition, clearly communicate industry needs to lawmakers, and lower transaction costs by providing policymakers and customers easy access to the expertise resident in the space cluster.

Second, industry should actively **support state-led marketing and industry-mapping efforts.** A global marketing campaign to raise the profile of Colorado's space cluster will help drive more business to companies across the cluster. In addition, a current and comprehensive industry map that catalogues the capabilities of all companies active in the state's space cluster can help companies or governments quickly match technology providers with current needs.

Finally, industry itself should **foster more effective collaboration** among the companies in the state's space economy. There is a perception shared by the smaller, newer space-based companies that Colorado's aerospace industry is almost a closed system that is difficult to break into either as a supplier or an influencer. There is an urgent need for the established, big players to be open to helping newer players get into the game, both as organizations and personally at the senior management levels. To add to that, the big players will also need to come up with processes that help the smaller innovative companies compete with established companies outside of Colorado.

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Industry will play the leading role in growing Colorado's space economy. After all, these companies are Colorado's space economy. Industry will drive growth in large part by doing what industry does best: recognizing the trends shaping the industry and responding aggressively to improve their own individual performance. However, it is also in industry's self-interest to recognize the benefit that greater collaboration can bring in speeding innovation. Investing in and strengthening the "industrial commons" of Colorado's space economy will benefit all involved. Private-sector leaders should actively support and shape state-led efforts to establish an AI innovation hub, raise the profile of Colorado as the leading source of innovation for the global space market, and maintain a strong cluster infrastructure that reduces transaction costs for those seeking to access its capabilities.

INDUSTRY AGENDA

$** = Little to no cost | **$$** = Low cost | **$$$** = Moderate cost | **$$$$ = High cost

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Focus on affordability to secure competitive positions in core government markets	**$-$$$**

Seize commercial opportunities in emerging new space, adjacent, and global markets

Build on product and technology knowledge in R&D to develop new products or take products to new markets	**$$-$$$**
Leverage existing customer relationships and familiarity with customers' requirements to expand offerings	**$**

Commit to innovation and owning the next great space technologies

Increase internal R&D investment in next generation technologies	**$$$$**
Actively support and help shape the state's efforts to establish a statewide advanced industries innovation hub	**$$-$$$**

Facilitate the availability of risk capital for small and medium-sized entrepreneurial firms

Reinvigorate corporate venture capital	**$$$$**

Bolster the workforce pipeline to secure Colorado's human capital advantage

Model future skill requirements	**$**
Develop a greater number of leaders conversant in commercial and international markets	**$**
Develop stronger partnerships with educational and training institutions	**$-$$**

Intensify cluster dynamics

Advocate for and actively engage with a new state space cluster champion	**$**
Support state-led marketing and industry mapping efforts	**$$**
Foster more effective collaboration	**$**

VIII. THE PUBLIC SECTOR: SETTING A PLATFORM FOR INNOVATION AND GROWTH

And yet, while the private sector must lead if Colorado is to become the global center for space economy innovation, companies cannot achieve this goal alone. The public sector—particularly state government—must also engage.

Of course, the next era of public-sector engagement in Colorado will be much different than the last one. For decades, government budgets—particularly at the federal level—have directly determined the emergence, nature, and dynamics of the state's space activity. That reality ensured that the industry's vitality remained inseparable from government funding and priorities.

In the coming decade, by contrast, a new brand of government engagement will be needed—one that will be supportive and strategic, rather than all-determining.

In this respect, the next phase of government support will be one of platform-setting and will in large part consist of efforts to address—in focused, strategic ways—the sorts of governance, institutional, and market challenges that this report has identified. Some of these efforts will remain squarely within the purview of the federal government, which sets major program parameters; supplies basic and applied research funds; and regulates the airspace, telecommunications spectrum, and exports. But other work will involve responding in smart, limited, but decisive ways to the key weaknesses of the Colorado space cluster's dynamics and positioning—and this work will be appropriately state-based and collaborative.

And so, at a time when a number of disruptive megatrends challenge the space economy, the state of Colorado—working with its congressional delegation—should organize its efforts around the six strategic initiatives that this report has extrapolated from an assessment of the state's competitive needs. In keeping with that goal, the state (working with the delegation) should seek to carry out actions that defend and maximize the state cluster's current position; help it seize opportunities in emerging market segments; stoke innovation and entrepreneurship; improve the availability of risk capital; bolster the workforce pipeline; and intensify cluster dynamics all across the state's space economy.

In all, while some work must necessarily focus on the space industry specifically, much of the needed engagement can and should focus quite broadly on the state's portfolio of advanced industries. In this fashion, a number of the suggested actions that follow should be implemented in ways that allow the state to work out cross-cutting solutions, achieve economies of scale, and promote synergies and collaboration across all of its AIs.

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

A first priority of advancing the Colorado space economy must be to consolidate and defend the "base"—the present platform of civilian and military government-oriented activity on which future preeminence will be built. Defending the base must be a key tenet of Colorado's space strategy because complacency about the state's current standing could leave the state vulnerable to erosion of its strong positioning in government contracting. Accordingly, Colorado leaders should work urgently and steadily to consolidate and maximize the state's present position in the many space markets in which the state's space cluster is active and prepare for continued budgetary pullbacks in Washington—which will remain the space economy's largest customer for the foreseeable future. In short, Colorado officials will need to advocate nationally as well as within the state to at once defend and enlarge the Colorado space economy. A number of action steps are critical:

To begin with, the state should work with industry to **produce and annually or biannually update a sophisticated strategy for bolstering Colorado's space economy preeminence.** To be developed in close consultation with industry and other cluster stakeholders, this continuously updated strategy would build on the work done through the state's Key Industry Networks Process and so aim to keep the state growing amid uncertainty. Such a strategy will then serve as a rallying point for industry and elected officials alike. Developed from the bottom up and consistently revisited, this strategy will help state leadership and their partners in industry remain responsive to changing needs without losing sight of longer-term priorities.

Once such a strategy is in place the governor should **lead in convening Colorado's congressional delegation to defend and advocate for the expansion of the state's space economy**. On this front, a recurring theme in the listening sessions that informed this report stressed the need for Colorado's congressional delegation to advocate forcefully and cohesively on behalf of the state's space industry. However, multiple stakeholders acknowledged that the industry and state government themselves could do a better job of conveying a single clear and coherent agenda to their federal partners. To that end, then, the governor's office and OEDIT should work closely together with the state's major cluster organizations not only to advance a clearly articulated federal agenda to the delegation each year (perhaps in partnership with the CSC, which does some of this now) but also to invest the governor's prestige and convening ability in further highlighting the importance of both defending the base in Washington and bolstering emergent new industries. Such an agenda should be conveyed to the delegation by the governor with the visible backing of the cluster.

The governor—working with the delegation—can and should lead in other ways as well. One way is by playing a national leadership role on space and advanced industry issues of cross-cutting, multistate importance. On these issues, the governor should **lead in convening the leading aerospace states,** including Colorado's competitors—as he recently did to discuss and prepare for the potential impacts of sequestration. Rallying more states around key priorities will not only serve to amplify the space economy's voice on these issues in Washington; it will also augment Colorado's prominence on space enterprise in general. Where opportunities for cooperation can be identified and the governor can convene other governors to advance them will be all to the good.[1]

In addition, the governor and state government can maximize the state's position in the space economy by acting urgently and deliberately to raise the industry's profile both within the state and beyond. Colorado must tell its story well—to itself and others—if it is to establish itself as the nation's premier space state and the global center for space economy innovation. Along these lines, then, the state should work with industry to **brand Colorado's unique space economy and market it relentlessly**. Currently, the capabilities of Colorado's space economy are as wide-ranging as is its contribution to the state's economic growth and prosperity. However, the space cluster's public profile and national and global reputation remain modest. Yet this can be readily changed. Everyone who passes through Denver International Airport, for example, should know that they are "a mile closer to space." Likewise, and more substantively, strong messaging—in both internal forums and communications and outward-facing ones—should reiterate the special capabilities of the Colorado space industry: its extraordinary civil and military traditions; its leadership in cutting-edge commercial businesses such as GPS and GIS, earth observation, and telecom; its involvement with the most jaw-dropping emergent technologies of the future; and the incubators and accelerators helping to drive space economy entrepreneurship. Colorado arguably possesses the "coolest"

potential space brand in the country—if not the world. The state must now lead its partners in articulating and marketing that brand.

Planning, branding, and talking won't suffice for state leadership, though. The state also needs to organize itself to execute. Specifically, the state needs to develop the capacity to focus intently over a period of years not just on strategy setting and message unification but also on the mechanics of marshaling, aligning, and delivering multistate and other initiatives for the advancement of the space industry. Which is why the state needs to **name a dedicated "sector champion" to spearhead space cluster development**. Single-mindedly focused, the sector champion or cluster point person would not replace but rather augment and link up the good work being done by Colorado's existing cluster organizations and industry associations as well as the Lieutenant Governor, with his broad portfolio. This fulltime professional would help bridge the distance between the civil, military, and private sectors as well as geographic and cultural divides to advance shared interests and coordinate actions. More substantively, this point person would work to improve and coordinate disparate state programs and policies, address legislative issues, and drill down with industry to remedy particular challenges, whether they be supply chain gaps, workforce needs, or university partnership issues. In short, whether situated in state government at OEDIT or elsewhere, the state needs and should establish a go-to professional tasked with doing whatever it takes to accelerate space-sector growth and diversification.

Finally, the state should **ensure that Colorado remains a business- and military-friendly state by engaging in regular dialogue with stakeholders**. In this respect, the best and most cost-effective way for the state to make sure that it is supporting the continued development of Colorado's space economy is to listen and respond—which should be a central activity of the space industry champion and state government more broadly. Happily, the Colorado Blueprint and its Key Industry Networks Process have put in place a framework for such continuous dialogue. Now the state should build on the relationships it has forged and capitalize on the goodwill that the process has already engendered to ensure that listening and bottom-up organizing become habitual competitive strategies. In addition, regular check-ins will keep both the state and its industry partners accountable as industry and government move to expand their collaboration on the execution of Colorado's space strategy.

In all of these ways, then, state government—working closely with industry—can play a key role in helping to maximize the state's position in the space economy, even amid uncertainty as government contracting flatlines.

Seize commercial opportunities in emerging new space, adjacent, and global markets

But given the modest growth prospects in conventional government space, the state must do more than simply defend the base. In addition, the state must help the space industry radically *improve* its strategic position.

Specifically, state government—with the support of the state's congressional delegation—should now begin to aid and abet Colorado private-sector actors' search for new markets, whether in buzzy new space niches, compelling adjacent markets, or abroad.

To begin supporting the emergence of next-generation space technologies and business models in Colorado, the state will need to drill down on the new opportunities and truly understand them. To get started in this direction, the state should first **survey the competitive landscape in additional detail**. To do that, the state should award (on a competitive basis) a cluster planning grant to a leading cluster entity to support the preparation of a detailed, in-depth target analysis exploring the state's specific opportunities in emerging new, non-traditional, adjacent, or international space markets. Aimed at obtaining more granular information on specific emerging technology and business opportunities, the needed analysis would be conducted at a greater level of detail than the present one and would systematically map Colorado's core competencies and key technology strengths onto a future-leaning, fine-grained description of emerging opportunities in

new markets.

With such intelligence in hand, the state and its industry partners will then be in position to move on a number of action steps to support Colorado companies' drive toward new markets. For one thing, the state—armed with this additional strategic information—could then **promote the new opportunities and celebrate companies seizing them** as part of its new marketing strategy. Such proactive marketing and related outreach to relevant entrepreneurship networks, investor communities, and national talent pools would allow the state to create strategic buzz both at home and in national and global space networks. One way or another, the state needs to tell its story of diversification, new markets, and new capacities.

From there, the state could then work with industry to craft a sophisticated, quick-moving push to grab first-mover advantage in emerging new space, adjacent, and emerging markets.

To begin with, state government—working with industry—should exert itself to **position the state for leadership in next-generation aerospace / space platforms** that will provide the foundation for the next era of commercial space growth. In this respect, momentum is building but needs to be maintained and extended, especially into the realm of UAVs and UASs. Coloradans, in this respect, have rallied around Front Range Airport Authority's spaceport application and were duly rewarded with a feasibility study grant from the FAA. Now begins the hard work of turning a vision into something economically and technically viable. As it currently stands, the spaceport remains a long-horizon effort whose viability depends on future technological and regulatory innovations. By contrast, the market for UAVs and UASs and the capabilities they enable, for example, represent a far larger and nearer-term market opportunity for Colorado given its existing strengths in aeronautics, materials, propulsion, and remote sensing. All of which means that the state—in seeking to secure more platforms for new space achievement—should leverage the civic infrastructure being built up around the spaceport effort to establish additional platforms for future growth. Specifically, Colorado's diversification strategy clearly calls for a concerted effort to secure one of the six UAV / UAS pilot test range sites that will soon be designated by the FAA as a prerequisite for expanding the state's UAV and UAS capabilities, which are already significant at the Air Force Academy and CSU. In addition, Colorado should strive to position itself and the Denver International Airport at the forefront of "NextGen" air traffic control technology adoption, given the state's market leadership in precision, navigation, and timing technologies.

At the same time, the state could **offer modest "deal closers" or small relocation incentives for innovative small firms** to relocate to Colorado, provided that they have patented new innovations and possess potentially disruptive capabilities or business models in new commercial niches prized by the state. Far from indiscriminate "smokestack-chasing," these interventions would only be deployed to fill clearly documented, high-value industry gaps, whether in remote sensing and GIS technologies and applications, the UAV / UAS value chain, or key cybersecurity and secure communications solutions.

Yet the state could go even further to stimulate ferment in new market areas. The governor, for example, could seek to induce path-breaking entrepreneurship in new space and adjacent markets by moving to **launch a governor's prize for new space business plans**. Prize competitions have proven to be effective tools for mobilizing ingenuity and spurring high-potential innovation under the right circumstances.[2] Therefore, the state should convene experts from across its space economy to design a transformative prize initiative that furthers clearly defined goals as part of a broader push toward industry diversification and development.

Prizes could be designed around discrete objectives to boost collaboration across space economy communities, to stimulate the development of new technologies for latent markets, or to solve well-defined challenges retarding growth.[3] Along these lines, a first round award of a modest $50,000 to $100,000 prize might recognize the year's hottest technology spinout from the military or the scientific sector into commercial markets. A second round offering a similar or larger purse might call for the best new space or location-based services app that harnesses the state's GPS and software expertise; or it might direct entrepreneurship toward the integration of GIS technologies on UAV platforms to advance some public interest like preventative monitoring for wildfires. Eventually an ambitious third round—possibly co-sponsored by a venture capitalist—could tackle the biggest barrier to cluster development of them all with a $250,000 to $500,000 prize for game-changing technologies that reduce the cost of accessing space. In any event, a well-designed governor's prize competition would spawn new ideas, direct attention toward new commercial opportunities, build buzz, boost the profile of winners and

runners-up, and open the door to follow-on investment.

Likewise, the state could **facilitate the convening of technology "boot camps" around opportunities for innovation**, building off of Colorado's existing strengths in emerging markets. For example, the state could help sponsor a day-long session—led by industry and open to innovators and financiers nationally or globally—focused on leveraging the augmented GPS III for novel commercial applications. Such boot camps would highlight areas of opportunity, facilitate idea exchange, build out networks among firms and civil institutions, and stoke the cluster's competitive ferment. What is more, such camps would help build buzz around Colorado as the hub for emerging space technologies. Importantly, the boot camp sessions and agendas must be "owned" by industry, with the state stepping back into a supporting role.

Finally, in the spirit of seeking out new opportunities, the state should actively encourage space economy actors to seek markets outside of the United States. As a first order of business, the governor should **spearhead a space and new space trade mission** abroad, choosing target countries in close consultation with industry. The purpose of the mission would be to promote the exports of Colorado businesses to foreign firms (including civilian government agencies where demand for space capabilities is high) and should showcase services as much as manufactured products. In addition, the governor should actively **solicit foreign direct investment** in Colorado's space and aerospace sector in order to further build out the cluster and realize the vision of becoming the *global* leader in space economy innovation.

In short, even as the state moves to consolidate and defend its critical base in civil space and national security work, it should actively lead in accelerating the emergence of Colorado's advantages in the growing new space, adjacent, and global markets.

Commit to innovation and owning the next great space technologies

Ultimately, however, Colorado's ability to emerge as the number one space state in the nation will depend on its ability to strengthen its innovation system—the ultimate source of value in space and all AIs. And of course, the efficacy of the state's innovation system will depend heavily on the effectiveness with which private companies invest in developing key "need-to-own" technologies and business models in the next few years.

And yet, government can and must play a role in fostering innovative activity, with states playing an especially catalytic role. To be sure, federal research grants and contracts remain central to the space enterprise. Yet, states have in recent years been moving more and more to engage in ways that address inherent market problems and link actors so as to enhance the economic capacity of their regions through innovation.[4] For Colorado the opportunity to make a difference is large given the quality of the state's research complex and the persistence of evidence that it is under-exploited. And so the state can and should play an active role in helping to speed the rate by which innovative research discoveries in Colorado are translated into commercially viable space technologies.

Two key initiatives should form the centerpiece of Colorado's space economy innovation agenda.

First, to address the frequent lack of sufficient funding for early-stage technology development in the space sector, Colorado should **create a program that bridges the AI technology development gap** (or "valley of death") by providing targeted, modest-scale matching grants to researchers, incubators and accelerators, and companies across the entire continuum of the technology commercialization process, including proof of concept, early-stage development, and infrastructure development.[5] This program need not—and probably ought not—focus solely on space technologies. Instead, the grant sequence should be made available to the full range of the state's multiple AIs.[6] In any event, such a set of grants could provide cost-effective support to the state's space-sector innovation system by helping venturesome companies undertake the research, testing, and development needed to prepare disruptive new technologies and business models for

additional third-party funding. Colorado already has in place a solid model to build on—the state's six-year-old Bioscience Discovery Evaluation Grant Program (BDEGP), which deploys three targeted grant programs to help the state's bioscience industry overcome the technology demonstration gap.[7] Now, the state should expand the program to include support for the state's broad array of advanced industries.[8]

Bridging the advanced industries technology development gap: Colorado's Bioscience Discovery and Evaluation Grant Program

As it happens, Colorado already has in place a successful model to build on as it seeks to bridge the technology commercialization "valley of death" in space and other advanced industries. That model is the state's Bioscience Discovery Evaluation Grant Program (BDEGP), which deploys three targeted grant programs to help the state's bioscience industry overcome the technology demonstration gap.

Established in 2006 by the General Assembly and administered by OEDIT, the BDEGP was initiated to accelerate the commercialization of new bioscience technologies developed in the state's research institutions by providing modest-sized, competitively awarded grants for proof of concept and early-stage activities as well as commercialization infrastructure projects.

By statute, at least 30 percent of the BDEGP grant funds go to technology transfer offices to support proof-of-concept activities, while another 30 percent is reserved for early-stage bioscience firms using a technology licensed from a research institution or office of technology transfer. These two grant categories require a one-to-one match at minimum to ensure that grantees leverage public dollars for greater impact. Funds not used for these two purposes can be awarded to research institutions and firms partnering to build infrastructure that supports the commercialization of technologies in the biosciences industry.

Over the years the BDEGP has been praised for its effectiveness. Since its inception, the program has awarded 184 grants totaling just over $22 million. These funds supported the creation of 34 new companies, over 300 direct jobs, and more than 1,000 indirect jobs, as well as almost $109 million in additional investment from matching funds and follow-on capital. These investments have helped bolster the state's biosciences industry by encouraging stronger connections between Colorado's research institutions and its bioscience firms.

A grant program modeled on the BDEGP could have a similarly stimulative effect on Colorado's space industry. By providing funds to expedite the commercialization of newly developed space technologies that originate in Colorado's research institutions, a space industry-focused state grant program would help strengthen the relationships between research institutions and companies that are necessary for the efficient transfer of technology.

Source: Colorado Bioscience Discovery and Evaluation Grant Program website.

Second, the state should complement this early-stage intervention with the establishment of a more robust institutional platform through which industry, universities, community colleges, and government can enter into longer-term public-private partnerships to conduct applied (or "translational") technology development and commercialization.[9] Specifically, Colorado should work with industry to **establish a statewide advanced industries innovation hub** to work on cross-cutting technology challenges that are critical to the state's designated AIs.[10] In this connection, the state has before it a compelling opportunity: the chance to secure significant federal support for such a hub through the build-out of the Department of Commerce's proposed $1 billion National Network for Manufacturing Innovation, which will comprise 15 institutes for manufacturing innovation that will serve as regional hubs of engineering and innovation excellence focused on specific technologies.[11] To date just a single pilot institute has been established to focus on additive manufacturing technologies.

However, significant support exists in Congress for the build-out of the network, which suggests that there is a real opportunity for the state to secure a significant infusion of federal resources, matched by industry and state investment, through a future NNMI competition. Funding through NNMI would allow the state to establish a needed center for collaborative AI innovation that would help bridge the gap between basic research and product development on key topics; provide shared assets to help companies (including smaller firms) access cutting-edge capabilities and equipment; support high-level education and training; and otherwise contribute to the state's AI industrial commons. Compelling, cross-cutting themes for such a hub will not be hard for industry and academia to work out and could range from advanced materials or autonomous systems to advanced sensing and measurement, optics, or advanced forming and joining technologies. A priority for such a hub would also be to review existing technologies in particular industries and explore their applications in newer, adjacent markets. In this way the private sector, through intense collaboration with academia, would be able to refine their R&D endeavors and deliver new improved technologies and capabilities faster and at lower cost and risk.

Fostering a collaborative advanced industries culture: Ohio's National Additive Manufacturing Innovation Institute

In March 2012, the Obama Administration announced its intention to create a National Network of Manufacturing Innovation in order to bolster the nation's competitiveness in the production economy. If authorized and funded by Congress, this network will comprise 15 regional institutions that would conduct applied research on a particular technological theme, encourage technology transfer and continuous innovation, and provide training opportunities for current and future members of the manufacturing workforce.

Five months after the administration's announcement, the National Additive Manufacturing Innovation Institute (NAMII) in Youngstown, OH was selected through a competitive process as the first NNMI pilot. Composed of five community colleges, nine research universities, 11 non-profit organizations, and 40 companies, this public-private consortium was awarded $30 million in federal funds, to be matched by $40 million from NAMII, to establish a regional center of excellence focused on retooling existing manufacturing-related research capabilities for the emerging field of additive manufacturing. As such, an extraordinarily effective and assertive regional collaboration has seized on a special opportunity to bolster its standing in advanced industries.

By providing a central hub for collaborative research on additive manufacturing, NAMII will help foster a more robust industrial ecosystem in the Youngstown region. The innovations developed at NAMII will have a far-reaching effect, with private-sector engagement ensuring that the research conducted is most relevant to solving the challenges that manufacturers face. In addition, NAMII will provide area manufacturers large and small with access to cutting-edge equipment and innovative technical capabilities, thereby further extending the impact of the institute's work.

Perhaps the most important aspect of this pilot competition was the incentive provided for cross-sector collaboration on a single, cross-cutting technological theme—in this case, additive manufacturing. This theme provided a focal point for action that helped the various stakeholders conceptualize just what they might contribute to—and what they might gain from—such an endeavor. In this respect, NAMII was not to be merely collaboration for collaboration's sake, but rather an effort to align all involved toward a common goal: collaborative innovation in the additive manufacturing sector.

By selecting a thematic focus with application across a wide array of advanced industries, NAMII expanded its pool of potential collaborators in Ohio while at the same time encouraging a new appreciation for the ways that various advanced industry activities and functions intersect. In time, this approach could help stimulate further innovation, as individuals and firms from one advanced industry adopt and adapt product and process innovations developed by other AIs.

Source: "We Can't Wait: Obama Administration Announces New Public-Private Partnership to Support," (Washington: The White House, 2012); and David M. Hart, Stephen J. Ezell, and Robert D. Atkinson, "Why We Need a National Network for Manufacturing Innovation," (Washington: Information Technology & Innovation Foundation, 2012).

In addition to these major ventures, meanwhile, Colorado should also consider adopting a number of more modest strategies aimed at fostering innovation all along the commercialization pathway.

To start with, Colorado should **bolster the Colorado Higher Education Competitive Research Authority** (CHECRA) to boost the matching pot available to the state's research institutions when applying for federal grants. CHECRA was instituted to put Colorado's universities on a level playing field when competing against universities in other states that could access dedicated sources of state matching funds.[12] While the program has been beneficial in helping the state's universities secure new federal research awards, the program remains small and under-leveraged—partly due to a lack of dedicated staff time to support the work. To bolster CHECRA's effectiveness, it should be expanded to create a larger pot of money for matching investments at a level of approximately $10 million.[13] A more robust CHECRA could provide a cost-effective means for the state to support cutting-edge research programs at its universities and research institutions. Evidence supporting an increase in the size of CHECRA can be found in Massachusetts. The success of Massachusetts's research institutions in capturing a disproportionate share of federal research dollars has been attributed to some extent to its state government's creation of a large R&D matching grant program—the Massachusetts Research Center Matching Fund—which provides $30 million in matching funds to researchers applying to federal research programs.[14]

Meanwhile, to stimulate more collaborative interaction, including knowledge transfer from universities and research institutions to smaller firms, Colorado should consider instituting two initiatives that will create strong incentives for industry-university collaboration. The first would have Colorado **create an innovation vouchers program** targeted at small and medium-sized enterprises (SMEs) and the second would have the state **launch a matching grants program for collaborative R&D projects**.

Innovation vouchers have emerged as an increasingly popular tool for state and regional governments interested in spurring knowledge exchange. These voucher programs simultaneously empower SMEs to "buy" innovation services from pre-approved universities and research institutions even as they serve to make universities and labs more responsive to private-sector needs. In this vein, the state could move to award a number of vouchers each year—ranging in value from $5,000 to $30,000—to promising SMEs for use in purchasing innovation expertise, whether it be problem analysis, technology assessment, business / technology development, or even intellectual property management. Such a program would go a long way toward better connecting knowledge users and producers of knowledge—and in the process enable the state to build a database of experts—by facilitating the kinds of knowledge exchanges that are critical to a vibrant innovation ecosystem.

Helping SMEs access innovation expertise: Innovation Vouchers

For companies looking to stay ahead of the curve, investing in innovation is of paramount importance. Unfortunately, the limited personnel capacity and narrower profit margins of small and medium-sized enterprises (SMEs) result in a tendency to underinvest in innovation activity. Over time, this underinvestment puts SMEs at a disadvantage by hampering their ability to adapt and refine product design and production processes as the market evolves.

Innovation vouchers offer one possible solution to this dilemma. First introduced in the Netherlands province of Limburg in 1997, innovation voucher programs grant SMEs a voucher that can be redeemed for specific assistance from a research institution. By providing financial support—often with a co-financing requirement—to smaller firms seeking external expertise on innovation-related matters, innovation vouchers directly address the specific market failure of SME underinvestment in innovation activity. Furthermore, these demand-driven vouchers help SMEs establish and cultivate productive relationships with research institutions that can persist well beyond the voucher-funded project.

The stimulative effect of an innovation voucher program not only enhances the innovative edge of individual firms but can also benefit the surrounding regional industry cluster. With the support of the vouchers, SMEs can more readily engage innovative activity, which tends to produce positive spillover effects that extend well beyond the company using the voucher. These spillovers of information, creative problem-solving, and novel design and production solutions in turn

Innovation Vouchers (continued)

help strengthen the broader innovation ecosystem, reinforcing the interconnections and knowledge exchanges that enable a regional industry cluster to thrive.

Strong voucher programs aim to minimize administrative cost for SMEs by employing a simple, expedited application process that quickly connects SMEs to the innovation expertise they need. The parameters for eligibility vary widely, with some, such as the Invest Northern Ireland Innovation Voucher program, inviting applications from a variety of industries, while others, like the program run by the South Australian government, employ a sector-specific approach. States looking to implement their own voucher programs will need to determine which eligibility guidelines will best support their economic development goals.

In Canada, Alberta Innovates Technology Futures (AITF) has created its own innovation vouchers program as part of its larger suite of support services for knowledge-based businesses in the province. Established in 2008, this program offers two tiers of voucher support ($15,000 and $50,000) to early-stage technology-driven SMEs seeking the expertise from external service providers on specific commercialization efforts. Vouchers are awarded four times each year and can be used to cover up to 75 percent of the cost of these expert services. By providing financial assistance to smaller technology-oriented firms, the AITF Innovation Vouchers program is improving the productivity and competitiveness of Alberta SMEs—and the industry clusters in which they reside.

Source: Alberta Innovates Technology Futures Innovation Vouchers Program website.

Likewise, Colorado may choose to create a state matching grant program to directly fund collaborative R&D projects involving Colorado universities and research institutions on the one hand and companies on the other.[15] Here, again, the objective would be to promote collaboration between companies and research institutions. However, in this case the state's funding would be matched by company contribution. Depending on the size and maturity of the company the state would provide between 50 percent and 75 percent of the total cost.

Taken together, the innovation voucher and state matching grant programs should be considered as potentially complementary tools in support of the state's broader innovation strategy. While the former can be used by smaller entrepreneurial companies to solve minor technological problems or scope out solutions to larger technological challenges, the state matching grant program can support the next step on the innovation continuum for those companies at more advanced stages of business and technological development.

In addition to providing financial support for industry-university collaboration, meanwhile, the state should also consider **appointing a SWAT team of innovation "site miners"** to help participating universities actively seek out commercial opportunities, say for aerospace and space technologies relevant to both traditional and adjacent markets.[16] As technology transfer professionals with specific knowledge of market needs, site miners would inject strong commercial and entrepreneurial experience into the tech transfer process. These individuals would be tasked with actively searching for promising intellectual property under development within the university in order to transfer it out of the lab and into local companies. In addition to working closely with their host university, the site miners would foster collaboration among the state's other universities to identify complementary technologies and leverage the commercial potential of the universities' research. The site miners should also leverage the expertise and resources of the state's accelerators and incubators that are already playing an important role in helping universities transfer research to commercialization. Along these lines, the recently launched Maryland Innovation Initiative's Innovation Discovery Program offers some lessons in the design and implementation of such a program for Colorado.

The collaboration between Colorado's research institutions and private industry can also be strengthened if those institutions **develop more industry-friendly university-to-business technology licensing agreements**. Technology transfer from universities to the commercial market is more likely to happen in the presence of effective and transparent intellectual property (IP) policies and terms that are attractive to the industry.[17] However, in Colorado in the recent past the perception has been that the universities were getting the sweeter end of the tech-transfer deal and that may have in some cases discouraged firms from exploring university partnerships. Now, though, significant changes are afoot in the state's universities to change this perception—and these need to be lauded and further strengthened to keep the momentum going.[18] In this respect, university-industry R&D and technology development partnerships can only be successful when there is complete understanding—at the very beginning of the process—of each partner's missions, expectations, and rules of engagement. To that end, both partners should agree at the outset on how to determine IP ownership, control, and patenting. While the state's universities have made great strides in developing transparent, streamlined IP policies—that are consistent with other research universities—care needs to be taken that universities invest in follow-on efforts for developing agreements for each industry sector that are attuned to the unique characteristics and specific needs of each industry. Furthermore, universities should facilitate a better understanding of technology transfer process across academic disciplines by providing more detailed information—such as invention disclosures, patents filed and awarded, and license revenue—by academic field.[19] This will be helpful in facilitating more in-depth analysis of how the dynamics of innovation vary across academic disciplines.

Improve the availability of risk capital

Steps to improve the availability of risk capital for small and medium-sized entrepreneurial firms, meanwhile, will be just as critical as encouraging more innovation.

The importance of new, innovative startup companies to the economy—in terms of the technologies they bring to the market, job creation, and overall economic growth—is well documented.[20] And yet, the present analysis has shown that access to capital represents a significant barrier to the growth of such companies in the space economy.

Ranging from market assessment to prototyping to scaling up for manufacturing, the costs associated with developing a product or service and taking it to market run high in the space sector, particularly given the levels of uncertainty involved. Moreover, this report has shown that space-specific market realities ensure that there are at present relatively fewer obvious sources of available private capital—and a slower-moving pipeline of deals—for the sector as compared to other sectors.

Given that, the state should move to facilitate increased availability of risk capital to encourage startup and growth activity in the state's space economy. To this end Colorado can engage in a number of actions.

To start, the state should take steps—as part of its broader branding and marketing campaign—to bring the Colorado space economy opportunity more fully to the attention of VC sources that reside outside the state. Already, the state ranks highly in terms of general VC activity; now the state and its industry partners need to convince more out-of-state investors that Colorado presents significant opportunities for profitable investment in the space economy. To do this, the state should partner with industry to tell the state's story to national investment communities, convene investors whenever it can, and further leverage the incredible asset of the Space Foundation's annual National Space Symposium in Colorado Springs. In addition, and more concertedly, the state should undertake to work with industry to **establish an annual space economy investor's conference** at which top-quality opportunities could be presented, deals discussed, and networking accelerated. A focused, high-level, closed-door event of this sort could be instrumental in increasing the interest of national investors in Colorado technologies and space-enabled entrepreneurs.

At the same time, though, given the challenges associated with changing investor preferences, the state will also likely need to take matters into its own hands. Four actions—two that would improve upon existing programs and two that would create

new ones—offer ways to improve promising space firms' access to capital.

The first two of these actions would seem to be obvious next steps: The state should further leverage the invaluable SBIR / STTR technology development and commercialization program and improve its existing state-run venture capital fund.

Begin with the SBIR / STTR program. Colorado has enjoyed great success in attracting SBIR and STTR grants, including those from DoD, NASA, and NOAA. While this track record is impressive, Colorado can do more. Specifically, the state should consider beginning to **provide matching grants to SBIR / STTR award recipients** and moving to **create a Phase 0 Fund** to help companies prepare SBIR / STTR proposals. Many states—including Florida, Kentucky, Nebraska, North Carolina, Oregon, and Washington—now operate SBIR / STTR matching fund programs and/or Phase 0 funds, a number of which have demonstrated attractive returns on investment.[21] And so maximizing Colorado firms' access to SBIR / STTR awards represents a winning strategy for helping innovative new companies in Colorado commercialize their products and services. Colorado should do all it can to help its firms tap this program. Adding a special focus affirming the importance of AI forays into new markets would further bend the program toward Colorado's emerging strategy. Colorado could even go so far as to advocate that the SBIR program set aside funding for incubators and accelerators to assist SBIR recipient companies with their technology commercialization process.

Turning to the venture capital issue, the state should **improve its existing state-run venture capital fund**—the Venture Capital Authority (VCA), created in 2004 to make seed and early-stage capital investments in businesses—in order to allow it to more effectively deploy capital.[22] With more and more VC firms avoiding early-stage deals in favor of investments in less risky, later stages of development, growing numbers of states are engaging in such venture investment themselves.[23] Colorado's VCA has roughly $15 million in current capital but the remaining funds for seed and early-stage capital investments in businesses are insufficient for growth industries like aerospace, cleantech, and the biotech sectors. Furthermore, the VCA as currently structured includes several restrictions that prevent its capital from being deployed with optimal effectiveness. For instance, one of the fund's operating restrictions requires that 25 percent of funding be deployed in rural areas and another 25 percent in enterprise zones. That means that effectively only half of the VCA's capital is available for investment in high-technology AIs, which tend not to locate in the specified locales.[24] Colorado may therefore want to consider some restructuring of the VCA to improve the program's outcomes. For one thing, the state should consider eliminating the rural and urban distressed businesses set-asides and shifting the focus of VCA activities toward support for advanced industries.

Yet the SBIR / STTR and VCA adjustments are incremental: They improve the leveraging of existing programs. To go farther, the state should consider developing two new mechanisms. One potentially helpful move would be for Colorado universities to **create university-based venture capital funds** to accelerate the commercialization of academic research and invest in startups founded on university research. University-affiliated VC funds are proliferating around the nation, offering a direct mechanism for getting investment capital to promising entrepreneurs whose technologies have been developed at or in partnership with a university.[25] And here there is both a precedent and a need. While CSU launched a $3 million venture capital fund in 2010, the state's other two big research universities—the University of Colorado and the Colorado School of Mines—lack such instruments, although the creation of such a fund has been a topic of discussion at CU. Creating such funds would seem a timely next move. Money invested in these funds can come from private investors, including individuals and large investment funds. Or, as an alternative to creating individual university funds, the state's universities may consider teaming up to address the need for early-stage funding of innovative technologies through the creation of a single entity. Such an approach is being taken by the Ohio State University and Ohio University, which have jointly committed to a $35 million venture capital fund.[26] Irrespective of the approach taken, the creation of such a fund could go a long way toward spurring commercialization by investing in early-stage companies.

In addition, the state should consider launching an initiative to **create an advanced industries fund of funds** to direct investments from privately managed venture funds toward Colorado AIs, including space. Through a fund of funds, the state would channel resources into private VC funds that would be required to target critical Colorado AIs as a condition of the state investment. Likewise, the state could require that portions of the fund's money be invested in funds that focus on seed or early-stage investments—say, in companies operating in new space, emergent, or adjacent markets. Along these lines, a $250 million fund of funds could potentially be capitalized with investments from the state pension funds (the Public

Employees' Retirement Association), university foundations, and other institutional investors.[27] In any event, such an approach would have the benefit of marrying public investment dollars to private investment and risk analysis while also requiring investment professionals to pay attention to Colorado. For these reasons the fund of funds concept offers a sophisticated model for increasing the amount of capital funding available to high-growth, early-stage companies in the state. That states as diverse as Iowa, Indiana, Ohio, Oklahoma, and Utah have implemented such funds means that concrete lessons in design and implementation are available should legislators decide to authorize the creation of a fund of funds for Colorado. And here Colorado could innovate if it wanted to by working to develop a multistate fund of funds to invest in AIs, in partnership with Arizona and Utah, for example.

Improving entrepreneurs' access to venture capital: Utah Fund of Funds

The availability of capital is a critical factor in the health of an industry's innovation ecosystem. Readily available capital bolsters entrepreneurialism, helps younger firms secure funds needed for continued growth, and allows companies to capitalize on innovations as they arise.

Although the provision of investment for early-stage and growth companies is undoubtedly a private-sector function, the public sector can play a role in encouraging private-sector engagement in this area. One compelling example of an effective state intervention to improve the investment environment is the Utah Fund of Funds (UFOF). Recognizing that a lack of capital resources was hindering entrepreneurialism and economic growth in the state, the Utah state legislature passed the Utah Venture Capital Enhancement Act establishing UFOF in 2003. Capitalized by funds from Deutsche Bank and Zions Bank, UFOF invests in investment firms both within and outside Utah that have committed themselves to providing venture capital for Utah-based companies. In the event that UFOF loses money, the legislature authorized a total of $300 million in tax credits to compensate UFOF investors, though to date the UFOF has not needed to use these credits.

Over the past decade, UFOF has grown to include 28 investment firms, which together have provided $304 million in capital to 56 companies in the state. The effects of these investments on the state economy have been sizable, with over 1,600 jobs created that pay an average annual salary of $64, 286—significantly higher than the state average of $39,811. In addition, these 56 firms have generated over $30 million in incremental tax revenue for the state, with future tax revenue from UFOF-funded firms projected to increase to over $75 million through 2020. By expanding access to investment funds, UFOF is working to ensure that Utah is a state where entrepreneurialism can thrive.

Source: Utah Fund of Funds Annual Report 2011.

Bolster the workforce pipeline to secure Colorado's human capital advantage

And yet, neither improvements to the innovation system nor enhanced access to risk capital will yield optimal growth if the quality of Colorado's space economy workforce begins to erode. For that reason, it will be critical for the state to work closely with industry to ensure the continued availability of top-quality engineering and space / aerospace workers.

For this reason, Colorado should move now to craft and implement a bold new vision for workforce development that fully engages the private sector even as it seeks to inspire students at every step to consider future careers in high-tech

advanced industries, including the space economy. To that end a number of strategies should be considered to address challenges across the entire education and workforce continuum—starting in high school and continuing into college and working life.

For one thing, Colorado should coordinate the many STEM initiatives already underway in the state to ensure that they become more than the sum of their parts. Colorado has great STEM education resources and programs in place but needs to do a better job of coordinating and sharing these resources. To that end the state would do well to **create a dedicated statewide STEM education initiative or entity** tasked with organizing and aligning Colorado's myriad state, regional, and local STEM programs, practices, and policies to maximize their impact.[28] Such a statewide entity should be entrusted with the responsibility of creating a statewide STEM network of practitioners, policymakers, and researchers; identifying best practices generated at the local, state, and national levels; proactively facilitating knowledge sharing among the network members and serving as a conduit for the sharing of best practices; and evaluating the quality and impact of various STEM programs to guide future actions and communications. In doing this the state should to the greatest extent possible leverage the resources and network of the existing Colorado Experiential STEM Learning Network, created by the University of Colorado Denver.[29]

Perhaps of greater importance than these organizational responses will be a strong focus on engaging students directly in AIs through immersive STEM experiences. Such engagement can make a difference at every step along a student's path toward employment.

Too often students graduate from high school and even college without a clear conception of the career they want to pursue or the pathway to a career. One way to address this problem would be for the state and its school districts to **create a set of focused high school advanced industries career academies** designed to allow high school students to explore potential careers in AIs. These academies would be smaller learning communities within the state's high schools with a thematic focus that would expose students to potential careers in AIs and, in many instances, would provide students the opportunity to obtain career certifications before they graduated from high school. In some cases academies would even partner with companies to offer company-sponsored courses as well as apprenticeships. Emerging evidence confirms that students graduating from career academies have a much better understanding of the career they want to pursue and tend to perform well in the labor market.[30] Fortunately, Colorado already has a good model on which to build. The Jack Swigert Aerospace Academy, which is a partnership between the Space Foundation and the Colorado Springs School District 11, uses aerospace themes and principles to build student proficiency in STEM.[31]

In addition, Colorado should greatly **expand and strengthen advanced industries apprenticeship opportunities**. In recent years a growing consensus of industry, academic, and policy voices has affirmed the value of industry apprenticeships. Such placements are increasingly viewed as a viable way to engage potential workers, address skills challenges, and mitigate declining manufacturing employment.[32] Furthermore, investing in future employees serves to strengthen their loyalty to companies, thereby decreasing turnover and improving productivity. Given these positive outcomes, the state should take a proactive approach to encouraging employers to offer apprenticeships; improving access to apprenticeships, especially in the state's key AI sectors; and expediting apprentices' pathways to postsecondary degrees and industry-recognized credentials. To that end Colorado could give employers a state tax credit for each apprentice in each year of their employment, following the model of South Carolina's Apprenticeship Carolina initiative. Or the state could fund and train staff at Workforce Investment Act (WIA)-supported One-Stop locations and community colleges to conduct employer outreach and subsidize tuition for related technical instruction delivered at community colleges as a way to cut employer training costs. Finally, Colorado should establish a state certification process for registering pre-apprenticeship and apprenticeship programs to ensure quality control of these programs.[33]

In a similar vein, Colorado's four-year colleges and universities—in partnership with industry—need to make a concerted effort to link work and learning by moving to **provide far more opportunities for work-based learning including co-operative education** (co-op education). Co-op education, in this respect, is a tested model that provides students with extensive work experience, creates a much tighter relationship between students' programs of study and their future careers, and ultimately better prepares them to enter the workforce. Several stakeholders consulted during the preparation of this report spoke enthusiastically of the relevance of co-op education to workforce development in AIs. Given the

exceptional benefits of these programs, Colorado's colleges and universities should move aggressively to greatly expand co-op education programs and industry, for its part, should partner with educators to offer students co-op opportunities directly relevant to their programs of study. Alternatively the state could consider creating a "Colorado Cooperative Education Program" that would provide a single entry point for companies seeking qualified students while at the same time allowing students from any state school to apply to this centralized program.

Incorporating work experience into undergraduate degree programs: Co-operative Education at the University of Waterloo

Recognizing the critical importance of work-based learning, some colleges and universities are looking to cooperative education programs to improve their graduates' post-college employment prospects. Students enrolled in cooperative education programs take alternating four-month terms of academic coursework and on-the-job work experience in their field of study, receiving both academic credit for their employment as well as remuneration from their employers. Because employers pay students for their work, students in cooperative education programs require less financial aid while in college, which translates to reduced student loan burdens following graduation.

The co-op program at the University of Waterloo in Ontario, Canada offers one well-established model to look to. As the world's largest co-op program, it enrolls some 16,500 undergraduates and embeds them within 4,500 employers participating both within and outside Canada. Eighty percent of undergraduate programs at Waterloo offer a co-op component, including all 13 majors in the school of engineering. Cooperative education at Waterloo is overseen by Co-operative Education and Career Action (CECA), which also manages the university's career guidance services. CECA staff support co-op students during and after their time at Waterloo, assisting them with the co-op job search and placement process, acting as career advisors, and helping them map out career paths and post-graduation plans. In addition, CECA actively recruits employers offering work opportunities relevant to Waterloo courses of study and maintains a job database to help co-op students connect with employers offering employment in their fields of study. As liaisons between students, faculty, employers, and alumni, CECA staff work to improve the alignment of Waterloo's course offerings and labor demands so that students are more likely to graduate with marketable skills and training.

Although cooperative education programs typically take five years to complete, students enrolled in co-op programs graduate with 16 months to two years of paid work experience in addition to their bachelor's degree. When combined with their degree, this work experience often allows graduates to begin their careers at a higher level than they would have with only a college diploma. As such, a number of Colorado space economy stakeholders believe that such programs could be instrumental in helping to address the state's growing need to replenish the aerospace workforce.

Source: University of Waterloo Co-operative Education website.

Internship programs offer another great way to provide serious opportunities for work-linked learning to students at four-year colleges and universities. While Colorado's higher education institutions each offer their own internship programs, there is an opportunity to scale them up by instituting a statewide internship initiative. To that end, Colorado should **launch an "Intern in Colorado" initiative** with the goal of connecting students to various AI internship opportunities across the state. Led by the state, the development of a detailed, keyword-driven online database would enable all companies with Colorado-based internships to post their available internships, creating a one-stop shop for students searching for such opportunities. In developing this initiative, the state would also need to collaborate both with state colleges and universities, to ensure that they market it to their students, as well as companies, to encourage use of the statewide internship database. Michigan's Intern in Michigan and the Massachusetts Stay Here internship programs offer two strong examples of recent state endeavors to create more focused statewide internship programs.[34]

At the graduate and postgraduate levels, students—including highly trained scientists—often face significant difficulty in

transitioning from academia to industry. University graduate students tend to be viewed as overqualified for technical positions in industry and under-qualified for senior positions, since they usually lack relevant industry experience. The result is a loss for the state, whose companies may miss out on superior technical talent and whose top students miss a chance to engage in industry. To address this problem Colorado could **launch an advanced industries fellows program** to place state-funded graduate and postdoctoral students in emerging entrepreneurial companies.[35] Such a program could be extremely beneficial for both students and companies. Fellows would gain valuable industry experience including unique insights into the workings of smaller, entrepreneurial firms in the private sector. Companies, for their part, would benefit by gaining access to highly trained workers and collaborating with university partners.

In order to address the growing skills gap challenging many of the state's advanced industries and establish a process for meaningful industry engagement, Colorado should move to **create industry skills panels** to better align the needs of employers with education and training options.[36] Such panels would serve as highly collaborative forums for bringing together representatives from the private sector, labor, and the state's educational system to discuss common workforce and skills challenges in a particular industry and to devise feasible and effective solutions—thereby fostering a robust workforce and economic development ecosystem in the state. At the same time, the individual panels would provide a crucial platform for companies—many of which under other circumstances are competing with one another—to collaborate on defining the critical skills needs of their industry. For example, an aerospace / space industry skills panel could have a transformative effect on the industry as a whole. Such a forum could recommend new training programs where none before existed, demand greater training capacity when there are not enough graduates to meet demand, and identify those industry-recognized credentials that should be incorporated into new or existing curricula. In this way the state's AIs, including the space industry, would gain a structured framework for establishing skills requirements, working out needed institutional arrangements, and developing the necessary feeder systems and career pathways to supply growing industries with a quality workforce. The state's effort on this front should be closely tied to its ongoing initiative of employing a sector-based approach as a strategic framework for its workforce and economic development programs. Aligning industry skill panels with sector strategies will enable Colorado to integrate other powerful industry-focused strategies, particularly career pathway programs and regional industry clusters.[37]

Intensify cluster dynamics

Finally, the state—with its ability to convene stakeholders and reach across the space economy's several divides—needs to attend to the cohesion of the cluster, the optimal functioning of which will be critical for maximizing future growth in Colorado.

State government's primary responsibility when it comes to intensifying the space economy's cluster dynamics involves helping to bridge some of the cultural and geographic divides that exist among Colorado's space communities.

Chapter III demonstrated that the full spectrum of space economy activities is present in the state. This truly unique continuum endows Colorado with an exceptionally rich asset base. Chapter V, though, observed that the state's space communities often remain isolated from one another even despite their proximity.

The reasons for this are both manifold and understandable: Mission differences and divergent sector cultures represent just two challenges among many. But in any event such divides mean that potential opportunities for cross-fertilization and collaboration between actors and communities either do not occur, or occur at suboptimal intensity.

And so it falls to the state—working in partnership with Colorado's several space-community cluster organizations—to work tactfully to bridge the divides that have naturally arisen in the absence of coordinated efforts to do so.

To that end, the state should **leverage existing cluster partnerships** to increase the levels of collaboration, inclusivity, and exchange within the cluster. To begin with the state should get the existing cluster organizations to coordinate more with

each other and adopt strategies that leverage their individual strengths across the cluster. Second, the state should strengthen its partnerships with these organizations, which operate in the trenches and on the frontlines of industry development. These organizations are closest to the constituent elements of the cluster and typically have the networks and knowledge that the state must tap in order to execute any cluster strategy effectively. By partnering with them, the state will ensure that its efforts are supportive of and complementary to—instead of accidently at cross-purposes with—the vibrant bottom-up initiative that is a hallmark of this cluster.

Complementing this direct partnership, the state should seek to **build the capacity of the state's cluster organizations through a competitive grant program**. Such a program could offer three types of small-scale competitive grants: planning grants, startup and technical assistance grants, and program grants.[38] Planning grants would fund feasibility studies to evaluate the viability of any cluster initiative. Somewhat larger startup and technical assistance grants would be made to early-stage cluster initiatives to sharpen and energize management, facility, and program operations. The largest set, program grants, would be awarded to support well-defined, collaborative activities of proven cluster organizations in areas such as training, R&D, technology transfer, and marketing. All would be awarded on a competitive basis with a matching requirement to the best-focused and documented proposals for enhancing the collaborative action and inclusivity of the space cluster.

In a related measure Colorado should facilitate the development and launch of a **multi-sectoral / multidisciplinary road-mapping and collaboration forum** to draw disparate actors into needed collaborations in the state's space economy and its advanced industries as a whole. Such an exercise would strengthen Colorado's competitiveness by identifying the challenges facing AIs, emerging market requirements, technology gaps, and both private- and public-sector interventions that can help the state's AIs carve out their share of future markets both nationally and globally. This forum should have a broader focus to engage with the state's entire spectrum of advanced industries. No single industry—or for that matter a single company—has the resources to develop the full range of technologies required to grow the state's economy. And so Colorado's competitiveness can get a significant boost from creating an alliance of AIs that together can focus on cross-cutting technology issues and solutions.

The state may also want to consider directly incentivizing collaborative behavior in several promising and cost-effective ways. One way for the state to incentivize collaboration between industry and the universities, federal labs, or other consortia would be by moving to **create a collaborative R&D tax credit**. State R&D tax credits have been shown to be effective in stimulating increased company R&D expenditures within the state, with empirical results suggesting that the presence of such tax credits result in $75 to $118 more R&D dollars per capita.[39] And yet there are growing concerns that the R&D tax credit—one of the main ways in which the industry is encouraged to invest in R&D—has not been effective in incentivizing research collaborations between business and research institutions, despite their growing importance.[40] These collaborations are essential not only for increased technological innovation but also for increased competitiveness and job creation. If Colorado is to remain nationally competitive in R&D-based activities—and, by extension, in advanced industries—instituting a collaborative R&D tax credit is a necessary first step.

Another way for Colorado to incentivize collaboration between the various cluster actors and also achieve economies of scale is to **prioritize or provide incentives for multi-actor applications to state funding programs**. For instance, workforce development grant programs could offer incentives for collaboration by making cross-sector engagement a criterion for selection. The state could also redirect some of its funding to multi-firm proposals by awarding grants to consortia of companies for innovation-related activities or even technical or managerial training services. Bottom line, the state will need to examine its competitive programs to determine how various incentives for collaboration among the different set of cluster actors can produce economies of scale for the state and best distribute benefits to multiple stakeholders.[41]

Finally, to facilitate the flow of knowledge and technology out of universities and laboratories the state should **sponsor or provide matching grants for an "entrepreneurial leave" program**. Such programs—somewhat like the proposed fellows program—embed researchers in local companies (often startups but sometimes established firms) for a limited period of time to commercialize technologies and expand companies, with their former positions at research institutions guaranteed upon return.[42] Distinct from those taking sabbatical, individuals taking entrepreneurial leave on their own must typically finance their time in industry independently—an especially big risk when working with startups. Colorado should improve on

this framework and elevate it by sponsoring such leaves and branding those taking them as "Colorado Technology Commercialization Scholars." The state could also extend this program to graduate students.[43] Ultimately, entrepreneurial leave programs could become a win-win innovation for the state, universities, research institutions, and industry. All at once, such leaves would increase faculty knowledge of industry in the state, improve the commercial focus of research, enhance the potential for successful commercialization of research, and forge collaborative ties with industry that will outlive the appointments. Such an initiative would add to the social capital and flow of knowledge in the cluster and so intensify the power of the cluster to accelerate Colorado innovation.

* * *

In sum, while industry must lead the growth of the Colorado space economy, state government (in partnership with business and the state's congressional delegation) retains an important role in addressing certain cluster deficiencies, encouraging innovation, and supporting continued space industry growth.

The federal government must do its part to support Colorado's space economy preeminence

The state of Colorado is rededicating itself to a collaborative partnership with industry and other governments to advance the state's extraordinary space cluster. So should the state's congressional delegation.

The federal government exerts significant influence over the levers of competitiveness that will directly affect the trajectory of Colorado's space economy. Its policies shape the national technology, innovation, business, and regulatory environments, to name a few. What is more, the federal government remains the Colorado space economy's largest customer. And so, with budgets flat-lining and disruptive forces at work, alert, responsive, and cohesive advocacy in Washington will be increasingly important in the coming years, whether to defend the Colorado footprint of the nation's national security mission; to advocate for important military and civilian space resources and programs; or to secure the innovation investments that will catalyze future commercial market growth.

Fortunately, the state's congressional delegation appears poised now to build on recent momentum. A string of recent successes reflects increased cohesion and includes saving the Orion project, securing funding for a spaceport feasibility study, and shaping legislation opening the door to satellite export control reform. Meanwhile, ongoing dialogue exhibits a renewed commitment to making Colorado the center of innovation for the global space economy. And so the Colorado congressional delegation—in the same manner as industry actors and state government—should organize its efforts in Washington around the six strategy initiatives this report has extrapolated from an analysis of the state's competitive positioning. What follows are some key priorities:

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Colorado needs the federal government to resolve a number of issues in order to safeguard the existing space industrial base—the state's primary source of future success. Specifically, all actors must take pains to ensure that fiscal consolidation does not erode the space industrial base. On this front, the state needs the federal government to:

- **Circumvent sequestration** and provide a more predictable path toward budget stability
- **Maintain commitment to the nation's civil space program**, the public services it provides, and the intangible benefits of its science and exploration missions. Specifically, maintain commitment to flagship programs already underway such as the James Webb Space Telescope, Orion Multi-Purpose Crew Vehicle, and Commercial Crew Integrated Capability Programs. In addition, renew commitment to weather and earth science programs relied on by science communities and the public
- **Support the National Space Policy's priorities** in the near term, translate them into an executable strategy, and articulate a clear long-term vision for NASA and civilian space programs as is customary in national security space.[44] Communicate this vision across Washington and the country
- **Move to reduce the recent uncertainty in budgeting and programming** that continues to plague the private investment environment for capital, workforce training, and R&D

Seize commercial opportunities in emerging new space, adjacent markets, and global markets

Colorado also needs the federal government to go farther in creating an environment in which next-generation space technologies can flourish:

- **Implement export control reform** as swiftly as possible and streamline licensing and compliance[45]
- **Accelerate spectrum sharing initiatives** and technology adoption to free unused spectrum and unleash wireless innovation[46]
- **Accelerate the integration of UAVs / UASs into national air space** with concerted efforts to resolve lingering technical and privacy issues and then set the market's regulatory parameters so that new industries can emerge
- **Assure and expand commercial access to space** by improving affordability and reinvigorating the domestic commercial launch market with strategic policy reform[47]

The federal government must do its part (continued)

- **Embrace the spirit of frugal innovation throughout the procurement process** with increased utilization of contracting models that unleash private sector innovation by specifying needed outcomes at fixed costs
- **Pursue multilateral trade agreements** to reduce trade barriers and boost market access for manufacturers and service providers

Commit to innovation and owning the next great space technologies

The federal government's policies and investments hugely shape national and regional innovation systems. Colorado needs the federal government to commit to creating at the national level an environment that fosters innovation, technology development, and entrepreneurship. Along these lines, Colorado needs the federal government to:

- **Boost investment in advanced R&D** by fulfilling the President's plan to double the research budgets of three key science agencies over the next decade and direct increases in funding toward top cross-cutting technology areas that address key national needs such as advanced sensing, nanomanufacturing, and industrial robotics.[48] Leverage this funding to structure the national R&D enterprise as a mutually supporting partnership among industry, the federal government, universities, and other public and private entities[49]
- **Move to create and scale up a national network of advanced industries "innovation hubs,"** beginning with the Department of Commerce's proposed National Network for Manufacturing Innovation. A Colorado advanced industry hub—structured as a long-term partnership between industry and Colorado universities, with extensive federal, state, and local government and educational partnership —would bring to the state compelling new innovation infrastructure situated amid an exceptionally strong AI cluster[50]
- **Expand and make permanent the research and experimentation tax credit**[51]
- **Institute a collaborative R&D tax credit** for multi-stakeholder research[52]
- **Scale up mission-oriented, outside-the-box innovation initiatives** like DARPA, ARPA-E, and the DARPA Grand Challenge
- **Expand the focus of the nation's research enterprise** from basic early-stage R&E to later-stage RD&D and technology commercialization[53]

Improve the availability of risk capital

Colorado needs the federal government to ease capital constraints on SMEs:

- **Support continued or expanded funding of SBIR and STTR programs** across agencies
- **Leverage the Export-Import Bank of the United States** (Ex-Im Bank) to support space related exports particularly from small firms and satellite services providers
- **Create tax incentives for start-up operating capital** to facilitate early-stage financing for promising entrepreneurial new firms[54]

Bolster the workforce pipeline to secure Colorado's human capital advantage

Talent fuels Colorado and its space economy. Their present and future competitiveness—as with the nation's—relies on a skilled technical workforce. The federal government must partner with the state to maintain, replenish, and improve this workforce to align with the labor demands of a 21st century productive economy. In this endeavor, Colorado needs the federal government to:

- **Create and fund a nationwide manufacturing skills standards initiative** that would establish industry-defined national standards and nationally portable certifications[55]
- **Promote the creation of STEM-focused elementary, middle, and high schools** across the country[56]
- **Create a "Race to the Shop" competition** to reward "bottom up," business-led creativity in reforming and modernizing the delivery of federal workforce education and skills training for advanced industries[57]
- **Reform the immigration regime for growth**—and to fill critical workforce shortages—by creating an immigrant entrepreneur visa program; increasing the H1-B worker cap for qualified workers; and offering green cards to foreign-born students graduating with STEM degrees[58]

The federal government must do its part (continued)

Intensify cluster dynamics

Modest efforts to support regional industry clusters are likely to be particularly effective in boosting innovation and growth in Colorado, where strong collaborative networks and a critical mass of innovation activities are already in place. The federal government should capitalize on this opportunity by maintaining and expanding competitive grant programs for cluster initiatives and by leveraging its own footprint in the state. In this vein, Colorado needs the federal government to:

- **Support maintenance or expansion of bottom-up competitive grant programs** for cluster development such as the i6 Challenge or the Advanced Manufacturing Jobs and Innovation Accelerator Challenge[59]
- **Explore avenues for intensifying federal laboratories' engagement in regional economic development** by, for example, streamlining agreements for collaboration with industry or directing federal labs to institute entrepreneurial leave programs that enable scientists and engineers to help expand or start up new companies[60]

STATE AGENDA

$ = Little to no cost	**$$** = Low cost	**$$$** = Moderate cost	**$$$$** = High cost

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Produce and annually or biannually update a sophisticated strategy for bolstering Colorado's space economy preeminence	**$**
Lead in convening Colorado's congressional delegation to defend and advocate for the expansion of the state's space economy	**$**
Lead in convening the leading aerospace states	**$**
Brand Colorado's unique space economy and market it relentlessly	**$$**
Name a dedicated "sector champion" to spearhead cluster development	**$$**
Ensure that Colorado remains a business and military friendly state by engaging in regular dialogue with stakeholders	**$**

Seize commercial opportunities in emerging new space, adjacent, and global markets

Survey the competitive landscape in additional detail	**$**
Promote the new opportunities and celebrate the companies seizing them	**$**
Position the state for leadership in next-generation aerospace / space platforms	**$$-$$$**
Offer modest "deal closers" or small relocation incentives for innovative small firms	**$$$**
Launch a governor's prize for new space business plans	**$-$$$**
Facilitate the convening of technology "boot camps" around opportunities for innovation	**$**
Spearhead a space and new space trade mission	**$$**
Solicit foreign direct investment	**$**

Commit to innovation and owning the next great space technologies

Create a program that bridges the advanced industries technology development gap	**$$$$**
Establish a statewide advanced industries innovation hub	**$$$$**
Bolster the Colorado Higher Education Competitive Research Authority	**$$$**
Create an innovation vouchers program	**$$$**
Launch a matching grants program for collaborative R&D projects	**$$$**
Appoint a SWAT team of innovation "site miners"	**$$**
Develop more industry-friendly university-to-business technology licensing agreements	**$**

Improve the availability of risk capital

Establish an annual space economy investor's conference	$
Provide matching grants to SBIR / STTR award recipients	$$-$$$
Create a "Phase 0" Fund	$$
Improve the existing state-run venture capital fund	$
Create university-based venture capital funds	$$$$
Create an advanced industries fund of funds	$$$$

Bolster the workforce pipeline to secure Colorado's human capital advantage

Create a dedicated statewide STEM education entity or initiative	$-$$
Create a set of focused high school advanced industries career academies	$$-$$$$
Expand and strengthen advanced industries apprenticeship opportunities	$$
Provide far more opportunities for work-based learning including cooperative education	$
Launch an "Intern in Colorado" initiative	$$
Launch an advanced industries fellows program	$$
Create industry skills panels	$

Intensify cluster dynamics

Leverage existing cluster partnerships	$
Build the capacity of the state's cluster organizations through a competitive grant program	$-$$$
Launch a multi-sectoral, multidisciplinary road-mapping and collaboration forum	$-$$
Create a collaborative R&D tax credit	$$$
Prioritize or provide incentives for multi-actor applications to state funding programs	$
Sponsor or provide matching grants for an "entrepreneurial leave" program	$$-$$$

FEDERAL AGENDA

$ = Little to no cost	**$$** = Low cost	**$$$** = Moderate cost	**$$$$** = High cost

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Circumvent sequestration	**$**
Maintain commitment to the nation's civil space program	**$-$$**
Support the National Space Policy's priorities	**$$**
Move to reduce recent uncertainty in budgeting and programming	**$**

Seize commercial opportunities in emerging new space, adjacent, and global markets

Implement export control reform	**$**
Accelerate spectrum sharing initiatives	**$-$$**
Accelerate the integration of UAV / UASs into national air space	**$-$$**
Assure and expand commercial access to space	**$-$$$**
Embrace the spirit of frugal innovation throughout the procurement process	**$**
Pursue multilateral trade agreements	**$**

Commit to innovation and owning the next great space technologies

Boost investment in advanced R&D	**$$$$**
Move to create and scale up a national network of advanced industries innovation hubs	**$$$$**
Expand and make permanent the research and experimentation tax credit	**$$$**
Institute a collaborative R&D tax credit	**$$$**
Scale up mission-oriented, outside-the-box innovation initiatives	**$$-$$$$**
Expand the focus of the nation's research enterprise	**$**

Improve the availability of risk capital

Support continued or expanded funding of SBIR and STTR programs	**$-$$$**
Leverage the Export-Import Bank of the United States	**$**
Create tax incentives for startup operating capital	**$$$**

Bolster the workforce pipeline to secure Colorado's human capital advantage

Create and fund a nationwide manufacturing skills standards initiative	**$$**
Promote the creation of STEM-focused elementary, middle, and high schools	**$$$**
Create a "Race to the Shop" competition	**$$$$**
Reform the immigration regime for growth	**$**

Intensify cluster dynamics

Support maintenance or expansion of bottom-up competitive grant programs	**$-$$$**
Explore avenues for intensifying federal laboratories' engagement in regional economic development	**$$**

IX. CONCLUSION

In the end, the measurements and trends reviewed here warrant confidence but also counsel urgency. This strategy report has confirmed that Colorado's world-class space industries cluster is extremely well positioned. The state possesses a strong "base" in civil and military space activity but it also boasts promising emergent positions in an array of dynamic service segments and adjacent commercial industries—all supported by a unique confluence of civil and military contracting, leading-edge hardware production, and a rich cluster of related actors.

And yet, key portions of the analysis presented here underscore that the state must now recognize and master an extremely challenging set of environment factors. Flatlining federal contracting, the rise of new competitors, and a proliferation of bold new commercial experiments in the new space realm all make it imperative that industry and government work together to upgrade and in many ways reimagine the operations of the Colorado space cluster. A new period of collaborative, deep-going experimentation must commence now in which business, government, and myriad related actors seek to innovate on every aspect of the space enterprise—from technology development to business strategy to workforce development—to move the state from leadership to preeminence.

In that sense, what is needed now is substantial—a new surge of aspiration, creativity, and collaboration in business and government—but it is not beyond the capacities of one of the nation's extraordinary state industry clusters.

For that reason, the potential for success seems high, and the opportunity for gains large, should industry and government focus together now—and execute.

APPENDIX A. METHODOLOGY

Defining the space economy

Brookings set out to find a definition of the space economy that would capture, but not overstate, its true and full importance to the state of Colorado.

Brookings started with the assumption that everything that goes into space, everything that supports systems in space, and all terrestrial economic activities that are directly enabled by space are reasonably and appropriately considered part of the "space economy."

In Brookings' view this expansive but thematic and natural definition best captures "space" as it manifests itself in the real economy, and best approximates an industry cluster: a shared knowledge and technology base, integrated into a wider regional economy. Nor is this definition without precedent: Other leading research organizations such as the Organization for Cooperation and Development and the Space Foundation utilize at similar definitions.[1]

Identifying space economy firms and establishments

Brookings' definition of the space economy called for a unique high-resolution approach to measuring the industry. Encompassing far more than the straightforward manufacturing of satellite, launch vehicles, and spacecraft, the space economy—defined as all economic activity that touches space—is a rich and varied assemblage of activities that cuts widely across conventional industry definitions. From the transponders, data processors, and the sensors to the software programming services for space situational awareness that make space accessible—and profitable—for governments and civilians, the space business is often indistinguishable from the non-space business in standard industry classification schemes.

Given the inadequacy of conventional datasets for the task at hand, Brookings adopted a novel approach to measurement and analysis for this report: a bottom-up identification and count of every business active in Colorado's space economy.

Hence the smallest unit of analysis in this report is the business establishment, which is a single discrete address where business is conducted. Every business establishment belongs to a firm (a firm is synonymous with a company, in this report). Firms can have any number of establishments. For example, a neighborhood mom-and-pop coffee shop with only one location is a single-establishment firm. A neighborhood Starbucks is also an establishment, but one that belongs to a much larger firm (Starbucks Inc., headquartered in Seattle).

To construct this dataset Brookings identified all of the *firms* that comprise Colorado's space economy and recorded job data and other information for each corresponding business *establishment* in the state. In short, firms had to meet the inclusion criteria for their establishments to be included in the dataset.

Brookings' method of identifying space firms was novel: It began with firms' own self-identification as space companies. Brookings then confirmed the decision to include every company and every establishment identified in this initial scan by visiting each and every website to determine that space-related activity was, in fact, the predominant economic activity at each location.

Companies were deemed to have self-identified as space companies if they appeared in any of the following lists:

- Colorado Space Coalition membership
- Colorado Space Business Roundtable membership
- Colorado Space Coalition directory

- Metro Denver EDC Aerospace Industry Cluster Profile
- Satellite Industry Association membership
- American Institute of Aeronautics and Astronautics membership
- Association for Unmanned Vehicle Systems International membership
- National Defense Industries Association membership (Mile High Chapter; Rocky Mountain Chapter)
- NASA space-related contract, grant, and award winners (source: spending.gov; sbir.gov)
- NOAA space-related contract, grant, and award winners (source: spending.gov; sbir.gov)
- DOD space-related contract, grant, and award winners (source: spending.gov; sbir.gov)

In addition, Brookings sought to complete its dataset and fill any gaps in the space economy landscape that its methodology may have missed by scouring the following sources for mention of Colorado-based space companies:

- Local news sources (*The Denver Post*, *Denver Business Journal*, *Colorado Springs Gazette*, *Colorado Springs Business Journal*)
- National news sources (e.g. *SpaceNews*)
- Space industry reports (e.g. Space Foundation's "The Space Report")
- Dun & Bradstreet (D&B) generated lists of establishments classified under "pure space" and "primarily space" NAICS codes (including NAICS codes 334220, 334290, 334511, 336414, 336415,336419, 517400, 541712)

Data checks and adjustments along the following lines were conducted to ensure accuracy:

- The website of every company identified as part of the space economy was visited to verify that a) the primary activity of its Colorado establishment(s) involved space and b) it was still in business. Some establishments had been acquired by other firms and changed names; in such cases, these were entered into the database under whichever company name was associated with the address in National Establishment Time Series (NETS) and D&B
- Websites were visited for a random sampling of firms to cross-check reported employment levels at Colorado locations with those in the database
- E-mails were sent to a number of the largest firms and to any firms for which records appeared suspicious or potentially faulty in order to verify employment levels at Colorado addresses. Any self-reported numbers overrode those in NETS
- In cases in which Brookings' methodology captured large companies with significant space-related activities but also large—in some cases dominant—lines of business completely unrelated to space, Brookings determined on a case-by-case basis whether to leave them out entirely (e.g., Woodward), include only the establishment in the state with the smallest number of jobs (e.g., Agilent Technologies or IHS Global), or include all jobs at all establishments (e.g., SAIC)
- Finally, professional services companies—specifically accounting, consulting, and law firms—posed a special challenge. In order to neither significantly overstate nor understate their contribution to the space economy, Brookings decided to include only establishments that were directly awarded federal contracts for a space-related activity in the consulting realm (e.g., select establishments belonging to Accenture and Booz Allen Hamilton) and ones renowned for their space expertise in the law realm (select establishments belonging to Holland & Hart). One accounting firm active in space industry associations, Grant Thornton, was included too, as was one civil engineering company, Merrick & Company. In including this handful of establishments, Brookings believes to have reasonably approximated—erring on the conservative side—direct space-related employment across all firms in the professional services domain

Segmenting and categorizing the space economy

The space economy is an array of in some ways distinct, in some ways related activities united by a common element: their ties to space. Accordingly, this report broke the space economy down into segments representing discrete areas of activity based on products and markets.

The 11 more granular segments identified for this report were then grouped logically into three larger categories: the manufacture, placement, and operation of space-based assets; the provision of services via those assets; and the components and services providers serving both.

Brookings' segmentation and subsequent categorization of the industry primarily draws on previous work conducted by the Space Foundation in their annual "Space Report," by the Satellite Industry Association in their "State of the Satellite Industry" report, and by the Organization for Economic Cooperation and Development's "The Space Economy at a Glance." Numerous other readings informed the final segment and category names and delineations.

Brookings slotted establishments into segments according to the primary activity conducted at each establishment. Primary activities were most often determined upon visiting company websites. Brookings cross-checked and refined its assignments based on establishment industry codes (both NAICS codes and the far more specific SIC codes) provided in each establishment record by D&B and NETS; extensive reading of national and local media and economic resources; contract information; and stakeholder knowledge provided at listening sessions, in person, and over e-mail. Brookings continuously updated and refined its classifications during the entire study period. Appendix B presents the final list of companies whose establishments appear in each segment analyzed in this report.

In cases where multiple activities falling under different segments were underway in a single establishment, the establishment was classified according to the predominant activity. If a wide range of activities were underway, more often than not the establishment naturally fell into, and in other cases was placed into, either one of the two broadest segments: components or IT, engineering, and professional services suppliers.

Multi-establishment firms presented a special case but not a problem for classification. These tended to be large primes active in a number of segments. The existence of multiple establishments enabled one company's employees to be apportioned—on an establishment-by-establishment basis—according to each establishment's primary activity rather than the parent company's primary activity. As such, some company names appear under multiple segments in Appendix B. (In a similar vein, one segment could contain multiple establishments of one company if all establishments conducted similar activities). Brookings went "under the hood" of these companies' Colorado footprints to refine their segmentation through direct outreach to companies and internet-based research.

How military and civil sector jobs were counted

Space-related active-duty and civilian government employment on military bases in Colorado was calculated using publicly available information from base websites or annual economic impact analyses. (Private contractors were not counted because they already would have been captured at their employer's address in the establishment analysis). After obtaining information on total base employment, Brookings then consulted with local economic development officials to estimate the share of employment related to space.

Civil-sector space-related job information was obtained in a similar manner. Brookings identified organizations and institutions based on contract and grant analyses, industry association membership reviews, stakeholder input, and internet research. Employment information was obtained by visiting websites. In the case of universities, relevant departments were identified and their faculty counted to arrive at total space-related employment. Care was taken not to double-count researchers with dual appointments (e.g., at both Colorado State University and the Cooperative Institute for Research in the Atmosphere).

How revenues and output were calculated

Brookings and the project team estimated total revenue earned by Colorado's space economy in 2011 based on company-reported revenue and employment data when available; Bureau of Economic Analysis (BEA) "Gross Output by Industry" and "Full and Part-time Employees by Industry" tables; and establishment-level employment data from the Brookings-developed NETS database of Colorado space economy firms. Brookings first calculated company-specific revenue per employee based on total global revenue and total global employment for the 19 companies active in Colorado's space economy that reported such data in their annual report. (These companies were Lockheed Martin Corporation, DISH Network Corporation, ITT

Corporation, Ball Corporation, Northrop Grumman Corporation, Boeing Company, IHS Inc, Agilent Technologies Inc, Raytheon Company, Honeywell International Inc, L-3 Communications Holdings Inc, SAIC Inc, United Launch Alliance LLC, Integral Systems Inc, Harris Corporation, Accenture Inc, DigitalGlobe Inc, Merrick & Company, General Dynamics Corporation, and Viasat Inc.; average revenue per employee for United Launch Alliance (ULA) was assumed to be the average of ULA's parent companies, Lockheed Martin and The Boeing Company). For the remaining companies, Brookings calculated average U.S. revenue (or gross output) per employee for each industry (as defined by NAICS codes) represented in the Colorado space economy using 2011 BEA gross output and employment data. Brookings then joined that estimate to each establishment record by establishment industry code. Finally, Brookings multiplied this 2011 industry-average per-employee revenue estimate by each company's total 2011 Colorado employment as reported in the NETS database to estimate total revenue earned by Colorado's space economy that year.

How growth was calculated

The methodology behind calculating growth rates deserves special attention. Because of the way companies were identified—using member lists, grantee lists, and so on—no means of recreating the same universe of space economy companies for past years existed for the research team. Yet, the employment history of firms currently existing was available through the NETS dataset. As such, information about three of the four components of job change over time—job growth from the expansion of existing establishments, job growth from the birth of new establishments, and job losses from establishment contractions—were available to calculate a measure of growth.

The lack of information about job losses from establishments that closed between 2002 and 2011 meant that job levels in the base year of Brookings' database, 2002, were artificially lower than actual total space economy employment in 2002. Had this information been available, space economy job counts in 2002 would have been higher; but by lowering the base level, the methodology overstates growth rates.

This poses no serious complications when comparing growth across segments, for which the same methodology was used. The challenge arises when making comparisons to non-space activities or the broader economy. To overcome this challenge, Brookings adjusted Colorado's statewide private sector growth rate from 2002 to 2011 for the loss of jobs from establishments that closed during the period by obtaining information from the Bureau of Labor Statics' Business Employment Dynamics series. This series, which reports job losses from private establishment closings each year, enabled Brookings to reduce base-year employment for the entire economy equivalently and arrive at a comparable figure for statewide growth. Accordingly, average annual growth rates reported here for the state of Colorado are overstated in light of the adjustment but accurate for comparison to the space economy's overall and segment growth rates.

How wages were calculated

Average wages at each private sector space economy establishment were estimated by using Colorado-wide wage information from the Bureau of Labor Statistics' Quarterly Census of Employment and Wages (QCEW). The QCEW reports the average wage in each 6-digit NAICS industry code for the state of Colorado. Brookings matched that wage information to the 6-digit NAICS codes attached to each establishment record provided by NETS / D&B. The average wage in each establishment was then multiplied by the number of jobs in 2011 to calculate the total establishment wage bill. These were summed by segment and then divided by total jobs in each segment to arrive at average segments wages.

Strengths and weaknesses of the methodology

The biggest strength of a bottom-up establishment-based analysis such as the one presented here lies in its ability to offer extremely granular information at a far higher resolution and without the multiyear lag of publicly-provided government datasets.

Such an approach also offers complete transparency: Each record included in the dataset is publicly available and accessible with the information provided in this report and its appendices.

What is more, by identifying establishments individually based on the exact characteristics called for by the analysis, this methodology empowers research unencumbered from standardized industry classification codes that erect artificial walls all across the economy, which is by nature an organic entity,

A weakness of this methodology in conducting an analysis of such a dynamic and fast-changing industry is that it lacks the recentness that stakeholders often expect from a survey of the economic landscape such as this. For example, several companies which started up in 2011 and were brought to Brookings' attention by stakeholders have not been included in this analysis, now being released in 2013, because the firms have yet to appear in Hoovers / D&B.

Other weaknesses of this approach stem from weaknesses in D&B's database itself. To be sure, the NETS dataset which was used here corrects for many discrepancies in D&B's database from year to year. But given the sheer volume of data and the herculean nature of the task at hand—tying every place of business in the economy to an address and a history—some error remains. In a previous Brookings report, for example, large discrepancies in the records for public-sector establishments were identified.[2] As a result, Brookings chose not to include any public-sector establishments in this dataset, explaining why civilian government and military establishments were excluded from the establishment-level analysis. When other records in the Colorado dataset were flagged for potential inconsistencies, Brookings went directly to the companies to obtain accurate information. This happened for a number of large firms and establishments, and the vetting process has significantly boosted confidence across the entire dataset.

Finally, this approach also opens itself up to some degree of subjectivity. Although Brookings relied on a number of external sources and publicly available characteristics of establishments to determine their inclusion in the dataset and subsequently to classify them into segments, many decisions on the margin constituted, in the end, informed judgment calls. Brookings fully recognizes that few know a cluster better than those embedded in it, and Brookings consulted with industry stakeholders extensively, in part, for that very reason. In the end, Brookings is completely confident in the resulting classification scheme and its findings, but recognizes that some decisions reflected in Appendix B may have been made differently by others. It is for this reason that all data and methodology are made transparent here.

How Brookings' methodology compares to others'

Brookings' counts differ from those conducted by other economic research organizations in the state, most notably the Metro Denver EDC in collaboration with Development Research Partners (DRP)—whose 2012 report identified 160 aerospace companies in Colorado employing 24,990 people—because the organizations adopt different approaches.[3]

Differences in approach, naturally, stem from differences in goals. Many other economic surveys endeavor to scan the entire economic landscape to isolate clusters of competitiveness and compare one geography of interest to other similar geographies on certain measures. Brookings, on the other hand, set out to capture the full spectrum of space-related activities in Colorado—by design abandoning conventional and narrow industry classification schemes—in order to reveal where and how space seeps into the economy and weaves across it. As such, Brookings purposefully set out to identify all business establishments engaged in space-related activities irrespective of their official industry codes. The end result is a high-resolution view of Colorado's space economy and how it meshes with Colorado's other competitive clusters, built from the bottom-up. The approach does not, however, enable direct comparison to other sectors of the economy in Colorado or to the space economy in other states.

In practice, Brookings' "space" industry builds on the familiar "aerospace" industry core—even as it drops much of the "aero"—but draws in portions of broadcasting and telecoms, IT-software, and environmental sciences clusters as well. Ultimately, Brookings' approach yields added insight into and a novel perspective on the state's economic understanding of itself. Space, this analysis reveals, is not just an industry designated by the Census Bureau but rather an entire knowledge base with linkages across the economy. A major insight of this report is that space is bigger and far more integral to Colorado's economy than previously realized.

Metro Denver EDC and DRP use 23 discrete SIC codes (rather than cruder NAICS codes) to calculate the number of jobs in the state's aerospace cluster. In 2012 they identified 160 aerospace companies in Colorado employing a total of 24,990

people. By contrast, Brookings' approach considers how space activity spills over into other clusters and SIC codes that are not purely space-related on their own—like telecoms, software, and IT—even if firms and establishments within those codes may be specialized in space-related activities. In the end, establishments classified under 93 four-digit SIC codes and 203 eight-digit SIC codes appear in Brookings' database.

Of course, using standardized industry classification codes for economic analysis—as the industry cluster profiles that Metro Denver EDC and DRP produce do—is an approach with several strengths. Most importantly, standardization enables comparability across time (e.g., growth rates), comparability across geographies (e.g., to other metropolitan areas, states, or national averages), and comparability across industries and other discretely-defined clusters. Those requirements are paramount for their study, and many others, and explain the difference in approach adopted by their analyses and Brookings'.

Finally, another study of Colorado's space economy merits mention. In 2000, Princeton Synergetics, commissioned by the Space Foundation for Gov. Owens, set out to devise a comprehensive space strategy for the state of Colorado. The study adopted a survey-based approach and found that the space industry in Colorado provided 24,000 private jobs in 1999 across 100 companies.[4] It defined the space industry as follows: "the broad-based space industry encompasses both the Department of Defense and civil sectors, and includes the manufacture, assembly, test, and operation of launch vehicles and satellites (including communication, direct broadcast, earth observation, navigation and control, weather, and intelligence satellites) and related infrastructure." Brookings defines the space economy similarly except that Brookings also includes companies delivering services via satellite, because of their novel application of space-based technology. As such, this survey-based approach falls somewhere between Metro Denver EDC's and the one presented in these pages in scope.

APPENDIX B. COMPANIES BY SEGMENTS

PRIVATE SECTOR

Components

2B Technologies Inc
ABSL Power Solutions Inc
Acta Technology
ADA Technologies Inc
Adamworks LLC
Advanced Composite Technology Inc
Advanced Thin Films LLC
Aerocom Industries Inc
Aeroflex Colorado Springs Inc
Agilent Technologies Inc
Albido Corporation
ALD Nanosolutions Inc
Allied Motion Technologies Inc
Amergint Technologies LLC
Aqwest LLC
Arctic Slope Regional Corporation
ARINC Incorporated
Ascent Solar Technologies Inc
ASTC Inc
Astronix Research LLC
Avantes Inc
BAE Systems Power Inc
Balzers Thin Films Inc
Barber-Nichols Inc
Beyond Photonics LLC
Black Forest Engineering LLC
Blue Canyon Technologies LLC
Blueline Engineering Co Inc
Bolder Vision Optik Inc
Broad Reach Engineering Co
Bron Aerotech Inc
Bye Energy Inc
Cable Net Wiring Products
CLMax Engineering LLC
Coldquanta Inc
Colorado Power Electronics Inc
Colorado Precision Products
Colorado Satellite Services
Colutron Research Corporation
Composite Technology Development Inc
Coorstek Inc
DBM Technologies Inc
Demmer Investments Inc.
Design Net Engineering LLC
Dieterich Standard Inc
Digital Wave Corporation
Droplet Measurement Tech
Eaton Aviation Corporation
Electricon Corp
Equinox Interscience Inc
Exelis Inc
Extreme Diagnostics Inc
Fiberforge Corp
First RF Corporation
Fivefocal LLC
Freewave Technologies Inc
Frontline Aerospace Inc
GE Analytical Instruments Inc
Genessee Wester Inc.
High Precision Devices Inc
Highlands Research & Tech
Hittite Microwave Corporation
Honeywell International Inc
Hyperfine Inc
Infinite Design Solutions Inc
Infinity Photo-Optical Corp
Instrutech Inc
ITN Energy Systems Inc
ITT Corporation
KYG Systems LLC
L C Wright Inc
L-3 Services Inc
Laser Technology Inc
Left Hand Design Corporation
Lexycom Technologies Inc
Lockheed Martin Corporation
Mannatek Solutions LLC
Micro Analysis and Design Inc
Microelectronics Research Development Corp
Micro-G Lacoste Inc
Microsemi Corp Colorado
Mile-Hi Machine Inc
MW General Inc
Neumann Systems Group Inc
NFT Incorporated
Noqsi Aerospace Ltd
Ocean Thin Films Inc
Ophir Corporation
Perceptek Inc
Peterson Machining Inc
Phase IV Engineering Inc
Precision Photonics Corp
Primus Metals Inc
Quest Product Development
Radiation Assured Devices Inc

Rainbow Research Optics Inc
RDM Precision Metals Corp
Reaction Systems LLC
Redstone Aerospace Corporation
Research Electro-Optics Inc
Reyco Precision Machining Inc
RJR Circuits Inc
RMB Products Inc
Roadnarrows LLC
Rocky Mountain Instrument Co
Saint-Gobain Ceramics & Plastics
Sangat Knife Co
Scion Industries LLC
SEAKR Engineering Inc
Shadow Microtek
Sibelloptics
Space Scientific Instruments
Spectron Engineering Inc
Spectrum Laser & Technologies
Sporian Microsystems Inc
Stratom Inc
Stratton Park Engineering Co Inc
Stvrain Manufacturing Inc
Summitek Instruments Inc
Synkera Technologies Inc
Sypris Electronics LLC
TDA Research Inc
Technology Applications Inc
Teledyne Cougar Inc
Textron Inc
Thin Metal Parts LLC
Tri-Gon Precision Inc
Unicircuit Inc
Vaisala Inc
Vertec Tool Inc
Vescent Photonics Incorporated
Wild Pig Aerospace Inc
XTAL Optronics Inc
Zolo Technologies Inc
Zybek Advanced Products Inc

Consumer

DIRECTV Inc
DISH Network LLC
Echosphere LLC
EchoStar Corporation
Liberty Media Corporation

Consumer Ground Equipment

180 Connect Inc
EchoStar Corporation
Mezotronics
Pixel Technologies Incorporated

IT Engineering and Professional Services

Accenture LLP
Accuvant Inc
Action Engineering LLC
Advanced Solutions Inc
Advanced Technology Associates
Advantage Electronic Product Development Inc
AI Solutions
Aleut Management Services LLC
Alion MA&D Corporation
Alion Science and Technology Corporation
Allied Mountain LLC
American Automation Inc
Analytical Graphics Inc
Analytical Systems Inc
ARES Corporation
ARINC Incorporated
Ascent Technologies Inc
ASRC Aerospace Corp
Autometric Inc
B D Systems Inc
BAE Systems
Barrios Technology Ltd
Blue Sun Enterprises Inc
Boecore Inc
Boeing Company
Booz Allen Hamilton Inc
Brandes Associates Inc
Bye Engineering LLC
Colorado Aerospace Education Foundation
Colorado Consortium for Earth and Space Science Education
Colorado Engineering Inc
Colorado Engineering Research Laboratory
Colorado Professional Resources LLC
Colsa Corporation
Computer Technology Associates Inc
Conduant Corporation
Cullimore and Ring Technologies
Data Fusion Neural Networks LLC
David Alan & Associates LLC
Distributed Infinity
DSoft Technology Company
Dynetics Inc
Eltron Research & Development Inc
Flying Eagle Aerospace Consultants
General Dynamics Advanced Information Systems
Genova Engineering LLC
Grant Thornton LLP
HKM Enterprises Inc
Holland & Hart LLP
Honeywell Technology Solutions Inc
IHS Global Inc
Imprimis Inc
Information Technology Engineering Corp
Ingenuity Research Corporation
Innovative Space Engineering Services
Instar Engineering & Consulting
Intecon LLC
Intelligent Payload Solutions Inc
Intelligent Software Solutions Inc
International Space Development Authority Corp

International Photonics Consultants Inc
ISYS Incorporated
ITT Exelis
Kepler Research Inc
Key Management Systems Inc
Kromatid Inc
L-3 Services Inc
Lockheed Martin Corporation
Mantech Inc
Master Solutions LLC
MEI Technologies Inc
Merlin International Inc
Merrick & Company
Miller Space LLC
Miller Technology Group Inc
Mitre Corporation
Modern Technology Solutions
Moltek Inc
Northrop Grumman
N-Science Incorporated
Nutronics Inc
Oakman Aerospace Inc
OAO Corporation
Omitron Inc
Pathfinder Systems Inc
Patriot Technical Services LLC
Practical Aeronautics Inc
R W Beck Inc
RadiantBlue Technologies Inc
Raytheon
Red Canyon Software Inc
Rick Ward Consulting LLC
RST Bioscience
Science Applications International Corp
Scitor Corporation
SDS International Inc
Secure World Foundation
Shape Technologies LLC
Sigmatech Inc
SMI International LLC
Southwest Research Institute
Space Connections Inc
Space Foundation
Space Science Institute
Spatial Corporation
SRA International Inc
SRC Computers LLC
sysrand Corporation
Systems Research Applications Corp
Systems Research Group Inc
Systems Studies & Simulations
Syzygyx Incorporated
Tech-X Corporation
Tecolote Research
Teledyne Brown Engineering
Teledyne Collaborx Inc
URS Operating Services Inc
Wacari Group
White Dwarf Research Corp
Wyle Information Systems LLC

Launch Manufacturing and Services

Ch4 Aerospace Inc
Darma Technology Inc
Electric Propulsion Lab Inc
IBL JV LLC
Kassoy Innovative Science Solutions
Lockheed Martin Corporation
Space Launch Technologies
United Launch Alliance LLC
UP Aerospace Inc

Navigation and Geolocation

AMCI International Inc
American Millennium Corp Inc
Assetlink Global LLC
Binet Inc
Boeing Company
Celestial Aerospace LLC
Colorado Fleet Solutions
Compass Holdings Inc.
General Dynamics
GPS Networking Inc
GPS Source Inc
Harris Corporation
ITT Exelis
Jeppesen Sanderson Inc
Lat-Lon LLC
Lockheed Martin Corporation
MITS LLC
Moody Enterprises Inc
Morpho Design Group
NavSys Corporation
Overlook Systems Technologies
Raytheon Company
RW Carlson Consulting
Science Applications International Corp
Sextant Strategies LLC
Sky-Shield LLC
SpaceDev Inc
Spider Tracks North America Limited
Symmetricom Inc
Trimble Navigation Limited

Network Ground Equipment

Aleut Communications Services LLC
Automated Systems Engineering
EchoStar Corporation
Front Range Airport Authority
General Dynamics C4 Systems Inc.
Harris Software Systems Inc
L-3 Communications Corporation
Northrop Grumman
Raytheon Company
Satcom Resources LLC
Spectrum Communication Electronics
Welkin Sciences LLC

Remote Sensing and Earth Observation

3D At Depth LLC
Advanced Radar Corporation
Airdat LLC
Alpha Spectra Inc
Analytical Spectral Devices Inc
Arete Associates
Atmospheric & Space Technology Research Associates
Atmospheric Observing Systems
Ball Aerospace & Technologies Corp
Blueline Publishing LLC
Boulder Environmental Sciences Technologies LLC
Center for Severe Weather Research Inc
Computational Physics Inc
Data Fusion Corporation
DigitalGlobe Inc
E W Defense Systems Inc
Environmental Systems Research Institute Inc
Exelis Systems Corporation
Free Space Research
General Dynamics Advanced Information Systems
Geospatial Partners LLC
Green Mountain Geophysics Inc
I-Cubed Information Integration and Imaging
InterMap Technologies Inc
Exelis Visual Information Solutions
Look Dynamics Inc
Lucid Dimensions Inc
MDA Information Systems Inc.
Neva Ridge Technologies Inc
Nu-Metrics Inc
Raytheon Company
Riverside Technology Inc
Sanborn Map Company Inc
Science and Technology Corp
Science and Technology in Atmospheric Research (STAR) LLC
Science Applications International Corp
Sierra Nevada Corporation
Six Degrees of Freedom LLC
Solmirus Corporation
Space Imaging Inc
Summit Sensor Inc
Technigraphics Inc
Unavco Inc
Vaisala Inc
Vexcel Corporation
Weather Detection Systems
Woolpert Inc

Satellite and Space Systems Operations

Aerospace Corporation
Apogee Engineering LLC
Boeing Company
Braxton Technologies LLC
EchoStar Satellite Services Company
Infinity Systems Engineering LLC
Integral Systems Inc
ITT Exelis
Lockheed Martin Corporation
Mission Research Corporation
Northrop Grumman Space and Mission Systems
Numerica Corporation
Paragon Dynamics Inc
Quantum Research International Inc
Raytheon Company
Real Time Logic Inc
Saber Astronautics
Science Applications International Corp
Serco Services Inc
Space Awareness Services LLC
SpaceNav LLC
Stellar Solutions Inc

Satellite and Space Vehicle Manufacturing

AERA Corporation
AeroAstro Inc
Altius Space Machines Inc.
Ball Aerospace & Technologies Corp
Deep Space Systems Inc
Fujiwara Industries
General Dynamics
Lockheed Martin Corporation
Mars Aerospace & Applied Research Systems LLC
Microsat Systems Inc
MMA Design LLC
Near Space Systems Inc
Next Giant Leap LLC
Pioneer Astronautics
Prowler Aerospace Systems LLC
Redefine Technologies Inc
Sierra Nevada Corporation
SkySentry LLC
Space Environment Technologies
Sprague Astronautics Company
Surrey Satellite Technology US LLC
The eSpace Center for Space Entrepreneurship

Telecommunications

Advanced Distributed Sensor Systems
Aircell LLC
Aleut Technologies LLC
Ericsson Inc
Harris CapRock
Harris Corporation
Honeywell Technology Solutions Inc
Hunter Communications Inc
L-3 Communications Corporation
Lazer-Com LLC
Loral Space Communications Ltd
Mobilesat Communications US
SES Americom Inc
WildBlue Communications Inc

CIVIL SECTOR

Universities

Colorado School of Mines (CSM) Center for Space Resources
CSM Department of Geophysics
CSU Department of Atmospheric Sciences
Metropolitan State University of Denver Department of Aviation and Aerospace Science
CU-Boulder Department of Aerospace Engineering Sciences
CU-Boulder Department of Astrophysical and Planetary Sciences
University of Colorado-Colorado Springs (UCCS) Department of Mechanical and Aerospace Engineering
National Institute of Science, Space, and Security Centers (UCCS)
University of Denver (multiple departments)

Laboratories

Cooperative Institute for Research in Environmental Sciences
Cooperative Institute for Research in the Atmosphere
Institute for Telecommunications Sciences (NTIA)
JILA NIST-CU
Laboratory for Atmospheric and Space Physics
National Corporation for Atmospheric Research
NOAA Space Weather Prediction Center
NOAA Earth Systems Research Laboratory
NOAA National Geophysical Data Center
University Corporation for Atmospheric Research

MILITARY SECTOR

Air Force Academy (AFA)
Academy Center for Space Situational Awareness (AFA)
Aeronautics Research Center (AFA)
Center for Unmanned Aerial Systems Research (AFA)
Eisenhower Center for Space and Defense Studies (AFA)
Space Physics and Atmospheric Research Center (AFA)
Space Systems Research Center (AFA)
Buckley Air Force Base
Schriever Air Force Base
Peterson Air Force Base

APPENDIX C. Benchmarking Colorado's Space Economy (Selected Metrics)

Metric	Colorado	Alabama	Arizona	California	Florida	Maryland	New Mexico	Texas	Virginia
General Economic Competitiveness									
Kauffman Index of Entrepreneurial Activity, 2011 (entrepreneurs per 100,000 people)	**420**	260	520	440	380	290	250	440	200
State Business Tax Climate Index, 2012	**16**	20	27	48	5	42	38	9	26
Small Business Survival Index, 2011	**9**	6	15	46	8	38	28	3	10
Annualized Growth in Exports, 2003-2010	**7.2%**	7.1%	1.6%	6.1%	5.8%	5.6%	2.6%	8.6%	5.6%
Annualized Growth in Aircraft Products and Parts Exports, 2003-2010	**9.1%**	4.4%	3.7%	8.6%	11.9%	4.2%	2.3%	8.1%	-2.1%
		* * *							
Federal Contracts in Core Space									
DoD-NASA-NOAA Core Space Contracts, 2011 ($mil)	**$4,700**	$1,500	$4,300	$11,700	$1,700	$2,100	$100	$4,900	$1,600
DoD-NASA-NOAA Core Space Contracts, 2011 (average contract value)	**$1,805,000**	$679,300	$732,700	$556,700	$197,300	$403,300	$160,000	$575,500	$306,900
DoD-NASA-NOAA Core Space Contracts, 2011 (normalized contract value)	**$151,300**	$71,900	$100,000	$42,400	$33,600	$41,500	$4,400	$52,000	$48,700
Annualized Growth in Core Space Contracts, 2000-2011	**14.6%**	9.2%	7.4%	7.2%	-3.5%	9.7%	10.9%	7.7%	12.3%
Annualized Growth in Core Space Contracts, 2009-2011	**24.4%**	20.6%	-6.3%	-1.8%	-6.7%	3.5%	-1.5%	8.7%	-2.0%
Federal Contracts in Adjacent Markets									
DoD-NASA-NOAA Adjacent Market Contracts, 2011 ($mil)	**$35**	$38	$96	$1,421	$131	$1,119	$16	$727	$1,472
DoD-NASA-NOAA Adjacent Market Contracts, 2011 (average contract value)	**$387,400**	$397,000	$519,200	$1,374,200	$280,500	$1,216,500	$354,800	$1,389,500	$569,900
DoD-NASA-NOAA Adjacent Market Contracts, 2011 (normalized contract value)	**$1,100**	$1,800	$2,200	$5,100	$2,600	$22,400	$600	$7,600	$44,300
Innovation System									
Total Federal R&D Funding, 2009 (per capita)	**$737**	$630	$440	$656	$174	$2,767	$1,775	$232	$1,152
NSF Awards, 2007-2011 (dollar amount per 10,000 people)	**$3,307,500**	$482,500	$1,751,700	$1,303,800	$451,000	$1,328,200	$1,264,100	$524,100	$2,786,000
SBIR & STTR Awards, 2011 (dollar amount per 10,000 workers)	**$298,800**	$91,800	$126,900	$220,000	$54,800	$288,200	$218,300	$60,700	$175,300
DoD-NASA-NOAA SBIR & STTR Awards, 2011 (dollar amount per 10,000 workers)	**$103,700**	$54,400	$60,100	$54,300	$13,500	$64,200	$27,100	$18,600	$74,300
Patents Issued to State Universities, 2011 (per $100 million in research expenditure)	**5.0**	4.1	3.7	7.9	17.3	4.0	9.4	7.0	10.8
License Income by State Universities, 2011 (per $100 million in research expenditure)	**$454,100**	$1,270,600	$209,100	$4,256,000	$1,973,000	$491,500	$916,100	$2,124,600	$1,028,700
Startups from State Universities, 2011 (per $100 million in research expenditure)	**1.5**	1.7	1.8	1.2	1.7	0.5	1.8	0.8	1.4
					State Rankings Key:	1-10	11-20	21-30	31-40	41-51

APPENDIX C. Benchmarking Colorado's Space Economy (Selected Metrics) (continued)

Metric	Colorado	Alabama	Arizona	California	Florida	Maryland	New Mexico	Texas	Virginia
Talent Base									
Share of State Jobs in STEM, 2011	**6.8%**	4.5%	5.0%	5.5%	3.8%	6.8%	4.6%	5.3%	7.7%
Change in Share of State Jobs in STEM, 2001-2011	**4.6%**	2.5%	2.5%	3.2%	2.1%	4.6%	2.1%	2.8%	5.3%
Share of State Jobs in Engineering, 2011	**2.3%**	2.2%	2.2%	2.1%	1.4%	2.2%	2.6%	2.2%	2.2%
STEM Degrees & Certificates Conferred, 2010 (per 10,000 people)	**21.2**	35.1	28.2	17.2	11.7	20.2	15.4	16.7	18.7
Space Economy-Related STEM Degrees & Certificates Conferred, 2010 (per 10,000 people)	**7.7**	18.4	6.4	5.4	3.6	5.4	6.4	6.1	5.7
Change in Share of STEM Degrees & Certificates Conferred, 2001-2010	**-4.9%**	-0.7%	-4.1%	-1.0%	-2.6%	-2.2%	-3.1%	-3.8%	-6.0%
Change in Share of Space Economy-Related STEM Degrees & Certificates Conferred, 2001-2010	**0.7%**	0.6%	-2.3%	-0.3%	-0.8%	-0.7%	-0.3%	0.0%	-2.1%
Change in Share of STEM Workers Younger than 34, 2005-2010	**-2.6%**	-1.7%	-1.8%	-0.1%	-3.5%	0.4%	-4.8%	-1.6%	0.0%
Change in Share of STEM Workers Older than 55, 2005-2010	**4.5%**	5.3%	5.5%	2.7%	6.7%	2.8%	10.4%	4.0%	0.9%
State Appropriations for Higher Education, 2010 (share of state GDP)	**0.3%**	0.8%	0.4%	0.6%	0.5%	0.6%	1.1%	0.5%	0.4%
Risk Capital									
VC Dollars, 2005-2011 (per capita)	**$122**	$4	$28	$340	$17	$78	$27	$49	$59
VC Deals, 2005-2011 (per million residents)	**18.7**	1.2	3.7	39.7	2.5	16.0	7.3	6.6	9.9
Cluster Dynamics									
	NA	NA	NA	NA	NA	NA	NA	NA	NA
					State Rankings Key:	1-10	11-20	21-30	31-40	41-51

Data Sources for the Benchmarking

Metric	Source
General Economic Competitiveness	
Kauffman Index of Entrepreneurial Activity, 2011 (entrepreneurs per 100,000 people)	Brookings analysis of Kauffman Index of Entrepreneurial Activity, 2011.
State Business Tax Climate Index, 2012	Tax Foundation, "State Business Tax Climate Index 2011-2012."
Small Business Survival Index, 2011	Small Business & Entrepreneurship Council, "Small Business Survival Index 2011."
Annualized Growth in Exports, 2003-2010	Brookings analysis of data from Census Bureau, BEA, BLS, IRS, Moody's Analytics, NAFSA, and USITC.
Annualized Growth in Aircraft Products and Parts Exports, 2003-2010	Brookings analysis of data from Census Bureau, BEA, BLS, IRS, Moody's Analytics, NAFSA, and USITC.
* * *	
Federal Contracts in Core Space	
DoD-NASA-NOAA Core Space Contracts, 2011 ($mil)	Brookings analysis of General Services Administration's USA Government Spending Database, 2012.
DoD-NASA-NOAA Core Space Contracts, 2011 (average contract value)	Brookings analysis of General Services Administration's USA Government Spending Database, 2012.
DoD-NASA-NOAA Core Space Contracts, 2011 (normalized contract value)	Brookings analysis of General Services Administration's USA Government Spending Database, 2012 and Moody's Analytics, 2012.
Annualized Growth in Core Space Contracts, 2000-2011	Brookings analysis of General Services Administration's USA Government Spending Database, 2012.
Annualized Growth in Core Space Contracts, 2009-2011	Brookings analysis of General Services Administration's USA Government Spending Database, 2012.
Federal Contracts in Adjacent Markets	
DoD-NASA-NOAA Adjacent Market Contracts, 2011 ($mil)	Brookings analysis of General Services Administration's USA Government Spending Database, 2012.
DoD-NASA-NOAA Adjacent Market Contracts, 2011 (average contract value)	Brookings analysis of General Services Administration's USA Government Spending Database, 2012.
DoD-NASA-NOAA Adjacent Market Contracts, 2011 (normalized contract value)	Brookings analysis of General Services Administration's USA Government Spending Database, 2012 and Moody's Analytics, 2012.
Innovation System	
Total Federal R&D Funding, 2009 (per capita)	Brookings analysis of National Science Foundation's Survey of Federal Funds for Research and Development, 2009 and U.S. Census Bureau Population Estimates, 2009.
NSF Awards, 2007-2011 (dollar amount per 10,000 people)	Brookings analysis of National Science Foundation's Budget Internet Information System Award Summary by State/Institution, 2011 and U.S. Census Bureau Population Estimates, 2011.
SBIR & STTR Awards, 2011 (dollar amount per 10,000 workers)	Brookings analysis of data from Small Business Innovation Research (SBIR.gov), 2012 and Moody's Analytics, 2012.
DoD-NASA-NOAA SBIR & STTR Awards, 2011 (dollar amount per 10,000 workers)	Brookings analysis of data from Small Business Innovation Research (SBIR.gov), 2012 and Moody's Analytics, 2012.
Patents Issued to State Universities, 2011 (per $100 million in research expenditure)	Brookings analysis of data from Association of University Technology Manager's (AUTM) 2011 Licensing Activity Survey.
License Income by State Universities, 2011 (per $100 million in research expenditure)	Brookings analysis of data from Association of University Technology Manager's (AUTM) 2011 Licensing Activity Survey.
Startups from State Universities, 2011 (per $100 million in research expenditure)	Brookings analysis of data from Association of University Technology Manager's (AUTM) 2011 Licensing Activity Survey.
Talent Base	
Share of State Jobs in STEM, 2011	Brookings analysis of BLS Occupational Employment and Wage State Cross-Industry Estimates, 2011.
Change in Share of State Jobs in STEM, 2001-2011	Brookings analysis of BLS Occupational Employment and Wage State Cross-Industry Estimates, 2011.
Share of State Jobs in Engineering, 2011	Brookings analysis of BLS Occupational Employment and Wage State Cross-Industry Estimates, 2011.
STEM Degrees & Certificates Conferred, 2010 (per 10,000 people)	Brookings analysis of National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates, 2010.
Space Economy-Related STEM Degrees & Certificates Conferred, 2010 (per 10,000 people)	Brookings analysis of National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates, 2010.

Data Sources for the Benchmarking (continued)

Metric	Source
Change in Share of STEM Degrees & Certificates Conferred, 2001-2010	Brookings analysis of National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates, 2001-2010.
Change in Share of Space Economy-Related STEM Degrees & Certificates Conferred, 2001-2010	Brookings analysis of National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates, 2001-2010.
Change in Share of STEM Workers Younger than 34, 2005-2010	Brookings analysis of Population Reference Bureau, Trends in Science and Engineering Labor Force Project, 2012.
Change in Share of STEM Workers Older than 55, 2005-2010	Brookings analysis of Population Reference Bureau, Trends in Science and Engineering Labor Force Project, 2012.
State Appropriations for Higher Education, 2010 (share of state GDP)	National Science Foundation, "Science and Engineering Indicators 2012," Table 8-27.
Risk Capital	
VC Dollars, 2005-2011 (per capita)	Brookings analysis of from PricewaterhouseCoopers Moneytree Survey Data, 2012 and and Census Bureau Population Estimates, 2012.
VC Deals, 2005-2011 (per million residents)	Brookings analysis of from PricewaterhouseCoopers Moneytree Survey Data, 2012 and and Census Bureau Population Estimates, 2012.

APPENDIX D. COLORADO'S SPACE ECONOMY BY THE NUMBERS

Category	Segment	Jobs 2011	Average annual job growth 2002-2011	Average annual job growth 2008-2011	Estimated revenues 2011	Revenue per job	Average wage
Space Systems Manufacturing and Operations	Launch Manufacturing and Services	843	67.8%	67.0%	$320m	$381,000	$107,300
	Satellite and Space Systems Operations	5,480	0.5%	2.2%	$1,900m	$345,700	$100,800
	Satellite and Space Vehicle Manufacturing	6,513	-1.3%	0.3%	$2,800m	$435,700	$103,800
	Network Ground Equipment	1,024	0.8%	5.9%	$330m	$325,600	$94,300
	Subtotal	*13,860*	*0.2%*	*3.1%*	*$5,350m*	*$388,700*	*$106,600*
Satellite-based Services	Consumer	7,310	11.5%	-1.9%	$3,000m	$417,600	$66,200
	Navigation and Geolocation	3,984	3.6%	2.2%	$1,400m	$352,800	$106,600
	Remote Sensing and Earth Observation	3,847	7.4%	8.0%	$1,300m	$332,500	$96,600
	Satellite Telecommunications	1,620	9.7%	6.8%	$440m	$274,000	$92,400
	Consumer Ground Equipment	265	0.9%	2.4%	$90m	$350,900	$78,200
	Subtotal	*17,026*	*7.9%*	*1.9%*	*$6,230m*	*$368,500*	*$85,200*
Supply and Support Industries	Components	6,097	1.8%	2.8%	$1,800m	$289,700	$84,100
	IT, Engineering, and Professional Services	10,728	2.0%	2.1%	$3,200m	$294,700	$96,200
	Subtotal	*16,825*	*1.9%*	*2.4%*	*$5,000M*	*$292,900*	*$91,800*
	TOTAL	**47,711**	**3.1%**	**2.4%**	**$16,530m**	**$347,700**	**$92,500**
	Statewide Total (Private Sector)	1,862,600	8.8%	4.4%	N/A	N/A	$49,200

Source: Brookings analysis of NETS and Dun & Bradstreet data

APPENDIX E. BACKGROUND ON POLICY PROPOSALS

Consolidate and maximize the state's position in the space economy even as U.S. government space contracts

Produce and annually or biannually update a sophisticated strategy for bolstering Colorado's space economy preeminence

Colorado should produce a fact-based and focused economic development strategy for its space economy that would identify opportunities for growth in the context of the state's existing assets and capabilities. Critical to the strategy would be outlining a detailed plan for strengthening Colorado's innovation capacity, seizing opportunities in new space and adjacent markets, and bolstering its workforce training, among others. To ensure that the strategy does not remain a static document, Colorado should update it periodically to keep the state growing and remain responsive to changing industry and market needs.

For further information, see Space Florida; "Governor's Commission on the Future of Space and Aeronautics in Florida: Final Report" (Tallahassee, 2006).

Cost: $
Timeframe: 1–2 years

Example: **Space Florida Vision 2020** and **BioMaryland 2020 Strategic Plan**

Lead in convening Colorado's congressional delegation to defend and advocate for the expansion of the state's space economy

For public policy—especially economic development and innovation policy—to be effective in a federalist system , states and the federal government must forge a close and symbiotic partnership resting on frequent communication and policy coordination. The imperative is even greater in the space industry, where the federal government not only controls innovation inputs but also stands as the largest customer of space economy products and services. Colorado should convene its congressional delegation at regular intervals (for instance, quarterly) and convey a single and coherent agenda that the delegation should pursue in Washington.

For a primer on how states and localities can partner with the federal government, see Robert D. Atkinson, "Innovation in Cities and Innovation by Cities" (Washington: Information Technology & Innovation Foundation, 2012).

Cost: $
Timeframe: 1 year

Example: n/a

Lead in convening the aerospace states

Colorado should take the lead in catalyzing and uniting the nation's aerospace states on key priorities and topics of national importance. Such convenings will serve to amplify common issues at the federal level while enhancing Colorado's profile as a leading aerospace state.

Cost: $
Timeframe: 1 year

Example: **Aerospace States Association** and **Coalition of Northeastern Governors**

Brand Colorado's unique space economy and market it relentlessly

Creating a sophisticated strategy is just the first step in elevating Colorado's space economy. Much will also depend on the state's success in communicating and marketing its strategy to both internal and external audiences. Within the state, Colorado should avail itself of every opportunity to highlight its space economy assets and convey its new strategy to industry, local chambers of commerce, trade associations, and other stakeholders. State officials should utilize major economic development forums to celebrate Colorado's successes. Beyond that, Colorado should be proactive in marketing its new strategy outside the state through external speaking engagements, trade or recruitment missions, attending aerospace trade fairs, hosting site selectors, or calling on companies' headquarters. To achieve all of this, Colorado should consider revamping its website to convey in a compelling manner its new direction and strategy.

For further information, see "Unify, Regionalize, Diversify: An Economic Development Strategy for Nevada" (Washington and Las Vegas: Brookings Mountain West, 2011).

Cost: $$
Timeframe: 1–2 years

Example: **Washington State Quarterly Aerospace Bulletin**

Name a dedicated "sector champion" to spearhead cluster development

A full-time dedicated professional should be tasked with carrying out proactive in-state outreach, contributing to state-level problem-solving, and helping with strategic business recruitment for the space economy. The champion would work to identify current dynamics, supply chain gaps, and shared needs through dialogue with regional and cluster leaders, company officials, units of local government, and others. In defining the sector champion role, Colorado should look to existing models and tailor its own institutional arrangement to best fit its distinctive needs.

For further information, see "Unify, Regionalize, Diversify: An Economic Development Strategy for Nevada" (Washington and Las Vegas: Brookings Mountain West, 2011).

Cost: $$
Timeframe: 1–2 years

Example: **Space Florida** and Texas Governor's **Office of Aerospace, Aviation, and Defense**

Ensure that Colorado remains a business and military friendly state by engaging in regular dialogue with stakeholders

The Colorado Blueprint Process has built networks into every business community in the state and created the civic infrastructure for ongoing dialogue with industry stakeholders. Colorado should not squander the goodwill generated through its convening and listening process. Instead, it should build on the networks and relationships it has forged in order to institutionalize a regular forum for discussing economic development issues with industry stakeholder groups. Regular dialogue will enable the state to make sure that its priorities match those of its constituents and will help the state flag areas where its competitiveness lags. As the state strives to maximize its total value proposition, only regular communication with the private sector can guarantee success.

Cost: $
Timeframe: 1 year

Example: **Washington Aerospace Partnership** and **Oklahoma Business Roundtable**

Seize commercial opportunities in emerging new space, adjacent, and global markets

Survey the competitive landscape in additional detail

A thorough drill-down by industry and technology experts into the subsectors of Colorado's space economy (or other advanced industries) will help the private and public sectors identify real opportunities in emerging, adjacent, and global markets, and will inform any public or private investments made. Colorado would also be well-served by a national and global survey that positions the state against peers and competitors in the industry broadly, or in particular segments. Lastly, a local mapping exercise will reveal clusters of competiveness within the state, and better disseminate information about the specific capabilities that exist in the Colorado space economy. With such material in hand, the state would be able to craft policy interventions suited to the conditions on the ground and industry, for its part, would be able to incorporate this information into short- and long-term planning.

Cost: $
Timeframe: 1–3 years

Example: **CyberMaryland** and **The CyberMaryland Map**

Promote the new opportunities and companies seizing them

Awards recognizing outstanding achievement in business and innovation can help build buzz around the targeted sector and draw investor attention from both within and outside the state. A governor's award acknowledging excellence in advanced industries, technology commercialization, or the space sector specifically, would provide a way to highlight specific firms at the top of their fields while also raising the state's profile as a critical site of innovation activity. Since the primary goal of such an effort would be to garner positive attention for winners, the award need not include a cash prize. An awards program can also be a cost-effective investment in goodwill with industry and science communities, as it demonstrates interest, attentiveness, and respect.

Cost: $
Timeframe: 1–2 years

Examples: Florida's **Innovators in Business** awards, Utah's **Governor's Medal for Science and Technology**, and Wisconsin's **Governor's Export Achievement Awards**.

Position the state for leadership in next-generation aerospace / space platforms

Public-sector investments may be required to position Colorado competitively in emerging industries such as cybersecurity and UAVs. Historically, such investments, be they modest or sizable, have taken the form of infrastructure projects—for example, a port, an airport, and perhaps even a spaceport. The more modern variant goes beyond conventional understandings of infrastructure to include investments in technology infrastructure like broadband, a test and demonstration facility for a particular emergent technology, a specialized research center, or a workforce training institution. Therefore, the state must work with cluster organizations to identify the investments that are most likely to be catalytic. In certain instances, the state's role may be to marshal resources or obtain approval from the federal government. In other cases, the state will need to focus its efforts on securing investment from the private sector. By moving quickly and intelligently on initiatives that leverage the state's existing competitive advantages, the state can position itself a step (or more) ahead of the competition.

Cost: $$ – $$$
Timeframe: 2–10 years

Examples: **CyberMaryland** and **Kansas City's Google Fiber**

Offer modest "deal closers" or small relocation incentives for innovative small firms

Economic development incentives should be deployed with strings attached to ensure accountability and effective use of taxpayer dollars. Targeted use of incentives can help fill gaps in the space economy ecosystem by encouraging UAV propulsion suppliers, GIS or location-based services startups, and other firms with needed capabilities to locate in Colorado. On the whole, incentives should be awarded to smaller growth companies, which tend to produce the highest levels of job creation. A focus on such "gazelle" firms will help ensure that any incentives granted leverage state funds to the fullest extent. The state should liberally attach as many strings, provisions, and clawback clauses on behalf of the taxpayer as are necessary to guarantee return on investment.

For further information, see Richard Kaplan & Associates, "Analysis of State Level Economic Development Contingency Funds" (Topeka: Kansas Inc, 2009), and Economic Incentives Group,"Economic Incentives: The Intersection of Site Selection and Economic Development" (CB Richard Ellis, 2010).

Cost: $$$
Timeframe: 1–3 years

Example: Florida's **Quick Action Closing Fund**

Launch a governor's prize for new space business plans

Well-designed prize schemes have proven effective in inducing innovation towards desired ends and encouraging novel configurations of problem-solvers to tackle challenges. Prize competitions can be used to advance a variety of goals, including accelerating technology development and demonstration, revealing latent demand and stimulating new markets, forging better linkages across knowledge communities, mobilizing capital, and exciting entrepreneurship. Such competitions are most likely to be successful when the goal is clear and achievable, when there are many potential problem-solvers, and when the problem-solvers are willing to bear some risk in developing potential solutions.

For further information, see "'And the Winner Is...,' Capturing the Promise of Philanthropic Prizes" (New York: McKinsey & Company, 2009), and Lauren Culver and others, "Policies, Incentives, and Growth in the NewSpace Industry." Working Paper (Massachusetts Institute of Technology, 2007).

Cost: $ - $$$
Timeframe: 1 year

Example: Oklahoma's Innovation to Enterprise (i2e) **Governor's Cup** business plan competition

Facilitate the convening of technology "boot camps" around opportunities for innovation

A prerequisite for achieving Colorado's goal of becoming the global center for space economy innovation will be acquiring a solid reputation as a space technology hub. The responsibility for building this reputation the hard way—through action, deed, and demonstrated success—lies with industry, with the state complementing such efforts through marketing and communications. Given the success of the National Space Symposium (NSS) in raising Colorado's profile, the state of Colorado should host technology "boot camps" designed and convened by industry and cluster organizations to brainstorm about the next big space-based technologies and their applications. These boot camps could be held throughout the year or timed to coincide with the annual NSS. Through these convenings, the private and public sectors could work together to create buzz about Colorado as a state that is pushing the frontiers of space applications while at the same time encouraging innovation in Colorado's space economy by introducing ideas brought in from other national and global space communities.

Cost: $
Timeframe: 1–3 years

Example: NSF's Future Renewable Electric Energy Delivery and Management **Innovation Bootcamp** and Louisville, KY's **IdeaFestival**

Spearhead a space and new space trade mission

Despite the prowess of domestic satellite and launch technology producers, they still lag behind the world in terms of exports due to trade restrictions associated with International Traffic in Arms Regulations (ITAR). While Congress debates easing these trade restrictions, Colorado's space industry should push forward into adjacent sectors and foreign markets not subject to ITAR. After identifying the most promising markets, Colorado should arrange a series of high-level trade missions through the governor's office to connect key industry leaders to foreign importers.

For further information, see Bruce Katz and Emilia Istrate, "Boosting Exports, Delivering Jobs and Economic Growth" (Washington: Brookings Institution, 2011).

Cost: $$
Timeframe: 1–2 years

Example: **Washington Export Resource Center**, **Virginia Economic Development Partnership** and **Pennsylvania Envoy Program**

Solicit foreign direct investment

Inward FDI brings with it new technologies, production processes, and knowledge that can spill over into the cluster. While abroad on trade missions, Colorado should dispatch a taskforce with the explicit mandate to attract FDI from leading global players in space and new space technology. The task force should target key investment opportunities, network with potential investors, and develop sharp presentations marketing Colorado's unique space economy assets.

For further information, see Lee Branstetter, "Is Foreign Direct Investment a Channel of Knowledge Spillovers? Evidence from Japan's FDI in the United States." *Journal of International Economics* 68 (2) (2006): 325-344; Georg Holger and Eric Strobl, "Foreign Direct Investment and Local Economic Development: Beyond Productivity Spillovers." In Theodore Moran, and others, eds., *Does Foreign Direct Investment Promote Development?* (Washington: Peterson Institute for International Economics, 2005).

Cost: $
Timeframe: 1–2 years

Example: **World Business Chicago** and **Enterprise Florida**

Commit to innovation and owning the next great space technologies

Create a program that bridges the advanced industries technology development gap

A program to address the technology development gap would provide matching funds to support the commercialization of technologies at three discrete stages: proof of concept (Phase I), early-stage development (Phase II), and commercialization and development (Phase III). These grants would be available to university researchers, incubators and accelerators, and companies, which could be required to provide a 1:1 match. Phase I grants would be awarded to research institutions to accelerate the development of new technologies that possess the potential to create new companies. Incubators, entrepreneurs, and companies that have licensed a university technology would be eligible for Phase II grants, which support readying technology for commercial launch. Phase III grants would be awarded to entrepreneurs and companies working with technology licensed from the state's research institutions to support the commercialization stage.

For further information, see George Ford, Thomas Koutsky, and Lawrence Spiwak, "A Valley of Death in the Innovation Sequence: An Economic Investigation" (Washington: Phoenix Center for Advanced Legal and Economic Public Policy Analysis, 2007); Bloomberg New Energy Finance, "Crossing the Valley of Death" (New York, 2010); Eliot Jamison, "From Innovation To Infrastructure: Financing First Commercial Clean Energy Projects" (San Francisco: CalCEF, 2010); Jesse Jenkins and Sara Mansur, "Bridging the Clean Energy Valley of Death" (Oakland: The Breakthrough Institute, 2011); and Erin Sparks and Mary Jo Waits, "Making Our Future: What States are Doing to Encourage Growth in Manufacturing through Innovation, Entrepreneurship, and Investment" (Washington: National Governors Association, 2013).

Cost: $$$$
Timeframe: 1–2 years

Example: **Colorado Bioscience Discovery Evaluation Grant Program**.

Establish a statewide advanced industries innovation hub

Colorado's advanced industries innovation hub would bring together industry, universities, community colleges, and government to accelerate innovation in AI technologies with broad applications. The hub would bridge the gap between basic research and commercialization, provide companies—especially SMEs—access to cutting-edge university research and collaboration, stimulate university technology transfer, and create an environment to educate and train a skilled workforce. In close collaboration with the private sector, the state should seek to leverage the opportunity provided by the federal government's proposed $1 billion National Network for Manufacturing Innovation.

For further information, see Devashree Saha and Mark Muro, "Create a Nationwide Network of Advanced Innovation Hubs" (Washington: Brookings Institution, 2012). See also President's Council of Advisors on Science and Technology, "Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing" (Washington: 2012) and David M. Hart, Stephen Ezell, and Robert D. Atkinson, "Why America Needs a National Network for Manufacturing Innovation" (Washington: Information Technology & Innovation Foundation, 2012).

Cost: $$$$
Timeframe: 2–5 years

Example: **Virginia Commonwealth Center for Advanced Manufacturing** and **National Additive Manufacturing Innovation Institute**

Bolster the Colorado Higher Education Competitive Research Authority

The Colorado Higher Education Competitive Research Authority (CHECRA) offers incentives to the state's universities and research institutions in the competition for federal research grants and contracts. Since federal agencies often require institutions to match funds for research projects to demonstrate state and institutional commitment, Colorado universities can utilize CHECRA to leverage research funding from the federal government and other sources. However, as currently funded, CHECRA offers only a small amount of matching funding. To bolster the competitiveness of Colorado's universities and research institutions in their search for federal funds, CHECRA should be expanded to include approximately $10 million for such matching investments. Colorado could consider making it a performance-based program by allocating funds among the universities based on their success in generating external research support in the previous fiscal year.

For further information, see Sarah Nash, "State-Based R&D Innovation Strategies," in Annex 2: Select State Strategies to Foster Innovation of Research & Development, Innovation, and the Science and Engineering Workforce (Washington: National Science Foundation, 2012); and National Governors Association, "Innovation America: A Final Report" (Washington: 2007).

Cost: $$S
Timeframe: 2–3 years

Example: **Massachusetts Research Center Matching Fund** and **Texas Emerging Technology Fund**

Create an innovation vouchers program

Innovation vouchers are state grants to SMEs that enable them to purchase innovation services from qualified universities and research institutions (knowledge providers). At the outset the state would need to define the eligibility criteria for participation in the program in terms of who qualifies as knowledge providers (e.g., public universities and research institutions) and what types of companies can make use of the program. For instance, the state could mandate that recipient companies be startups employing fewer than 10 people or profitable stage 2 companies that employ between 11 – 100 people. Eligibility criteria for projects to be supported by the program would also need to be defined. The vouchers could range in value from $5000–$30,000 with small vouchers awarded for consulting services, preparatory work for R&D, or small-scale prototyping and large vouchers for projects that involve substantial technology development. Large vouchers could also require a company match. The state would need to put in place a more rigorous vetting process for larger vouchers.

For further information, see Cristina Navarrete-Moreno, "Policy Instruments for Regional Innovation: Innovation Vouchers" (Brussels: Technopolis Group, 2010); OECD Innovation Policy Platform, "Innovation Vouchers" (2010); and Erin Sparks and Mary Jo Waits, "Making Our Future: What States are Doing to Encourage Growth in Manufacturing through Innovation, Entrepreneurship, and Investment" (Washington: National Governors Association, 2013).

Cost: $$$
Timeframe: 2–3 years

Example: **Alberta Innovation Vouchers Program**

Launch a matching grants program for collaborative R&D projects

The state matching grant program would encourage industry and the state's universities and research institutions to engage in collaborative R&D on innovative projects. The introduction of a matching-grant requirement would ensure that companies were willing to share the costs of the innovation and screen out those companies that are less committed to introducing innovative technologies in their businesses. The program can be designed to provide a sliding-scale matching

grant for every dollar invested by the company. Depending on the size and maturity of the company, the state can decide to provide anywhere between 50 percent to 75 percent of the total cost.

For further information, see Robert D. Atkinson, "Innovation in Cities and Innovation by Cities" (Washington: Information Technology & Innovation Foundation, 2012).

Cost: $$$
Timeframe: 2–3 years

Example: **Maryland Industrial Partnerships Program**

Appoint a SWAT team of innovation "site miners"

Innovation "site miners" are technology commercialization experts responsible for identifying promising technologies in their universities and fostering collaborations across academic programs, technology transfer offices, and institutions. Universities will have the responsibility of selecting well qualified site miners that possess experience working with both industry and tech transfer offices. The state can enter into an agreement with universities to reimburse them for salaries and other costs attributed to the site miners.

Cost: $$
Timeframe: 1–2 years

Example: **Maryland Innovation Initiative (MII) Innovation Discovery Program**

Develop more industry-friendly university-to-business technology licensing agreements

As the leading producer of new ideas, technologies, and products, universities play an important role in fostering economic development. One way universities disseminate their research is through technology transfer to the commercial market via IP transactions with industry. In order to expedite the tech transfer process, careful agreements on IP rights need to be worked out at the outset between the state's universities and industry. Care also needs to be taken that universities are receptive to mutually beneficial partnerships and do not impose restrictive terms (e.g., demand for excessive equity for IP or imposing unpredictable or unreasonable financing terms) when negotiating IP agreements. Furthermore the state's universities should adopt transparent, standardized IP policies and license negotiations to reduce the lag time in harvesting new discoveries and technologies. Universities should invest in follow-on efforts for developing agreements for each industry sector that are attuned to the special needs of the industry.

For further information, see Joseph DeSimone and Lesa Mitchell, "Facilitating the Commercialization of University Innovation: The Carolina Express License Agreement" (Kauffman Foundation, 2010).

Cost: $
Timeframe: 2–3 years

Example: **Carolina Express License Agreement**

Improve the availability of risk capital

Establish an annual space economy investors' conference

A major purpose of the annual space economy investors' conference would be to provide a platform for highlighting Colorado space economy investment opportunities to venture capital and private equity firms. To do this the state should collaborate closely with industry to organize and host the conference, which should include business roundtables, company presentations, and one-on-one investor meetings.

Cost: $
Timeframe: 1-2 years

Example: **Massachusetts Investor Conference**

Provide matching grants to SBIR/STTR award recipients

Colorado should move to create a SBIR / STTR state matching grant program. The purpose of such a program would be to increase the amount of money flowing into early-stage entrepreneurial companies via the SBIR / STTR process. States that possess such matching programs typically do not incorporate a screening process that replicates the federal SBIR/STTR process. Instead any company within the state receiving the federal award is given a state matching award. Matching awards tend to vary from state to state, with some states matching 50 cents for each federal dollar awarded and others matching dollar for dollar.

For further information, see Sarah Nash, "State-Based R&D Innovation Strategies," in Annex 2: Select State Strategies to Foster Innovation of Research & Development, Innovation, and the Science and Engineering Workforce (Washington: National Science Foundation, 2012).

Cost: $$ - $$$
Timeframe: 2-3 years

Example: **Kentucky SBIR-STTR Matching Funds Program** and **Connecticut SBIR Acceleration and Commercialization Program**

Create a Phase 0 fund

A Phase 0 fund would provide grant-writing support to Colorado's small businesses looking to apply for Phase I or Phase II SBIR / STTR funding. By awarding grants of up to $5,000 for expert reviews and financial support, Colorado's Phase 0 program could improve the success rate of SBIR / STTR applicants. After receiving Phase 0 funding from the state, companies should be required to submit Phase I or Phase II draft proposals for review at least few weeks before submitting their proposals to the federal agency.

For further information, see Sarah Nash, "State-Based R&D Innovation Strategies," in Annex 2: Select State Strategies to Foster Innovation of Research & Development, Innovation, and the Science and Engineering Workforce (Washington: National Science Foundation, 2012).

Cost: $$
Timeframe: 2-3 years
Example: **Innovate Washington SBIR/STTR Phase 0 Program**

Improve the existing state-run venture capital fund

Colorado's existing state-run venture capital fund—the Venture Capital Authority (VCA) created in 2004—provides investment capital to create and grow startup and early-stage businesses. However, the VCA as currently structured includes several restrictions that prevent the capital from being deployed with optimal effectiveness. At present, only 50 percent of the VCA fund can be used to invest in qualified businesses located anywhere in the state. The other fifty percent must be invested in qualified businesses located in designated, economically disadvantaged rural and urban communities. Colorado should consider eliminating the rural and urban distressed businesses set-asides and shifting the focus of VCA's activities toward support for the state's advanced industries.

For further information, see Russell Nichols, "State Governments: The Latest Venture Capitalists," *Governing* (March 2011).

Cost: $
Timeframe: 2-3 years

Example: **Invest Maryland**

Create university-based venture capital funds

The purpose of university-based venture capital funds is to channel seed money to startups founded on research from the state's universities and research institutions. Although CSU already possesses such a fund, the creation of similar VC funds at Colorado's other universities would be a timely move to accelerate the commercialization of academic research and build businesses around university discoveries and inventions. Such funds can be capitalized by private investors, including individuals and large investment funds, as well by the universities and through state grants. Companies that receive an investment from the fund must have an established association with a state's university, such as a licensing relationship, research partnership, joint venture, or similar business relationship. The fund would operate with significant input and support from the universities' technology transfer offices. As opposed to an individual university-based venture capital fund, Colorado could also explore the creation of a single university fund that would entail a joint agreement among the state's universities. By combining resources, the fund would have access to the state's entire research catchments.

Cost: $$$$
Timeframe: 2-5 years

Example: **Michigan Wolverine Venture Fund** and Australia's **Uniseed**

Create an advanced industries fund of funds

A fund of funds is a state fund that invests in VC firms, which in turn invest in individual businesses. The goal of a fund of funds is to increase the amount and diversity of funding available for early-stage companies in the state. Instead of investing directly in these companies, the fund of funds provides incentive for VC and private equity funds to invest in the state. The fund of funds can be capitalized with investments from the state pension fund (the Public Employees' Retirement Association), university foundations, and other institutional investors. Colorado can require that portions of the fund's capital be invested in VC funds that focus on seed or early-stage investments in the state's advanced industries. Those funds in which the state's fund of funds have invested would then conduct deal sourcing and make investment decisions about eligible companies. The state would monitor the aggregate performance of its portfolio against a set of performance criteria.

For further information, see Battelle's Technology Partnership Practice, "Colorado Bioscience Roadmap 2008" (Battelle Memorial Institute, 2008); Robert G. Heard and John Sibert, "Growing New Businesses with Seed and Venture Capital: State Experiences and Options" (Washington: National Governors Association, 2000).

Cost: $$$$
Timeframe: 2-5 years

Example: **Utah Fund of Funds**

Bolster the workforce pipeline to secure Colorado's human capital advantage

Create a dedicated statewide STEM education initiative or entity

The purpose of creating a statewide STEM education initiative would be to coordinate and align Colorado's myriad state, regional, and local STEM programs. To do this, Colorado may consider creating an entity (for instance, a STEM Advisory Council) that would be entrusted with the responsibility of promoting changes in STEM education statewide to improve effectiveness and coordination. Either way such an initiative or entity should solicit input from a variety of sectors including businesses (especially in advanced industries), educational institutions, and state agencies to define STEM education and goals, identify critical components needed for improvement in STEM education, determine outcomes and common measures to assess statewide performance on outcomes, and leverage current state funding opportunities to support STEM education work.

Cost: $ – $$
Timeframe: 1–2 years
Background:

Example: **Oregon STEM Education Initiative** and **Iowa Governor's Science, Technology, Engineering and Mathematics (STEM) Advisory Council**

Create a set of focused high school advanced industries career academies

High school career academies that emphasize education and training related to Colorado's advanced industries would be structured using a school-within-a-school model. The career academies would incorporate integrated academic and career technical education, mentoring, and internships with the purpose of introducing high school students to future careers in advanced industries. Managed by Colorado's Department of Education, the academies could be supported by competitive state grants. The state could further stipulate that state grants would have to be matched by the local district and contributions from local employer partners. As a quality assurance mechanism, the state could require each academy to submit an extensive annual report detailing the quality of the program implementation and performance of students enrolled in the academy, which could then be taken into account in the next cycle of state grant awards.

For further information, see Harvard Graduate School of Education, "Pathways to Prosperity: Meeting the Challenge of Preparing Young Americans for the 21st Century" (2011); Stephen Ezell and Robert D. Atkinson, "Fifty Ways to Leave Your Competitiveness Woes Behind: A National Traded Sector Competitiveness Strategy" (Washington: Information Technology & Innovation Foundation, 2012).

Cost: $$ – $$$$
Timeframe: 2–5 years

Example: **California Partnership Academies** and **Project Lead The Way**

Expand and strengthen advanced industries apprenticeship opportunities

Apprenticeship programs train individuals to gain proficiency in a certain occupation through supervised work-based learning and related academic instruction. Colorado should create a statewide initiative that would expand and strengthen apprenticeship opportunities, especially in the state's advanced industries. The state's community college system could host such a program, with community college staff tasked with actively marketing apprenticeship opportunities to companies and encouraging employers to use community colleges and other resources for the provision of relevant courses. Colleges could also consider giving credit for courses taken by apprentices as part of their classroom instruction. In addition,

Colorado should explore giving employers a state tax credit for each apprentice in each year of their employment as well as providing tuition subsidies for those in apprenticeship training.

For further information, see David Altstadt, "Improving Access to Apprenticeship: Strengthening State Policies and Practices" (The Working Poor Families Project, 2011); Robert Lerman, "Training Tomorrow's Workforce: Community College and Apprenticeship as Collaborative Route to Rewarding Careers" (Washington: Center for American Progress, 2009).

Cost: $$
Timeframe: 2–3 years

Example: South Carolina's **Apprenticeship Carolina** and **Wisconsin Youth Apprenticeship Program**

Provide far more opportunities for work-based learning including cooperative education

The main goal of work-based learning programs such as cooperative education (co-op education) is to provide opportunities for students to learn under real-life work conditions and to develop occupational competencies for their chosen career. Colorado's colleges and universities should create, expand, and strengthen co-op education programs. To do so, they would first need to perform occupational surveys in the state to understand the number and types of opportunities available, determine and/or revise curricula, identify enrolment procedures, and market the program to companies. Alternatively Colorado could consider creating a centralized "Colorado Cooperative Education Program" as a one-stop resource for the state's students seeking co-op education opportunities and companies looking to hire such students. The state would have to create co-op education guidelines and could also form a co-op education advisory committee comprising employers, university personnel, and other relevant entities to secure advice and information regarding the planning and implementation of the program.

For further information, see Harvard Graduate School of Education, "Pathways to Prosperity: Meeting the Challenge of Preparing Young Americans for the 21st Century" (2011).

Cost: $
Timeframe: 1–2 years

Example: **University of Waterloo Co-Operative Education Program** and **Georgia Tech Co-Operative Education Program**

Launch an "Intern in Colorado" initiative

The statewide internship program is an important step for creating and promoting employment opportunities for the state's college students while at the same time offering employers a one-stop resource to tap into the state's skilled human capital. Colorado would need to create an online hub connecting college students seeking internships to companies looking to hire them. The website should aggregate and link to all student-focused initiatives that exist throughout Colorado. In addition, the online tool could promote the assets of the state encouraging college graduates to stay in Colorado and include resources for employers on how to develop good internship programs and related guidance. The state would need to collaborate with colleges and universities, the private sector, and regional entities (for instance, the Metro Denver EDC) to successfully roll out this initiative.

Cost: $$
Timeframe: 1–2 years

Example: **Intern in Michigan** and **Massachusetts Stay Here**

Launch an advanced industries fellows program

The advanced industries fellows program would provide emerging entrepreneurial companies access to highly skilled graduate and postgraduate scientists and engineers while enabling these students to gain valuable industry experience. The state should provide up to $75,000 (or a comparable amount to be worked out by the state) to early-stage AI firms to hire graduate and postgraduate students from Colorado's research institutions. These funds would then be used to provide salaries for the fellows. An advanced industries fellows program would encourage each fellowship recipient to establish their career in a field close to their academic program and continue their research with Colorado companies. Every year at least 10 such fellowships could be awarded, depending on the state's resources. The students should be selected through a competitive application process that takes into account the specific needs of the companies looking to hire the fellows.

Cost: $$
Timeframe: 1–2 years

Example: **New Jersey Technology Fellowship Program**

Create industry skills panels

Sector-specific industry skills panels bring together employers, labor organizations, and education and training organizations to identify and address current and near-future skills needs. Colorado should move forward to institute industry skills panels for its advanced industries. Through these panels industry leaders would work with education and training organizations to identify key skills gaps and skills standards for the targeted industry, ensure that training curricula are continually updated to meet employer needs, and share promising practices for replication and adoption statewide. The state should play a key role in providing the platform to bring the diverse stakeholders together, identify state programs that can be leveraged for the process, and develop new programs and resources to address the defined needs of the industry. The skills panels would meet on an ongoing basis (ideally once per quarter in the first year) until they have achieved their primary objective, after which time the panel would continue to meet periodically.

Cost: $$
Timeframe: 2–3 years

Example: **Washington State Industry Skills Panels**

Intensify cluster dynamics

Leverage existing cluster partnerships

Cluster organizations—neutral conveners and associations of relevant stakeholders—will be critical collaborators in the state's efforts to design and implement an economic development strategy. Strong cluster organizations, which are by nature close to companies and stakeholders, serve as wellsprings of low-cost ideas to better connect policy to on-the-ground economic realities. Colorado should seek constructive input from cluster organizations when developing economic development strategies, collect relevant cluster data to track and assess performance, and create cross-agency structures that can respond to cross-industry needs on a system-wide rather than piecemeal basis.

For further information, see National Governors Association, "A Governor's Guide to Cluster-Based Economic Development" (Washington: 2002).

Cost: $
Timeframe: ongoing

Example: **Oregon Business Plan** and **Portland Economic Development Strategy**

Build the capacity of the state's cluster organizations through a competitive grant program

A cluster grant program should provide modest grants on a competitive basis to support a small number of cluster initiatives—existing or startups, in the space economy or in advanced industries more broadly—to expand the capacity of actors. Three different types of grants at increasing denominations should be offered in Colorado: planning grants to fund initial feasibility studies; startup and technical assistance grants to sharpen and energize management, facility, or program operations in existing entities; and competitive program grants to support well-defined, collaborative activities to strengthen clusters in specific areas such as training, R&D, tech transfer, and marketing.

For further information, see Karen Mills, Andrew Reamer, and Elisabeth B. Reynolds, "Clusters and Competitiveness: A New Federal Role for Stimulating Regional Economies" (Washington: Brookings Institution, 2008); Mark Muro and Kenan Fikri, "Job Creation on a Budget: How Regional Industry Clusters Can Add Jobs, Bolster Entrepreneurship, and Spark Innovation" (Washington: Brookings Institution, 2011).

Cost: $ - $$$
Timeframe: 1–3 years

Example: **Maine Technology Institute** and **SBA Clusters Initiative**

Launch a multi-sectoral, multidisciplinary road-mapping and collaboration forum

Business leaders see a shift underway from a walled-off approach to corporate R&D to a more open and collaborative model—at least for early-stage R&D—where companies share and refine early-stage technologies with other firms, customers, and university research institutions to lower the cost, risk, and time to market of innovative technologies. Colorado can help drive and coordinate initiatives to create a physical forum for such activities in the space economy or advanced industries more broadly.

For further information, see Daniel Pacthod and Michael Park, "How Can the U.S. Advanced Industries Sector Maintain its Competitiveness?" (New York: McKinsey & Co., 2012).

Cost: $ - $$
Timeframe: 1–2 years

Example: **SEMATECH** and **Georgia Research Alliance**

Create a collaborative R&D tax credit

Offering additional tax credits to businesses that collaborate with universities, federal labs, or other research consortia stands as a powerful tool for expanding private-sector R&D. Providing incentives for collaboration throughout the innovation system creates mutual benefits, giving public and university researchers new sources of funding while at the same time attuning public research to the practical demands of the private sector. To enhance the effectiveness of a collaborative R&D tax credit, Colorado should establish cluster-specific technology centers to operate as the commons for cross-sector knowledge-sharing, experimentation, and development.

For more information see Matthew Stepp and Robert D. Atkinson, "Creating a Collaborative R&D Tax Credit" (Washington: Information Technology and Innovation Foundation, 2011).

Cost: $$$
Timeframe: 1–2 years

Examples: Israel's **MAGNET program**, **Maryland Industrial Partnership**, and Mexico's **PROINNOVA program**

Prioritize or provide incentives for multi-actor applications to state funding programs

Instead of funding firm-specific innovation activities and workforce development projects, states should adopt a more cross-cutting approach that enables cluster organizations to submit applications on behalf of multiple firms facing similar issues. From an administrative standpoint this approach achieves greater economies of scale by making it easier to design, implement, monitor, and evaluate the use of state funds while at the same time ensuring the broadest possible positive impact on industry. To enact smarter funding programs, Colorado should conduct direct multi-firm outreach through cluster organizations, develop a more streamlined multi-firm application process, and create a funding system with sophisticated monitoring and implementation capabilities.

For further information, see Mark Muro and Kenan Fikri, "Job Creation on a Budget: How Regional Industry Clusters Can Add Jobs, Bolster Entrepreneurship, and Spark Innovation" (Washington: Brookings Institution, 2011).

Cost: $
Timeframe: ongoing

Example: **USTAR**, **Utah Cluster Acceleration Partnership**, **NYSTAR**, and **Ohio Third Frontier**

Sponsor or provide matching grants for an "entrepreneurial leave" program

One way to enhance the flow of knowledge between university researchers and the private sector is through "entrepreneurial leave" programs, which enable scholars to temporarily embed in a local company without leaving their current research position. On the university side, this program enhances faculty knowledge of industry and opens potential employment opportunities for student research assistants. On the business side, it allows companies to tap the expertise of professional researchers and test the waters of high-risk, high-reward research without a long-term payroll commitment. To secure its position as a center of innovation, Colorado's universities and research labs should begin to pilot an "entrepreneurial leave" program that pairs businesses and its top researchers.

For more information see J. Stephen Rottler, "Clustering Around the Lab—Best Practices in Federal Laboratory Commercialization: Sandia National Laboratories as a Catalyst for Regional Growth." In *Clustering for 21st Century Prosperity* (Washington: National Academy of Sciences, 2012); Innovation Associates, "Partners on a Mission: Federal Laboratory Practices Contributing to Economic Development" (Washington: 2003).

Cost: $$ - $$$
Timeframe: 1–3 years

Example: **Sandia Entrepreneurial Separation to Transfer Technology (ESTT) program**, **Stanford University's Entrepreneurship Network**, and **University of Minnesota's Entrepreneurial Leave Program**

APPENDIX F. KEY INDUSTRY NETWORKS PROCESS STEERING COMMITTEE AND TACTICAL TEAM MEMBERS

STEERING COMMITTEE MEMBERS

Henry Baird	Director, Strategy and Business Development, ATK Aerospace Systems
Alison Brown	President and Chief Executive Officer, NAVSYS Corp.
Lisa Buckley	Chief Executive Officer, American Automation Inc.
Jim Budimlya	President and Chief Executive Officer, ADA Technologies
Chris Chavez	Senior Communications Manager, United Launch Alliance
Robert Cleave	President, Commercial Launch Services, Lockheed Martin
Robert Cone	Vice President, Western Aerospace & Defense Operations, ARES Corporation
Matthew Duncan	President, SpaceNav, LLC
John Frederick	Director, State & Local Government Relations, Boeing Company
Sheryl Genco	Chief Executive Officer, Zybek Advanced Products
Tom Kole	President, Shadow Microtek
Ira Lehrman	Chief Operating Officer, Primus Metals, Inc.
Gary Masner	Chief Executive Officer, Advanced Mobile Propulsion Test
Sean McClung	Executive Director for Space Innovation, Millennium Engineering and Integration Company
Eric Miller	Principal, PADT
Michelle Miller	President, Miller Technology Group
John Roth	Vice President, Business Development, Sierra Nevada Corporation
Michael Ruggles	Program Director, Space and Environmental Mission Solutions, Raytheon
Jose Ruiz	Vice President and Chief Information Officer, Raytheon
Robert Schlue	Director, Missions Operations, Boeing Company
Kevin Schrantz	Sales Manager, ABSL Space Products
Michael Semmens	Principal and Co-Founder, Imprimis Inc.
Rick Ward	President, Rick Ward Consulting, LLC

TACTICAL TEAM MEMBERS

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Penina Axelrad	Department Chair, Aerospace Engineering Sciences, University of Colorado, Boulder
Joe Barela	Regional Workforce Director, Arapahoe/Douglas Works
Mike Bennett	District Director, Office of Representative Cory Gardner
Paul Bergman	Regional Representative for Colorado and Wyoming, U.S. Commercial Service, U.S. Department of Commerce
Danielle Blakely	Senior International Trade Specialist, U.S. Commercial Service, U.S. Department of Commerce
Priscilla Bohl	Business Services Program Coordinator, Jefferson County Workforce Center
John Brackney	President and CEO, South Metro Denver Chamber of Commerce
Chris Budden	Dean, Community College of Denver
Chris Chavez	Senior Communications Manager, United Launch Alliance
Michelle Claymore	Vice President, Jefferson County Economic Development Corporation
John Cody	President and Chief Executive Officer, Longmont Area Economic Council
Stephen Davis	Trade Commissioner, Consulate General of Canada
Diane Dimeff	Executive Director, eSpace: The Center for Space Entrepreneurship
Greg Dorman	Legislative Liaison, Colorado Department of Military and Veterans Affairs
Derek Duran	Business Specialist, Jefferson County Workforce Center
Mike Fitzgerald	President and Chief Executive Officer, Denver South Economic Development Partnership
Chris Gray	Business Development Officer, City of Westminster
Jim Gunning	Mayor, City of Lone Tree
Randy Hildreth	Communications Manager, Denver South Economic Development Partnership
Dick Hinson	Senior Vice President, Aurora Economic Development Council
Edgar Johannson	President and Chief Executive Officer, Colorado Space Business Roundtable
Peter Kenney	Principal and Co-Founder, Civic Results
Mark Lake	Executive Consultant, Eagle Rock Consulting
Vicky Lea	Aviation and Aerospace Industry Manager, Metro Denver Economic Development Council
Emily Lesh	Assistant Director of Policy and Partnerships, Colorado Workforce Development Council
David Lung	President and Principal Consultant, DA2 Consulting
Kelly Manning	State Director, Colorado Small Business Development Center
Catherine Marinelli	Principal, Civic Results, and Director, Metro Mayors Caucus
Phil McCready	Principal, Innovation Economics
John Metzger	Chief Executive Officer, Metzger Associates
Becca Montgomery	State Policy Director, Office of Senator Michael Bennet
Ben Nesbitt	Program Director, Skilled Trades and Technical Sciences, Colorado Community College System
Cathy Noon	Mayor, City of Centennial
Bill Possell	Director of Mission Operations and Data Systems, LASP, University of Colorado, Boulder
Morris Price	District Director, Office of Representative Diana Degette
Brandon Rattiner	Denver Metro Area Regional Director, Office of Senator Mark Udall
Jake Rishavy	Economic Development Analyst, Denver South Economic Development Partnership
Jason Sanders	Patent Attorney, Kilpatrick Townsend & Stockton LLP

T. Lynn Sargent	Business Development Representative, Denver Office of Economic Development
Andy Schultheiss	District Director, Office of Representative Jared Polis
Toya Speckman	Senior HR Manager, Ball Aerospace
Dave Tabor	Senior Vice President, Business Partnerships, Colorado Association of Commerce and Industry
Wade Troxell	Director, Center for Networked Distributed Energy and RamLab, Colorado State University
Paul Washington	Executive Director, Denver Office of Economic Development
Jerry Wheeler	Legislative Aide, Office of Representative Bob Gardner
Charlie Whelan	Director, Pikes Peak Workforce Center
Sarah Wilson	Business Representative, Workforce Boulder County

CHAPTER I

[1] James Manyika, Daniel Pacthod, and Michael Park, "Translating Innovation into U.S. Growth: An Advanced-Industries Perspective," *McKinsey Quarterly*, May 2011.Daniel Pacthod and Michael Park, "How Can the U.S. Advanced-Industries Sector Maintain its Competitiveness?" (New York: McKinsey & Company, 2012). See also, Devashree Saha, Kenan Fikri, and Siddarth Kulkarni, "Defining Advanced Industries." (Forthcoming).

CHAPTER II

[1] That entity exists today as the Colorado Space Business Roundtable.

[2] Princeton Synergetics, "Colorado's Strategic Plan for Space" (Colorado Springs: Space Foundation, 2000).

[3] Development Research Partners, Inc., "Aerospace: Colorado Industry Cluster Profile" (Denver: Metro Denver Economic Development Corporation, 2012).

[4] Colorado Office of Economic Development and International Trade, "Colorado Blueprint: A Bottom-Up Approach to Economic Development" (Denver: Colorado Office of Economic Development and International Trade, 2011).

[5] Colorado Office of Economic Development and International Trade, "Key Industry Strategic Initiatives," available at http://www.advancecolorado.com/about-oedit/blueprint/key-industry-strategic-initiatives (2012).

[6] A business establishment is a discrete location in which business is conducted. Each business establishment is part of a company or a firm, and companies may have one or more business establishments. For example, Starbucks Corporation is a company or firm, while the reader's neighborhood Starbucks is a business establishment.

CHAPTER III

[7] This choice of terminology and definition is not without precedent. Other research organizations, most notably the Space Foundation and the Organization for Economic Cooperation and Development (OECD), have adopted similar approaches. See "The Space Economy at a Glance" (Paris: Organization for Economic Cooperation and Development, 2011) and "The Space Report" (Colorado Springs: The Space Foundation, 2012). In addition, the OECD's 2012 report, "Handbook on Measuring the Space Economy," contains a very useful discussion of the complications of defining the space economy, and offers a number of alternative definitions.

[1] Different sources were used to calculate different figures. See the methodology appendix for a detailed description of the methodology.

[2] The "bottom-up" methodology employed in this report identifies establishments presently part of the space economy. It does not, however, include those establishments that used to exist as part of the space economy—establishments that closed prior to 2011, when we conducted our searches. As a result, growth rates are overstated because one of the four components of net job growth—job losses from closing establishments—is missing from the equation. The other three components of net job growth are job losses from contractions, job gains from expansions, and job gains from new openings. Benchmark state and national datasets have been adjusted to ensure comparability throughout. Ultimately, the "growth" figures presented here are best understood as the jobs history of establishments presently in business.

[3] In order to have been counted, the predominant activity of business establishments in this category and its constituent segments must be related to space. Firms and establishments in this category may well have capabilities that extend beyond space—indeed this category is the locus of many of the space economy's spillovers into materials, IT and software, systems engineering, and other markets. We have made no attempt to estimate the number of employees within an establishment employed in space-related endeavors; establishments were included or excluded as one unit and inclusion was determined at the establishment level. Accordingly, "pure space" employment may be overstated in this category more than the others, but this fact importantly signals the broad application of space capabilities and knowledge bases in the wider marketplace, and vice versa. Space is, after all, integrated into the economy as a technology base, not separate from it.

[4] The GPS story illustrates this perfectly: Littleton-based Lockheed Martin Space Systems is manufacturing the satellites for the GPS III constellation, anchoring a deep supplier and contractor network including Boeing and Exelis on the manufacturing side, in response to demand from military and commercial customers—many of whom are located in Colorado—for increasingly sophisticated GPS, GIS, and PNT capabilities.

[5] See Chapter IV for additional discussion.

[6] Proximity intensifies the interactions and feedback between system users and creators, giving each a competitive advantage in innovation. This is one of the ways in which clustering leads to increased competitiveness.

[7] Manufacturing here refers to the set of Census Bureau NAICS codes categorized as manufacturing (those beginning with 31 through 33), and bears no relation to Brookings' segmentation scheme. Establishments that the Census Bureau categorizes as manufacturing appear in a number of different Brookings segments. For example, navigation and geolocation is full of establishments that the census classifies as 3345—navigational instrument manufacturers.

[8] See Mark Muro and Bruce Katz, "The New 'Cluster Moment:' How Regional Innovation Clusters Can Foster the Next Economy." (Washington: Brookings Institution, 2010).

CHAPTER IV

[1] Satellite Industry Association, "State of the Satellite Industry Report 2011" (2012).

[2] Space Foundation, "The Space Report 2012" (2012); Satellite Industry Association, "State of the Satellite Industry Report 2011."

[3] Satellite Industry Association, "State of the Satellite Industry Report 2011"; Space Foundation, "The Space Report 2012."

[4] All figures are in real terms. Based on analysis of data compiled by the Satellite Industry Association. Revenue estimates for any given year are taken from the most recent report when that data is available. Satellite Industry Association, "Satellite Industry Statistics" (2001–2004), and "State of the Satellite Industry Report" (2005–2011).

[5] Based on analysis of World Industry Service data from IHS Global Insight.

[6] Satellite Industry Association, "State of the Satellite Industry Report" (2008–2011); OECD, "The Space Sector in 2011 and Beyond." In *The Space Economy at a Glance 2011* (2011).

[7] Ibid. and several Euroconsult brochures, including: "Mobile Satellite Communications Market Survey, Prospects to 2020" (2011); "Mobile Satellite Communications Markets Survey, Prospects to 2020" (2011);" "Satellite Communications & Broadcasting Markets Survey Forecasts to 2019, Preparing for a Showdown" (2010); "Satellite-Based Earth Observation, Market Prospects to 2019" (2009); "Satellites to be Built & Launched by 2020, World Market Survey" (2010).

[8] Potential missions for these platforms include tourism, training, basic and applied research, deployment of small satellites into orbit, and remote sensing. These estimates assumes that initial launches take places in 2013 as planned. The Tauri Group, "Suborbital Reusable Vehicles: A 10-Year Forecast of Market Demand" (2012).

[9] Jeff Foust, "Is Commercial Spaceflight's 'Netscape Moment' Near?" *The Space Review*, July 30, 2012.

[10] Teal Group, "World Unmanned Aerial Vehicle Systems, 2012 Market Profile and Forecast" (2012).

[11] MarketsandMarkets, "MarketsandMarkets: Global Cyber Security Market worth $120.1 Billion by 2017" (2012).

[12] Satellite Industry Association, "State of the Satellite Industry Report" (2009, 2010).

[13] NASA, "Fiscal Year 2013 Budget Estimates" (2012) and U.S. Department of Defense, "Overview—FY2013 Defense Budget" (2012).

[14] The Obama administration's FY 2013 DoD budget requests $8 billion for procurement and R&D for space programs through 2017, compared to $10 billion in the FY 2012 budget. U.S. Department of Defense, "Program Acquisition Costs by Weapon System" (2011) and U.S. Department of Defense, "Program Acquisition Costs by Weapon System (2012).

[15] Congressional Budget Office, "Final Sequestration Report for Fiscal Year 2012" (2012).

[16] Maryland Department of Business and Economic Development, "The Business of Space Science" (2011); Performance Management Group at Virginia Commonwealth University, "Competitive Analysis of Virginia's Space Industry" (2011); Office of the Governor of Texas, Economic Development and Tourism, "Texas Aerospace & Aviation Industry Report" (2011); and Alaska Aerospace Corporation, "A Diversified, Sustainable Aerospace Industry for Alaska Strategic Plan 2011-2016" (2011).

[17] A 286 percent cost increase for major DoD space programs led to the cancellation of several developmental projects. Government Accountability Office, "Space Acquisitions: DOD Delivering New Generations of Satellites, but Space System Acquisition Challenges Remain" (GAO-11-590T, 2011). Overruns in NASA's two largest programs—the James Webb Space Telescope and the Mars Science Laboratory—led the administration to propose cancelling funding for the ExoMars/Trace Gas Orbiter (EMTGO) joint project with the European Space Agency

(ESA), in addition to pulling money from several other programs. Government Accountability Office, "NASA: Assessments of Selected Large-Scale Projects" (GAO-12-207SP, 2012).

[18] FAA Commercial Space Transportation (AST) and the Commercial Space Transportation Advisory Committee (COMSTAC), "2012 Commercial Space Transportation Forecasts" (2012).

[19] Futron Corporation, "Futron's 2012 Space Competitiveness Index: A Comparative Analysis of How Countries Invest In and Benefit" (2012).

[20] Direct-to-home television represented 48 percent of total industry revenues in 2011. Satellite Industry Association, "State of the Satellite Industry Report" (2011).

[21] Euroconsult, "Satellite Communications & Broadcasting Markets Survey Forecasts to 2019, Preparing for a Showdown," brochure (2010).

[22] Futron Corporation, "Futron's 2012 Space Competitiveness Index."

[23] Ibid.

[24] AST and COMSTAC, "2012 Commercial Space Transportation Forecasts."

[25] "Interim Report: Most Telecom Sats Could be Removed from USML," *Space News International* (2011); Europe's Thales Alenia Space sells a version of its Spacebus platform that is produced without ITAR-restricted components. AST and COMSTAC, "2012 Commercial Space Transportation Forecasts."

[26] The Center for Strategic and International Studies notes that "By 2007, China partnered with Bangladesh, Indonesia, Iran, Mongolia, Pakistan, Peru, and Thailand to develop an earth observation satellite system; had organized a satellite association in Asia (the Asia Pacific Space Cooperation Organization); and had designed, built, and launched a communications satellite for Nigeria." Center for Strategic and International Studies, "National Security and the Commercial Space Sector: An Analysis and Evaluation of Options for Improving Commercial Access to Space" (2010): 24.

[27] Satellite Industry Association, "Satellite Industry Statistics" (2002) and "State of the Satellite Industry Report" (2011).

[28] Satellite Industry Association, "Satellite Industry Statistics" (2001–2004), "State of the Satellite Industry Report" (2005–2011). Inflation estimate based on Bureau of Labor Statistics Consumer Price Index for Urban Consumers as of December 31, 2012.

[29] Euroconsult, "Satellites to be Built & Launched by 2020, World Market Survey."

[30] The U.S. Air Force's Milstar constellation, for example, provides secure delivery of national and nuclear command and control orders from five large (some 10,000 pounds each), jam-resistant, redundant, and nuclear-blast resistant satellites. Each of the five satellites was years late and over-budget, due in large part to very high technical requirements. Robert S. Dudney, "Game Changers in Space," *Air Force Magazine* 25 (10) (October 2012): 49–53.

[31] Forrest McCartney and others, "National Security Space Launch Report" (Santa Monica: RAND Corporation, 2006).

[32] Dudney, "Game Changers in Space."

[33] NASA, "NASA's Commercial Crew Program Progressing for Future of U.S. Human Spaceflight" (2012).

[34] Government Accountability Office, "Briefing on Commercial and Department of Defense Space System Requirements and Acquisition Practices" (January 2010).

[35] Ledyard King, "SpaceX Success Boosts NASA's Venture with Private Companies." *USA Today*, May 25, 2012; "SpaceX: Entrepreneur's Race to Space," *CBS News,* June 3, 2012.

[36] Government Accountability Office, "Briefing on Commercial and Department of Defense Space System Requirements and Acquisition Practices."

[37] Eutelsat claims to broadcast over 4,250 digital television channels and 1,100 radio stations with an audience of 204 million cable and satellite TV homes. Eutelsat, "Key Figures," (2012).

[38] The Tauri Group, "Suborbital Reusable Vehicles."

[39] Teal Group, "World Unmanned Aerial Vehicle Systems."

[40] For a primer on the emerging global market for UAV technologies and a forecast of its growth see Teal Group, "World Unmanned Aerial Vehicle Systems."

[41] Ian Christiansen, David Vaccaro, and Dustin Kaiser, "Market Characterization: Launch of Very-Small and Nano-Sized Payloads Enabled by New Launch Vehicles" (Bethesda: Futron Corporation, 2011); Jeff Foust, "Emerging Opportunities for Low-Cost Small Satellites in Civil and

Commercial Space" (Bethesda: Futron Corporation, 2010); and Jeff Foust, "If You Build It, Who Will Come? Identifying Markets for Low-Cost Small Satellites" (Bethesda: Futron Corporation, 2008).

[42] National Science Board, "Science and Engineering Indicators 2012" (Arlington: National Science Foundation: 2012). The other R&D-intensive industries are chemicals, computer and electronic products, automotive manufacturing, software and computer-related products, and R&D services.

[43] Ibid.

[44] Ibid.

[45] Foust, "Is Commercial Spaceflight's 'Netscape Moment' Near?"

[46] National Science Board, "Science and Engineering Indicators 2012."

[47] Space Foundation, "The Space Report 2012." In presenting these figures, the Space Foundation cites data from the Bureau of Labor Statistics and the Census Bureau.

[48] In 2009, when 13 percent of the workforce was retirement eligible, only 2 percent of the workforce actually retired. Carole Rickard Hedden and others, "Aviation Week 2010 Workforce Study" (2010).

[49] Carole Hedden, "Worried A&D Workforce Braces for Defense Cuts," *Aviation Week*, August 20, 2012.

[50] Ibid.

[51] See Charles River Associates, "Innovation in Aerospace and Defense" (Boston: 2009). The report states that "The need to innovate is becoming more important than ever. Given the backdrop of global economic challenges and changing market conditions, defense budgets that are shifting to meet evolving threats, and sweeping new environmental regulations," 2.

[52] Christine Greenhalgh and Mark Longland, "Running to Stand Still? The Value of R&D, Patents, and Trade Marks in Innovating Manufacturing Firms," *International Journal of the Economics of Business* 12 (3) (2005): 307–328.

[53] Peter Bisson and others, "What Happens Next? Five Crucibles of Innovation that will Shape the Coming Decade," (McKinsey & Company, 2010).

[54] Ibid.

[55] Ibid.

[56] Ibid.

[57] Hitachi Consulting, "Creating a Culture of Innovation in Aerospace and Defense" (Los Angeles: 2010).

[58] See, among others, Zhenzong Ma and Yender Lee, "Patent Application and Technological Collaboration in Inventive Activities: 1980–2005," *Technovation* 28 (2008): 379–390; Walter Powell and Stine Grodal, "Networks of Innovators." In Jan Fagerberg, David C. Mowery, and Richard R. Nelson, eds., *The Oxford Handbook of Innovation* (Oxford University Press: 2005); and Muro and Katz, "The New 'Cluster Moment.'"

CHAPTER V

[1] The Kauffman Index of Entrepreneurial Activity is a leading indicator of new business creation in the country. In 2011, the five states with the highest entrepreneurial activity rates were Arizona (520 businesses created per 100,000 people), Texas (440 per 100,000 people), California (440 per 100,000 people), Colorado (420 per 100,000 people), and Alaska (410 per 100,000 people). See Robert Fairlie, "Kauffman Index of Entrepreneurial Activity 1996–2011" (Kansas City: Kauffman Foundation, March 2012). Colorado especially performs favorably on this metric in comparison with several of its peer states. Florida (380 businesses per 100,000 adults), Maryland (290 per 100,000 adults), Alabama (260 per 100,000 adults), New Mexico (250 per 100,000 adults), and Virginia (200 per 100,000 adults) exhibited entrepreneurial activity rates lower than Colorado in 2011.

[2] The recent success of NASA's Mars Science Laboratory—also known as the Curiosity rover—was made possible by three of Colorado's major space companies. Centennial-based United Launch Alliance (ULA) launched the Mars Science Laboratory, containing the Curiosity rover and all related mission instrumentation, on an Atlas V rocket. Lockheed Martin Space Systems Company, located in Jefferson County, developed the aeroshell protecting the Curiosity rover during cruise and descent. Sierra Nevada Corporation Space Systems designed the descent system to lower the Curiosity rover to the planet's surface, and also built the precision gearbox assemblies that power the instruments needed to drill, collect, and analyze samples of Martian soil. For other similar examples of the state's high innovation capacity, see Colorado Space Coalition, "Colorado Aerospace 2012–2013" (Denver: Colorado Space Coalition, 2012).

[3]Among its peers though, Maryland ($2,767 per person), New Mexico ($1,775 per person), and Virginia ($1,152 per person) beat Colorado by a wide margin.

[4] The only other states receiving a major portion of NASA R&D dollars over the same period are California (30 percent in 2009) and Maryland (16 percent in 2009). See National Science Foundation, Survey of Research and Development Expenditures at Universities and Colleges (FY 2009).

[5] Brookings analysis of data from SBIR / STTR, www.sbir.gov. SBIR / STTR awards represent the largest source of early-stage, high-risk technology financing in the country. The SBIR program encourages small businesses to explore their technological potential and provides an incentive to profit from commercialization. The related STTR program is designed to facilitate the transfer of technological innovation from nonprofit research institutions to small commercial enterprises. It is primarily a program linking research universities to commercialization efforts. Twelve federal agencies participate in this program, providing roughly $2 billion for early-stage R&D projects leading to the commercialization of resulting products or services. The awards granted by these programs are indicative of the extent to which the state's entrepreneurial community is engaged in innovation and the state's research institutions are pursuing opportunities for technology commercialization. For this analysis, both overall SBIR/STTR grants as well as awards made by DoD, NASA, and NOAA have been taken into account.

[6] The majority of workers in the space economy have a science, mathematics, engineering, and information technology background. For instance, the space economy includes engineers, technicians, and information technology specialists involved in designing, manufacturing, and operating space and ground segments. In addition, scientists with expertise in astronomy, astrophysics, astrobiology, and atmospheric physics develop and test the instruments that fly on satellites. Finally, there are engineering and scientific jobs in applicative areas that use satellite data, including GIS, remote sensing, and climate and atmospheric monitoring.

[7] Brookings analysis of Bureau of Labor Statistics May 2011 Occupational Employment and Wage State Cross-Industry Estimates.

[8] Among its peers, only Maryland (at 1.2 STEM doctorates per 10,000 people) exceeds Colorado's 0.9 STEM doctorate degrees granted per 10,000 people, with Colorado awarding 460 STEM doctorates each year. With respect to doctorate degrees utilized within the space economy, again Maryland and New Mexico (both with 0.4 doctorates per 10,000 people) lead Colorado's 0.3 doctorate degrees granted per 10,000 people, with Colorado granting 159 doctorates each year that have particular relevance to the space sector. Brookings analysis of National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates.

[9] A comparison of four indices that rank state economic competitiveness reveals that overall Colorado fares well in these rankings. The ALEC-Laffer State Economic Competitiveness Index (2012), the Beacon Hill State Competitiveness Index (2011), and the Small Business Survival Index (2011) rank Colorado in the top ten of all states while the Tax Foundation (2012) ranks Colorado in the top twenty.

[10] At 2.9 percent, Colorado's sales tax is the lowest of the 45 states that impose such a tax. Colorado's corporate income tax rate is among the lowest in the country at 4.63 percent. Colorado offers a simple corporate income tax structure based on single-factor apportionment which allows businesses to pay taxes based solely on their sales in the state. Colorado assesses a flat tax of 4.63 percent of an individual's taxable federal income—with most small businesses paying the individual rate for their business—ranking Colorado the sixth lowest among states that levy an individual income tax and making the tax environment for small businesses very competitive compared to other states.

[11] Brookings analysis of data from Census Bureau, Bureau of Economic Analysis, Bureau of Labor Statistics, Internal Revenue Service, Moody's Analytics, NAFSA, and the U.S. International Trade Commission.

[12] The space-related research centers are: Academy Center for Space Situational Awareness Research, Academy Center for Cyberspace Research, Aeronautics Research Center, Center for Unmanned Aerial Systems Research, Space Physics and Atmospheric Research Center, and Space Systems Research Center.

[13] In 2010, the National Research Council (NRC) ranked CU-Boulder's PhD program in aerospace engineering fourth and mechanical engineering 13th nationally in terms of program quality. CU-Boulder's LASP has designed and built space instruments that have been on every spacecraft that have orbited all planets in our solar system. The NRC also ranked CSU's PhD program in atmospheric science number one in the nation in 2010 while CU-Boulder's PhD program in atmospheric and oceanic sciences was ranked seventh nationally. For more information see National Research Council, "A Data-Based Assessment of Research-Doctorate Programs in the United States" (Washington: The National Academies Press, 2011).

[14] For the full list of laboratories, visit the CO-LABS consortium's website at: www.co-labs.org.

[15] The CSC is a group of industry stakeholders including space companies, military leaders, academia, and economic development organizations. The CSC compiles an annual briefing for the Colorado congressional delegation that outlines legislative strategies to support the state's space industry. See Colorado Space Coalition, "Briefing for the Colorado Congressional Delegation" (Summer/Fall 2012). Colorado is also home to the internationally recognized Space Foundation, which supports the global space industry through information and education programs. Each year the Space Foundation hosts the National Space Symposium in Colorado Springs—an event that attracts more than 9,000 space-focused government and industry representatives from all around the world.

[16] eSpace is a partnership between the University of Colorado and Space Systems Group of Sierra Nevada Corporation that is dedicated to creating new entrepreneurial space companies, commercializing technologies created within these companies, and developing the workforce to support them. Since its inception in 2009, the eSpace Incubator program has incubated 13 companies, submitted 18 SBIR proposals (10 of which won SBIR awards), and generated over $3 million in revenue (both SBIRs and industrial contracts). See eSpace, "eSpace Delivers Stellar ROI in Aerospace" (Boulder: 2012).

[17] Colorado's unique concentration of military assets helps drive the state's space economy in multiple ways. Employing over 73,000 personnel from military, civilian, and contract ranks with an economic impact of approximately $6.9 billion, the military is a major economic force in its own right. Second, the military serves as a sophisticated and demanding customer of cutting-edge technology and innovation around which a dense network of highly technical suppliers and service providers has grown. Finally, the military is an important draw for talent, attracting and training highly skilled workers who subsequently remain in the state and add to its unrivalled stock of space-related talent.

[18] Among the state's most recent coups include a $1.5 billion contract awarded to ULA from the U.S. Air Force for nine rocket launches, a $1.4 billion contract awarded to Raytheon from NASA to provide ground control for weather satellites, a $248 million contract awarded to Ball Aerospace from NASA to build the JPSS-1 satellite and integrate the instruments, and a $212.5 million contract to Sierra Nevada Corporation from NASA to continue development on its Dream Chaser Space System in support of NASA's Commercial Crew Integrated Capability Program.

[19] Brookings analysis of 2011 DoD-NASA-NOAA core aerospace contracts data for Colorado and peer states reveals that Colorado outranks all its peers in terms of absolute contract value, average contract value, and contracts normalized by aerospace employment. The definition of "core aerospace" contracts includes the following: spacecraft technology, guided missile technology, rocket technology, advanced components and equipments, earth research and science, instruments and detection systems, and professional services. Absolute contract value is the inflation-adjusted (for 2011) value of contracts in the core aerospace category. The normalized contract value normalizes the contract value according to the sum of employment for each state in Aerospace Product and Parts Manufacturing (NAICS 3364); Navigational, Measuring, Electromedical, and Control Instruments Manufacturing (NAICS 3345); and Scientific Research and Development Services (NAICS 5417). Despite Colorado's relative size, it still ranks in the top three for absolute intake of core aerospace contracts. It leads among its peer states in average contract value, with the average size nearly three times that of its closest peer. Moreover, Colorado's space sector wins the largest contracts by a long shot. Even after normalizing, Colorado leads its nearest peer by one and a half times in winning core aerospace contracts. Brookings analysis of the General Services Administration's USA Government Spending Database, accessed August 14, 2012.

[20] Brookings analysis of General Services Administration's USA Government Spending Database and Brookings NETS Revenue Database. To estimate contract shares of revenue, Brookings searched the DUNS numbers for all contracting firms in Colorado between 2008 and 2010 and matched those to DUNS identification numbers in the Brookings NETS Revenue database. After matching the data, the contracts and revenue data were inflation-adjusted in 2011 dollars using BLS Producer Price Indexes for Aerospace Product and Parts Manufacturing (3364). The 2008, 2009, and 2010 contract and revenue estimates were then averaged and divided to create shares. This methodology was only applied to firms that appeared in both the contracts and revenue data sets. The data only covers firms that appeared in both databases with an average contract size of $75,000 or more.

[21] Ibid.

[22] There is no Colorado representation on the Senate committee on Commerce, Science, and Transportation or on the House committees on Science, Space, and Technology; Homeland Security; or Intelligence.

[23] Kristen Leigh Painter, "Sierra Nevada's Louisville Unit Awarded $212.5 Million from NASA for Dream Chaser," *The Denver Post*, August 3, 2012 and Anne Schrader, "Louisville's Sierra Nevada Unit Gets $80 Million for Reusable Spacecraft," *The Denver Post*, April 19, 2011.

[24] Guillaume Houde, "American Company to Send First Commercial Astronauts to Moon," *Space Safety Magazine*, November 23, 2012.

[25] Metro Denver EDC, "Aerospace: Colorado Industry Cluster Profile" (Denver: 2013).

[26] Ibid.

[27] To build the aerospace industry contracts dataset, Brookings developed a classification system for all aerospace Product Service Codes and extracted all transactions under these codes for specified agencies (Commerce, DoD, and NASA) and for all years between 2001 and 2011. The data was inflation-adjusted in 2011 dollars using the National Defense Equipment and Software Price Indexes from BEA Table 3.9.4 and was normalized using the sum of employment in Aerospace Product and Parts Manufacturing (NAICS 3364), Navigational, Measuring, Electromedical, and Control Instruments Manufacturing (NAICS 3345), Scientific Research and Development Services (NAICS 5417). The raw contracts data was obtained through the General Services Administration's USA Government Spending Database, accessed August 14, 2012.

[28] For useful discussion of the "valley of death" problem see Bloomberg New Energy Finance, "Crossing the Valley of Death" (New York, 2010); Jesse Jenkins and Sara Mansur, "Bridging the Clean Energy Valleys of Death" (Oakland: Breakthrough Institute, 2011); Matt Hourihan and Matthew Stepp, "Lean, Mean, and Clean: Energy Innovation and the Department of Defense" (Washington: The Information Technology & Innovation Foundation, 2011).

[29] When comparing Colorado universities with peer state institutions it has to be noted that the success metrics of a university technology transfer program depend on a number of factors, including the characteristics of the university (for instance, whether it is public, private, or land grant and whether it has a medical school), the composition of its research, the quality of its faculty, and the resources it allocates toward technology transfer. These factors vary by institution and can make it difficult to directly compare tech transfer success levels among universities. With these caveats in mind, the Brookings analysis looks at three metrics—patents issued, license income, and startups created—to compare the performance of Colorado universities with peer state universities.

[30] In FY 2011, Colorado's three big universities—CU, CSU, and CSM—together filed for 314 new patent applications and had 58 patents (1.3 percent of all patents) issued. In terms of individual institutions, CU is ranked 35th on new patent applications per $100 million in research expenditure, CSU 113th, and CSM 34th out of 153 research institutions. On patents issued per $100 million in research expenditure, CU drops to 104th position, CSU ranks 94th, and CSU 60th. Brookings analysis of data from Association of University Technology Manager's 2011 Licensing Activity Survey.

[32] In FY 2011 technologies created at CU, CSU, and CSM provided the basis for eleven, five, and two startups formed, respectively. In the same year the University of California System had 58 startups, Massachusetts Institute of Technology 25, University of Illinois 21 and the University of Texas System 20. Universities with smaller total research expenditures but higher numbers of startups formed are University of Utah with 19 startups, Columbia University with 15, and University of Florida with 12. Comparing Colorado to its peer states, Arizona and New Mexico universities (1.8 startups created each for every $100 million spent on research) and Alabama and Florida universities (1.7 startups each for every $100 million spent on research) perform better. Brookings analysis of data from Association of University Technology Manager's 2011 Licensing Activity Survey.

[33] It should be noted that there are pockets of commercialization excellence within the state's universities. For instance, Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA)—a collaboration among four academic partners including CSU, the University of Massachusetts, the University of Oklahoma, and the University of Puerto Rico and a multi-sectoral partnership among academic, industry, and government sectors—has had a successful record of transitioning university-derived technologies to the marketplace.

[34] Brookings analysis of University of Colorado Technology Transfer Office, "Technology Transfer Annual Report," FY 2006–07 through FY 2010–11. The two companies identified as operating in the space economy are Tigon EnerTec (FY 2009–10), which creates hybrid propulsion systems with a potential market in UAVs and ColdQuanta (FY 2006–07), which produces ultracold atoms and has potential applications in the navigation of spacecraft and submarines.

[35] Brookings analysis of startup companies assisted by CSU Ventures—a nonprofit corporation dedicated to commercializing intellectual property developed at CSU—available at www.csuventures.org/content.php?page_id=224. The three companies identified as operating in the space economy are ATMET, providing computer solutions for meteorological, dispersion, and air quality research and applications; Numerica, providing software solutions in air and missile defense, cybersecurity, GIS, and space situational awareness, among others; and Ridgeline Instruments, developing hardware systems for remote sensing applications.

[36] Data obtained from e-mail communication with CU's Technology Transfer Office. The aerospace and space-related patent applications and patents issued are approximations since the numbers are only based on inventions from the Department of Aerospace Engineering Sciences. There are likely inventions from other departments as well as CU-Colorado Springs campus that have aerospace and space applications and have not been captured in this data.

[37] Data obtained from e-mail communication with CSU's Technology Transfer Office. The majority of the patents issued in the aerospace and space sector were related to innovations in dual polarization radar and networked radar systems.

[38] Unlike the biotechnology and IT sectors, where licenses of drugs and software to the industry provide universities licensing revenues, the space sector functions in a very different manner because the customer and technology development partner is the federal government. The federal government—which provides the bulk of the research funding—receives a royalty-free license to use the inventions created under that funding. Furthermore, university technology transfer offices typically tend to stay away from commercializing technologies if there is no clear pathway to recover the investments in patent costs and personnel. This is especially true for CU where there is no operational support of technology transfer budgets out of federal grants, the university general fund, or the state general fund.

[39] Weak connectivity between Colorado's research institutions and industry is borne out by the data to some extent. In 2009, of a total R&D budget of $648.4 million at the CU system, only 6 percent came from industry. The one exception is CSM, which has a significant percentage (36 percent) of its 2009 R&D funding coming from the industry, although it had a much smaller research budget of $40 million. At CSU 6 percent of its 2009 R&D funding came from industry. The low percentage of funding from industry to CU and CSU is due in part to their successful track record in attracting federal funding—77 percent and 70 percent, respectively, of CU and CSU total funding in 2009 came from the federal government as opposed to 59 percent nationally. At the same time, the disconnect between industry and the state's research universities appears worse if looking at aeronautical and astronautical engineering R&D funding. In 2009 the CU system attracted $23.7 million in this area, out of which a staggering $20 million (85 percent) was federally funded. Nationally approximately 70 percent of total aeronautical and astronautical engineering R&D funding came from the federal government in 2009. Brookings analysis of National Science Foundation, Academic R&D Expenditures: FY 2009 data, available at www.nsf.gov/statistics/rdexpenditures.

[40] See Laurie Wiggins, "Mitigating Risk for Investment in Aerospace Companies," (LJW Enterprises, LLC).

[41] Charles River Associates, "Innovation in Aerospace and Defense," (Boston: 2010).

[42] Ibid.

[43] As a result, a typical defense sector company often ends up with a large and varied portfolio of products, each developed for a specific defense or civilian program and each targeting a small niche market opportunity. See Laurie J. Wiggins, "Mitigating Risk for Investment in Aerospace Companies."

[44] While far behind California, Massachusetts, and New York in absolute VC investment in 2011—with their big technology hubs in Silicon Valley, Boston, and New York City—Colorado holds its own in VC funds raised per capita. In 2011 Colorado attracted $121 in VC funding per person, behind Massachusetts ($453) and California ($385). Brookings analysis of data from PricewaterhouseCoopers Moneytree Survey Data.

[45] Brookings analysis of data from PricewaterhouseCoopers Moneytree Survey Data, 2007–2011. In 2011 the four sectors attracted 77 percent of Colorado VC investment, 84 percent in 2010, 69 percent in 2009, 74 percent in 2008, and 62 percent in 2007.

[46] VC investment in Colorado companies between 2005 and 2012 reveals that only three companies in the state's space economy—Zolo Technologies in 2005 and 2007, SpaceDev in 2006, and Digital Globe in 2008—succeeded in securing VC funding.

[47] Eric Peterson, "Down Decade for VCs: Venture Funding in Colorado is Up but Nowhere Near Dot-Com Peak," *Colorado Biz Magazine*, May 31, 2012.

[48] Recent advances in technology, changes in government funding priorities, and changes in the public attitude toward access to space and space travel are spurring investment opportunities in the new space market. Early in 2012 California company XCOR Aerospace—which is building the Lynx, a piloted, two-seat, fully reusable, liquid-rocket-powered vehicle that takes off and lands horizontally and can be used for research and scientific missions, private spaceflight, and microsatellite launch—received $5 million in VC funding from several Silicon Valley entrepreneurs and venture capitalists. See PR Newswire, "XCOR Aerospace Closes $5 Million Round of Investment Capital," *PR Newswire*, February 27, 2012. Bay Area venture firms also invested $70 million in California-based Skybox Imaging, which seeks to make satellite imagery more widely accessible for commercial applications. See "Mountain View-Based Skybox Imaging Raises $70 Million in Third Round," *Silicon Valley Wire*, April 17, 2012. In addition the investor group Space Angels Network has seen its membership double in the past year to two dozen people and the number of space startups seeking to connect with its members has been rising. See Todd Bishop, "Angels in Space: More Investors Betting on the Final Frontier," *GeekWire*, October 11, 2012.

[49] Nationally, however, the aerospace and space sector has not drawn much VC activity, despite the few VC firms that have invested in SpaceX and Virgin Galactic. Currently the biggest investors are high-net-worth individuals who have made their fortunes in other industries, including Elon Musk of SpaceX, Jeff Bezos of Blue Origin, and John Carmack of Armadillo Aerospace.

[50] Aerospace Industries Association, "Launching the 21st-Century American Aerospace Workforce" (Arlington: 2008).

[51] On a positive note, retirement—while representing a net skills loss—can also be viewed as an opportunity. An aging workforce tends to be more risk-averse and thus are often hesitant to undertake risky exercises in new markets. With older workers exiting the workforce, a premium should be placed on hiring engineers and scientists with an entrepreneurial mindset.

[52] Brookings analysis of Population Reference Bureau, Trends in Science and Engineering Labor Force Project, accessed August 2012. This dataset has a broader definition of STEM (it uses the phrase "science and engineering labor force") and includes workers in architecture, computers/IT, engineering, life sciences, physical sciences, mathematics, and social sciences.

[53] Space economy STEM represents a subset of STEM that includes degrees more relevant to the space economy in fields such as engineering, physics, and math.

[54] Brookings analysis of National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates.

[55] To forecast the share of STEM degrees and certificates conferred, Brookings took shares of these populations, found the compounded annualized growth rate from 2005 to 2010, and projected that trend until 2020. The projections were adjusted to sum to 100. The raw data is from the National Science Foundation's WebCASPAR Integrated Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates.

[56] To forecast the share of STEM workers in Colorado aged 34 and under and aged 55 and over, Brookings took shares of these populations, found the compounded annualized growth rate from 2005 to 2010, and projected that trend until 2020. The projections were adjusted to sum to 100. The raw data is from the Population Reference Bureau, Trends in Science and Engineering Labor Force Project accessed August 2012.

[57] Brookings analysis of U.S. Census Bureau, 2009–2011 American Community Survey.

[58] To forecast the number of STEM degrees and certificates conferred in Colorado, Brookings applied the compounded annualized growth rate from 2001–2010 and projected that trend until 2020. The raw data is from the National Science Foundation's WebCASPAR Integrated

Science and Engineering Resource Center's IPEDS Completions Survey on Degrees/Awards Conferred (NSF population of institutions) and Census Bureau Population Estimates. To forecast the number of Colorado STEM jobs, Brookings projected trends associated with the Georgetown Center on Education and the Workforce STEM database and Population Reference Bureau, Trends in Science and Engineering Labor Force Project. Anthony Carnevale, Nicole Smith, and Michelle Melton, "STEM" (Washington: Georgetown University Center on Education and the Workforce, 2011). The Georgetown researchers employed a STEM definition that includes computer, math, architecture, engineers, life and physical scientists.

[59] National Science Foundation, "Science and Engineering Indicators 2012," Table 8-27.

[60] Change in state appropriations for higher education operating expenses by GDP was calculated using data from the National Science Foundation's "Science and Engineering Indicators 2012," Table 8-27.

[61] Public research universities play a critical role in the overall higher education landscape in terms of performing over half of academic R&D, educating a disproportionately large number of students at the undergraduate and graduate levels, and yielding many potential gains for the state and local economies such as the creation of startup companies.

[62] National Science Board, "Diminishing Funding and Rising Expectations: Trends and Challenges for Public Research Universities," (Arlington: 2012). Data pulled from Table: Trends in Enrollment and State Funding for the Nation's 101 Major Public Research Universities.

[63] See, again, Walter Powell and Stine Grodal, "Networks of Innovators," and Muro and Katz, "The New 'Cluster Moment'" for more on the centrality of collaboration to innovation and the many ways that regional industry clusters facilitate such collaboration.

[64] The Rocky Mountain Center for Innovation and Technology will work on technologies and products ranging from advanced alternative fuels for ground and air transportation to next-generation wind turbine systems—all based on technologies developed by NASA, the National Renewable Energy Laboratory, and other federal laboratories. The partnership with NASA is driven by the agency's new mandate to push its technology into the private sector. For more information see www.rmcinnovate.com.

[65] For example, the CSC's membership covers just under 50 percent of private space economy employment, based on Brookings' measurements. Large firms and prime contractors at the top of the supply chain are best represented.

[66] For interesting discussions of aerospace industry institutional arrangements see Belz, "Models for Technology Transfer in the Aerospace Industry;" Charles River Associates, "Innovation in Aerospace and Defense;" Hitachi Consulting, "Creating a Culture of Innovation in Aerospace and Defense;" and R.J. Terrile, "Pathways and Challenges to Innovation in Aerospace," 2010 IEEE Aerospace Conference Proceedings.

CHAPTER VII

[1] Research team analysis of General Services Administration's USA Government Spending database, the Brookings NETS database, and data from the Bureau of Economic Analysis's "Value Added by Industry." To estimate share of total sector income, the team first estimated the average value added per employee by industry in 2010 for all industries represented in the Brookings NETS database that defines Colorado's space cluster. Those averages were then multiplied by the total number of employees within Colorado's space cluster in each industry to arrive at an estimated total value added, or total output, for Colorado's space cluster. That number was then compared to the total value of contracts received by Colorado's space cluster in 2010.

[2] Daniel Pacthod and Michael Park, "How Can the U.S. Advanced-Industries Sector Maintain its Competitiveness?"

CHAPTER VIII

[1] It should be noted here that the Aerospace States Association (ASA) provides one such forum for representing states' interests in federal aerospace and aviation policy. It comprises lieutenant governors and state-appointed delegates. ASA was formed to promote a state-based perspective in federal aerospace policy development. See www.aerostates.org. Colorado should continue to maintain its presence and involvement in ASA.

[2] Those circumstances are: when goals are clearly defined, when potential problem solvers are numerous, and when contenders are willing to bear some of the cost and risks. For more on prize design and success see McKinsey, "'And the Winner Is...,' Capturing the Promise of Philanthropic Prizes" (New York: 2009). For more on the use of prizes in the space business, see Luciano Key, "The Effect of Inducement Prizes on Innovation: Evidence from the Ansari X Prize and the Northrop Grumman Lunar Lander Challenge," *R&D Management* 41 (4) (2011): 360-370, and Lauren Culver and others, "Policies, Incentives, and Growth in the NewSpace Industry." Working Paper (Boston:

Massachusetts Institute of Technology, 2007). For more on the use of prize competitions throughout the federal government, see Office of Science and Technology Policy, "Implementation of Federal Prize Authority: Progress Authority, A Report from the Office of Science and Technology Policy in Response to the Requirements of the America COMPETES Reauthorization Act of 2010" (2012).

[3] See McKinsey, "'And the Winner Is...'" for a list of prize archetypes.

[4] For a richer understanding of the pivotal role played by states in driving innovation forward, see National Governors Association, "Innovation America: A Final Report" (Washington: 2007).

[5] "Proof of concept" is usually the first round of capital that a company attempts to secure. Funds of this type are used to provide evidence that a product, technology, or service is viable and capable of solving a particular problem. "Early-stage" funding supports an intermediate stage of development in which a prototype is being developed or tested but the company is technically still in the product development stage. "Commercialization" is the final stage of technology or product development. At this point the company is ready with its product and moving to introduce it to the marketplace and scale it up. See George Ford, Thomas Koutsky, and Lawrence Spiwak, "A Valley of Death in the Innovation Sequence: An Economic Investigation" (Washington: Phoenix Center for Advanced Legal and Economic Public Policy Analysis, 2007). See also Jesse Jenkins and Sara Mansur, "Bridging the Clean Energy Valley of Death" (Oakland: The Breakthrough Institute, 2011).

[6] Colorado has identified seven advanced industries in the state: aerospace, advanced manufacturing, bioscience, electronics, energy and natural resources, technology and information, and infrastructure engineering.

[7] The Bioscience Discovery Evaluation Grant Program (BDEGP) was created in 2006 by the Colorado General Assembly to grow the bioscience industry in the state. The program, created through H.B. 1001, provides five years of funding through FY 2012–13, at approximately $5.5 million each year. The funds raised from gaming revenues are appropriated through OEDIT. More information about the program is available at www.advancecolorado.com/funding-incentives/financing/bioscience-discovery-evaluation-grants. University technology transfer offices in Colorado were strongly instrumental in the success of the BDEGP program, administering proof of concept grants to advance early-stage research within their respective universities. For instance, the University of Colorado's proof of concept grant has yielded 61 projects, over $185 million in follow-on investment (mostly from private sources), and licenses to 12 Colorado-based companies. E-mail communication from Rick Silva, director, Technology Transfer Office, University of Colorado Denver, January 21, 2013.

[8] As it happens, H.B. 13-1001, known as the Advanced Industries Accelerator Act, has already been introduced in the 2013 General Assembly and would create a program providing universities and companies in the state's advanced industries with three types of technology commercialization grants: proof of concept grants, early-stage capital and retention grants, and infrastructure funding. For more details see www.metrodenver.org/news-center/metro-denver-news/advanced-industries-accelerator-act-announced.html. Care needs to be taken that the bill—which has bipartisan support in the legislature—does not divert funding from university-directed research.

[9] CU-Boulder's AeroSpace Ventures currently provides one such platform for university and industry researchers to work together to advance solutions in climate, weather, and the space environment. For more information see www.colorado.edu/aerospace/AeroSpaceVentures.html.

[10] There is significant interest within the state in defining Colorado's advanced industries and creating an institutional mechanism to promote AI growth across the state. The Colorado Association for Manufacturing and Technology (CAMT)—a statewide manufacturing assistance center dedicated to increasing the competitiveness of Colorado's manufacturers and also serving as the state affiliate of the national Manufacturing Extension Partnership—is actively participating in the discussion on AIs. CAMT is currently working to define the AI ecosystem in a straightforward and practical manner by carving out the component parts of the ecosystem (such as composite and additive manufacturing-focused companies) and defining the capabilities, capacities, and interconnections of those companies to the AI supply chain. CAMT is also supporting the efforts of the still nascent Colorado Alliance for Advanced Manufacturing (CAMA) to promote AIs in the state.

[11] For background on NNMI and the need to scale up a larger network of AI hubs, see Devashree Saha and Mark Muro, "Create a Nationwide Network of Advanced Innovation Hubs" (Washington: Brookings Institution, 2012). See also President's Council of Advisors on Science and Technology, "Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing" (Washington: 2012) and David M. Hart, Stephen Ezell, and Robert D. Atkinson, "Why America Needs a National Network for Manufacturing Innovation" (Washington: Information Technology & Innovation Foundation, 2012).

[12] When awarding federally sponsored research projects, the federal government often requires universities to provide state matching funds or simply gives preference to applicants that demonstrate an ability to provide such matching.

[13] In 2011 CHECRA provided funding for five projects, four of which received $400,000 each and one project which received $150,000. CHECRA had a total income of just over $2 million and distributed $1,750,000 in matching grants. CHECRA gets funding from waste tire fee distribution and the Limited Gaming fund. See "Annual Report of the Colorado Higher Education Competitive Research" (Denver: 2012).

[14] See Sarah Nash, "State-Based R&D Innovation Strategies," in Annex 2: Select State Strategies to Foster Innovation of Research & Development, Innovation, and the Science and Engineering Workforce (Washington: National Science Foundation, 2012). Also see www.malegislature.gov/Laws/GeneralLaws/PartI/TitleVII/Chapter40j/Section4f. The Massachusetts Research Center Matching Grant Program provides state matching funds—20 percent match, up to $2 million—for proposed academic research centers in Massachusetts that

are seeking funding from the federal government, where there is an expectation that the state match will improve the competitive position of the proposal and enhance collaboration with companies in the commonwealth. The program is administered by the John Adams Innovation Institute, a division of the Massachusetts Technology Collaborative.

[15] The Maryland Industrial Partnerships Program (MIPS), for instance, is a good example of a program that provides matching funds for collaborative projects between companies in the state and university faculty and students. These collaborations provide companies access to technology expertise and state-of-the-art university lab facilities and also serve as a mechanism for transferring university technology to Maryland-based firms. For more information see www.mips.umd.edu/overview.html.

[16] There are a number of private efforts in this area that the state should consider leveraging and coordinating. For instance, the Innovation Center of the Rockies—formerly known as the Boulder Innovation Center—provides support for entrepreneurial activities and startups. The Center has entered into a commercialization partnership with CSU's technology transfer office to develop promising technologies in markets such as bioscience, cleantech, aerospace, information technology, and software. Similar partnerships exist with the University of Colorado and the Colorado School of Mines. For more information see www.innovationcenteroftherockies.com. eSpace uses a similar approach in its eSpace Incubator and Venture Design programs. See www.espacecenter.org/sub1.php.

[17] The transfer of technology between universities and industry can happen in several ways, each of which presents a variety of risks and benefits for both partners. Types of transfer include: transfer of university-developed technology to industrial companies under exclusive or non-exclusive licenses; establishment of spin-off companies by university researchers to further develop technology with external investment; industry funding of university research with little or no direct industry involvement in the research; industry funding of university research with significant participation from industry; and industry funding and sharing of existing proprietary technology with the university.

[18] For instance, the University of Colorado, Colorado Springs has initiated an innovative approach to address IP access early in the partnership process. Using a "co-development model" that lists the university and the company as co-developers allows the firm to keep its IP while giving the university a portion of any future profits that the company earns from the new or co-developed product. For more information see Monica Mendoza, "Research Partners: UCCS Creating Legal Terms to Court Private Industry," *The Colorado Springs Business Journal*, November 9, 2012. The University of Colorado is a member of the University-Industry Demonstration Partnership (UIDP)—an initiative sponsored by the National Academies to facilitate industry-university collaboration and best practices—through which CU is exploring ways to streamline the process of engaging with industry. For more information see www.sites.nationalacademies.org/pga/uidp/index.htm.

[19] Darrell West, "Improving University Technology Transfer and Commercialization" (Washington: Brookings Institution, 2012).

[20] Zoltan Acs, "How is Entrepreneurship Good for Economic Growth?" *Innovations: Technology, Governance, Globalization* 1 (1) (2006): 97-107. See also David Audretsch and Max Keilbach, "Does Entrepreneurship Capital Matter?" *Entrepreneurship: Theory and Practice* 28 (5) (2004):419-29.

[21] Kentucky, Michigan, and North Carolina provide useful models for implementation of such programs. Kentucky's SBIR-STTR Matching Funds Program matches, on a competitive basis, both Phase 1 and Phase 2 federal SBIR and STTR awards to high-tech small businesses, ranging from up to $150,000 and up to $500,000, respectively. The program completed its 17th round in October 2012. For more on Kentucky's program visit http://thinkkentucky.com/DCI/DCIFunding.aspx. Michigan's Pure Michigan Venture Match Fund (PMVM Fund) launched in 2012 and matches, also on a competitive application basis, equity investments from qualified venture funds at 50 percent for outside investments of $700,000 to $1,000,000 and with a flat $500,000 award for outside investments of $1 million to $3 million. For more on Michigan's see www.michiganadvantage.org/Pure-Michigan-Venture-Match-Fund. North Carolina taken a slightly different approach with its One North Carolina Small Business Program, which launched in 2006. This program consists of two programs: a North Carolina SBIR / STTR Phase I Incentive Funds Program that reimburses qualified North Carolina businesses for a portion of the costs incurred in preparing and submitting Phase I proposals to the federal SBIR and STTR Programs; and the SBIR / STTR Phase I Matching Funds Program, which awards matching funds to North Carolina businesses who have been awarded a SBIR or STTR Phase I award. To date, the North Carolina program has awarded more than $9 million in state matching funds to 114 projects. This support has helped small businesses create and retain more than 200 additional jobs, most at the managerial, scientific, or technical level; make an additional $14 million in internal capital investments; and leverage more than $38.7 million in external capital investments and $41.8 million in Phase II Federal SBIR / STTR funding. For additional background on North Carolina's program see Sarah Nash, "State-Based R&D Innovation Strategies." Washington State offers Phase 0 awards to assist the state's small businesses by providing funds for SBIR / STTR proposal preparation. These awards are intended to help defray the costs for small businesses applying to these two federal grant programs and increase their chances of submitting a successful proposal. For more on Washington State's program see www.innovatewashington.org/sbir-program-details.

[22] In 2004 the Colorado General Assembly established a Colorado Venture Capital Authority (VCA). The VCA received $50 million in premium tax credits, which were later sold to insurance companies. In 2005, the VCA selected High Country Venture, LLC as a fund manager and established Colorado Fund I, which totaled approximately $25 million. In 2010, the VCA created Colorado Fund II, a second $25 million fund that is also managed by High Country Venture, LLC. Both funds focus on seed and early-stage capital investments.

[23] Russell Nichols, "State Governments: The Latest Venture Capitalists," *Governing* (March 2011).

[24] The VCA may also make an investment in a qualified rural business that is not a seed or early-stage investment if the investment is appropriate and later-stage capital investments are not otherwise available to the qualified rural business.

[25] Research universities across the nation have in recent years stepped up their commercialization efforts. Some examples include the University of Michigan's Wolverine Venture Fund, the University of Texas' UT Horizon Fund, New York University's Innovation Venture Fund, and the University of Washington's W Fund.

[26] Doug Buchanan, "Ohio State, OU Create $35M VC Funding Pool," *Business First*, April 5, 2012. Outside of the United States, Australia's UniSeed is a university-based venture capital fund that operates with investment capital provided by the Universities of Queensland, Melbourne, and New South Wales. For more information see www.uniseed.com.au.

[27] If the Fund of Funds loses money, the state would issue contingent tax credits to the fund's investors to make up for the loss. This lowers the risks for the investors and makes it easier for the Fund of Funds to raise money. To date, no state has had to use tax credits to reimburse investors.

[28] As it happens, Colorado is working on creating a STEM Action Plan, which would be entrusted with the responsibility of coordinating the state's myriad STEM initiatives.

[29] The mission of the Colorado Experiential STEM Learning Network is to implement innovative experiential learning practices in STEM education and foster integrated STEM approaches in Colorado schools. For more information see www.stemconnector.org/state-by-state/colorado.

[30] See Harvard Graduate School of Education, "Pathways to Prosperity: Meeting the Challenge of Preparing Young Americans for the 21st Century" (2011).

[31] For more information on the Jack Swigert Aerospace Academy, see www.spacefoundation.org/education/partnerships/jack-swigert-aerospace-academy.

[32] A number of reports, especially from the OECD, have recommended expanding apprenticeship programs as a way to address issues of skills mismatches, wage inequality, declines in manufacturing employment, and high youth unemployment.

[33] For more details on how states are improving their apprenticeship programs see David Altstadt, "Improving Access to Apprenticeship: Strengthening State Policies and Practices" (The Working Poor Families Project, 2011). Pre-apprenticeship programs are designed to prepare individuals to enter and succeed in apprenticeship programs. Such programs include basic, introductory information about an apprenticeable occupation; some form of entry-level education and skills covering job readiness; specific vocational and occupational elements; and a range of supportive services.

[34] For more information on these two programs see www.interninmichigan.com and www.massitsallhere.com/stayhere.

[35] The Colorado Biosciences Roadmap 2008 had a similar recommendation targeted at the state's bioscience industry. See Battelle's Technology Partnership Practice, "Colorado Biosciences Roadmap 2008" (Battelle Memorial Institute, 2008).

[36] A pioneer in developing industry skills panels, Washington State adopted this approach in 2000 and over the course of the past decade the number of skills panels has expanded both geographically and within industries. In 2008, the Corporation for a Skilled Workforce and the Paros Group published a report for the state which noted that "skill panels have been highly successful at adapting to specific regional and industrial conditions to meet the needs of their members…that have resulted in strong and vibrant partnerships, exceptional products and services, and impressive impacts and outcomes." See, Scott Cheney, Stacey Wagner, and Lindsey Woolsey, "Evaluating Industry Skill Panels: A Model Framework" (Corporation for a Skilled Workforce and Paros Group, 2008).

[37] For a discussion of effective state sector strategies see Lindsey Woolsey and Garrett Groves, "State Sector Strategies Coming of Age: Implications for State Workforce Policymakers" (National Governors Association, Corporation for a Skilled Workforce, and National Skills Coalition, 2013).

[38] Mark Muro and Kenan Fikri, "Job Creation on a Budget: How Regional Industry Clusters Can Add Jobs, Bolster Entrepreneurship, and Spark Innovation" (Washington: Brookings Institution, 2011).

[39] Yongong Wu, "The Effects of State R&D Tax Credits in Stimulating Private R&D Expenditure: A Cross-State Empirical Analysis," *Journal of Policy Analysis and Management* 24 (4) (2006): 785–802.

[40] Matthew Stepp and Robert D. Atkinson, "Creating a Collaborative R&D Tax Credit" (Washington: Information Technology & Innovation Foundation, 2011).

[41] For more information see National Governors Association, "A Governor's Guide to Cluster-Based Economic Development" (Washington: 2002).

[42] Stanford University, the University of Minnesota, and the University of Louisville have all piloted this concept. For more on laboratories, see J. Stephen Rottler, "Clustering Around the Lab—Best Practices in Federal Laboratory Commercialization: Sandia National Laboratories as a Catalyst for Regional Growth." In *Clustering for 21st Century Prosperity* (Washington: National Academy of Sciences, 2012) and Innovation Associates, "Partners on a Mission: Federal Laboratory Practices Contributing to Economic Development" (Washington: 2003).

[43] Stephen Ezell, "Roundtable on Developing and Strengthening High-Growth Entrepreneurship: Perspectives from ITIF." Testimony submitted to the U.S. Senate Committee on Small Business and Entrepreneurship, February 1, 2012.

[44] Committee on NASA's Strategic Direction, "NASA's Strategic Direction and the Need for a National Consensus" (Washington: National Research Council, 2012); Colorado Space Coalition, "Briefing for the Colorado Congressional Delegation" (Summer/Fall 2012); "National Security and the Commercial Space Sector: An Analysis and Evaluation of Options for Improving Commercial Access to Space" (Washington: CSIS Defense-Industrial Initiatives Group, 2010). See also: "National Space Policy of the United States of America" (Washington: The White House, 2010) and National Security Space Strategy: Unclassified Summary" (Washington: Department of Defense and Office of the Director of National Intelligence, 2011).

[45] President Obama signed the National Defense Authorization Act for FY 2013 on January 2, 2013. The legislation authorizes the President to remove commercial satellites and related components and technology from the U.S. Munitions List consistent with the Arms Export Control Act. It remains for the President to remove these technologies from the list, and, following that, for multiple agencies to review each application before any license is granted. For further reading see: Pierre Chao, "Toward a U.S. Export Control and Technology Transfer System for the 21st Century" (Washington: Center for Strategic and International Studies, 2008) and Guy Ben-Ari and Pierre Chao, "Health of the U.S. Space Industrial Base and the Impact of Export Controls" (Washington: Center for Strategic and International Studies, 2008).

[46] President's Council of Advisors on Science and Technology, "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth" (Washington: Executive Office of the President, 2012). For a primer on spectrum policy, see Michael Calabrese, "Some Spectrum Basics" (Washington: New America Foundation, 2012) and J.H. Snider, "The Citizen's Guide to the Airwaves" (Washington: New America Foundation, 2003).

[47] For a survey on the current state of the commercial launch market and options for reform, see "National Security and the Commercial Space Sector: An Analysis and Evaluation of Options for Improving Commercial Access to Space" (Washington: CSIS Defense-Industrial Initiatives Group, 2010).

[48] Those three agencies are the National Science Foundation, the Department of Energy's Office of Science, and the National Institute of Standards and Technology. Appropriate research budgets of other research agencies should be ensured too. President's Council of Advisors on Science and Technology, "Ensuring American Leadership in Advanced Manufacturing" (Washington: Executive Office of the President, 2011) and ibid., "Capturing Domestic Competitive Advantage in Advanced Manufacturing" (Washington: Executive Office of the President, 2012).

[49] President's Council of Advisors on Science and Technology, "Transformation and Opportunity: The Future of the U.S. Research Enterprise" (Washington: Executive Office of the President, 2012).

[50] President's Council of Advisors on Science and Technology, "Capturing Domestic Competitive Advantage in Advanced Manufacturing" (Washington: Executive Office of the President, 2012). See also Devashree Saha and Mark Muro, "Cut to Invest: Create a Nationwide Network of Advanced Industries Innovation Hubs" (Washington: Brookings Institution, 2013) and David Hart and others, "Why America Needs a National Network for Manufacturing Innovation" (Washington: Information Technology & Innovation Foundation, 2012).

[51] Jessica Lee and Mark Muro, "Cut to Invest: Make the Research and Experimentation Tax Credit Permanent" (Washington: Brookings Institution, 2012).

[52] Stephen Ezell and Robert D. Atkinson, "Fifty Ways to Leave Your Competitiveness Woes Behind: A National Traded Sector Competitiveness Strategy" (Washington: The Information Technology & Innovation Foundation, 2012).

[53] See, for example, Stephen Ezell and Robert D. Atkinson, "Fifty Ways to Leave Your Competitiveness Woes Behind: A National Traded Sector Competitiveness Strategy" (Washington: The Information Technology & Innovation Foundation, 2012), 18.

[54] "The Startup Act" (Kansas City: Ewing Marion Kaufmann Foundation, 2011).

[55] President's Council of Advisors on Science and Technology, "Capturing a Domestic Competitive Advantage in Advanced Manufacturing: Report of the Advanced Manufacturing Partnership Steering Committee, Annex 3: Education and Workforce Development Workstream Report" (Washington: Executive Office of the President, 2012).

[56] President's Council of Advisors on Science and Technology, "Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future" (Washington: Executive Office of the President, 2010).

[57] Bruce Katz and Peter Hamp, "Cut to Invest: Create a Race to the Shop Competition for Advanced Manufacturing" (Washington: Brookings Institution, 2013).

[58] President's Council of Advisors on Science and Technology, "Ensuring American Leadership in Advanced Manufacturing" (Washington: Executive Office of the President, 2011).

[59] Karen Mills and others, "Clusters and Competitiveness: A New Federal Role for Stimulating Regional Economies" (Washington: Brookings Institution, 2008).

[60] President's Council of Advisors on Science and Technology, "Transformation and Opportunity: The Future of the U.S. Research Enterprise" (Washington: Executive Office of the President, 2012) and J. Stephen Rottler, "Clustering Around the Lab—Best Practices in Federal Laboratory Commercialization: Sandia National Laboratories as a Catalyst for Regional Growth." In *Clustering for 21st Century Prosperity* (Washington: National Academy of Sciences, 2012).

APPENDIX A

[1] See "The Space Economy at a Glance" (Paris: Organization for Economic Cooperation and Development, 2011) and "The Space Report" (Colorado Springs: The Space Foundation, 2012). In addition, the OECD's 2012 report, "Handbook on Measuring the Space Economy," contains a very useful discussion of the complications of defining the space economy and offers a number of alternative definitions.

[2] Mark Muro, Jonathan Rothwell, and Devashree Saha, "Sizing the Clean Economy" (Washington: Brookings Institution, 2011).

[3] "Colorado Industry Cluster Profile: Aerospace" (Denver: Metro Denver EDC, 2012). "Industry Cluster Methodology" (Littleton: Development Research Partners, 2011).

[4] Princeton Synergetics, "Colorado's Strategic Plan for Space" (Colorado Springs: The Space Foundation, 2000).

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