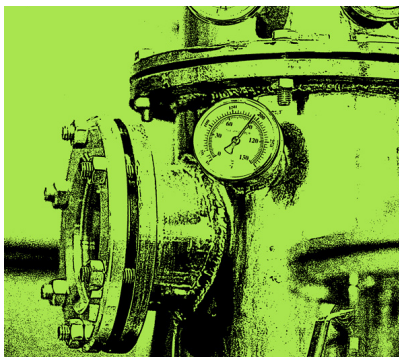
The Emergence of an Innovation Cluster in the Agricultural Value Chain along Colorado's Front Range



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Innovators in an increasingly integrated Agriculture-Water-Food-Beverage-Bioenergy innovation ecosystem are gathering and growing along Colorado's Front Range, creating next-generation technologies and business models to nourish, refresh, and energize the world.

Colorado State University

Acknowledgments

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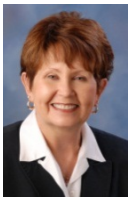

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Executive summary

Colorado has long embraced **agriculture** as central to its economy and **innovation** as an essential driver of economic growth. These two—***agriculture*** and ***innovation***—have been converging in Colorado for some time now, and the pace is picking up. This study proposes that a number of geographic, demographic, and economic factors are driving investment and engagement in innovation in the agricultural and food system, and the essential elements are in place along the Colorado Front Range for the emergence and growth of an innovation-led industry cluster in agriculture and food.

The objectives of this study

- To **recognize the emergence of an innovation-led industry cluster,** reframing conventional views of the industry to consider overlapping interests across the entire integrated value chain of agriculture.
- To **identify the geographic footprint** of this emergent innovation cluster, deriving it empirically from a landscape analysis of innovation data. This is important to update conventional notions of agricultural innovation as only involving rural areas.
- To **explore the fundamental factors that are favoring the Colorado Front Range** as a location for innovation in the agricultural value chain, including geographic, demographic, and economic factors.
- To **identify the main technology categories** in which Colorado firms and research institutions are innovating, as well as **their structural interrelationships** within the value chain.
- To **provide an inventory of companies and organizations** in Colorado that are engaged in innovation in the agricultural value chain, and their locations.
- To **recommend next steps** for encouraging growth of this emergent innovation cluster, such as cultivating talent, coordinating mechanisms for collaboration, and financing of innovation.

What is an innovation cluster? Why is it important?

An innovation cluster has been defined as "*a geographically proximate set of interconnected companies and associated institutions in a particular field*" where "*co-location of the various stakeholders accelerates knowledge sharing and development of new products and services*." The emergence and growth of an innovation cluster has implications both for the industry and for the geographic region within which the cluster arises. **Companies benefit** from economic advantages of engaging within a cluster. **The region benefits** from increasing employment and tax revenues, resulting in better services and a higher standard of living. **The global economy benefits** too from the emergence of a regional ecosystem driving innovation.

The value chain of agriculture dictates the structure and scope of its innovation ecosystem

Understanding the full scope and structure of **the value chain of agriculture** is crucial to seeing the range of overlapping interests and thus the potential scope for clustering dynamics within what is effectively **an agricultural-water-food-beverage-bioenergy complex**. The value chain of agriculture can be understood to encompass "*the entire flow of inputs and outputs that enable agricultural enterprises to realize the value of their unique capital base by meeting the needs of final consumers."* The value chain involves greater than 200 separate industry subsectors. These range from farm land, irrigation, labor, and other agricultural inputs, to commodity marketing and processing, food and beverage manufacturing, wholesale, and retail of food, beverage, and other agriculturally-derived products and services.

The global imperatives, or opportunities, for innovation in agriculture

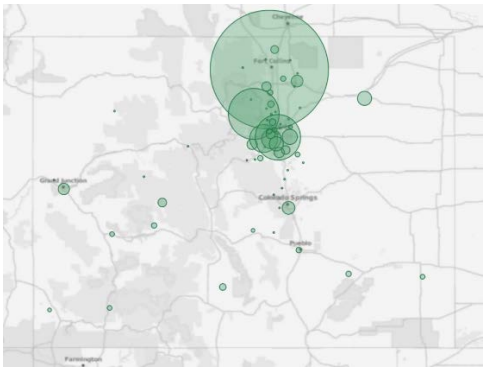
Globally, agriculture confronts a number of cross-cutting challenges. Global **growth in commodity prices** is a powerful indicator of the need—and the value proposition—for innovation in agriculture. Prices have risen at an average pace of 6 percent annually since 2000, after almost a century of real food prices declining by an average of 0.7 percent per year. A number of factors are driving **fundamental resource scarcity** in agriculture and food on both the demand side and the supply side. These scarcity factors can be interpreted as imperatives—or, conversely, as opportunities—for innovation.

Surveying the landscape of agricultural innovation in Colorado

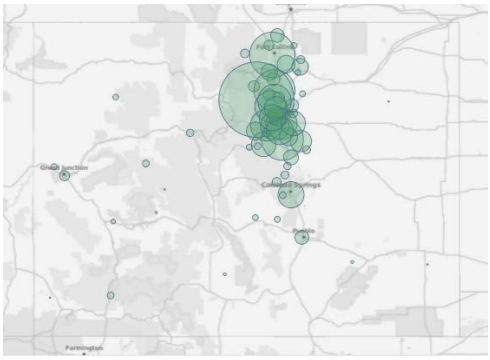
To understand who is innovating in the agricultural and food value chain within Colorado, and where, a **landscape analysis** mapping two R&D output proxies—scientific publications and U.S. patents—is conducted to provide a cross-sectional view of Colorado's evolving science base and Colorado's outputs of technological innovations.

Colorado's science base in agriculture: Between 1990 and 2012, Colorado authors generated 14,913 scientific publications in the fields of science that encompass the industry's value chain (including agriculture, agronomy, horticulture, plant sciences, water, soil sciences, entomology, veterinary health, and food science.) Of these scientific publications, 86 percent were by authors at public sector institutions (universities, public agencies, and nonprofits), 11 percent were by authors in industry, and a handful, just over 3 percent, were published jointly by authors at both (considered "public-private" collaboration). Overall, publication rates have grown steadily at 3.25 percent per year over the past two decades, from about 400 per year in 1990 to about 800 per year in 2012. Mapping where publications come from within Colorado, shows over 95 percent concentrated the northern Front Range and metro Denver. The single largest share is from Fort Collins.

Colorado's inventions in agriculture: During the same years Colorado inventors generated 2,548 patent applications and 2,455 granted U.S. patents in these fields of technology, for a combined total of 5,003 patent records. Of these, 10 percent were by public sector inventors at universities, public agencies, and nonprofit, 85 percent were by private sector inventors in industry, and a handful, just over 5 percent, were by inventors at both (considered "public-private" collaborators). Patenting grew at an average growth rate of 6.5 percent per year. A mapping of inventors within Colorado shows about 90 percent concentrated in the northern Front Range and Metro Denver. The single largest share is from Boulder.



a. Scientific articles published, by city of author's institutional affiliation



b. U.S. patents filed and granted, by city of inventor's residence

Some observations based on this landscape analysis:

- Colorado's R&D in agriculture and food is highly **concentrated geographically** within the relatively compact urban corridor including metro Denver and the northern Front Range.
- Colorado's R&D activities in agriculture and food have been **growing** two to four times **faster than the state's economy** overall, over the last two decades.
- Patenting activities have been growing two times faster than scientific publishing, over the last two decades, indicating that Colorado's **private-sector R&D** in agricultural and food technologies has been expanding relative to the state's already sizable science base.

Why the Colorado Front Range?

Several fundamental economic, geographic, and demographic factors that, together, are likely responsible for driving the emergence of an innovation cluster in the agricultural value chain along the Front Range:

Colorado has a long history of innovation in agriculture, food, and beverage: The Front Range has given rise to such companies as Coors (founded in 1873), Monfort (1930), Leprino (1950), and Celestial Seasonings (1969). These companies have shaped the region's economy and created a culture in which agriculture and food entrepreneurs are seen as pillars of the community.

Colorado has become a nationally recognized center of innovation and entrepreneurship: For example, in 2013 the U.S. Chamber of Commerce ranked Colorado number two for entrepreneurship and innovation, and in 2014 the Kauffman Foundation ranked Colorado number five for entrepreneurship. Such national comparative studies and indices are general indicators that the region has a good mix of conditions required to foster innovation in any industry.

The Front Range enjoys a quality of life that attracts and retains talent: The most important factor, in any industry, for building innovation capacity is attracting and retaining talent. The region's quality of life makes it possible for the Colorado Front Range to attract and keep world class management and scientific talent from the coasts and from other major metro areas.

The major research institutions in the state are strategically co-located: Rather than being dispersed widely around the state, the major research universities and federal research labs in Colorado are all situated within an hour's drive from one another. This relatively close co-location facilitates ongoing collaboration and exchange among these research institutions and companies in the region.

The Front Range has one of the highest regional concentrations of publicly-funded agricultural R&D in the nation: In 2011, Colorado was third in the nation in federal agricultural R&D spending, exceeded only by California and Texas. Most of this funding was directed at the universities and USDA labs on the Front Range.

Close proximity between major production agriculture and a major urban corridor: This proximity brings the agricultural infrastructure and workforce of northern Colorado into direct contact with an increasingly dense non-agricultural population, a growing high-tech urban and suburban business community, and increasingly sophisticated retail markets.

The sustainability challenges confronting Colorado agriculture are shared in many regions around the world: The benefits from tackling the cross-cutting challenges endemic to Colorado are not limited to the region. The market for innovations that can solve Colorado's problems is decidedly global.

An inventory of Colorado innovators in the agricultural value chain

Who are the innovators in the agricultural value chain in Colorado? And what are the main technologies or industry sectors in which they are innovating? An inventory was taken of all private sector firms and public sector organizations engaged in innovation, based on (1) those companies and organizations generating the publications and patents identified in the landscape analysis, and (2) referrals from industry associations, networking events, interviews, news accounts, and other expert sources. The inventory includes 550 innovators, of which 460 are private-sector companies and 90 are public-sector (academic, non-profit, and government) organizations.

There appears to be a critical mass of innovating organizations active in Colorado within each of a dozen categories:

1. Innovators in **water** technology, infrastructure, analytics, and management
2. Innovators in **soil fertility** and **pest control**
3. Innovators in **plant genetics** and new crop varieties
4. Innovators in **animal** health, nutrition, and herd management
5. Innovators in **agricultural information systems**
6. Innovators in **sensors**, testing, and analytics for product quality and biosafety
7. Innovators in **bioenergy**
8. Innovators in commodity **processing** and food **manufacturing**
9. Innovators in dairy production and **dairy** product manufacturing
10. Innovators in **beer, wine, & spirits** production and marketing
11. Innovators in **natural, organic, and local** foods and marketing
12. Innovators in "**Fast & Fresh**" food service
13. Innovators in other emergent subsectors

Next steps

Based upon this analysis, several next steps are recommended for cultivating and capitalizing upon this economic growth opportunity.

0. ***As a prerequisite, realize the economic significance and technological sophistication of innovation activities occurring in the agricultural and food value chain.*** The economic significance of introducing game-changing innovations within agriculture, food, water, and bioenergy present real economic opportunity for Colorado.

1. ***First and foremost, develop and attract talent.*** Talent is identified, repeatedly, as the most important factor driving growth of an innovation cluster. The availability of skills is the factor most commonly cited by the executives interviewed for this study. Talent can be attracted to Colorado from other states based on the high

quality of life. To develop talent, it falls primarily to universities to supply the kind of high-quality professionals needed in the sciences, engineering, management, law, and finance to really drive the growth of an innovation cluster. For those in the farming and ranching community, there is opportunity for younger generations coming off the farm to combine their knowledge of agriculture with specialized skills in science, engineering, or business.

2. ***Identify and support existing activities, and connect existing companies.*** There is already much going on that has arisen in response to market forces and thus has real market potential. Growth of a cluster needs mechanisms to facilitate mixing and the spawning of collaborations. State government and the universities are in an excellent position to invite private sector innovators into networking events and thereby into deeper discussions.

3. ***Exercise tolerance of different points of view.*** Innovation is, by its very definition, a challenging of the status quo, and it requires a willingness to question how things are done. As a state, Colorado has recently been at the center of national debates, such as labelling of genetically modified organisms or cultivation of industrial hemp. Simply taking sides and defending ones interests is not helpful. Innovation requires listening to other's concerns, respecting others' intellectual and emotional responses to issues, and seeking common ground wherein solutions may lie.

4. ***Coordinate vertically, to pilot locally, then sell globally.*** Given the complexity of the value chain, vertical coordination is required for piloting many new technologies. The necessary upstream and downstream partners can be found in the Front Range. And, the region's market is large enough to grow within, before seeking to expand nationally and even globally.

5. ***Develop financing mechanisms to assure access to risk capital.*** There may be new opportunities for agricultural innovation by creating financing mechanisms that bring together the market knowledge of agriculturalists with the risk capital expertise of venture investors.

6. ***Take the long view.*** The cultivation of an innovation cluster is a long term effort, measured in decades. By some measures, innovation in the agricultural and food value chain has been mounting already in Colorado for at least two decades. Success may require another decade of dedicated effort.

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Photo courtesy of Dan Hilleman

Section 1. Introduction

Colorado has long embraced agriculture as central to its economy and its Western way of life. Colorado has also long embraced innovation as an essential driver of economic growth and part of its pioneer culture. Yet, Colorado has not always put these two together, at least within the public imagination. But, these two—*innovation* and *agriculture*—have been converging in Colorado for some time now, and the pace is picking up.

A number of geographic, demographic, and economic factors are driving greater investment and engagement in innovation in the agricultural and food system in Colorado. These forces are particularly strong in the Denver metro region and the northern Front Range. A number of companies and investors have taken note of these factors—or have happily stumbled upon them—as they have started new ventures, invested in existing businesses, or moved operations into this region. These factors include the quality of the region's talent pool, the strength of public research institutions, the sheer amount of primary agricultural production, the proximity of that agricultural production to other economic activities, and the size of the local consumer market. The essential elements are in place for the emergence and growth of an innovation-led industry cluster in agriculture and food along the Colorado Front Range.

Public recognition of this innovation cluster has understandably been slow. Perhaps it is because agriculture is still seen by many in Colorado as an established, mature, primary industry, largely confined to rural regions. Many see agriculture as tied to a more traditional way of life and engaged in the low-margins business of producing a handful of well-known commodities. At the same time, popular images of innovation are often more closely associated with "hi-tech" industries, like semiconductors, software, or aerospace. There are other reasons that innovation in agriculture may get overlooked. Some of the most interesting innovation going on within the agricultural value chain are readily associated with other industries, such as biotechnology, clean tech, manufacturing, retail, or tourism. It may also be due in part to the size and complexity of the value chain, with interrelated industry sectors and a wide range of different production methods and technologies being utilized. It is difficult for the public—and even for many agricultural professionals—to recognize and account for all of the various businesses that work together to feed, clothe, and fuel today's consumers.

Innovation in the agriculture and food value chain is of crucial importance. It is what arguably kept agricultural production ahead of global population growth during the 20th century, averting massive famine.[1] Further innovation will be essential to achieving an additional 70 percent of global agricultural production by 2050 to meet the needs of a largely middle class population of 9 billion,

[1] D. Gale Johnson, "Agriculture and the Wealth of Nations," (1997) *American Economic Review* 87(2): pages 1-12.

while sustaining the quality of our landscapes and water resources.[2] Many potential efficiency gains and quality improvements can be made to the current system. Yet, many potential innovations go beyond single, one-off, incremental improvements and will necessarily involve multiple players bound together in complex supplier-buyer or competitor relationships.

The value chain of agriculture has strong internal connections. Innovative changes introduced in one part of the value chain can impact a number of others, either directly or indirectly. For example, an innovative restaurant chain with a new business model can create new requirements for its wholesale food suppliers. That, in turn, can affect what is profitable for farmers to produce, which, in turn, can change the kinds of fertilizers or animal health supplements that they utilize and, therefore, purchase from farm and veterinary suppliers. Because of these deep interdependencies, vertical and horizontal coordination can help the introduction of an innovation to succeed. A lack of coordination can stymie or stall innovation. One of the fundamental tenants of cluster theory is that vertical and horizontal coordination are enhanced when all of those involved are co-located within a single geographic region.

Innovation can drive Colorado's economic development in a number of ways. The most significant economic benefits result when new products and services are introduced that make life better for consumers. Other impacts come from reducing the costs—or increasing the efficiencies—of providing already familiar products and services. Yet, the activities of undertaking innovation are, in themselves, primary drivers of economic development—whether it be conducting R&D, consulting for clients, launching new ventures, or providing specialized business, legal, and financial services. These activities require highly-skilled and well-paid knowledge workers. When adopted in the market, an innovation can make profits for the company that introduces it. While many of these economic development benefits are realized globally, or at least nationally, they can particularly benefit the region where the innovator is located and its innovation activities are conducted.

The objectives of this study

- To **recognize the emergence of an innovation-led industry cluster** by reframing conventional views of the industry to consider overlapping interests across the entire integrated value chain of agriculture.
- To **identify the geographic footprint** of this emergent innovation cluster, deriving it empirically from a landscape analysis of innovation data. This is important to update conventional notions of agricultural innovation as only involving rural areas.

[2] Pardey, P. G., Beddow, J. M., Hurley, T. M., Beatty, T. K.M. and Eidman, V. R. (2014), A Bounds Analysis of World Food Futures: Global Agriculture Through to 2050. *Australian Journal of Agricultural and Resource Economics.*

- To **explore the fundamental factors that are favoring the Colorado Front Range** as a location for innovation in the agricultural value chain, including geographic, demographic, and economic factors.
- To **identify the main technology categories** in which Colorado firms and research institutions are innovating, as well as **their structural interrelationships** within the value chain.
- To **provide an inventory of companies and organizations** in Colorado that are engaged in innovation in the agricultural value chain, and their locations.
- To **recommend next steps** for encouraging growth of this emergent innovation cluster, such as cultivating talent, coordinating mechanisms for collaboration, and financing of innovation.

What is an innovation-led industry cluster?

Silicon Valley is the quintessential innovation-led industry cluster. It began with the spawning of a handful of businesses with expertise in silicon-based computer chip technologies, and later blossomed into related software and internet businesses. Napa Valley became the leading cluster in the U.S. for innovation in the wine industry. Detroit has concentrated expertise in automotive technologies; Northern Georgia, in textiles and carpet mills; and Hollywood, in movies.

Michael Porter popularized the concept of an **industry cluster** in the late 1990s. as "*a geographically proximate set of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities.*"[3] **Innovation** can be broadly understood as *technological, organizational, or marketing changes that improve economic productivity, increase the value of products and services, or improve other attributes, such as environmental sustainability*. Combining these concepts, an **innovation-led industry cluster** is a community of companies and research institutions that "*involves some degree of R&D*" and in which the "*co-location of the various stakeholders accelerates knowledge sharing and development of new products and services*."[4] When they are located in the same region, companies find it easier to share information, tacit capabilities, specialized human capital, and other common-access intangible resources than when they are located at a distance from one another.

The dynamics of innovation-led industry clustering holds important implications both for the industry of which they are a part as well as for the geographic region within which such a cluster arises. For firms competing within an industry, as they gain advantage by introducing new technologies,

[3] Michael Porter, *Clusters, innovation, and competitiveness: New findings and implications for policy*, Stockholm, January 2008, cited in The Economist Intelligence Unit (EIU), *Fostering innovation-led clusters: A review of leading global practices*, London, 2011.
[4] Navi Radjou, Judge Business School, University of Cambridge, cited in EIU, *ibid.*

their production costs decrease or revenues increase, increasing profits and improving their competitive position within the national or global industry. As those companies succeed and grow, new knowledge workers are attracted into the region where they are located, following the new employment opportunities created.

Other companies located in that same region are then able to pull from a more skilled labor force. As suppliers and buyers locate into the area, coordination costs decrease and opportunities for more complex vertically-coordinated innovation are created. According to Porter, "*clusters also often extend downstream to customers and laterally to manufacturers of complementary products and to companies in industries related by skills, technologies, or common inputs.*"[5]

Companies within a cluster have greater incentive to invest in shared resources—such as specialized workforce training programs or testing laboratories—which, in turn, further increase productivity and drive down the costs and risks of innovating within that regional cluster. As the industry grows, increasing employment and sales, tax revenues increase for local governments, resulting in better services and a higher standard of living.

How are clusters created?

What is it that causes firms initially to locate together and begin to synergize? Is it simple coincidence? Is it public funding of research and development institutions? Is it concentration of the supply chain? The origins and drivers of cluster growth have been debated for decades. Different theories have pointed to a range of important behavioral, geographical, and technological factors.

One pioneering theorist, Stanford sociologist Woody Powell, explains that "*spatially concentrated production involves the cooperation of local government, proximity to centers of higher education, a highly skilled labor pool, extensive ties to research institutes and trade associations, and cooperation among firms with specialized skills and overlapping interests*." Powell notes other key causes, including the desire to reduce transportation costs of materials by co-locating all parts of the supply chain in the same region, emergence of specialized financing of the industry's activities, and the quality of life in the region attracting and retaining highly-mobile knowledge workers. Culture can also play an important role in cluster formation as "*diversity of talent, trust across social barriers, motivations that rise above short term gain, and social norms that promote rapid promiscuous collaboration and experimentation among individuals*" all contribute to cluster formation.[6]

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[5] Michael Porter, "Clusters and the New Economics of Competition," *Harvard Business Review*, November-December 1998, pages 77-90.
[6] Walter Powell, "Neither Market nor Hierarchy: Network Forms of Organization," *Research in Organizational Behavior*, Volume 12, 1990, pages 295-336.

The value chain of agriculture

Understanding the full scope and structure of the value chain of agriculture is crucial to understanding the scope of overlapping interests and thus the potential scope for innovation-led clustering dynamics. While the value chain is centered on crop and livestock production, it includes much more. (See Figure 1, next page.) According to a 2013 study by Colorado State University[7], the **value chain of agriculture** can be understood to encompass *the entire flow of inputs and outputs that enables agricultural enterprises to realize the value of their unique capital base by meeting the needs of final consumers*. The unique capital base of farms and ranches consists of natural capital (land and water), physical capital (equipment, livestock and crop inventories), specialized human capital, and financial capital owned and employed by farm and ranch operations. In 2011 the supply of agricultural inputs—such as seeds, fertilizers, feed supplements, and fuel—by Colorado agribusinesses contributed $2 billion to the state economy. Colorado farms and ranches produced more than $8 billion worth of crop and livestock harvests. Economic activity utilizing those harvests—including commodity marketing, processing, and food and beverage manufacturing—was over $15 billion. The total retail value of products sold in Colorado that derive from agricultural production was over $28 billion. Ultimately, any economic activity derives its value from what final consumers are willing to pay for its contribution to their wellbeing. Altogether, the value chain of Colorado agriculture involves more than 200 separate industry subsectors, as categorized by official NAICS business classification codes.[5]

Private sector R&D expenditures for the agriculture and food value chain was almost $20 billion worldwide in 2007, according to a recent analysis by the USDA Economic Research Service.[8] In high income countries, such as the U.S., spending on agricultural and food R&D is almost evenly split between the public and private sectors. In evaluating private sector R&D, the USDA study considers innovation in nine industry sectors along the value chain: (1) crop genetic improvement, (2) crop protection chemicals, (3) fertilizers, (4) farm machinery, (5) animal health, (6) animal genetic improvement, (7) animal nutrition, (8) food and beverage manufacturing, and (9) biofuel production. The study finds that R&D trends have been uneven across these nine sectors. R&D has been growing most quickly in crop genetics, farm machinery, and food manufacturing, but has been declining in crop protection chemicals and animal nutrition. The USDA study also finds that private sector R&D in each of the nine sectors has come to be quite concentrated into just a few large multinational companies. This global concentration has significant implications for regional efforts in agricultural R&D.

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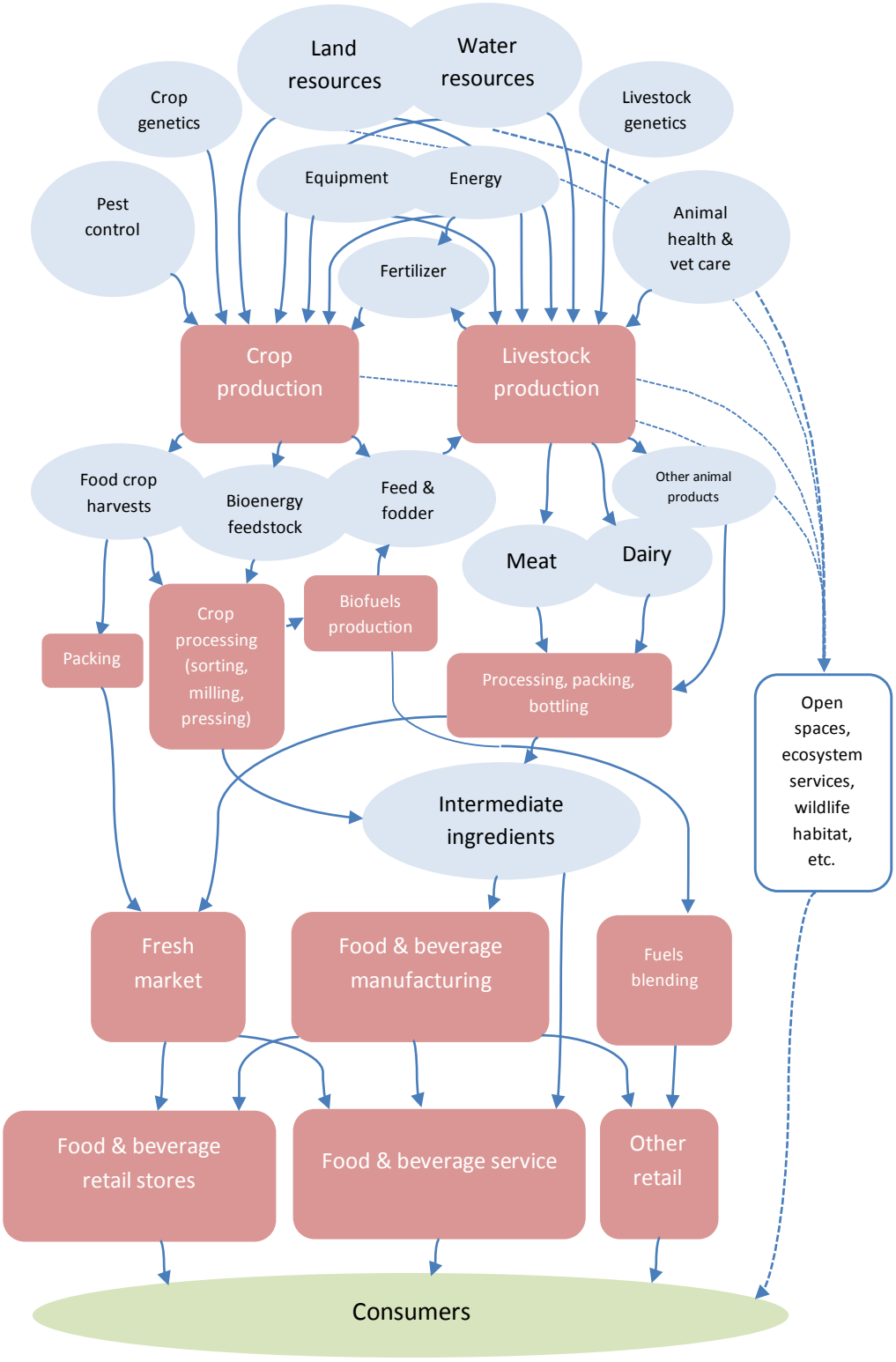
[7] Gregory Graff, Ryan Mortenson, Rebecca Goldbach et al, *The Value Chain of Colorado Agriculture*, Colorado State University, February 2013.

[8] Kieth Fuglie, Paul Heisey, John King et al, *Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide*, USDA-ERS, Economic Research Report Number 130, December 2011.

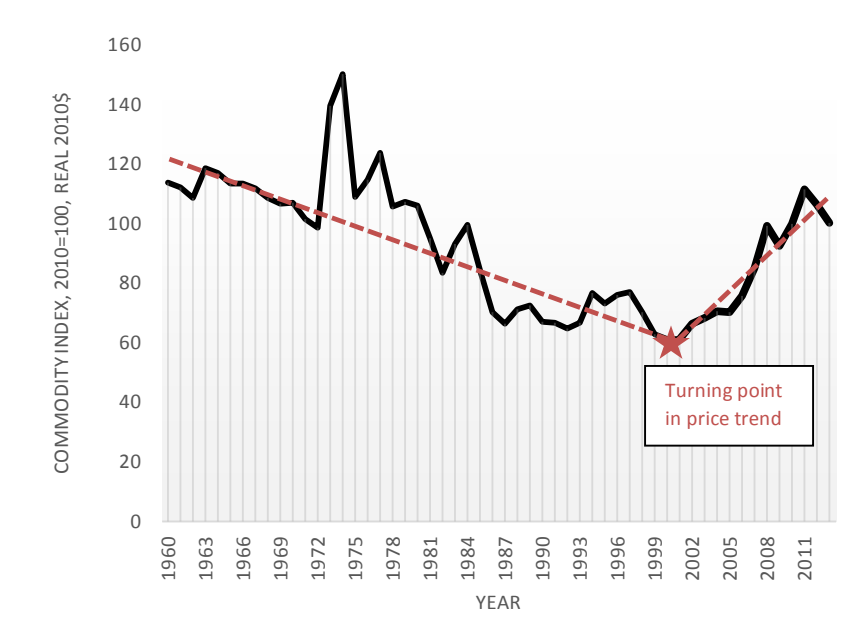
Figure 1. Given the complexity of the industry's value chain, innovation in one sub-sector can impact others to which it is linked vertically or horizontally.



Global imperatives for innovation in agriculture

Globally, agriculture confronts a number of cross-cutting challenges that can be interpreted as imperatives—or, conversely, as opportunities—for innovators. According to analysts at McKinsey Global Institute, these challenges are evidenced by global commodity price trends, which shifted fundamentally around 2000.[9] After almost a century of real food prices declining by an average of 0.7 percent per year, real food prices have risen at an average pace of 6 percent annually since 2000 (illustrated in Figure 1). This is a response by global markets to fundamental resource scarcity.

Figure 2. The shift in global agricultural commodity prices around 2000 signals a new global reality of resource scarcity.



Data source: World Bank, Global Economic Monitor (GEM) commodities database, 2014

At the same time, agricultural commodity prices have become more volatile since 2000. This is also understood to reflect fundamental resource scarcity, according to McKinsey Global Institute. As global demand grows, the quantities demanded in the market at a given point in time can exceed the capacity of farmers and agribusinesses to respond. Already stretched to their current capacity limits, farmers and agribusinesses find it difficult to react quickly to

[9] Richard Dobbs, Jeremy Oppenheim, Fraser Thompson, et al, *Resource Revolution: Tracking global commodity markets*, McKinsey Global Institute, September 2013.

meet such surges in demand. The market response is a temporary spike in prices.

Finally, agricultural commodity prices and energy commodity prices have come to be much more closely linked, such that when energy prices increase, it can be expected that food prices will increase as well. This is due both to the growing importance of energy as an input to agricultural production as well as to the growing importance of agricultural commodities as an input to energy markets, given the rise of biofuels.

According to McKinsey Global Institute, a number of factors can be understood to be driving fundamental resource scarcity in agriculture:[10]

- Aggregate demand continues to increase with growth in global population. We now have 7.2 billion mouths to feed, while mid-line U.N. estimates project population will reach 9 to 10 billion by 2050.

- Demand increases more rapidly as *per capita* incomes rise. In particular, world meat consumption is growing rapidly, driven by the growing numbers and affluence of middle-income urban consumers in emerging economies like Brazil, India, China, and South Africa. Production of meat is more resource intensive than production of crop-based foods.

- Demand from biofuels accounts for an ever greater share of global grain. While fermentation produces distillers' grains (DGs), which are used as livestock feed, a growing share of primary agricultural productivity is being directed toward energy markets.

- Agricultural practices in many developing countries—such as parts of China and Latin America—have converged with agricultural practices in developed countries. Where this has occurred, yields have converged and there are no longer gains to be realized from modernization and adoption of "best practices." Further yield increases will be more incremental.

- Prime agricultural lands are being displaced by urbanization in both developed and developing countries around the world.

- A share of existing agricultural lands are being degraded by soil nutrient depletion and soil salinization.

- New agricultural lands that could be brought into production are of more marginal quality, are not as well connected to transport infrastructure (such as in Africa or parts of Latin America), or are

[10] Dobbs et al, McKinsey Global Institute, 2013.

located in countries with higher levels of conflict or political risk (such as Ukraine).

- Limits on water availability, due to competition with other uses, is slowing expansion of irrigation on agricultural lands and, in some regions, removing irrigation water from agricultural lands.

- Pubic demand for improvements in environmental quality and product safety, in both developing and developed countries, is leading to greater regulatory requirements being placed on agricultural production practices. This can increase costs and curtail productivity.

- Policies imposed in some countries constrain the adoption of newer yield-enhancing technologies, such as biotechnology.

The global imperatives for innovation are to come up with answers to these scarcity challenges. Many can be met by changes in technology or production practices to increase productivity or to decrease waste and inefficiency. Other scarcity challenges can be met by new business models, bringing the virtues of market discipline and price signals to bare on resource allocations heretofore plagued by market failures.

Photo courtesy of Dan Hilleman

Section 2. Surveying the landscape of agriculturally-related R&D in Colorado

Innovation can be difficult to observe, let alone to quantify. Yet, innovation can be thought of as a process that requires inputs of time and effort—which can be measured by proxies such as R&D expenditures or numbers of scientists, engineers, or other "knowledge workers" employed. The innovation process also generates outputs of new knowledge and technologies—which can be measured, albeit imperfectly, by proxies such as scientific publications, patents, clinical trials or field trials, new firm births, or new product launches.

To understand, in a systematic fashion, who is innovating in the agricultural and food value chain and where, within the state of Colorado, we conducted a **landscape analysis** of R&D indicators. Landscape analyses are used by governments and policymakers "*to map scientific and technological trends within specific fields of science and technology… along temporal, technical or spatial dimensions… to represent network connections or the density of clusters of scientific or technological fields.*" [11] This landscape analysis draws upon two R&D output indicators: peer reviewed scientific publications and patents. The results provide a cross-sectional view of Colorado's evolving science base and its output of technical inventions within the agricultural and food value chain.

Colorado's science base in agriculture and related fields

Colorado is one of the largest performers of research under USDA funding in the nation. In 2011 (the latest year for which data is available) Colorado was third among states in conducting federally funded agricultural R&D, at $196 million, exceeded only by California and Texas. The lion share of this was directed at the universities and USDA labs in metro Denver and the northern Front Range, driving one of the highest regional concentrations of publicly-funded agricultural R&D in the nation.

Table 1. Top states by federal agricultural research expenditures

		USDA research funding *(2011)* *$ million*	***State population*** *(est. 2011)*	***Gross state product*** *(2011)* *$ billion*
1.	California	$ 411	37,691,912	$ 2,030
2.	Texas	$ 298	25,674,681	$ 1,357
3.	Colorado	$ 196	5,116,796	$ 266
4.	Pennsylvania	$ 190	12,742,886	$ 610
5.	Nebraska	$ 179	1,842,641	$ 98
6.	Maryland	$ 162	5,828,289	$ 326
7.	North Carolina	$ 161	9,656,401	$ 430

Sources: *USDA CRIS; US Census Bureau; US Bureau of Economic Analysis*

[11] Tania Bubela, Richard Gold, Gregory Graff, et al. "Patent landscaping for life sciences innovation: toward consistent and transparent practices," *Nature Biotechnology*, Vol. 31, No. 3, March 2013, pages 202-206.

To characterize the activities and dynamics of Colorado's science base in agriculture and related disciplines, the Web of Science (WoS)—a leading global database of scientific and technical publications provided by Thomson Reuters—was searched for all publications between 1990 and 2012 by authors with a Colorado address, in all major disciplines related to the agricultural value chain, including the fields of agriculture, agronomy, horticulture, plant sciences, water, soil sciences, entomology, veterinary health, and food science.

This search retrieved 14,913 publications. Of these, 86 percent were by authors at universities, public agencies, and nonprofit research institutions (collectively considered "public sector" R&D), 11 percent were by authors employed in industry (considered "private sector" R&D), and a handful, just over 3 percent, were published jointly by authors at public sector and private sector organizations (considered "public-private" collaboration). As may be expected, the large majority of publications come from public sector R&D, as researchers at universities and government labs are much more likely than researchers at companies to use publication as a primary mode of knowledge dissemination. Overall, the state's rate of production of scientific publications in this industry has grown steadily over the past two decades, doubling from about 400 per year in 1990 to about 800 per year in 2012, following an average rate of growth of 3.25 percent per year (Figure 3).

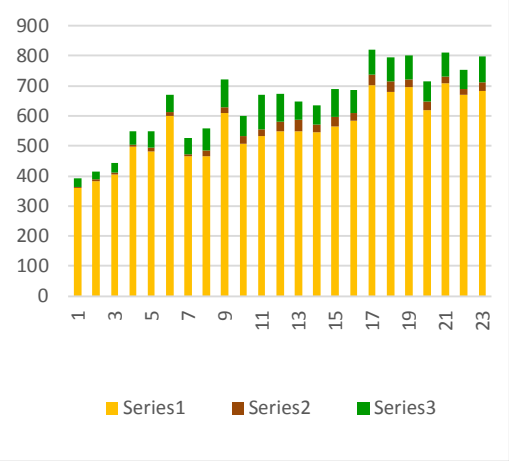


Figure 3. Scientific and technical publications by Colorado authors in agricultural science, food science, water, animal health, bioenergy, and related disciplines.

Data source: *Web of Science*

Relative to the size of the state's economy, Colorado's output of scientific publications in the agricultural sciences and related disciplines is more than double that of the national average and other states, such as California and Texas, which conduct large amounts of agricultural research, (Figure 4). Only North Carolina, with a level of USDA funding and state GDP comparable to that of Colorado (see Table 1), has a relative rate of agricultural publications comparable to Colorado.

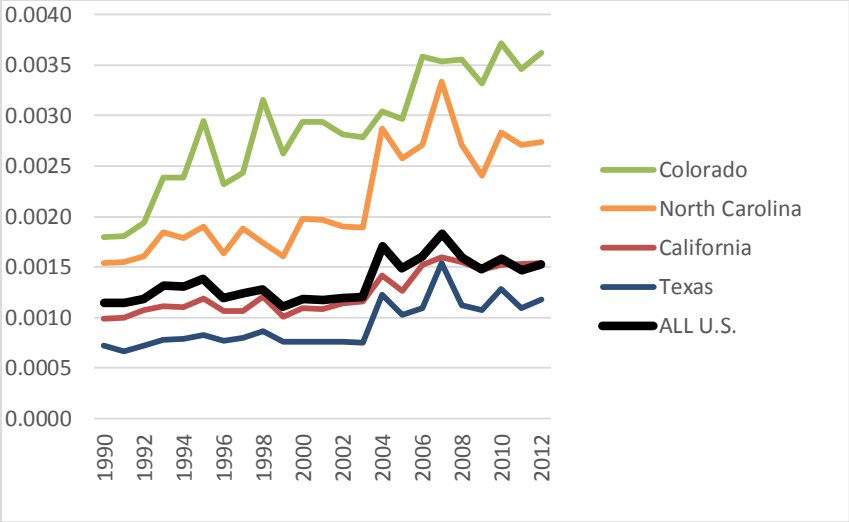


Figure 4. The ratio of annual scientific publications in agriculturally-related disciplines per million dollars of state GDP, as an indicator of the intensity of agriculturally-related research activities relative to overall economic activity

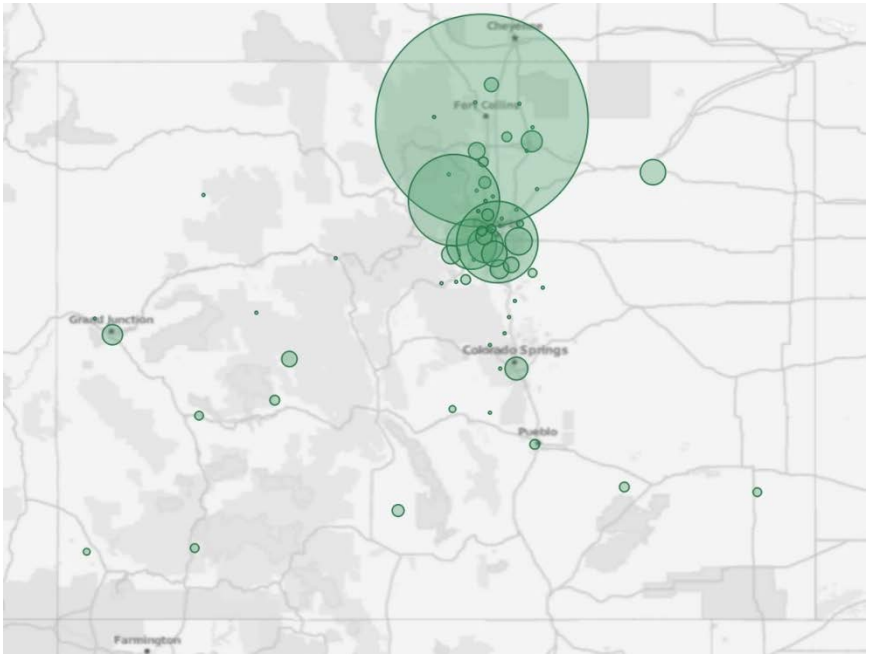
Data sources: *Web of Science; US Bureau of Economic Analysis*

Publications were mapped within the state of Colorado, based on location of the organizations with which authors are affiliated (Figure 5.a, next page). Over 95 percent of the agriculturally-related research in Colorado occurs in the northern Front Range and metro Denver, with the single largest share from Fort Collins. This is not surprising, given that Fort Collins is home to Colorado State University, with major programs in agriculture, veterinary science, natural resources, water, and food science. Fort Collins is also home to several federal laboratories, including the USDA Agricultural Research Service (ARS), the USDA Animal and Plant Health Inspection Service (APHIS), the USDA National Center for Genetic Resource Preservation (NCGRP), the U.S. Forest Service, the U.S. Geological Survey, and the Centers for Disease Control.

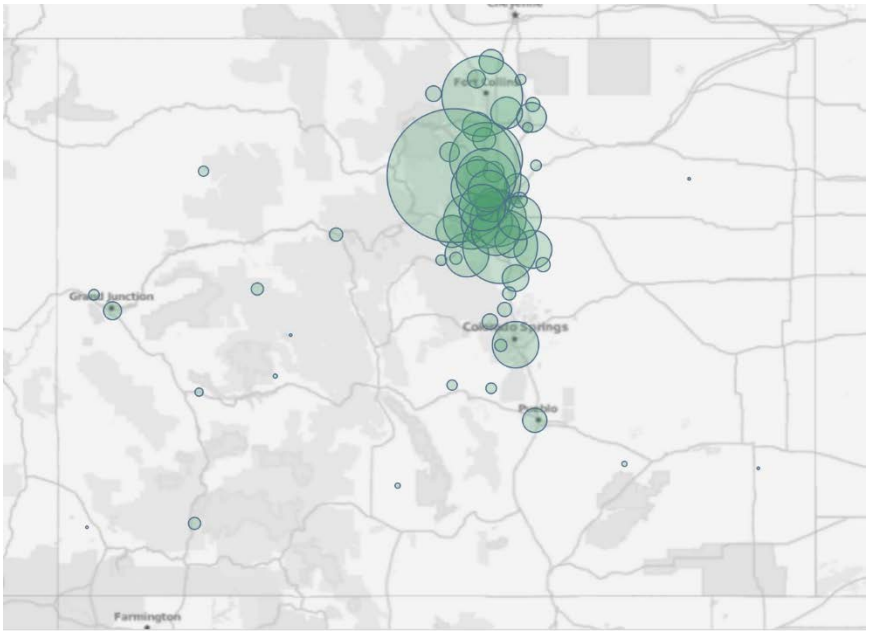
Significant numbers of publications also come from Boulder, where the University of Colorado has major programs in the biosciences, water resources, and other related fields and labs such as the National Center For Atmospheric Research (NCAR), and National Oceanic and Atmospheric Administration (NOAA). Denver, Golden, and other metro suburbs, also contribute to Colorado's science base in agriculture and food. Five percent of Colorado publications are more widely distributed around the smaller communities on the western slope and the eastern plains. Particularly notable is the relative lack of publications from the southern Front Range, including Colorado Springs and Pueblo, although these communities are not home to research institutions with emphasis in agriculture, food, water, or veterinary science.

Figure 5. Mapping R&D activities within agriculture, water, bioenergy, food, and related fields; cumulative counts from 1990 to 2012.

a. Scientific articles published, by city of author's institutional affiliation



b. U.S. patents filed and granted, by city of inventor's residence



Colorado's inventions in agriculture and related technologies

To characterize Colorado's technological innovation within the agricultural value chain, all U.S. patents and patent applications were searched—using the Thomson Innovation database by Thomson Reuters—for all inventions related to agriculture, water, veterinary medicine, food and beverage manufacturing, and bioenergy—with at least one inventor with a Colorado address. The search retrieved 2,548 patent applications filed from 2001 to 2013[12] (Figure 6.a, below) and 2,455 U.S. patents granted from 1990 to 2013 (Figure 6.b, below), for a combined total of 5,003 patent records. This represents roughly five percent of all patenting activity by Colorado inventors over this time period, which totaled over 58,000 records. It is a reasonable proportion for agricultural and food technologies, given the industry's share of total economic activity.

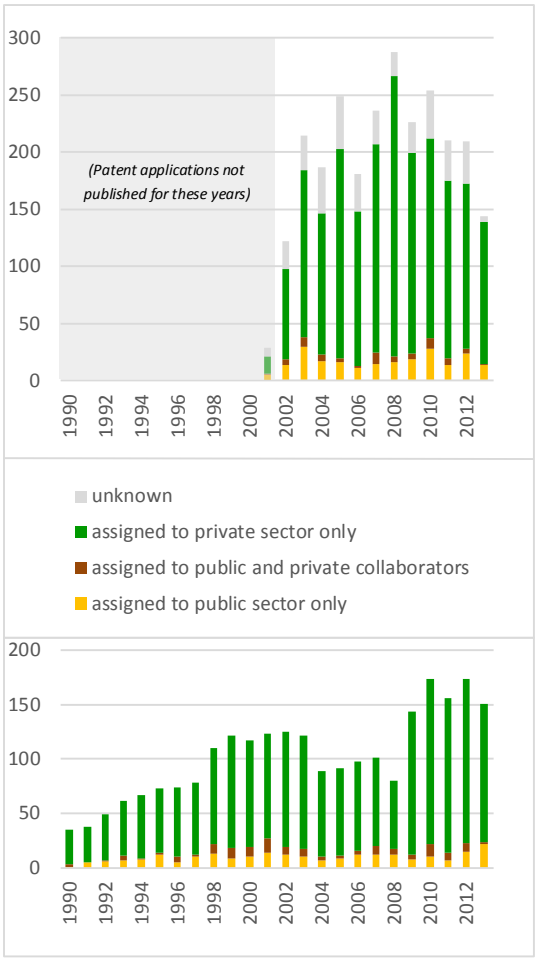


Figure 6.

a. U.S. patents applications filed by Colorado inventors of agricultural, water, food, beverage, and biofuel technologies, by publication year.

b. U.S. patents granted to Colorado inventors of agricultural, water, food, beverage and biofuels technologies, by grant year.

Data source: *Thomson Innovation*

[12] Published U.S. patent applications only became available following legislative changes adopted in the late 1990s.

Of the U.S. patents granted to Colorado inventors over technologies important in the agricultural value chain, 10 percent were by inventors at universities, public agencies, and nonprofit research institutions (collectively considered public-sector R&D), 85 percent were by inventors employed in industry (considered private-sector R&D), and just over 5 percent were by inventors at public sector and private sector organizations jointly (considered "public-private" collaborators). The rate of patenting grew exponentially during the 1990s, plateaued around 2000 when the tech bubble burst, wavered during the 2000s (as did patenting in much of the life sciences[13]), and rebounded after 2008. Overall, the rate quadrupled, from less than 40 patents per year for the state's entire agricultural and food industry in the early 1990s, to about 160 annually since 2010: an average growth rate of 6.5 percent per year (Figure 6.b). A mapping by address of Colorado inventors shows that about 90 percent of these were made by inventors living and working in the northern Front Range (Figure 5.b).

Key observations from Colorado's landscape of agriculturally-related R&D

There are several things to note from this survey of Colorado's R&D landscape.

First, Colorado's formal R&D activities in agriculture and food, as measured by these output proxies, have been growing two to four times faster than the state's economy overall, as measured by GDP. As a result, the volume of R&D activity within these sectors today makes up a greater share of the state's economic activity than it did two decades ago.

Second, Colorado's largely private-sector inventive activity in agricultural and food technologies has been growing more quickly than Colorado's already sizable public-sector science base in agriculture and food. The growth rate of patenting was twice the growth rate of scientific publishing. Virtually all of the increase in patenting comes from private sector inventors. In fact, patenting by inventors at public sector organizations was relatively flat over the two decades (see Figure 6.b). To the extent that patenting by public sector institutions provides an incentive mechanism for private investment in R&D to translate publicly-funded research into new technologies, products, and services, this may be indicative of underinvestment in patenting and technology transfer activities at Colorado's public sector research institutions.

Perhaps the most notable pattern to emerge from this landscape analysis is the geographic concentration of technological innovation within the relatively compact urban and peri-urban region of metro Denver and the northern Front

[13] Graff et al., "Not Quite a Myriad of Gene Patents" *Nature Biotechnology*, May 2013, 31(5), pp. 404-410 show that the total number of DNA-related U.S. patents peaked in 2001 but then declined steadily until 2005, after which they rebounded.

Range. While agricultural production is widely dispersed across the rural areas of the state, technological innovation—as measured by authorship on published scientific articles and invention on U.S. patents—does not appear to follow the same pattern. Even though conventional wisdom tends to equate agricultural innovation with rural economic development, and USDA programs often seek to promote rural development under the banner of "agricultural innovation", the reality appears to be that most agricultural innovation arises from that mix of institutions, companies, capital, and talent more readily found within the urban regions of the Front Range.

Also, within the Front Range, there are regional differences between where largely public-sector scientific research and largely private-sector inventing of new technologies are concentrated. Fort Collins dominates in terms of scientific publications, with the agricultural research of CSU and the USDA laboratories located there, but Fort Collins has a much lower output of patents relative to its share of publications. Boulder is home also to a large research university and a number of federal labs, but the institutions in Boulder have less explicit focus on agriculture and thus have produced fewer scientific publications in these fields. Yet, Boulder has a higher count of patents within the surveyed fields of technology. This is likely due to the preponderance of technology companies in and around Boulder—particularly in the biosciences, information technologies, and analytics. Within metro Denver, we see both: a significant level of scientific publications and a large number of patented technologies.

One note of caution is warranted in interpreting these results. It is important to be clear that these proxy measures of scientific publications and U.S. patents give a view of innovation that is focused on formal R&D activities. Our definition of innovation (see page 3) was, however, more broadly formulated, to include "*technological*, *organizational*, or *marketing* changes that improve economic productivity, increase the value of products and services, or improve other attributes". Since this analysis draws upon scientific publications and patents it does not directly measure organizational or marketing changes. These would include activities such as births of new businesses or launches of new products, for which consistent industry-wide data are more difficult to obtain. As a result, the picture created here does not show all kinds of innovation, but, for what it does measure—technology changes driven by formal R&D--this landscape analysis is quite comprehensive.

Photo courtesy of Dan Hilleman

Section 3. Why the Colorado Front Range?

What accounts for the concentration and growth of innovation in the agricultural value chain within the Colorado Front Range? Several hypotheses can be advanced, based on a number of features that have been identified as important for driving the growth of innovation-led industry clusters.[14] In some regards, the Front Range appears to be an ideal location for innovation in agricultural and food. Still, some key elements are lacking. There are several fundamental economic, geographic, and demographic forces that are likely together responsible for driving the emergence of an innovation cluster in the agricultural value chain along the Front Range.

Colorado has a long history of innovation in agriculture, food, and beverage

History matters. And Colorado has an established history of entrepreneurship and innovation in the agriculture, food, and beverage industries. Consider the founding and rise of several iconic companies. Adolph Coors Brewery, founded in 1873 (today MillerCoors), survived Prohibition to become a leader in the brewing industry. Monfort (today JBS), founded in 1930, transformed cattle feeding and meatpacking. Leprino Foods, founded in 1950, grew from a neighborhood deli in Denver to transform cheese manufacturing. Celestial Seasonings, founded in 1969 (today Hein Celestial), introduced mainstream Americans to herbal teas. These companies have shaped the region's economy, and, perhaps more importantly, have created a culture in which agriculture and food entrepreneurs are respected and celebrated as pillars of the community. For example, Denver's major league baseball team, the Colorado Rockies, is owned by Dick Monfort and plays in Coors Field.

Colorado has become a nationally recognized center of innovation and entrepreneurship

Today Colorado stands out nationally for its strengths in innovation and entrepreneurship generally, across all sectors of the economy. While the largest numbers of technology and venture capital firms are still found on the coasts, in places like Silicon Valley and the Boston area, this is changing. Colorado, and particularly the Front Range, has climbed in the national rankings to become competitive with the leading coastal regions in terms of innovation and entrepreneurship.

[14] Powell, 1991; Porter, 1998; Economist Intelligence Unit, 2011.

For example, in 2012 the Milken Institute ranked Colorado fourth in its State Technology and Science Index,[15] and in 2013 the U.S. Chamber of Commerce ranked Colorado number two for entrepreneurship and innovation.[16] In 2014 a study by the Kauffman Foundation ranked Colorado number five in its index for entrepreneurial activity.[17]

Another recent study published by the Kauffman Foundation looked at the *per capita* concentration of high-tech entrepreneurship in metro areas across the U.S. No less than four cities in Colorado's Front Range were listed among its "Top 10 Metro Areas in the U.S. for High-Tech Startup Density." Boulder and Fort Collins ranked first and second respectively, before third-place San Jose/Sunnyvale/Santa Clara (i.e. Silicon Valley) and fourth-place Cambridge, Massachusetts. Denver ranked sixth, coming in between Seattle and San Francisco. Colorado Springs ranked ninth.[18]

Such national comparative studies and indices draw upon a wide range of measures, and should thus be taken as general indicators that the region has a good mix of conditions required to foster innovation. Several of these commonly cited conditions merit further consideration, particularly as they relate to innovation in the agricultural value chain.

The Front Range enjoys a quality of life that attracts and retains talent

Perhaps the single most important factor, in any industry, for building innovation capacity is attracting and retaining top talent. The ability to attract and retain talent, in turn, is highly dependent upon the quality of life in the region. Experienced managers as well as highly skilled scientists and engineers have bargaining power, which they can exercise in choosing where to live, work, play, and raise their families.

Colorado, and particularly the Front Range, offers excellent communities with high quality K-12 education, a generally well-educated population, and numerous amenities. Due to its natural beauty and world class recreational opportunities, the region has long been regarded as a tourist and retirement destination. More recently, a renaissance in the music, arts, and culinary communities in Denver, the Front Range more broadly, and the mountain resort towns, has served to complement the region's traditional sources of attraction. Additionally, Denver is served by the fifth busiest airport in the U.S. (13th in the world) with direct flights to many domestic and international

[15] *2012 State Technology and Science Index*, Milken Institute, 2013
[16] U.S. Chamber of Commerce, *Enterprising States 2013: Getting Down to Small Business*, United States Chamber of Commerce, 2013.
[17] *Index for Entrepreneurial Activity*, Ewing Marion Kauffman Foundation, 2014
[18] Ian Hathaway, *Tech Starts: High-Technology Business Formation and Job Creation in the United States*, Ewing Marion Kauffman Foundation, August 2013.

destinations. Yet, much of the region still enjoys real estate prices near national averages.

There is an already established community of talent in the Front Range, including managers, scientists, and engineers, as well as skilled technicians and tradespeople with experience in the various sectors of the agricultural and food value chain. Given the history of agriculture and the food industry in the region, there are already a number of companies in the region. Add to that the concentration of universities, federal labs, and public agencies, which have hired top scientists and engineers to work in the region. The universities are actively training new talent, and many graduates prefer to stay in the region after finishing school. Given this existing community, it is already possible to recruit senior management, scientists, as well as skilled technicians locally.

Yet, talent attracts talent. And the existing community of talent, together with the region's quality of life factors, makes it possible to attract world class management and scientific talent away from the coasts and other major metro areas. Companies relocating to the Colorado Front Range find it relatively easy to entice their top management and R&D employees to move to the region.

Within the farming and ranching community, other factors such as land quality, water availability, and access to infrastructure have traditionally dominated decisions of where to locate and where to invest. However, even in the producer community, new realizations are emerging that quality of life factors may play an important role in shaping the future of the industry along the Front Range. As innovative agribusinesses are attracted to or created within the region, in turn that creates more opportunities for those with agricultural backgrounds to find jobs in the region. In particular, it creates opportunities for the younger generation coming off the farm to find agriculturally related jobs and remain in the region, albeit utilizing other skill sets, such as software engineering, genetics, biosafety, or social media marketing.

The co-location of major research institutions.

The northern Front Range has an excellent alignment of major universities and federal labs relative to one another and to the main population corridor. Historically, many states, for understandable reasons, spread their public universities out among different cities or regions. In Colorado, the main research universities—including the University of Colorado, Colorado State University, and Colorado School of Mines—were all located within the Front Range. That means that today each is less than an hour's drive from the others, from downtown Denver, and from the airport. Additionally, federal labs came to be located in the same cities as the universities. This relatively close co-location facilitates ongoing collaboration and exchange among these research institutions. It also makes it easier for companies in the region to meet and work with researchers at multiple institutions.

CASE STUDY: Ventria Biosciences

Ventria Bioscience is a biotechnology company specializing in plant-based biomanufacturing of recombinant proteins. Ventria can produce a wide range of proteins, in significant volume, by growing them in the grains of a bioengineered rice crop under carefully controlled conditions. Ventria's mission today is to "*ensure that people all over the world can share in biotechnology's benefits by making its products more affordable and more accessible.*" Ventria was originally founded in California, based on research at the University of California, Berkeley. In 2006 the company left California because of that state's unfavorable regulatory environment and tax rates. Ventria relocated much of its personnel to the high plains, establishing its growing and production operations in Manhattan, Kansas and its management offices and R&D facilities in Fort Collins, Colorado.

Why did Ventria choose the Front Range to base its R&D operations? According to Scott Deeter, Ventria's CEO, one main reason was the decreased risk that the region offered for potential employees when moving to start work at an early-stage biotechnology company. Fort Collins and the Front Range offers a variety of alternative work place opportunities for those with skills in the biotechnology industry, thus decreasing the risk of dislocation. If, for some reason, an employee had to leave unexpectedly they would have a higher likelihood of finding new employment without having to move their families. He also felt that, once located in a desirable place to live, employees would be more inclined to stay with the company. This had been illustrated by HP, as their Fort Collins location was on record as having the highest retention rate of all of their corporate locations.

The region also offered a great pool of entry-level employees for Ventria, given the numbers of CSU graduates entering the work force each year and the quality of life offered in the Front Range. In fact, they also found that recent graduates from other states were quite willing to move to Colorado for an entry level position, given the opportunities for outdoor recreation, the lifestyle amenities for young adults, and the favorable climate.

Nevertheless, Deeter has had a harder time recruiting senior level R&D employees from out of state, who are often later in their careers and thus less mobile. One solution to this challenge is emerging with the increased number of other plant genetics R&D-centric firms in the area, which according to Deeter, is beginning to put the Front Range "on the map" for leading plant biologists. Given CSU, the USDA's seed bank located on campus at CSU, the laboratories of USDA's ARS and APHIS divisions, and the number of seed companies located in the Colorado Front Range, the pieces are already in place to create an ecosystem for plant genomics research. Deeter believes that achieving critical mass of talent and employment opportunities in the field of plant genetics on the Colorado Front Range is imminently feasible, as long as Ventria and other companies, agencies, and the universities continue to attract top quality researchers to the area. •

Proximity of major agricultural production to a major urban corridor

Another important factor shaping the potential for agricultural innovation in Colorado is the fact that the state's greatest concentration of agricultural production, commodity processing, and food manufacturing is proximate to the main population corridor along the Front Range. Thus, there is a complex interface between agricultural production, at significant scale, and a burgeoning, urbanizing region. This brings the agricultural infrastructure and workforce into direct contact with an increasingly dense non-agricultural population, a growing high-tech urban and suburban business community, and increasingly sophisticated retail markets. While such intersection creates a unique set of challenges and tensions, it also creates interesting opportunities.

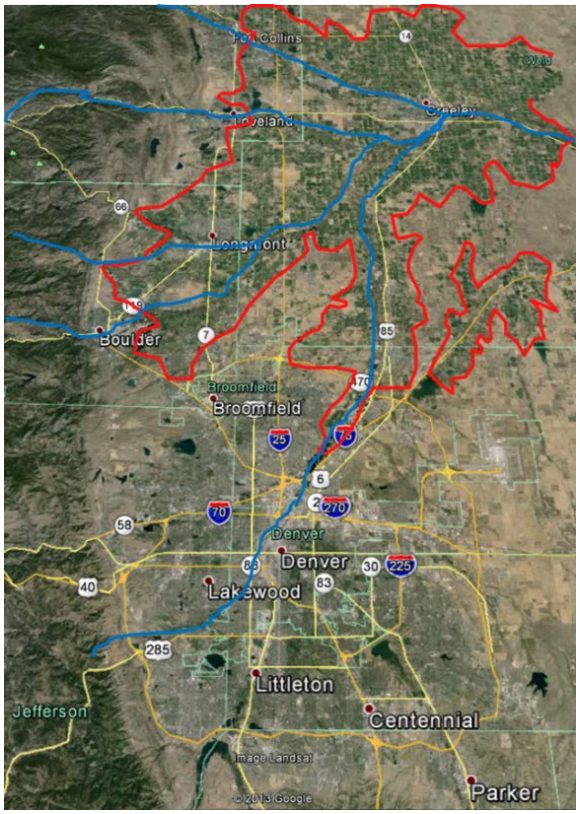


Figure 7. Google Earth imagery shows the high density of irrigated crops (green areas, outlined in red, fed by water from main rivers, in blue) intersecting with the growing urban corridor along I-25 north of Denver, including the cities of Broomfield, Boulder, Longmont, Loveland, Fort Collins, and Greeley.

Source: *Landsat, Google. (Highlights by the authors.)*

Weld County and the city of Greeley, opportunely situated along the South Platte River watershed where its tributaries leave the Rocky Mountains, has the highest concentrations of crop and livestock production and food manufacturing in the state. In the USDA's 2012 Census of Agriculture, Weld County had the 9th largest gross value of agricultural production among all counties in the U.S. Yet, the combined population in the northern Colorado

cities of Boulder, Longmont, Loveland, and Fort Collins—all accessible within an easy 45 minute drive—is close to 1 million residents (Figure 7). The population of the full Denver metro region is over 3 million.

The alignment of production agriculture and population within the northern Front Range is somewhat unique within the U.S. Most other major metro areas with populations on the same scale as the Denver region long ago crowded agriculture out well beyond the peripheries of their metro regions—particularly those innovation-intensive regions on the coasts, like Silicon Valley (which used to be a major fruit growing region.) Such crowding out has resulted, generally, in a reduction of interaction between the mainstream urban populations and business communities and the agricultural communities in those other states. In Colorado, connections between these communities have been retained to a greater extent simply due to geography.

The sustainability and market challenges confronting Colorado agriculture are shared in many parts of the world

Many of the cross-cutting challenges and opportunities that Colorado agriculture confronts are found elsewhere around the world, including

- managing water resources in a semi-arid environment,
- managing land use and environmental quality along a intensifying urban-agriculture-wilderness interface,
- managing livestock health, productivity, and impacts on environmental quality, in areas such as infectious zoonotic diseases and animal waste
- the improvement and deployment of crop genetics, given a divergence in views between industry and the public over what kinds of genetic interventions are acceptable,
- the integration of organic or "locally grown" quality-differentiated products into established supply chains.

Because of the immediacy of these challenges, Colorado's agricultural and food industry is focused on the potential gains to be made by developing and commercializing productivity-enhancing, risk-reducing, or value-generating innovations that address them. Once solutions are found that work well and sell in Colorado, adopters around the world will seek to emulate those solutions, whether copying, purchasing, or licensing them from the Colorado innovators that developed them. Thus, opportunities to benefit by tackling the cross-cutting challenges and opportunities endemic to the Colorado market are not limited to Colorado. The market for innovations is global. The Front Range provides an ideal location to pilot locally, then market globally.

CASE STUDY: Limagrain

The French company **Limagrain** (pronounced *lee-muh-grain*) is the fourth largest seed company in the world. In 2010 Limagrain opened a head office for their U.S. cereal seeds business in Fort Collins, under the leadership of Executive Vice-President and Chief Operating Officer, Frank Curtis. Curtis was instrumental in Limagrain's strategic decision to enter the U.S. market and locate their headquarters on the Colorado Front Range. Fort Collins was chosen from among more than ten locations under consideration, including California, Oregon, Montana, and Indiana, for several key reasons:

1. High quality of life. According to Curtis, "We were going to be recruiting very talented people from all over, and it had to be a place in which people would enjoy living". The company wanted to find a location that made themselves and their employees happy. After a 48 hour visit to Fort Collins over the 4th of July holiday weekend in 2009, Curtis felt completely comfortable and quite at home in what he described as a very welcoming community.

2. Serious agricultural production: The high level of wheat production in Colorado was another attraction for the company, combined with the favorable growing climate, low pest pressure, available water resources, and high altitude, all of which are favorable for crop research.

3. Proximity to a center of excellence in agricultural research: Most of the locations Limagrain considered were near major universities with leading programs in agriculture. The wheat breeding program and associated work in the soil and crop sciences at Colorado State University were particularly attractive.

4. Access to new talent: Limagrain's Fort Collins staff has increased from two to 25. Many are CSU graduates, first hired as interns. Curtis also cites the region's pool of available experts in agronomy, genetics, entomology, and plant breeding.

5. Access to a major international airport: Limagrain needed quick access to their wheat stations around the country, since crop variety development for a continental market requires multiple sites for testing under a variety of conditions. Moreover, their U.S. operations are part of an integrated global wheat breeding program. Denver International Airport met these needs for travel.

In addition to meeting the criteria that Curtis and his colleagues in management at Limagrain had established, Fort Collins offered nice people, an active lifestyle, and—according to the discerning palette of Curtis, a British national—great beer. In 2013, Limagrain partnered with O'Dell Brewing Company of Fort Collins to create "Innovation Ale". O'Dell was one of the many welcoming companies in the region that inspired Limigrain to give back to the community by procuring supplies and services locally whenever possible. Even though the state of Colorado did not offer additional incentives for relocating, in the form of infrastructure or money, like other states did, Frank Curtis believes Colorado has been—100 percent—the right investment for Limagrain. •

Section 4. An inventory of Colorado innovators in the agricultural value chain

To delve more deeply into who are the innovators in the agricultural value chain in Colorado, an inventory was taken of all private sector firms and public sector organizations engaged in innovation. The inventory is based on those companies and organizations generating the publications and patents identified in the landscape analysis of the previous section. Names of companies compiled from the Web of Science and from U.S. Patent data records since 1990 were checked against current information to verify whether they are still active in the state of Colorado. Additional companies were then added to the inventory based upon recommendations and referrals from industry associations, networking events, interviews, news accounts, and other expert sources. As a result, the scope of this inventory encompasses engaged in all kinds of innovation, including organizational and marketing changes, as well formal R&D activities introducing technological changes. The total inventory includes 550 innovating entities, of which 460 are companies and 90 are academic, non-profit, or government (i.e. public sector) entities.

These companies and research institutions were assessed in terms of the main technologies or industries in which they have expertise. A dozen categories emerged to summarize and characterize the main areas of innovation going on in Colorado:

1) **Innovators in water technology, infrastructure, analytics, and management**
2) **Innovators in soil fertility and pest control**
3) **Innovators in plant genetics and new crop varieties**
4) **Innovators in animal health, nutrition, and herd management**
5) **Innovators in agricultural information systems**
6) **Innovators in sensors, testing, and analytics for product quality and biosafety**
7) **Innovators in bioenergy**
8) **Innovators in commodity processing and food manufacturing**
9) **Innovators in dairy production and dairy product manufacturing**
10) **Innovators in beer, wine, & spirits production and marketing**
11) **Innovators in natural, organic, and local foods and marketing**
12) **Innovators in "Fast & Fresh" food service**
13) **Innovators in other emergent subsectors**

These categories roughly follow the vertical structure of the value chain, from natural resources to final retail markets. And, just as value flows among the subsectors in the value chain, so there is a significant amount of overlap and interdependence among innovations in these categories (See Figure 8).

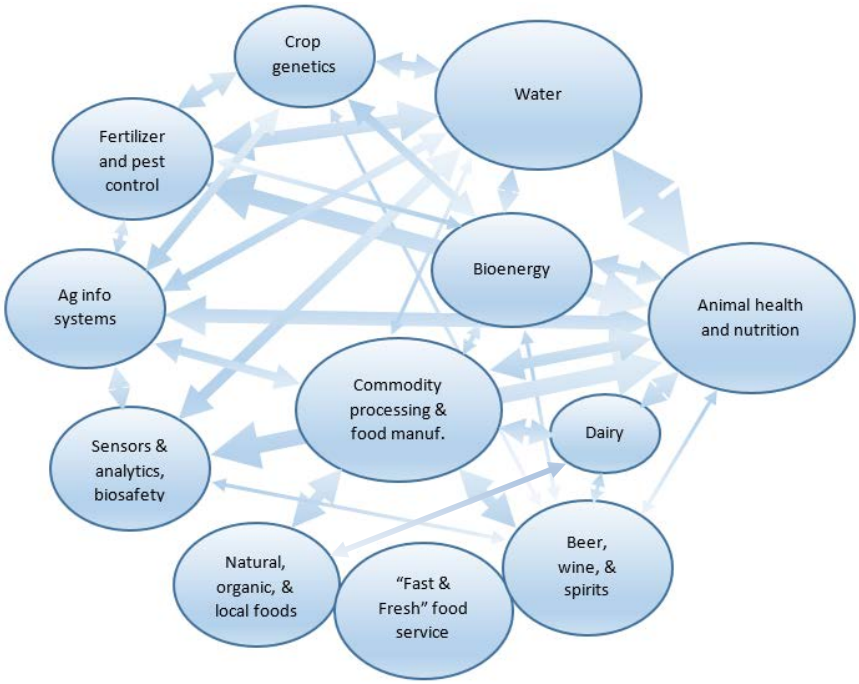


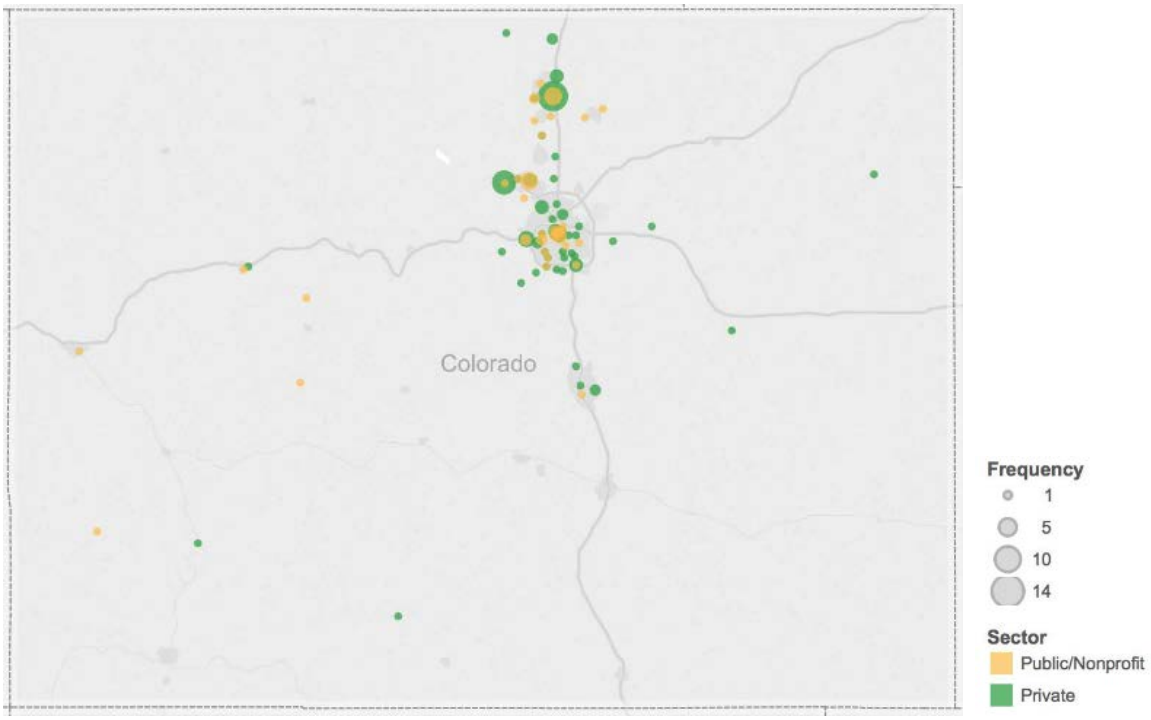
Figure 8. The innovators within Colorado's agricultural and food value chain congregate into a dozen or so distinct categories or subsectors. Innovation within each of these overlaps with innovation in a number of the others, illustrating the many opportunities for collaboration and for competition. (The weight of an arrow between two categories indicates how many firms are jointly listed in both.)

Quite a number of firms in the inventory are listed in more than one category, largely due to the convergence of technologies or the structure of industry. Innovation in one category may directly affect or involve innovation in other categories. For example, new advances in water-use efficiency can be made possible by combining irrigation system infrastructure design with moisture sensors, linked through agricultural information systems, to equipment planting seeds with precisely the right drought-tolerant crop genetics. Coordination of innovation across these categories is especially important when seeking to address the challenges confronting agriculture today—both in Colorado and globally—and underscores the importance of considering innovation within the context of the entire value chain.

The following sections provide a detailed lists of the companies and organizations involved in each of these innovation categories. The listings within each category are generally divided into five types of organizations: (a) anchor corporations; (b) other companies; (c) nonprofits and industry associations; (d) academic research institutions; and (e) public agencies. However, some categories have more, some have fewer. When applicable, data are provided regarding the total numbers of Web of Science publications and U.S. patent records associated with each organization.

1. WATER

1. Innovators in water technology, infrastructure, analytics, and management



As one of the early points of settlement in the arid regions of the American west, Colorado has historically been a leader in water storage, transmission, and irrigation infrastructure. Major water project engineering was undertaken in the 20th century to increase availability of water from the Rocky Mountains to growing agricultural and municipal uses along the Colorado Front Range. Today, Colorado companies and research institutions are active innovating in a range of water innovation. The largest set of companies consists of civil and environmental engineering firms with water project expertise. Other areas of expertise include water system design, hydrological analysis, environmental consulting, water quality monitoring, water supply and waste water treatment, and irrigation systems and equipment.

Photo courtesy of Dan Hilleman

Companies actively innovating in water technology, infrastructure, analytics, or management in Colorado

Company	City	Business or technology description	WoS Publications[19]	US Patents[20]
Advanced Environmental Technologies	Fort Collins	remediation of recalcitrant contaminants in waste water, contaminated groundwater and sediments, and waste to energy conversion		2
AECOM (incl. URS Corp and former ENSR Consulting & Engineering)	Fort Collins / Denver	architecture, design, engineering, and construction for multiple sectors, including energy, environment, and water	35	
AgProfessionals	Longmont	construction of agricultural production facilities		
Agri-Inject	Yuma	fluid injection systems for applying fertilizer and crop protection chemicals through irrigation systems		3
Agro Engeneering	Monte Vista	analyze and develop innovative and integrated solutions to agricultural and water resource problems	2	
Agsmart	Strasburg	aerobic waste treatment lagoon system for dairies, feed yards, and swine operations		5
AMEC	Denver / Golden / Boulder / Grand Junction / Durango	integrated engineering and environmental services throughout the water cycle		
Anderson Consulting Engineers	Fort Collins	water resources engineering consulting; irrigation engineering	1	
Applegate Group	Denver	water resources consulting	2	
Aqua Engineering	Fort Collins	irrigation system design	2	
Aqua Terra Consultants	Ouray	water engineering and management	1	
Aquacraft Inc.	Boulder	water engineering and management	11	
ARCADIS (formerly Red Oak Consulting, also includes former Blasland, Bouck, & Lee)	Boulder / Highlands Ranch	global environmental and water infrastructure design and engineering consulting	1	
Argus Engineering Inc.	Colorado Springs	water and environmental engineering	1	
Bioconversion Technology	Denver	complete solutions for industrial and municipal wastewater		5
Biovantage Resources	Golden	bioremediation solutions for industrial, agricultural, and municipal water treatment		8
Black & Veatch Consulting Engineers	Englewood	design, procurement and construction solutions to provide effective water management	5	
Brown and Caldwell	Golden	water and environmental engineering	9	
Carollo Engineering	Littleton	biologically-tailored, two-stage water treatment process for groundwater contaminants, waste streams	2	
CDM Smith	Denver	water and environmental engineering	18	
CH Diagnostic & Consulting Service	Berthoud	water-quality consulting for water treatment professionals, researchers, regulators, and homeowners	4	
CH2M Hill	Englewood	consulting, design, design-build, operations, and program management in energy, water, and environmental infrastructure	81	29
Clearwater Solutions	Boulder	water resources planning and management; infrastructure planning and design	1	
Earth Chem Inc. (division of Henwil Corp.)	Fort Collins	polymer based products to control erosion, increase water infiltration, and enhance water retention		2

[19] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[20] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

1. WATER

Engineering & Hydrosystems Inc.	Littleton / Highlands Ranch	water resource analysis and engineering	2	
Entrix Inc.	Golden	environmental and natural resource management consulting	1	
Fluid Dynamic Siphons Inc.	Fort Collins	dosing siphons, employed to make soil absorption systems more effective and long-lived		2
GEI Consultants Inc.	Denver / Fort Collins	integrated water resources, geotechnical, environmental, and ecological consulting services	6	
Genesis Laboratories Inc.	Wellington	environmental toxicology analytics	2	6
Geomega Inc.	Boulder	water management consulting	10	
Geosyntec Consultants (formerly Envirogroup Ltd)	Greenwood Village	environmental, natural resource, water engineering and remediation	5	
Golder Associates	Lakewood	consulting, design, and construction services in earth, environment, and related areas of energy	10	
HDR, Inc.	Denver	engineering for water, agribusiness, food & beverage manufacturing	8	
Hach Company	Loveland	Analytical instruments for water testing and water quality analysis	14	4
Henry T. Falvey & Associates Inc.	Conifer	hydro power engineering	10	
Hydrau Tech Inc.	Fort Collins	software for hydro engineering modelling	2	
Hydrosphere Resource Consultants	Boulder	water engineering consultants	12	
Idexx Laboratories	Westminster	veterinary and water quality diagnostics	14	
Innovyze	Broomfield	wet infrastructure business analytics software solutions	1	
In-Situ Inc.	Fort Collins	environmental and water monitoring systems		
Integrated Water Services Inc.	Aurora	denitrification up flow filter for wastewater applications		1
Intera Inc.	Lakewood	geosciences engineering, consulting, technical, and management solutions to environmental and groundwater resources	8	
Ivan Engineering Inc.	Centennial	water engineering and management	1	
Keeton Industries Inc.	Wellington	water quality management of ponds and lakes		9
Layne (formerly Colog Inc)	Denver	global water management, construction and drilling company	2	
Lehi Water	Livermore	water consulting		
McLaughlin Water Engineers	Denver	water engineering and management	1	
Mergen Ecological Delineation	Colorado Springs	botanical surveys, ecosystem and plant community mapping, and wetland delineations	1	
MWH (Montgomery Watson Harza) (incl. former Stepwise Utility Advisors)	Broomfield	international infrastructure engineering, consulting, and construction services	24	
Miller Ecological Consultants Inc	Fort Collins	ecological consulting, specializing in fishery, aquatic, in stream flow, and ecological modeling studies	2	
Natural Resources Consulting Engineers, Inc.	Fort Collins	water resources, irrigation, transportation, and municipal water and wastewater engineering	3	
Nested Nozzle Mixers Inc.	Centennial	high turbulence liquids mixer		2
Norwest Applied Hydrology	Denver	consulting in energy, mining, and natural resources, including analytical and numerical modeling to evaluate surface and groundwater flow and quality	1	
Nutrinsic (formerly Oberon FMR)	Aurora	extraction of protein biomass from food industry waste water, up-cycling for use as animal feed and fertilizer		4
Open Water Foundation	Fort Collins	open source software platform to help organizations make better decisions about water		
Orica Watercare Inc	Watkins	water cycle process solutions, advanced water treatment, risk management, engineering services	3	

Parker Ag Services	Limon	safe recycling of municipal wastewater bio solids for fertilizer application on agricultural land	1	
Parsons Engineering	Denver	construction for water and energy	10	
Pellaero	Frederick	home irrigation system for year round control and protection of landscape		2
Point380	Boulder	consulting for food, beverage, and bioenergy companies on strategies to save energy, water and material resources	1	
Pontius Water Consultants Inc.	Littleton	engineering consulting specializing in water	23	
Porzak, Browning, & Bushong	Boulder	water law involving the acquisition, adjudication, and protection of water rights	1	
Principia Mathematica, Inc.	Lakewood	applied research and development specializing in mathematical modelling and computational fluid dynamics for ground water and surface water systems	1	
Process Applications Inc.	Fort Collins	mathematical modelling and computational fluid dynamics	4	
PS Systems Inc.	Lakewood	Porosity Storage Reservoir (PRS) systems for underground water storage		2
Q Industries Inc.	Boulder	pulse drip irrigation equipment for home and small scale irrigation systems		5
Rachio	Denver	smart sprinkler system		
RAS Inc.	Golden	borehole sensor technologies for characterization and monitoring aquifers and ground water systems	1	
Regenesis Management Group	Denver	SWIIM System software suite, instrumentation and remote sensing package that enables agricultural water users to optimize water management	1	
Riverside Technology Inc.	Fort Collins	data and analytics for environmental, water resource, and agricultural systems	12	
RJH Consultants Inc.	Englewood	evaluation, design, and construction engineering for raw water supply	1	
Rockwater Resource	Denver	produced water treatment technologies for oil and gas industry		3
Rubicon Water	Fort Collins	advanced technology for improved efficiency and control of gravity fed irrigation networks		
S.S. Papadopulos & Associates Inc.	Boulder	water resource and environmental consulting for groundwater contaminant, remediation, and geochemistry	3	
Shepherd Miller Inc.	Fort Collins	water resource engineering	12	
Siemens Water Technology Corp.	Colorado Springs	water filtration and purification equipment	4	
Silver Bullet Water Treatment	Denver	water filtration system for animal drinking water purification		
Spronk Water Engineers	Denver	consulting in water resources engineering	1	
Stewart Environmental	Fort Collins	water infrastructure engineering		
Stratus Consulting Inc.	Boulder	consulting in environmental and natural resources, water economics, litigation support, and policy analysis	13	
SWCA Environmental Consultants	Broomfield / Fort Collins	environmental planning, permitting, regulatory compliance, natural resource management, GIS, and water resources	1	
TechKNOWLEDGEy Strategy Group (TSG)	Boulder	water and environmental consulting	25	
Telesto Solutions Inc	Fort Collins	water and environmental engineering	2	
Tetra Tech Inc	Denver	consulting, engineering, construction and technical services for resource management and infrastructure	11	
Trihydro (former Aquifer Solutions Inc)	Evergreen	engineering and remediation for agribusiness, ethanol, manufacturing, and other markets	2	
Trillium Technical LLC	Fort Collins	data, spatial, decision analysis and modeling		
TZA Water Engineering	Lakewood	development, protection, and effective management of water resources	1	
USFilter	Colorado Springs	water filtration and purification equipment	3	
Water Demand Management	Boulder	engineering consulting focused on demand side management of water resources		

Waterstone Environmental Hydrology and Engineering	Boulder	environmental consulting and STAR (Spatial Technology for All Resources) technology platform	5
Wildland Hydrology Inc	Fort Collins	hands-on training courses in river assessment and restoration	6
Wright Water Engineers	Denver	water consulting and engineering	23
Zancanella & Associates	Glenwood Springs	engineering consulting in water rights and water resources	1

Municipal or regional utilities, water districts, and other agencies active in water innovation in Colorado

Name	Location	Agency or technology description	WoS Publications[21]	US Patents[22]
Aurora Water	Aurora	municipal water supply	4	
Central Colorado Water Conservancy District	Greeley	development, management, and protection of water resources in northeast Colorado	1	
City of Boulder, Open Space & Mountain Parks	Boulder	management of lands and watersheds owned by City of Boulder	6	
Colorado River District	Glenwood Springs	protection, conservation, use, and development of water resources of the Colorado River basin	1	
Denver Water	Denver	municipal water supply	30	
Fort Collins Utilities	Fort Collins	municipal water supply	3	
Greeley Water & Sewer	Greeley	municipal water supply and treatment	2	
Larimer County Open Lands	Fort Collins	land preservation in urban and urban-rural environments	2	
Metro Wastewater Reclamation District	Denver	wastewater treatment for much of metropolitan Denver and parts of northern Colorado	4	
Northern Colorado Water Conservancy District	Berthoud	regional water supply	9	
Pine Brook Water District	Boulder	regional water supply	2	
Roaring Fork Conservancy	Basalt	watershed action and education for the Roaring Fork watershed to protect rivers	2	
SE Metro Stormwater Authority	Englewood	stormwater management services for protection, preservation, and enhancement of community and natural resources	1	
Urban Drainage & Flood Control District	Denver	flood control and water management	19	

[21] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[22] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Nonprofit organizations and industry associations active in supporting, promoting, and conducting water innovation in Colorado

Ducks Unlimited	Denver	habitat conservation and protection programs rooted in science and research		
Engineers Without Borders	Denver	community-driven development programs worldwide with local partners to design and implement sustainable engineering projects	1	
International Development Enterprises (IDE)	Denver	income and livelihood opportunities for poor rural households worldwide through agricultural technologies, including irrigation pumps and drip systems	5	
National Council for Air & Stream Improvement (NCASI)	Denver	research on environmental topics of interest to the forest products industry	1	
Nature Conservancy	Boulder	purchase and protection of private lands to preserve wild habitat and natural resources	4	
NatureServe	Boulder			
Trout Unlimited	Denver	conservation and education, water quality protection, stream flow maintenance, native trout habitat restoration		
Water Research Foundation (former AWWA Research Foundation)	Denver	water research to advance industry insights and practical solutions to complex challenges facing the water community	99	
Water Resource Advocates	Boulder	conserving urban water supplies and restoring rivers throughout the West		
The Wilderness Society	Denver	protection of America's shared wild lands	1	
Wright Paleohydrological Institute	Denver	furthering knowledge of past civilizations through study of ancient water management and practices	3	

Academic and non-profit research institutions active in water innovation in Colorado

Colorado College	Colorado Springs		31	
Colorado School Of Mines	Golden		381	12
Colorado State University	Fort Collins		7,616	59
Mesa State University	Grand Junction		15	
Metropolitan State University Of Denver	Denver		14	
National Center For Atmospheric Research (NCAR)	Boulder		175	
National Ecological Observatory Network	Boulder	continental-scale ecological observation system examining critical ecological issues; funded solely by National Science Foundation (NSF)	4	
National Snow and Ice Data Center	Boulder	information and data supporting polar and cryospheric research	3	
Rocky Mountain Biological Lab (RMBL)	Crested Butte	high-altitude ecological scientific research	50	
University Corporation For Atmospheric Research (UCAR)	Boulder		24	2
University of Colorado	Boulder		1,778	231
University of Denver	Denver		70	1
Western Water Assessment	Boulder	joint initiative of University of Colorado and NOAA		

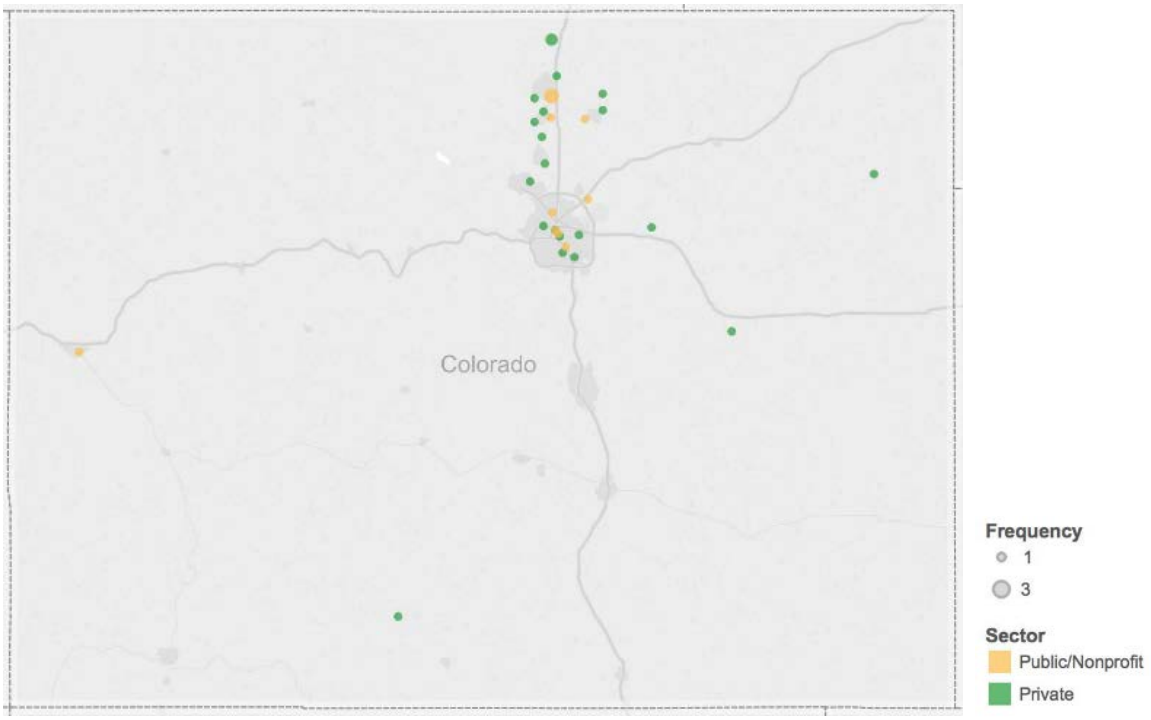
1. WATER

State and federal agencies active in water innovation in Colorado

State of Colorado, Department of Natural Resources	Denver	1
State of Colorado, Division of Parks and Wildlife	Denver	86
State of Colorado, Division of Reclamation	Denver	2
State of Colorado, Division of Water Resources	Denver	3
State of Colorado, Geological Survey	Golden	5
National Oceanic and Atmospheric Administration (NOAA)	Boulder	71
U.S. Army Corps of Engineers	Littleton	11
U.S. Bureau of Land Management	Lakewood	15
U.S. Bureau of Reclamation	Denver	240
U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins	1,080
U.S. Department of Agriculture, National Wildlife Research Center	Fort Collins	11
U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS)	Fort Collins	28
U.S. Department of Agriculture, U.S. Forest Service	Fort Collins	193
U.S. Environmental Protection Agency (EPA)	Denver	33
U.S. Fish and Wildlife Service	Denver	20
U.S. Geological Survey	Fort Collins	836
U.S. National Park Service		35

Photo by Gregory Graff

2. Innovators in soil fertility and pest control



Innovation in soil fertility primarily involves nitrogen, phosphorus, and potassium fertilizers, but can also include soil micronutrients, fertigation (application of fertilizer via irrigation water), biological soil amendments, and strategies to enhance nutrient use efficiency. Innovation in pest control primarily involves chemical pesticides and biopesticides to control fungal, insect, and vertebrate pests on crops and pastures, but can also include traps and other management strategies.

Innovation in soil fertility and pest control is closely tied to several other areas of innovation. It overlaps with innovation in crop genetics, as development of new varieties often selects for disease and pest resistance traits or drought tolerance, as well as recent development in seed coating technologies, where fertilizers and pest control agents are applied to the seed prior to planting and customized to the genetics in the seed. This overlap has only been strengthened with the rise of biotechnology. There is also a growing tie with innovation in agricultural information systems, as capabilities of precision application creates new opportunities for innovation in soil fertility and pest control technologies, as well as with water management, as control of soil moisture conditions can affect nutrient availability and pest pressure.

The following inventory lists separate types of organizations. First are major anchor institutions located in the Denver area, several of which operate mines to supply the market with mineral fertilizers; one of these, Agrium, owns a major farm supply distribution and sales subsidiary with a large network of outlets nationally. Then listed separately are other companies, academic and government research institutions, and government regulatory agencies active in soil fertility or pest control innovation.

2. SOIL & PESTS

Major anchor corporations active in soil fertility or pest control innovation in Colorado

Name	Location	Company or technology description	WoS Publications[23]	US Patents[24]
Agrium Inc.	Denver	agricultural nutrient and industrial products	4	19
Agrium Advanced Technologies (subsid of Agrium)	Loveland	fertilizer products for the professional turfgrass, horticulture, and consumer lawn and garden markets		
Crop Production Services (CPS) (subsid of Agrium; incl. United Agri Products, Snake River Chemical, and Platte Chemical)	Loveland	crop protection, fertilizers, Dyna-Gro Seeds		
Loveland Products Inc. (division of CPS / Agrium)	Greeley	seed treatment, plant nutrition, fertilizer, adjuvant and crop protection products		7
Luzenac America Inc. (owned by Imerys)	Englewood	fertilizers and crop protection chemicals		3
Borax Inc. (part of Rio Tinto Group)	Greenwood Village	borates for the agricultural industry; borate technology, research and development		8
Intrepid Potash	Denver	muriate of potash (potassium chloride) fertilizer		

Other companies active in soil fertility or pest control innovation in Colorado

Agfinity (incl. former Agland)	Eaton	ag supply; steam flaking of grains (as Agland)	3	4
Agrebon, Inc	Fort Collins	ethanol by-products to nitrogen fertilizer		
Agri-Inject	Yuma	fluid injection systems for applying fertilizer and crop protection chemicals through irrigation systems		3
Agro Engineering, Inc	Monte Vista	analysis and development of innovative and integrated solutions to agricultural and water resource problems	2	
Agsmart	Strasburg	aerobic waste treatment lagoon system for dairies, feed yards and swine operations		5
BioChar Now	Loveland / Berthoud	inert carbon soil amendments		
BioGreen Technologies, Inc.	Longmont	zeolites as natural mineral absorbents for agricultural applications		
Earth Chem Inc. (division of Henwil Corp.)	Fort Collins	polymer based products to control soil erosion, increase water infiltration, and enhance water retention		2
Genesis Laboratories Inc.	Wellington	rodent insecticidal bait; vector-borne disease control and pest management; avian invasive species control; environmental toxicology analytics	2	6
Mycologics	Aurora	biofungicides	6	2
Nutrinsic (formerly Oberon FMR)	Aurora	extraction of protein biomass from food industry waste water, up-cycling for use as animal feed and fertilizer		4
PANalytical (formerly ASD Inc.)	Boulder	spectroscopy for remote sensing, product testing, and laboratory screening, with wide applications in agriculture, biofuels, and food	2	
Parker Ag Services	Limon	safe recycling of municipal wastewater biosolids for fertilizer application on agricultural land	1	
Permagreen Organics Company	Arvada	organic soil amendment products	1	
Thin Air Nitrogen Solutions	Fort Collins	locally-sourced cyanobacteria as bio fertilizer		
Scimetrics Limited Corp.	Wellington	Kaput-D prairie dog control products		5

[23] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[24] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Academic research institutions active in soil fertility and pest control innovation in Colorado

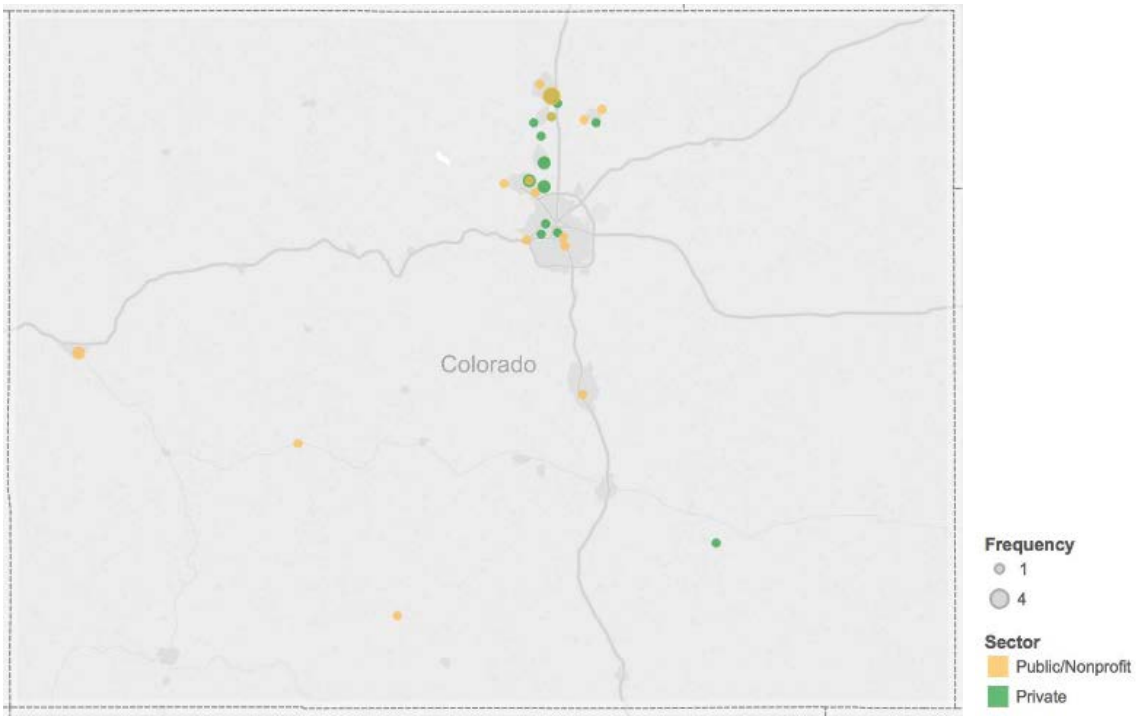
Colorado State University	Fort Collins	7,616	59
Front Range Community College	Westminster	4	
Mesa State University	Grand Junction	15	
University of Denver	Denver	70	1
University of Northern Colorado	Greeley	62	

State and federal agencies active in soil fertility and pest control innovation in Colorado

State of Colorado, Department of Agriculture	Denver	13
U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins	1,080
U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS)	Fort Collins	529
U.S. Department of Agriculture, U.S. Forest Service	Fort Collins	193
U.S. Environmental Protection Agency (EPA)	Denver	33

Photo courtesy of Dan Hilleman

3. Innovators in plant genetics and new crop varieties



Recent years have seen significant growth as well as some consolidation in crop genetics, plant breeding, and the seed industry. Innovation in plant sciences and crop genetics includes classical breeding, advanced breeding technologies, genetic sequencing and phenotyping, as well as genetic engineering.

Innovation in plant sciences and crop genetics is closely tied to several other areas of innovation, particularly innovation in soil fertility and crop protection and water management, as development of new varieties often selects for disease resistance, pest resistance, or drought tolerance traits. Innovation in crop genetics also overlaps with innovation in animal nutrition and biofuels, improving the quality of crops as feed, as biofuel feedstock, or both. Recent ties have strengthened between crop genetics and agricultural information systems, as consolidations between large seed and precision ag equipment and data services companies.

Although no major seed company is headquartered in Colorado, within the last decade several of the major global seed companies have established a presence in Colorado, including Cargill, Pioneer, Syngenta, and Limagrain. Several nonprofit and industry associations, including commodity associations, play key roles in this sector at the state level in Colorado. A significant number of academic and government research institutions, as well as government agencies, are active in plant sciences and crop genetic improvement.

Major anchor corporations active in plant genetics and crop variety innovation in Colorado

Name	Location	Company or technology description	WoS Publications[25]	US Patents[26]
Busch Agricultural Resources, Inc (Anheuser Busch InBev)	Fort Collins	barley agronomic research	7	
Cargill Specialty Seeds and Oils Innovation Center	Fort Collins	discovery, development and delivery of high-stability canola oils with reduced saturates and zero trans fats		
Crop Production Services (CPS) (subsidiary of Agrium)	Loveland	development and marketing of Dyna-Gro brand varieties of corn, cotton, and soybean seed		
Limagrain	Fort Collins	wheat breeding and seed marketing	3	
Pioneer Hi-Bred (subsidiary of DuPont)	Evans	drought tolerant varieties of corn for feed and ethanol markets; wheat varieties	1	
Syngenta Cereals	Berthoud	AgriPro wheat breeding program and seed marketing	6	
Syngenta Flowers	Boulder	horticultural flower breeding and propagation		
Syngenta Seeds	Longmont	Hilleshög sugar beet variety development and seed marketing	5	

Other companies active in plant genetics and crop variety innovation in Colorado

Applewood Seed Company	Arvada	wildflower, garden flower, native grass, and herb seed		2
Arkansas Valley Seeds	Denver	forage, cool and warm season grass, shrub, forbs and wildflower seeds for the high plains and mountain West		
Evolutionary Genomics Inc.	Lafayette	Adapted Traits Platform to identify plant genes responsible for yield, pest and disease resistance, salt tolerance, and flavor		24
GE Dharmacon Inc.	Lafayette	RNAi gene silencing and synthesis technologies		476
Hollar Seeds	Rocky Ford	development and improvement of cucurbit varieties	4	3
Pawnee Buttes Seed, Inc.	Greeley	pasture and native grass seed		
Plant Select	Fort Collins	cultivation and distribution of plants designed to thrive in the high plains and intermountain region		9
Rockey Farms	Center	certified seed potatoes		4
SDR Fruit	Boulder	apricot trees		9
STA Laboratories Inc.	Longmont	laboratory diagnostics for the seed and plant industry	3	
Venetria Biosciences	Fort Collins	system for production of nutritional and therapeutic proteins in rice		
Yucca Ridge Farm Inc / The Garlic Store	Fort Collins	garlic farming, seedstock supply, online retail	1	

[25] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[26] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

3. CROP GENETICS

Nonprofit organizations and industry associations active in plant genetics and crop variety innovation

Colorado Certified Potato Growers' Association	Monte Vista	joint management and marketing of new cultivars produced from the CSU Cultivar Development Program for both members' profit and for the generation of royalties to further support the potato research and breeding program		
Colorado Corn	Greeley	market development, promotion, research, education, advocacy and legislative support for corn farmers and their communities		
Colorado Wheat Growers' Association	Fort Collins	education, research, and promotional programs designed to develop, maintain, and increase domestic and export sales of Colorado wheat	1	
Sugar Beet Development Foundation	Denver	research and development, education and technical programs of common interest to sugar beet processors and seed companies	4	

Academic and nonprofit research institutions active in plant genetics and crop variety innovation

Colorado College	Colorado Springs	31	
Colorado Mesa University	Grand Junction	3	
Colorado State University	Fort Collins	7,616	59
Denver Botanical Gardens	Denver	3	
Mesa State University	Grand Junction	15	
University of Colorado	Boulder	1,778	231
University of Colorado Museum	Boulder	18	
University of Denver	Denver	70	1
University of Northern Colorado	Greeley	62	
Western State Colorado University	Gunnison	7	

State and federal agencies active in plant genetics and crop variety innovation

U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins	1,080	
U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS)	Fort Collins	529	
U.S. Department of Agriculture, National Center For Genetic Resources Preservation (NCGRP)	Fort Collins	26	
U.S. Department of Agriculture, U.S. Forest Service	Fort Collins	193	
U.S. Department of Energy, National Renewable Energy Laboratory (NREL) (incl. Alliance for Sustainable Energy LLC)	Golden	116	105

CASE STUDY: DuPont Pioneer

DuPont Pioneer is the largest hybrid corn seed company in the U.S. and the world. Originally founded in 1926, Pioneer has long been primarily a crop breeding company. According to Dr. Bill Curran, who directs Pioneer's breeding station and research center in Evans, Colorado, the company opened its facility in Colorado in 2004, with an initial staff of six people, to focus on breeding corn adapted to the arid high plains.

The Colorado team made significant contributions to the development of Pioneer's conventionally-bred, drought-tolerant *AQUAmax* corn hybrids, which have been widely adopted by farmers during the drought of the last few years. More recently, Pioneer has moved into breeding hybrid spring and winter wheat, taking up a line of work that the company had divested over 25 years ago. The research center now has 12 staff employees including 3 scientists. Workload has increase significantly since the center was opened in 2004 as a result of expanded drought testing.

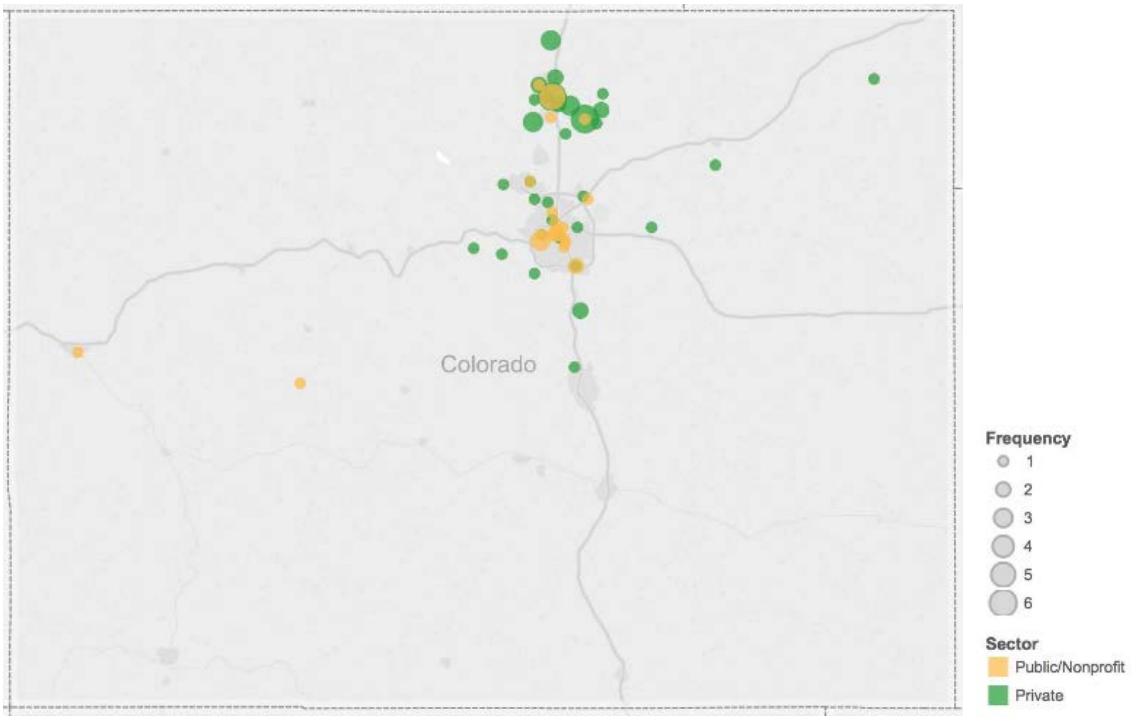
The Colorado Front Range provides an ideal climate for their R&D activities, says Dr. Curran. With over 240 days of sun and minimal rain, Pioneer is able to carefully control many of the environmental factors on their fields, enabling them to speed up production and genetic selection processes. In fact, given the ability to customize conditions, they can create and test varieties here for a range of different regions around the world, from Sub Saharan Africa to Ukraine. The seeds developed by DuPont Pioneer in Colorado, thus, are marketed worldwide.

Access to talent has proven to be another advantage of Pioneer's choice of location in the Front Range. The breeding station utilizes CSU students as interns, some of whom are then hired full time. The station currently employs four CSU graduates, who are well suited for Pioneer, given their familiarity with the drought-tolerance research at CSU and the unique growing environment of Colorado. Recent graduates with expertise in molecular biology and its applications in crop breeding are in high demand. Curran has found they are also able to recruit talented individuals to the facility from other states, given the desirability of the location.

While Pioneer does not often collaborate with other firms in the seed industry, given intellectual property and competition, it does partner with public research institutions in the Front Range. They are actively working with scientists at the USDA and at CSU. DuPont Pioneer also collaborates with local farmers, to utilize their land for variety testing. This gives farmers additional information about pests, water, and fertility, greatly benefiting farmers and local farmer co-ops.

In its latest developments, DuPont Pioneer is leveraging advanced technology to better refine precision agriculture and understand all aspects of agricultural production today and into the future. The company is increasingly utilizing big data and precision agriculture systems to create new tools that integrate crop genetics with agricultural information systems. According to Curran, Pioneer is helping farmers make sense of data to decide precisely where to plant specific varieties and how much to apply inputs like fertilizer and water to optimize yield and minimize waste, thus saving scarce resources and costs to the farmer. •

4. Innovators in animal health, nutrition, and herd management



Given the large populations of livestock in Colorado, particularly beef and dairy cattle, but also horses and sheep, the state is home to a number of innovators seeking to improve the quality of animal health and nutrition, reduce cost, and improve herd management.

A handful of major anchor companies are located in Greeley and other cities in northern Colorado, at the heart of the highly productive South Platte River Valley in the high plains. A wide array of other companies are active in veterinary diagnostics, vaccines, therapeutics, behavioral medicine, and epidemiology, including disease transmission within and between wildlife and domestic animal populations. Others are pursuing innovation in feed composition, including grain processing, supplements, and monitoring and feeding systems. Animal identification and traceability systems are another area of interest.

In addition to the companies active in animal health and nutrition, nonprofit organizations, academic and government research institutions, and government regulatory agencies are quite active in research and innovation. Basic biological research conducted in the universities and hospitals in the Denver area, while not focused on livestock applications directly, nonetheless has important crossover applications between human medicine and animal health.

Major anchor corporations active in animal health, nutrition, and herd management innovation

Name	Location	Company or technology description	WoS Publications[27]	US Patents[28]
Animal Health International Inc. (incl. former Lextron)	Greeley	animal feed supplements and feed lot management systems		74
Cargill	Fort Morgan	beef feeding	4	
JBS Five Rivers Cattle Feeding (incl. former ContiBeef)	Greeley	beef feeding	15	

Other companies active in animal health, nutrition, and herd management innovation

ADM Alliance Nutrition, Loomix Specialty Products Division	Johnstown	livestock feeds and supplements		2
Agfinity (incl. former Agland)	Eaton	ag supply ; steam flaking of grains (as Agland)	3	4
Agsmart	Strasburg	aerobic waste treatment lagoon system for dairies, feed yards and swine operations		5
Animal Care Systems	Centennial	animal caging systems	1	10
Animal Feed Technologies, LLC	Greeley	agricultural supplies	13	
Behavioral Response Technologies, Inc.	Boulder	neurological stimulation of milk cow feeding behaviors to enhance productivity		
Bovine Reproduction Specialists	Loveland	veterinary care of dairy cattle reproduction, and reproductive management	1	
Colorado Genetics Inc.	Loveland	bovine reproduction		
Colorado Quality Research Inc. / Feathertech Inc.	Wellington	livestock feed and biosafety research; poultry feeds	39	4
CowChips, LLC (former DDX Incorporated)	Denver	diagnostic and detection systems for the beef and dairy cow markets		5
Dairy Tech Inc.	Greeley	calf milk pasteurization and colostrum management systems for calf health		5
DVM Systems (incl. Bella Technologies)	Greely	bolus livestock temperature monitoring system	1	2
EI Medical Imaging	Loveland	real-time ultrasound scanner to serve veterinarians and livestock producers	3	
Front Range Energy	Windsor	bioethanol for fuel markets and distillers grains for livestock feed market		
Gene Check Inc.	Greeley	veterinary genetic testing for livestock		5
GlobeImmune, Inc.	Louisville	animal vaccines		28
Grandin Livestock Handling Systems Inc.	Fort Collins	handling system design and animal behavior consulting	1	
Heska Corporation	Fort Collins	animal vaccines and health	66	52
Horton Feedlot and Research Center	Wellington	livestock management and feeding	6	
Hydrahorse	Fort Collins	trailer mounted livestock watering system		1
Idexx Laboratories	Westminster	veterinary and water quality diagnostics	14	
Inco Digestive	Haxtun	animal feed and nutrition veterinary care and research		1

[27] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[28] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

4. ANIMAL HEALTH & NUTRITION

International Bovine Training Solutions	Fort Collins	reproductive performance on dairy and beef operations		
Membrane Protective Technologies	Fort Collins	nutrient media for maintaining sperm viability		6
Microbial Research Inc.	Fort Collins	veterinary services microbiology laboratory with experience in clinical trials	5	
Mountain Meadows Lamb Corporation	Denver	lamb feeding, slaughter, and processing		1
Multimin USA	Fort Collins	mineral micronutrient supplements for animal feed, forage, distillers grains, and drinking water	1	
Nutrinsic (formerly Oberon FMR)	Aurora	extraction of protein biomass from food industry waste water, up-cycling for use as animal feed and fertilizer		4
Optibrand	Fort Collins	animal retinal scanner for animal ID	3	5
Optimal Ag Consulting	Fort Collins	research and consulting for farms and ranches with special emphasis on risk management and decision	1	
Phase IV Engineering	Boulder	livestock data and ID systems		3
Pheno Imaging	Broomfield	animal sorting, measuring, grading systems		9
Research Management Systems (RMS) USA Inc.	Fort Collins	carcass assessment and live animal management technologies		4
Ritchey Manufacturing	Brighton	animal ID tags		15
Scimetrics Limited Corp.	Wellington	Kaput-D prarie dog control products		5
Silver Bullet Water Treatment	Denver	water filtration system to treat animal drinking water		
Summit View Solutions	Greely	animal retinal scanners for individual animal identification		
Venaxis, Inc (formerly AspenBio Pharma)	Castle Rock	bovine pregnancy tests		15
Veterinary Research and Consulting Services LLC	Greeley	production feedlot veterinary medicine and research	7	
VMC Inc.	Evergreen	veterinary consulting	94	
Where Food Comes From	Castle Rock	products and services to track, record, manage, report, and audit key data regarding livestock and other food products		
Wildlife Laboratories Inc.	Fort Collins	wildlife pharmaceuticals and specialized products for use in wildlife species—including safe animal control, chemical immobilization, remote drug delivery	6	1
Wildlife Pathology International	Fort Collins	veterinary pathology studies in wildlife species	5	
Wildlife Pharmaceuticals Inc,	Windsor	wildlife pharmaceuticals	17	
Willowcroft Pharm Inc.	Littleton	developer of injectable laminitis drug for equine		
XY Inc,	Navasota, TX	animal reproduction, sexing semen	33	63

Nonprofit organizations and industry associations active in conducting or supporting animal health, nutrition, and herd management innovation in Colorado

National Cattlemen's Beef Association	Centennial	R&D of interest to membership of beef producers	49	
North American Limousin Foundation	Englewood	national registry for Limousin cattle	7	
Professional Rodeo Cowboys Association	Colorado Springs	rodeo sanctioning	1	
Rocky Mountain Bird Observatory	Brighton	conservation of Rocky Mountain and Great Plains birds and their habitats through research, monitoring, education, and outreach	1	
U.S. Meat Export Federation	Denver	develop international markets for U.S. beef, pork, lamb and veal	2	

Academic and nonprofit research institutions active in animal health, nutrition, and herd management innovation in Colorado

Denver Zoo	Denver		48	
Colorado State University	Fort Collins		7,616	59
Front Range Community College	Westminster		4	
Mesa State University	Grand Junction		15	
Metropolitan State University of Denver	Denver		14	
National Jewish Health	Denver	research specializing in respiratory, cardiac, immune, and allergic disorders, with basic research of relevance to veterinary health applications	30	47
Regis University	Denver		13	
Rocky Mountain Biological Lab (RMBL)	Crested Butte	high-altitude ecological scientific research	50	
University of Colorado	Boulder		1,778	231
University of Denver	Denver		70	1
University of Northern Colorado	Greeley		62	

State and federal agencies active in animal health, nutrition, and herd management innovation in Colorado

State of Colorado, Department of Agriculture	**Denver**	13	
State of Colorado, Department of Public Health and Environment	Denver	23	
State of Colorado, Division of Parks and Wildlife	Denver	86	
U.S. Bureau of Land Management	Lakewood	15	
U.S. Centers for Disease Control and Prevention	Fort Collins	173	
U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins	1,080	
U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS)	Fort Collins	529	
U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS)	Denver	22	
U.S. Department of Agriculture, National Wildlife Research Center	Fort Collins	11	
U.S. Department of Agriculture, U.S. Forest Service	Fort Collins	193	
U.S. Environmental Protection Agency (EPA)	Denver	33	
U.S. Fish and Wildlife Service	Denver	20	
U.S. Food and Drug Administration (FDA)	Denver	76	
U.S. National Park Service		35	

CASE STUDY: Animal Health International

Animal Health International, headquartered in Greeley, Colorado, is a distributor of veterinary and animal nutrition products for commercial livestock producers, veterinary practices, and veterinary supply retailers. They distribute products manufactured by companies such as Bayer, Elanco, Merck, and Zoetis, among many others. Animal Health International was created in 2011 by the merger of Lextron Inc. and Walco International. Walco was founded as a livestock supply distributor in California in the 1950s. Lextron was founded under the name Great Plains Chemical in Denver in 1967. Great Plains Chemical moved to Greeley shortly after it was founded, and then changed its name to Lextron in 1986. In the 2011 merger, the Front Range was chosen as the base of operations for Animal Health International, according to Dave Wagley, Executive Vice President & CFO, because the area offered a reliable pool of employees and sat at the heart of the combined companies' North American supply and distribution chains.

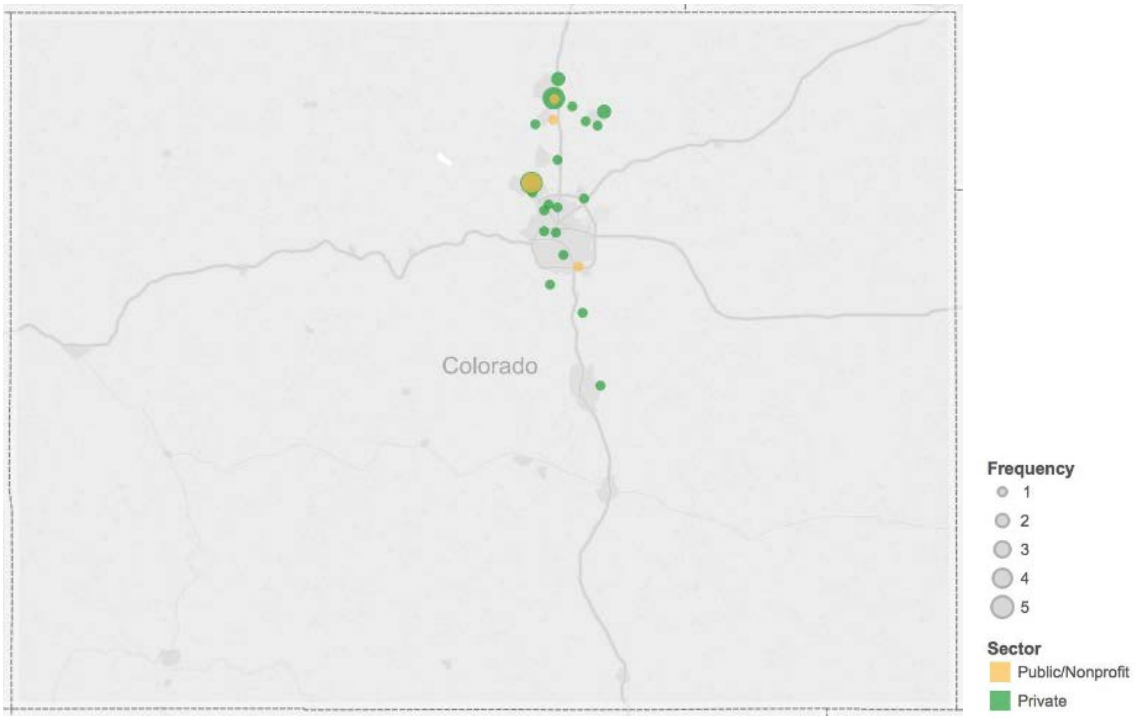
Animal Health International, and before it Lextron, has long been an innovator in the area of livestock feed management systems. They began developing "micro-ingredient" feed blending and dispensing equipment in the 1970s, in response to the needs of its livestock customers to properly administer correct dosages of feed additives to their herd. In time, the feed dispensers came to be computerized and Animal Health has developed software and data management systems. These track individual animals' feeding regimes and veterinary records. The systems also seamlessly managing the customer-supplier relationship, reordering fresh stocks as an operation's feed additives or veterinary supplies begin to run low. The economics of the business model can be considered somewhat similar to that of Hewlett Packard's printer business, providing the equipment, the software that runs it, and the ink cartridges. Feedlots that utilize Animal Health's feed management systems are much more likely to remain steady and satisfied customers of its feed additives.

According to Wagley, given the effectiveness of their in-house R&D program, Animal Health International is not actively collaborating with other companies in the Front Range. They do, however, keep in touch with animal nutritionists at Colorado State University. They support work at the CSU College of Veterinary Medicine, knowing that the future veterinarians graduating from CSU will be advising and serving Animal Health's clients in their use of veterinary products, feed supplements, and feed management systems.

Although Colorado generally offers a quality pool of potential employees, including recent CSU graduates, Wagley says they have faced some challenges in finding software programmers in the area with the right blend of expertise. This is a unique technology being pioneered by Animal Health International. CSU might have an opportunity, perhaps through collaboration between the College of Agricultural Sciences and the Department of Computer Science, to train programmers with expertise in SAP as well as agricultural systems.

Wagley notes that companies' incentives to innovate can be significantly affected by policies such as the state's tax exempt status on agriculturally related goods, including feed additives. He notes recent changes affecting innovation incentives, including dwindling federal R&D tax credits and depreciation accounting policies. •

5. Innovators in agricultural information systems



Information technology and big data are driving ever greater changes in agricultural production and in the marketing functions of the agricultural and food value chain. The first big impact of big data and IT is on the farm, where decades of development of "precision agriculture" systems—which combine digital mapping of farms, automation of farm machinery, and the collection of data from a battery of on-farm, aerial, and satellite sensors—has entered a new phase of adoption by most mainstream farm operations. Such technologies have been slower to penetrate livestock operations, but are not far behind in the area of herd management (see the case study on Animal Health International). The second main area of impact of big data and information technology is providing traceability or identity preservation along product supply chains, enabling verification of origins, standards compliance, and other types of information important to consumers, retailers, and regulators.

Innovation in agricultural information systems is closely tied to several other areas of innovation, including crop genetic innovation, soil fertility and pest control innovation, water systems innovation, and animal health and herd management. A particularly high degree of overlap is observed with innovation in sensors, analytics, and testing for product quality and biosafety, as these two together are poised to become, in a sense, the "eyes and ears" and the "central nervous system" of the "Internet of Things" as it continues to penetrate and automate production and marketing systems in agriculture and food.

5. INFORMATION SYSTEMS

Major anchor corporations active in agricultural information systems innovation

Name	Location	Company or technology description	WoS publications[29]	US Patents[30]
Lockheed Martin	Colorado Springs / Littleton / Aurora / Denver / Boulder	research, design, development, manufacture and integration of advanced technology systems, products, and services	1	
Trimble Navigation	Loveland / Boulder	precision agriculture navigation and control systems		

Other companies active in agricultural information systems innovation

Agrobotix	Boulder	unmanned aerial systems for agriculture		
Agworld	Windsor	farm management system online apps		
Animal Health International Inc. (incl. former Lextron)	Greeley	animal feed supplements and feed management software systems		74
aWhere	Wheat Ridge	integration of complex agricultural, environmental, and public health data into local, actionable insight		
Baus Tech	Fort Collins	unmanned aerial systems for agriculture		
Berry & Associates	Fort Collins	applications of geographic information system (GIS) technology	1	
Boulder Labs	Boulder	unmanned aerial systems for agriculture		
CartoPac	Fort Collins	enterprise GIS systems for resource management		
DigitalGlobe	Longmont	remote sensing systems		
ESRI	Broomfield	GIS systems		
FieldWing Aerial Systems	Boulder	unmanned aerial systems for agriculture		
InventWorks	Boulder	unmanned aerial systems for agriculture		
Phase IV Engineering	Boulder	livestock data and identification systems		3
Pheno Imaging	Broomfield	animal sorting, measuring, grading systems		9
Pixearth Corporation	Fort Collins	geographical information through mapping and digital photography		2
Red Hen Systems	Fort Collins	enterprise GIS systems for resource management		
Scion UAS	Loveland	unmanned aerial systems for agriculture		
SWCA Environmental Consultants	Broomfield / Fort Collins	environmental planning, permitting, regulatory compliance, resource management, air quality, GIS, and water resources	1	
TraceGains (AgInfoLink)	Westminster	web-based supplier, compliance, and regulatory document management system that automates supplier risk, data, and documentation		9
Where Food Comes From	Castle Rock	products and services to track, record, manage, report, and audit key data regarding livestock and other food products		

[29] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[30] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Academic and nonprofit research organizations active in agricultural information systems innovation

Colorado State University	Fort Collins		7,616	59
Global Development Analytics	Centennial	spatial modelling and analytics to provide information to enable small-holder farmers in developing countries increase productivity and reduce dependence on aid		
National Center For Atmospheric Research (NCAR)	Boulder		175	
National Ecological Observatory Network	Boulder	continental-scale ecological observation system for examining critical ecological issues; funded solely by National Science Foundation (NSF)	4	
University of Colorado	Boulder		1,778	231

State and federal agencies active in agricultural information systems innovation

National Oceanic and Atmospheric Administration (NOAA)	Boulder	71	
U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins	1,080	

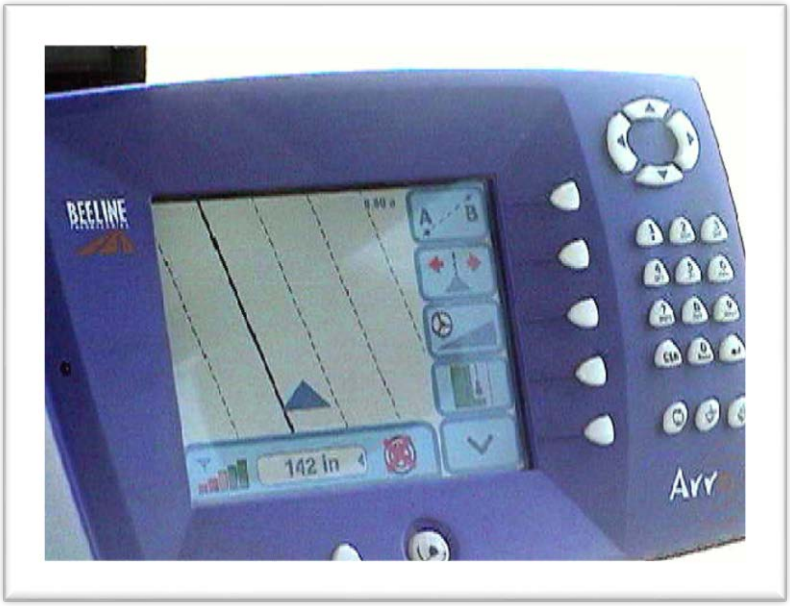
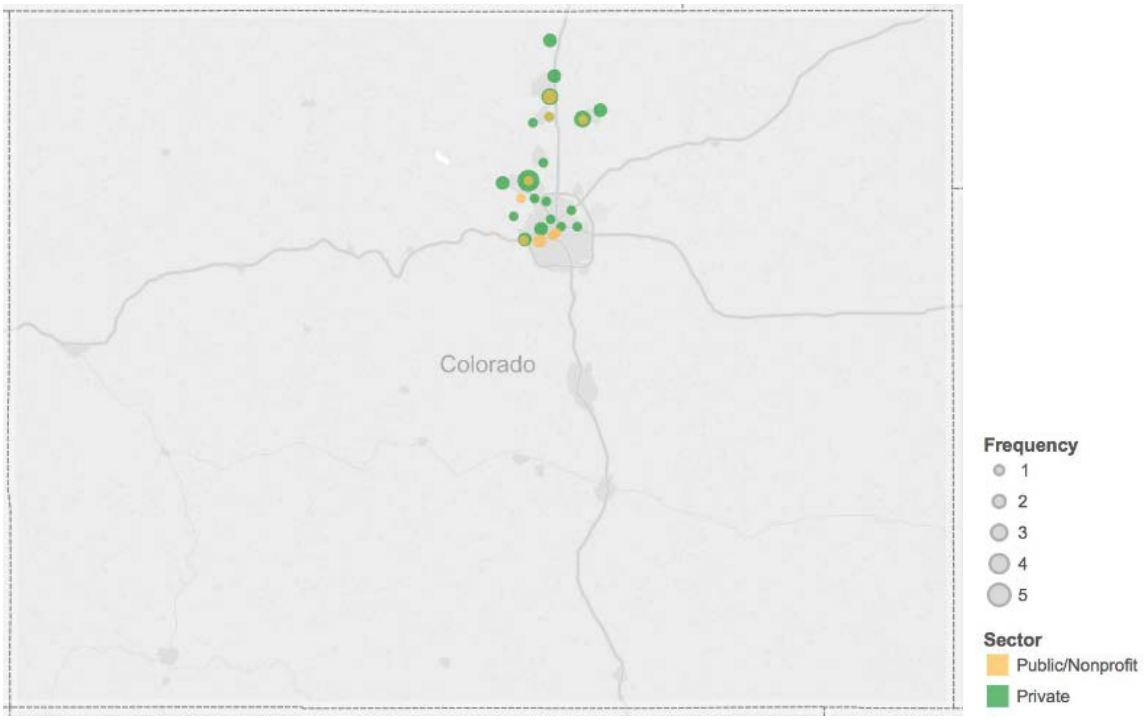


Photo courtesy of Dan Hilleman

6. Innovators in sensors, testing, and analytics for product quality and biosafety



Food safety and product quality have been top-of-mind issues in Colorado's agricultural community. They are, moreover, issues confronting agriculture and food globally. An entire category of businesses and public sector research programs are developing new technologies for monitoring and assuring product quality and safety. Monitoring involves sensors, testing, and analytical methods for detecting physical or chemical characteristics of materials being handled and turning that measurement into actionable data. Management strategies are also being developed for appropriately sorting, storing, or decontaminating water, food, and beverage products, in order to maintain product quality and food safety.

Innovation in this category necessarily overlaps with agricultural information systems, animal health, commodity processing and food and beverage manufacturing, as well as water, dairy, and beer, wine, and spirits production.

In Colorado a sizable number of companies are developing technologies and services in this category, everything from permanent real-time monitoring systems, to custom laboratory analytical services, to food safety products and services. Universities as well as state and federal agencies are also active in this area.

Companies innovating in sensors, testing, and analytics for product quality and biosafety in Colorado

Company	Location	Company or technology description	WOS publications[31]	US patents[32]
Analytical Spectral Devices (ASD)	Boulder	packaged product inspection systems		
Bintech	Louisville	high resolution measurement of large bulk inventory storage tanks and grain bins		1
Birko Corp	Henderson	food safety for food and beverage manufacturing facilities	1	15
CarboAnalytics	Fort Collins	accurate sugar analysis for food, beverage, bioenergy		
Chata Biosystems Inc.	Fort Collins	analysis and quality testing for animal feed, food and beverage, and ethanol manufacturers		4
ChromaDex Analytics Inc	Boulder	science-based solutions to the dietary supplement, food & beverage, animal health, cosmetic and pharmaceutical industries	11	
Colorado Quality Research/ Feathertech Inc.	Wellington	livestock feed and biosafety research; poultry feed	39	4
Dairy Authority	Greeley	animal and milk testing and monitoring for dairies in northern Colorado	8	
DVM Systems (incl. former Bella Technologies)	Greeley	bolus livestock temperature monitoring system	1	2
Epix Analytics	Boulder	risk analysis with applications in animal health	1	
Genesis Laboratories Inc.	Wellington	rodent insecticidal bait; vector-borne disease control and pest management; avian invasive species control; environmental toxicology analytics	2	6
Hach Company	Loveland	analytical instruments for water testing and water quality analysis	14	4
Hazen Research	Golden	biomass feedstock characterization and biorefining process development	1	4
Idexx Laboratories	Westminster	veterinary and water quality diagnostics	14	
IEH Labs & Consulting Group	Greeley	routine analytical support to food industry for microbiological, chemical, and toxicological issues in food	1	
IMI Global	Castle Rock	third party verification and certification for the livestock industry		
Industrial Laboratories Company	Wheat Ridge	food testing, microbiological analyses, and dietary supplement testing	5	
In-Situ Inc.	Fort Collins	environmental and water monitoring systems		
Lumiere Diagnostics	Fort Collins	food and water safety testing		
MicroBac (incl. Hauser Inc)	Boulder	testing services for food & beverage industries	6	7
OptiEnz	Fort Collins	highly sensitive enzymatic / fiber optic detectors for a range of pathogens and contaminants		
PANalytical (formerly ASD Inc)	Boulder	spectroscopy for laboratory screening, product testing, and remote sensing, with wide applications in agriculture, biofuels, and food	2	
Pheno Imaging	Broomfield	animal sorting, measuring, grading systems		9
RAS Inc.	Golden	borehole sensors for characterization and monitoring of aquifers and ground water systems	1	
Research Management Systems (RMS) USA Inc.	Fort Collins	carcass assessment and live animal management technologies		4
Rocky Mountain Instrumental Laboratories	Fort Collins	contract chromatographic and mass spectrometric analysis (HPLC/MS) with applications in water quality, agriculture, and food	2	

[31] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[32] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

6. PRODUCT QUALITY & BIOSAFETY

Sigma-Aldrich Corp (formerly Proligo)	Boulder	custom DNA and RNA oligonucleotides, including siRNA oligos for RNAi, LNA oligos for hybridization and biostability; and bi-labeled fluorescent probes designed for PCR		2
STA Laboratories Inc.	Longmont	laboratory diagnostics for the seed and plant industry	3	
Summit View Solutions	Greeley	animal retinal scanners for individual animal identification		
Thermo Fischer Scientific	Denver / Lafayette	pathogen reduction, therapeutic apheresis and cell processing		37
Weld Labs Inc.	Greeley	analytical testing for the agricultural and environmental communities	3	
Yocom McColl Testing Labs	Denver	commercial wool testing lab	4	

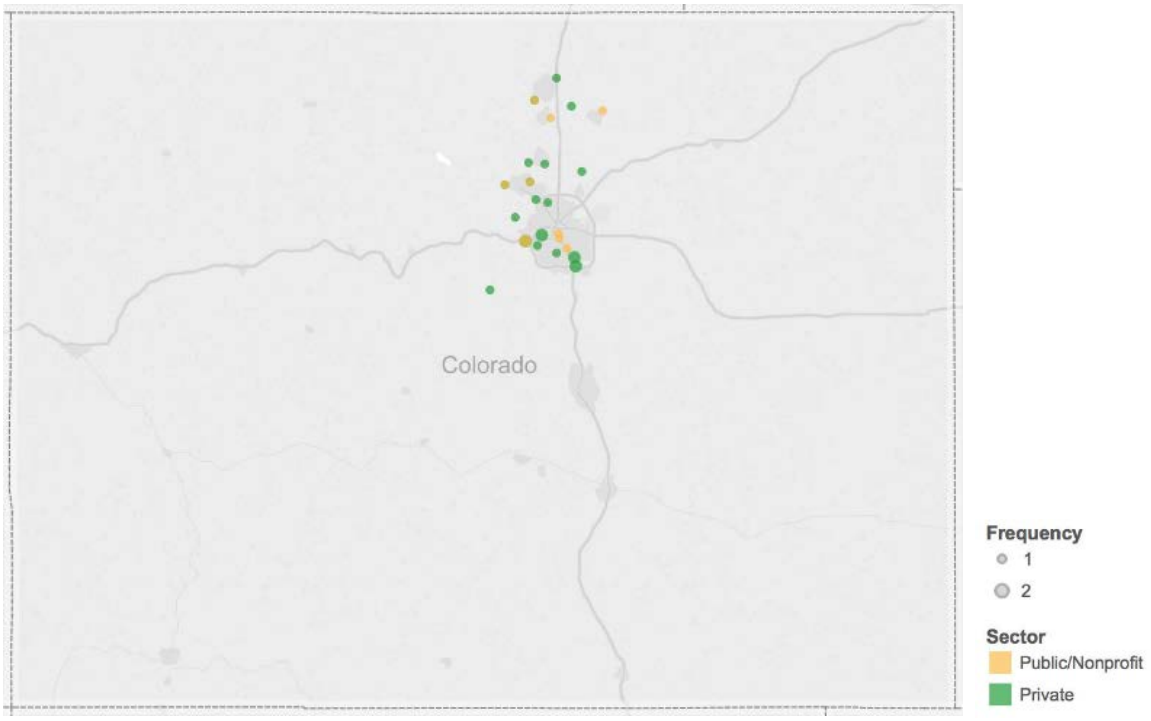
Academic research institutions innovating in sensors, testing, and analytics for product quality and biosafety in Colorado

Colorado School Of Mines	Golden	381	12
Colorado State University	Fort Collins	7,616	59
Metropolitan State University Of Denver	Denver	14	
University of Colorado	Boulder	1,778	231
University of Northern Colorado	Greeley	62	

State and federal agencies innovating in sensors, testing, and analytics for product quality and biosafety in Colorado

National Institute of Standards and Technology (NIST)	Boulder	10
U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins	1,080
U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS)	Denver	22
U.S. Department of Agriculture, U.S. Forest Service	Fort Collins	193
U.S. Environmental Protection Agency	Denver	33
U.S. Food and Drug Administration (FDA)	Denver	76

7. Innovators in bioenergy



Innovation in bioenergy includes increasing the efficiency of first-generation ethanol and biodiesel production as well as developing advanced biofuels production systems, including "cellulosic ethanol".

The Front Range has long been a center of innovation in advanced biofuels, particularly given the anchoring research programs of the National Renewable Energy Laboratory (NREL) and the universities. Innovation in advanced biofuels includes development of energy crops and algae as primary producers of biomass, biomass characterization and preprocessing, biomass conversion to fuels and fuel precursors, as well as fuel refining and blending technologies.

Innovation in biofuels is closely tied to several other areas of innovation, including crop genetics innovation, particularly in the development of feedstock varieties, and animal nutrition and dairy, as the co-products of bioethanol and biodiesel processes are high-value animal feeds. Bioenergy innovation also shares much with innovation in water management, as feedstock production is likely to be limited by availability of water resources. Another natural tie is with innovation in beer, wine, and spirits, not only around fermentation technologies, equipment, and facilities, but also because of the shared challenges of optimizing water inputs and animal feed co-products.

While there are no major energy corporations with R&D operations in Colorado, there is a sizable population of smaller technology ventures that have grown in or moved into the region. These are joined by a number of academic and public research institutions, as well as government agencies active in bioenergy innovation.

7. BIOENERGY

Companies active in bioenergy innovation in Colorado

Company	Location	Company or technology description	WoS publications[33]	US patents[34]
Aerophase Inc	Longmont	biodiesel fuel products		2
Agrebon, Inc	Fort Collins	ethanol byproducts to nitrogen fertilizer		
Blue Sun Biodiesel	Lakewood	biodiesel research, production, and distribution	1	
Camco Clean Energy	Louisville	renewable energy projects	1	
Ciris Energy, Inc.	Centennial	coal converted to natural gas using plants/chemicals		6
Cool Planet Energy Systems	Greenwood Village	green fuel and bio-char for energy, food, and water markets		
Du Pont Agriculture-Nutrition	Lakewood	biomass degradation		
Front Range Energy	Windsor	ethanol production		
GeoSynFuels	Golden	cellulosic biofuels		7
Gevo	Englewood	renewable chemicals and advanced biofuels (isobutanol) from biological conversion of woody biomass		115
GTL Energy	Wellington	technology to remove moisture from low rank coals and biomass		3
Hazen Research	Golden	biomass feedstock characterization and biorefining process development	1	4
Luca Technologies Inc.	Golden	biotechnology to produce natural gas		41
Merrick & Co. (with Coors)	Greenwood Village	ethanol production facility in Golden	2	
NEAtech	Denver	renewable energy consulting and project development		3
OPX Biotechnologies Inc.	Boulder	bio-based chemicals and fuels		5
Pioneer Hi-Bred (division of DuPont)	Evans	drought tolerant corn varieties widely used as feed and ethanol feedstock	1	
Point380 LLC	Boulder	consulting for food, beverage, and bioenergy	1	
PureVison Technology	Fort Lupton	cellulosic biorefining, biomass fractionation, and rapid hydrolysis converting biomass into sugars, lignin, and energy		
Range Fuels Inc.	Broomfield	biofuels production		20
Red Rock Biofuels	Fort Collins	gasification of cellulosic feedstock, resulting in jet, diesel, and naptha fuels		
Solix Biofuels	Fort Collins	photobioreactors for algae to biodiesel		8
Strategic Resource Optimization Inc.	Bailey	electrolytic chemistry technologies with applications in agriculture and bioenergy		4
Sundrop Fuels Inc.	Longmont	cellulosic biofuels production		8
Zeachem Inc.	Lakewood	cellulosic biofuels and other biomaterials		24

[33] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[34] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Nonprofit industry organizations active in supporting and promoting bioenergy innovation in Colorado

Colorado Corn	Greeley	market development, promotion, research, education, advocacy and legislative support for corn farmers and their communities		

Academic and public research institutions active in bioenergy innovation in Colorado

Colorado Center for Bio-refining and Biofuels (C2B2)		coordination of research among four major research institutions: National Renewable Energy Laboratory, University of Colorado, Colorado School of Mines, and Colorado State University		
Colorado School Of Mines	Golden		381	12
Colorado State University	Fort Collins		7,616	59
U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins		1,080	
U.S. Department of Energy, National Renewable Energy Laboratory (NREL) (incl. Alliance for Sustainable Energy)	Golden		116	105
University of Colorado	Boulder		1,778	231

State and federal agencies active in bioenergy innovation in Colorado

State of Colorado, Department of Transportation	Denver	8	
State of Colorado, Colorado Energy Office (CEO)	Denver	2	
U.S. Department of Energy	Denver	13	
U.S. Environmental Protection Agency	Denver	33	

Photo courtesy of Dan Hilleman

CASE STUDY: Front Range Energy

Front Range Energy, in Windsor, is one of several ethanol producers in Colorado. Front Range Energy has over 30 employees and sells more than $80 million annually in ethanol and distiller's grain. When looking for a location for a new biofuels plant in 2000, the founders of Front Range Energy hired BBI International (Denver) to help with a feasibility study. The study included factors such as regional ethanol and distillers' grains availability, to ensure there would be a market for their co-products, access to employees, and local infrastructure. Given the nature of the distillers' grains market, the company chose a location suitable for selling wet (as opposed to dried) distiller's grain, which, at that time, narrowed their search to Nebraska, Kansas, and Colorado.

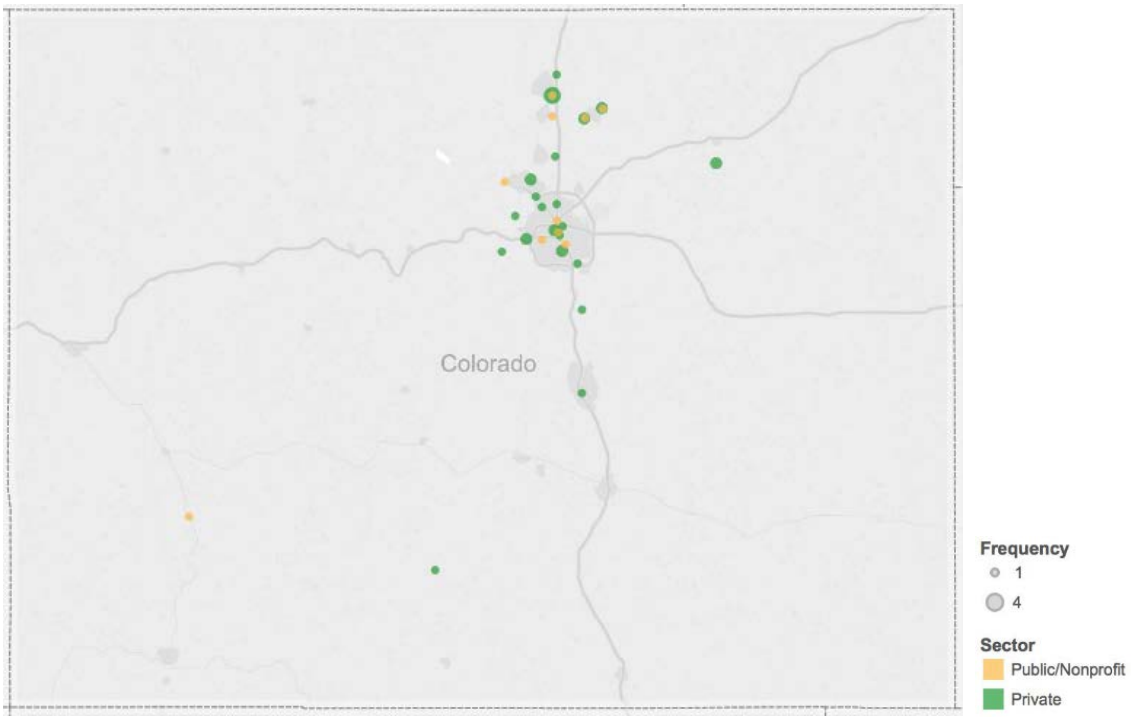
The Front Range of Colorado stood out, as it not only had large numbers of dairy and beef cattle, but it also offered a large ethanol market, given the energy demands of the metro region. Additionally, Colorado was not suffering the saturation of ethanol markets like the Midwest. Given the large livestock population, however, there was a lack of surplus corn in the state. Still, large scale production of wheat and other crops allowed for sourcing alternative feedstock. Also, the abundance of crop residues from large scale production of corn and wheat offered the potential to become an early mover in cellulosic ethanol production, once that technology matured. While the state of Colorado did not offer a producers' payment for ethanol, such as Nebraska's $0.10/gal., these factors, plus easy rail access, natural gas availability, and CO_2 capture potential, were enough to convince the team that the Front Range was the right location.

With a ruminant nutrition background, Brad Olson is Front Range Energy's manager of grain merchandising and works with farmers developing wet distiller's grain formulations for replacing corn, alfalfa, and other forages, and reducing feed costs. Front Range Energy seeks to produce high quality, consistent wet distiller's grain which they believe offers advantages over Dry Distiller's Grain. Growth of dairy market in the region means a stable market for their animal feed co-products.

Distillers' grains for animal feed is only one area in which Front Range Energy is innovating. They also have developed a zero discharge process in which all moisture created in the plant's processes stays in the system. They are working on how to incorporate a variety of feedstock. For example, in 2013 they were able to buy 14 million pounds of sugar from the USDA. They are conducting research on sorghum, including a pilot farm, to evaluate feasibility of using this low-water-requirement crop to better conserve water resources. They are planning to use technology provided by Sweetwater Energy of Rochester, New York, and originally developed at MIT, to develop a commercial cellulosic ethanol plant in Colorado that will be able to convert crop residues and even pine beetle kill timber to ethanol.

Other innovations by Front Range Energy include technology for capturing 40 percent of the CO_2 produced during fermentation and selling it to a CO_2 plant next door. Other Front Range companies use the CO_2 as an input, such as Coke and Pepsi, for carbonating beverages, and JBS, the world's largest meat producer, for flash freezing and transport on dry ice. •

8. Innovators in agricultural commodity processing and food and beverage manufacturing



Innovation in commodity processing and food manufacturing involves new product invention, development, product quality improvements, efficiency improvements, and food safety. Commodity processing is the first step after crops or animals are harvested. For field crops, this includes milling of grain and pressing of oilseeds. For vegetables and fruits, this includes washing, refrigerating, and packing for the fresh market, or peeling, slicing, dicing, pureeing, blending, parboiling, or freezing for processed or frozen food markets. In livestock, processing includes slaughter, rendering, butchering, curing, marinating, smoking, precooking, packing, freezing, and myriad other processes. Next in the value chain comes the manufacturing of food and beverage products, which can include hundreds of different sub-industries. In this inventory, several specialized sub-industries have been broken out as separate areas of innovation, including dairy products, brewing, winemaking, and distilling, and natural and organic food products.

The following inventory list includes a number of major anchor corporations innovating in the food and beverage industries. These are followed by other companies with particular specialties, some in developing certain types of ingredients, some in designing and manufacturing specialized processing and manufacturing equipment, and some in designing and providing information and product identity tracking systems.

8. PROCESSING & MANUFACTURING

Major anchor corporations innovating in agricultural commodity processing and food and beverage manufacturing

Company	Location	Company or technology description	WoS publications[35]	US patents[36]
Ardent Mills (incl. former ConAgra)	Denver	wheat milling	7	2
Boulder Brands (Smart Balance, Evol, Udi's)	Boulder	natural food products		
Cargill Meat Solutions	Fort Morgan	beef slaughter, processing and packing		
Celestial Seasonings Inc. (Hain Celestial Group)	Boulder	product development, production, and marketing of herbal teas and other natural food and beverage brands		3
Colorado Premium Foods	Greeley	integrated R&D program encompassing production, quality assurance, purchasing, and sales to develop and introduce new meat products		
DSM (formerly Martek, OmegaTech)	Boulder	omega-3 fatty acids, and other health enhancing food ingredients	12	246
EAS (owned by Abbott)	Golden	performance based nutritional supplements		1
GTC Nutrition (owned by Ingredion, former Corn Products International)	Golden	functional food ingredients, such as natural prebiotic fiber, for food ingredient and livestock markets	2	
JBS (incl. former Swift, Monfort)	Greeley	beef slaughter, processing and packing	2	68
Leprino Foods	Denver	cheese manufacturing	2	83
Penford Food Corporation	Centennial	food ingredients and manufacturing	2	22
Pilgrim's (owned by JBS)	Greeley	poultry processing		
Western Sugar Cooperative	Denver	sugar beet refining and co-products	2	2
WhiteWave Foods (incl. Horizon, Silk, Land O Lakes brands)	Broomfield	dairy and soy beverages	2	

[35] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[36] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Other companies innovating in agricultural commodity processing and food and beverage manufacturing

Ingredient or food product manufacturing and technology

Impact Confections Inc.	Colorado Springs	candy production		1
Keen Ingredients	Denver	quinoa processing		4
Lifeline Nutraceuticals Corp	Englewood	health enhancing food ingredients		3
MicroPure Technologies	Fort Collins	probiotics		5
MicroTender Industries	Denver	meat tenderizing		8
Mountain Meadows Lamb Corporation	Denver	lamb feeding, slaughter, processing and packing		1
Multigrain International LLC	Fort Collins	pulse commodities (pinto bean, sunflower, canary seed) production, processing, and marketing	2	
Nutrinsic (formerly Oberon FMR)	Aurora	extraction of protein biomass from food industry waste water, up-cycling for use as animal feed and fertilizer		4
Trinidad Benham Corp.	Denver	merchandising, packaging, trading and distribution of dry beans, rice		
Sagescript Institute / Colorado Aromatics	Longmont	bulk bases, herbs, and herb extracts for small cosmetics companies	1	

Equipment manufacturers

Atlas Pacific Engineering	Pueblo	food manufacturing equipment		26
CoorsTek	Golden	materials for use in food processing and beverage handling equipment		
HDR	Denver	engineering for water, agribusiness, food & beverage manufacturing	8	
Johns Manville	Denver	ag equipment and construction	2	13
Kryptane Systems	Louisville	rollers for ag processing and manufacturing equipment		1
Magnuson Corporation	Pueblo	supplier of food processing machinery to food processing plants		5
Noffsinger Manufacturing	Greeley	agricultural conveyor chain, along with related rollers, cones, and drive sprockets		1
Oliver Manufacturing	La Junta	equipment for processing and refining edibles and grains, including sizers, separators, de-stoners, and dryer/coolers		
Portec	Canon City	specialty conveyors		1
SB Packing House Equipment	Fort Morgan	hide pullers		1

Commodity and food product data and information systems

Hazen Research	Golden	biomass feedstock characterization and biorefining process development	1	4
Sugars International	Englewood	process modeling and simulation software to analyze and improve beet and cane sugar factories and refineries	5	
TraceGains (AgInfoLink)	Westminster	web-based supplier, compliance, and regulatory document management system that automates supplier risk, data, and documentation		9
Where Food Comes From	Castle Rock	products and services to track, record, manage, report, and audit key data regarding livestock and other food products		

8. PROCESSING & MANUFACTURING

Non-profit industry associations supporting and promoting agricultural commodity processing and food manufacturing innovation in Colorado

Beet Sugar Development Foundation	Denver	research and development, education and technical programs of common interest to sugar beet process and seed companies	4	
Colorado Corn	Greeley	market development, promotion, research, education, advocacy and legislative support for corn farmers and their communities		
Livestock Marketing Information Center	Denver	economic analysis and market projections concerning the livestock industry	1	
U.S. Meat Export Federation	Denver	developing international markets for U.S. beef, pork, lamb and veal	2	
Wheat Foods Council	Ridgway	increasing awareness of dietary grains as an essential component to a healthy diet	6	

Academic and nonprofit research institutions active in agricultural commodity processing and food manufacturing innovation in Colorado

Colorado State University	Fort Collins	7,616	59
Regis University	Denver	13	
University of Denver	Denver	70	1
University of Northern Colorado	Greeley	62	

Public regulatory agencies active in agricultural commodity processing and food manufacturing innovation in Colorado

U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins	1,080	
U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS)	Denver	22	
U.S. Food and Drug Administration (FDA)	Denver	76	

COMPANY BRIEF: Ardent Mills

Ardent Mills, a newly created three-way joint venture of ConAgra Foods (of Omaha, Nebraska), Cargill (of Minneapolis, Minnesota) and CHS (of St. Paul, Minnesota), is the largest wheat milling company in the U.S. and is setting up its new headquarters in Denver, Colorado. Innovation is part of the new company's core mission, as stated in a recent press release: "to be a trusted partner in nurturing customers, consumers and communities through innovative and nutritious grain-based solutions."

In another public statement, Ardent's CEO Dan Dye explained, "selecting the Denver area as the home for Ardent Mills will allow us to offer great quality of life for employees, provide excellent service to our customers, and position the business for long-term growth." Denver facilitates this due to direct flight accessibility to many of Ardent's milling facilities around the U.S., proximity to its mills in Commerce City and Denver, and its innovative linkages with Colorado's wheat farmers and industry associations, as well as opportunities to build relationships with Colorado's research universities, particularly CSU. The state's $5.6 million incentive package offered to Ardent Mills helped. But, fundamentally Dye believes Colorado "is reflective of the health conscious, active, innovative nature of the Ardent Mills' brand." •

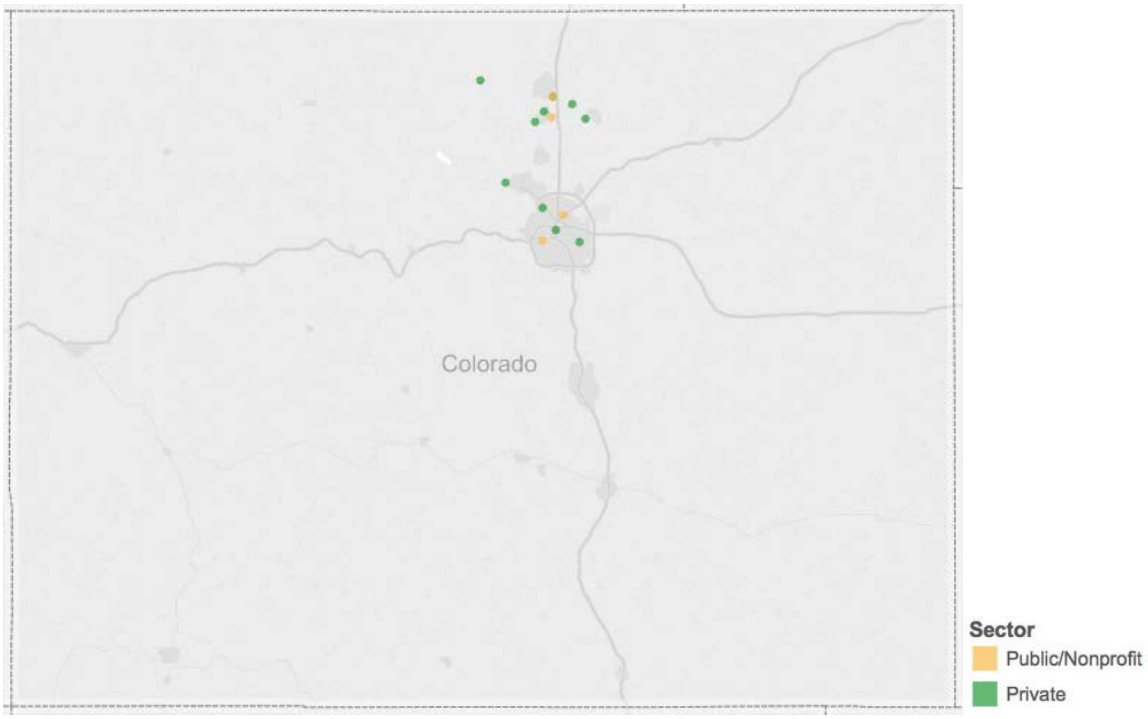
COMPANY BRIEF: JBS

JBS USA Inc., headquartered and operating large feedlots and a state of the art slaughter and meatpacking facility in Greeley, Colorado, is part of JBS SA, "the largest animal protein company in the world," based in Sao Paulo, Brazil. The operations in Greeley, can trace their roots back to the stockyards of the Monfort Company of Colorado, founded in 1930. Monfort entered the slaughter and meatpacking business in 1960. In 1987 ConAgra acquired Monfort and shortly thereafter also acquired Swift. Between 2002 and 2004 ConAgra spun off its combined red meat business under the name "Swift", which then in 2007 was acquired by JBS. Two years later, JBS bought neighboring Pilgrim's Pride. The parent company, JBS, was founded in 1953 as a beef slaughter company by Brazilian rancher Jose Batista Sobrinho (thus the initials "JBS").

Innovation by JBS focuses in two areas. JBS has introduced numerous incremental improvements internally that boost efficiencies and reduce costs of the butchering process while better meeting customer specifications. At the same time JBS is also developing and branding top quality meat cuts to fetch premium prices.

While corporate ownership and structure has changed through the years, the company has maintained its key location in northern Colorado. Given the large amount of animal production that the company has brought to the Front Range, they have been pivotal in attracting other agriculturally orientated companies, such as Front Range Energy, due to supply chain synergies. Today, the location also helps JBS recruit new talent. Their website extolls that: "The people of Northern Colorado embody the spirit and attitude that is the Colorado lifestyle. Not too hung up on pretention, it's a place where 'to each his own' dictates social norms. The cities of Northern Colorado combine the best in outdoor adventure, metropolitan culture, and a variety of shopping, dining and entertainment experiences with the welcoming charm of small-town life." •

9. Innovators in dairy production and manufacturing



While innovation in the dairy industry is closely related to several of the other categories considered in this report, the dairy industry has such distinct characteristics, and it has been growing at such a rapid rate in recent years, that it is being considered here as an area of innovation in its own right. Colorado's dairy industry has become nationally and internationally recognized as a leader in innovation. Leprino Foods has introduced large scale cheese manufacturing, and the industry has upgraded the entire supply chain to maintain the necessary levels of production. The Colorado dairy industry has also pioneered large scale organic dairy production, including Horizon Organic Dairy and Aurora Organic Dairy. Colorado companies, notably White Wave, have also introduced mainstream American consumers to alternative dairy products, including soy and almond milks and coffee creamers. Colorado has significantly contributed to expanding the diversity of product offerings in today's supermarket diary aisle giving consumers greater choice.

Innovation in dairy overlaps significantly with innovation in animal health and nutrition, and many of the companies on the list in this section are also listed there. Innovation in dairy also overlaps with innovation more broadly in commodity processing and food and beverage manufacturing, as well as with innovation in sensors and analytics for product quality and food safety. Also, a significant part of the innovation in natural and organic foods in Colorado has involved dairy products.

This inventory lists major anchor corporations of the dairy industry based in Colorado. Both are centered in dairy product manufacturing, but both assert significant vertical coordination within the dairy value chain. The inventory finds a handful of other companies active in dairy innovation in Colorado, all supported by the Western Dairy Association and public sector science at Colorado State University, and two federal agencies, the USDA-ARS and the FDA.

Major anchor corporations active in dairy innovation in Colorado

Name	Location	Company or technology description	WoS publications[37]	US patents[38]
Leprino Foods	Denver	cheese manufacturing	2	83
Whitewave Foods (incl. Horizon, Silk, and Land O Lakes brands)	Broomfield	dairy and soy beverages	2	

Other companies active in dairy innovation in Colorado

Aurora Organic Dairy	Aurora	organic dairy	1	
Behavioral Response Technologies, Inc.	Boulder	neurological stimulation of milk cow feeding behaviors to enhance productivity		
Bovine Reproduction Specialists	Loveland	veterinary care of dairy cattle reproduction, and reproductive management	1	
Dairy Authority	Greeley	animal and milk testing and monitoring for dairies in northern Colorado	8	
Dairy Tech Inc.	Greeley	milk pasteurization and colostrum management systems for calf health		5
Haystack Mountain	Longmont	premium, handcrafted raw and pasteurized cheeses		
International Bovine Training Solutions	Fort Collins	reproductive performance on dairy and beef operations		
Jumping Good Goat Dairy	Buena Vista	premium, artisan goat cheeses		
MouCo Cheese	Fort Collins	premium, soft ripened cheeses		
Noosa Yoghurt / Morning Fresh Dairy	Bellvue / Fort Collins	Aussie-style yoghurt / local fresh delivery dairy		

Nonprofit industry associations supporting and promoting dairy innovation in Colorado

Western Dairy Association	Thornton	promotion of health programs, science-based nutrition, education, dairy farm best practices, and dairy food products		

Academic and nonprofit research institutions active in dairy innovation in Colorado

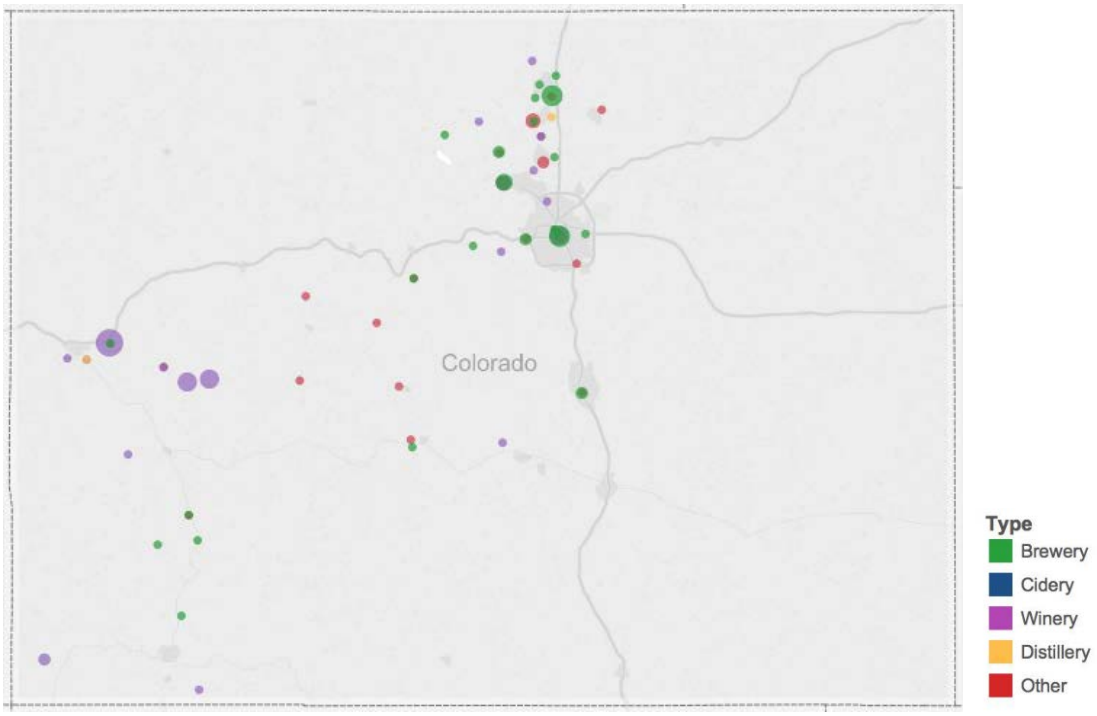
Colorado State University	Fort Collins		7,616	59

State and federal agencies active in dairy innovation in Colorado

U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins		1,080	
U.S. Food and Drug Administration (FDA)	Denver		76	

[37] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[38] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

10. Innovators in beer, wine, & spirits



The production of beer, cider, wine, and spirits may be as old as the history of agriculture, yet in the last twenty years, Colorado has emerged as a leader in the world of craft beverages, innovating new products and production that exploit the high quality water resources available in the Rocky Mountains. Colorado craft beverage companies have also innovated in marketing, promoting visits, tours, and tastings on location at the brewery, winery, and distillery, greatly expanding a new form of agtourism. The Front Range, from Denver to Fort Collins has been dubbed "The Napa Valley of Beer". Growing grapes for wines in the arid mountain west has required a couple decades of dedicated innovation by viticulturists and winemakers, including experimentation with some uncommon wine grape varieties well suited to the region. Recent vintages from both the Western Slope and the Front Range wineries have won accolades nationally, and the industry is poised to boom.[39] Most recently, Colorado has led the growth in craft distilling of spirits, with one of the largest populations of entrepreneurial distillers in the nation.

This inventory lists breweries, wineries, and distilleries separately. The list is not exhaustive; it includes only a selection of those producers who have gained some notoriety within the industry. In addition, this inventory lists a handful of service providers and academic research institutions whose innovations are helping the industry to grow. (None of the craft producers were found to have published scientific work in the Web of Science or to have patented inventions, and thus this portion of the tables were omitted for those groups.)

[39] See Dave Buchanan, *Drink It In: Wine Guide of Western Colorado*, Grand Junction Media, 2013

Major anchor companies innovating in beer, wine, and spirits production and marketing in Colorado

Name	Location	Company or technology description	WOS Publications[40]	US Patents[41]
Budwiser (owned by Anheuser Busch InBev)	Fort Collins	brewing		
Busch Agricultural Resources, Inc (Anheuser Busch InBev)	Fort Collins	barley agronomic research	7	
Molson Coors Brewing Co.	Denver	brewing	18	29
Rock Bottom Brewery	Denver	brewing and restaurants		

Craft brewers notable in beer and cider brewing innovation in Colorado

Name	Location	Company or technology description
Avery Brewing Co	Boulder	brewing
Black Bottle Brewery	Fort Collins	brewing
Blown Spoke Hard Cider	Loveland	cider making
Boulder Beer Co	Boulder	brewing
Breckenridge Brewery	Brekenridge	brewing
Bristol Brewing Co	Colorado Springs	brewing
BRU Handbuilt Ales	Boulder	brewing and restaurant
CB & Pots Brewing	Fort Collins	brewing and restaurant
Colorado Boy	Ridgway	brewing and restaurant
Colorado Cider Co	Denver	cider making
Compass Cider / Blossomwood Orchard	Fort Collins / Cedaredge	cider making and restaurant
Coopersmith's Pub & Brewing	Fort Collins	brewing and restaurant
Crooked Stave	Denver	brewing
Crow Hop	Loveland	brewing
Del Norte Brewing Co	Denver	brewing
Dry Dock Brewing	Aurora	brewing
Elevation Brewing	Poncha Springs	brewing
Equinox Brewing	Fort Collins	brewing
Fate	Boulder	brewing
Fort Collins Brewery	Fort Collins	brewing and restaurant
Funkwerks	Fort Collins	brewing
Golden City Brewery	Golden	brewing
Gordon Biersch	Broomfield	brewing

[40] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[41] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Grand Lake Brewing Co	Grand Lake	brewing	
Great Divide Brewing Co	Denver	brewing	
Left Hand Brewing Co	Longmont	brewing	
New Belgium Brewing Co	Fort Collins	brewing	1
Odell Brewing Co	Fort Collins	brewing	
Oskar Blues	Lyons	brewing	
Ouray Brewing	Ouray	brewing	
Palisade Brewing Co	Palisade	brewing	
The Post Brewing Co	Lafayette	brewing and restaurant	
Renegade Brewing	Denver	brewing	
River North Brewery	Denver	brewing	
Ska Brewing Co	Durango	brewing	
Shine Brewing Co	Boulder	brewing and restaurant	
Telluride Brewering Co	Telluride	brewing	
Tommyknocker Brewery	Idaho Springs	brewing	
Trinity Brewing	Colorado Springs	brewing	
Twisted Pine Brewing Co	Boulder	brewing	
Upslope Brewing Co	Boulder	brewing	
Wynkoop Brewing Co	Denver	brewing and restaurant	

Wineries notable for grape, fruit, and honey wine innovation in Colorado

Name	Location	Company or technology description	
5680	Paonia	viticulture and winemaking	
Alfred Eames Cellars	Paonia	viticulture and winemaking	
Balistreri	Denver	winemaking	
Black Bridge Winery	Paonia	viticulture and winemaking	
Black Canyon Vineyards	Hotchkiss	viticulture and winemaking	
Blue Mountian Vineyards	Berthoud	winemaking	
Bonacquisti Wine Company	Denver	winemaking	
Bookcliff Vineyards	Boulder	winemaking	
Boulder Creek Winery	Boulder	winemaking	
Canyon Wind Winery	Palisade	viticulture and winemaking	
Carlson Vineyards	Palisade	viticulture and winemaking	
Colorado Cellars	Palisade	viticulture and winemaking	
Colterris Winery	Palisade	viticulture and winemaking	
Cottonwood Cellars/ The Olathe Winery	Olathe	viticulture and winemaking	
Creekside Cellars	Evergreen	winemaking	
DeBeque Canyon Winery	Palisade	viticulture and winemaking	

Fire Mountain Vineyard	Hotchkiss	viticulture and winemaking	
Fox Fire Farms	Ignacio	viticulture and winemaking	
Garfield Estate Vineyard & Winery	Palisade	viticulture and winemaking	
Grand River Vinyards	Palisade	viticulture and winemaking	
Guy Drew Vinyards	Cortez	viticulture and winemaking	
Infinite Monkey Theorem	Denver	winemaking	
Jack Rabbit Hill / Peak Spirits	Hotchkiss	viticulture, winery, distillery	
Kingman Estates Winery	Denver	winemaking	
Leroux Creek Vineyards	Hotchkiss	viticulture and winemaking	
Meadery of the Rockies	Palisade	honey wine	
Medovina	Niwot	honey wine	
Plum Creek Cellars	Palisade	viticulture and winemaking	
Ptarmigan Vineyards / Stony Mesa Winery	Grand Junction	viticulture and winemaking	
Redstone Meadery	Boulder	honey wine	
Snowy Peaks Winery	Estes Park	winemaking	
Spero Winery	Denver	winemaking	
Stone Cottage Cellars	Paonia	viticulture and winemaking	
Sutcliffe Vineyards	Cortez	viticulture and winemaking	
Talon Wine Brands	Palisade	winemaking	
Ten Bears Winery	LaPorte	viticulture and winemaking	
Terror Creek Winery	Paonia	viticulture and winemaking	
The Winery at Holy Cross Abbey	Canon City	winemaking	
Turquoise Mesa Winery	Broomfield	winemaking	
Two Rivers Winery	Grand Junction	viticulture and winemaking	
Water 2 Wine	Denver	winemaking	
Woody Creek Cellars	Cedaredge	viticulture and winemaking	

Craft distilleries notable for distilled spirits innovation in Colorado

Name	Location	Company or technology description	
291 Distillery	Colorado Springs	distilling	
Altitutde Spirits / Vodka 14	Boulder	distilling	
Black Canyon Distillery	Longmont	distilling	
Boulder Distillery	Boulder	distilling	
Breckenridge Distillery	Breckenridge	distilling	
Colorado Gold Distillery	Cedaredge	distilling	
Copper Muse	Fort Collins	distilling	
Dancing Pines	Loveland	distilling	

Deerhammer Distilling Company	Buena Vista	distilling	
Downslope Distillery	Centennial	distilling	
Golden Moon Distillery	Golden	distilling	
KJ Wood Distillers	Berthoud	distilling	
Leopold Bros. Distillery	Denver	distilling	
Mile High Spirits	Denver	distilling	
Montanya	Crested Butte	distilling	
Peach Street Distillers	Palisade	distilling	
Peak Spirits / Jack Rabbit Hill	Hotchkiss	distilling, viticulture and winemaking	
Roundhouse Spirits	Boulder	distilling	
Spirit Hound Distillers	Lyons	distilling	
Spring 44	Loveland	distilling	
Stranahan's	Denver	distilling	
Syntax Spirits	Greeley	distilling	
Tesouro Distillery	Longmont	distilling	
Trailtown Distillers	Ridgway	distilling	
Two Guns Distillery	Leadville	distilling	
Wood's High Mountain Distillery	Salida	distilling	
Woody Creek Distillers	Basalt	distilling	
Zebra Vodka	Loveland	distilling	

Other companies providing innovative support services and equipment to the beer, wine, and spirits industry in Colorado

Brewing Science Institute	Woodland Park	yeast cultures, laboratory services, and products for professional brewing	
Colfax Project	Denver	design and merchandise branding services, including for beer and beverage markets	
Hymore Inc.	Evergreen	beverage dispensing equipment	1
Stadia Labels	Arvada	packaging labels that work in multiple temperatures and environments for the food and beverage markets	
Sturman BG LLC	Woodland Park	Tap-A-Draft used to maintain and dispense carbonated beverages for home market	7
White Goose Canning	Boulder	beverage canning lines and filling systems	
White Labs Colorado	Boulder	yeasts and lab services to brewers, winemakers, distillers, and others in the fermentation business	

Academic and public research institutions active in beer, wine, and spirits innovation in Colorado

Colorado State University, Fermentation Sciences program	Fort Collins	research and education in beer brewing and other food and beverage fermentation processes	
Colorado State University, Western Colorado Research Center, Ram's Point Winery	Grand Junction	research and extension in viticulture and winemaking	

CASE STUDY: New Belgium Brewing

In Fort Collins, craft brewing is a lifestyle—not just an industry—as evidenced by the consciously-casual fashions, the bike cruisers, and the craft beers on tap all around this college town. Many residents and visitors readily embrace the lifestyle. At the center of this cultural phenomenon lies New Belgium Brewing, together with over a dozen other local craft breweries. New Belgium is the third largest craft brewer by volume in the nation, and the eighth largest brewer overall.

The Fort Collins lifestyle lends itself in part to New Belgium's creative, sustainable production and advertising techniques not seen in the beer industry elsewhere. Jenn Vervier, Director of Strategy & Sustainability at New Belgium, emphasizes the fact that, while New Belgium does not advertise having the "coldest can" or the "best water", it advertises on the premise of environmental awareness and conservation, announcing things like onsite electricity production to reduce demand on the grid or its reduced water use to protect local watersheds. This theme is very much in tune with the lifestyle of the average Front Range craft beer drinker, who cares about outdoor recreation, water, and the environment. New Belgium has sought to engage these demographic groups through social media tools, such as Facebook and Twitter, to great success. New Belgium has almost 500,000 Facebook Friends and 200,000 Twitter followers, making it the second-most-recognized brewery on social media in the nation.

Companies such as Molson Coors (in Golden) and Anheuser-Busch (in Fort Collins) would appear to offer New Belgium fierce competition given their proximity to the craft brewery. Yet, according to Vervier, in reality, these companies help to define New Belgium, via the contrast between them and their environmental and cultural practices. These practices help to define New Belgium and increase demand from lifestyle craft beer drinkers, as well as mainstream, quality conscious consumers.

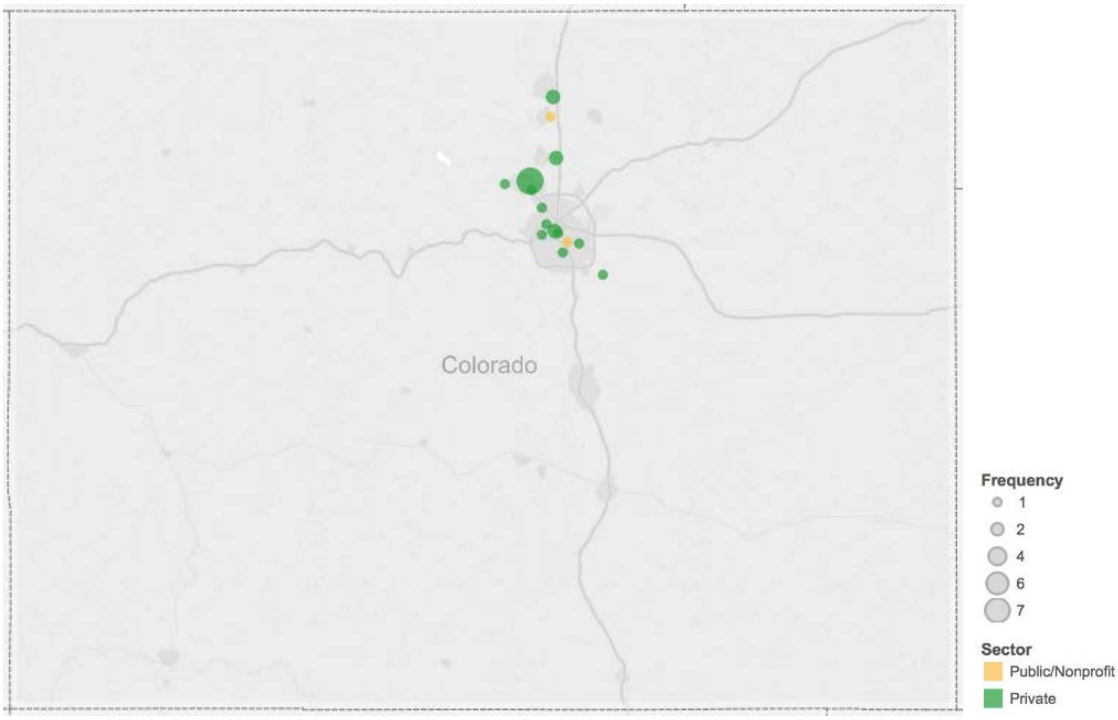
New Belgium has benefited in other ways from having these beer giants in close proximity. Their presence has facilitated hiring of quality employees, sourcing of glass bottles, and utilization of wholesale beverage distribution centers. When Anheuser-Busch consolidated and forced many of their senior staff to retire, New Belgium quickly offered those early retirees jobs, to benefit from their years of brewing experience. Additionally, there is the O-I Glass plant in Windsor, originally attracted to the Front Range to serve the bottling needs of Anheuser-Busch, and Rocky Mountain Glass in Golden, owned by Coors. New Belgium greatly benefits from the opportunity to recycle glass and to obtain new bottles locally, with lower energy inputs and a smaller environmental footprint than would be feasible without local glass partners.

New Belgium pushes the envelope in creative and innovative brewing, leading the way in reducing environmental impacts from brewing and increasing uptake of new technologies. New Belgium strives to be an early adopter of new technologies, but Vervier acknowledges that a percentage of such projects will fail. They also conduct their own research and have published in the scientific and trade literatures, including publications on best brewing strategies.

As one of more than a dozen breweries in Fort Collins, one might think New Belgium must compete against other local craft brewers. Instead, Vervier points out, New Belgium has collaborations with over 12 other craft breweries, reaching out both locally and nationally. The company lends lab space, advises on technology, shares diagnostic capabilities, and provides fermentation services. The friendly competition that does arise among craft brewers is largely played out in the marketplace.

New Belgium's disposition has also led to several larger collective projects, such as the "Fort ZED" (Fort Collins Zero Energy District) project, conducted together with the City of Fort Collins and CSU, and aimed at reducing local net energy use to zero. New Belgium is also working with local farmers to make crop, livestock, and beer production a closed loop system. Like many breweries in the Front Range, New Belgium has relationships with local dairies and livestock operations that buy the breweries' spent grains to use as feed. This provides additional income to the brewers and a reliable supply of grain for the animals. In North Carolina, where New Belgium is scheduled to open a second production brewery in Asheville in 2015, the company will partner with a number of small farmers for spent grain distribution to increase local feed supply and boost the local economy. Water quality and conservation is another area in which New Belgium has worked—through collaborations with Regenesis and the Nature Conservancy among others—to improve water use on the Front Range. The high quality water available in the Front Range decreases the brewery's input requirements and costs for water treatment. It is valuable natural capital, and investments in innovation is an important way to maintain its value. •

11. Innovators in natural, organic, and local foods



Innovation in natural and organic foods involves a complex set of adjustments along the value chain, beginning with innovation in inputs used and methods of farming, to managing them in the value chain, as well as innovations in manufacturing and marketing as quality differentiated products.

Colorado has become recognized nationally as a center of the natural and organic foods industry. A handful of major anchor corporations in this space were founded in, are based in, or have major operations in Colorado. A variety of other companies, some quite small, are engaged in various aspects of ingredient processing, food product development and manufacturing. Two specialized retailers are based in Colorado. The following inventory also includes nonprofits and industry associations, academic research institutions, and public agencies involved in natural and organic food and beverage innovation.

The local foods movement is born out of the same ethos and shares many of the goals of natural and organic foods. While some of the natural and organic brands have scaled nationally, the intent of local foods is to maintain smaller scale production and marketing, embellishing the offerings available to consumers with tastes from home. “Local” foods pose a challenge, as they are most in demand by urban consumers. Fortunately, the Front Range is opportunely configured to meet the demand of 3 million urban consumers with locally grown produce, meats, dairy, beverages, and other products.

Innovation in these categories, of course, is a subset of innovation in food and beverage manufacturing and marketing. It also strongly overlaps with innovation in dairy, as well as innovation in beer, wine, and spirits, albeit more so on the marketing side. At the retail end of the value chain there is also strong link in innovations by the “fast and fresh” restaurant chains, many of which have sought out natural and organic food suppliers.

11. NATURAL & ORGANIC FOODS

Major anchor corporations innovating in natural and organic food and beverage product development and marketing in Colorado

Name	Location	Company or technology description	WoS publications	US patents
Boulder Brands (Smart Balance, Evol, Udi's, etc)	Boulder	natural food products		
Celestial Seasonings Inc. (Hain Celestial Group)	Boulder	herbal teas		3
Whitewave Foods (incl. Horizon, Silk, Land O Lakes brands)	Broomfield	dairy and soy beverages	2	

Other companies innovating in natural and organic food and beverage product development and marketing in Colorado

America's Best Organics Inc.	Boulder	organic gift baskets		
Aurora Dairy	Aurora	organic dairy	1	
Bhakti Chai	Boulder	spiced teas		
Bioresponse	Boulder	DIM (diindolylmethane) Complex with guaranteed, patented absorption. DIM is a powerful component found naturally in cruciferous vegetables that balances estrogen metabolism		13
CannaEnergy	Denver	hemp infused energy drink		
Castle Mountain Enterprises	Arvada	launched Colorado Local First marketing network		4
Circle Fresh Farms	Denver	local, organic Colorado produce		
Compass Natural	Boulder	integrated marketing and communications strategies for natural and organic product companies		
Eco-Products	Boulder	food service containers		
EnerHealth Botanicals	Longmont	health food ingredients and herbals		
Good Belly Probiotics	Boulder	probiotic fruit drinks		
GTC Nutrition (owned by Ingredion, former Corn Products International)	Golden	functional food ingredients, including natural prebiotic fiber, for food ingredient and livestock markets	2	
Hemp Health	Boulder	hemp seed, fruit, and nut energy bars, branded 'evo hemp'		
Keen Ingredients	Denver	quinoa processing		4
Larabar	Denver	fruit and nut energy bars		
Lifeline Nutraceuticals Corp	Englewood	health enhancing food ingredients		3
Madhavi Natural Sweeteners	Longmont	honey and agave syrup		
MicroPure Technologies	Fort Collins	probiotics		5
Rowdy Mermaid	Boulder	kombucha (fermented tea drink)		
Rudi's Bakery	Boulder	baked goods		
Sagescript Institute / Colorado Aromatics	Longmont	bulk bases, herbs, and herb extracts for small cosmetics companies	1	
St. Claire's Organics	Boulder	breath mints, sweets, tarts and aromatherapy pastilles		

Tea Spot Inc.	Boulder	loose leaf teas		2
Vymedic	Englewood	amino based nutritional therapies, over-the-counter supplements, and clinical applications for optimal health management; formulas composed of amino acids, vitamins, minerals and fatty acids		2
Yucca Ridge Farm Inc / The Garlic Store	Fort Collins	garlic farm, seedstock supplier, online retailer	1	

Retailers of natural, organic, and local food and beverage products based in Colorado

Alfalfa's	Boulder	natural/organic foods grocery retail stores		
Natural Grocers	Lakewood	natural/organic foods grocery retail stores		

Other companies in Colorado providing innovative support services and equipment to the natural, organics, and local foods industry

New Hope Natural Media	Boulder	media resource and information provider for the natural, organic and healthy-lifestyle products industry; NewHope360 digital marketplace connects suppliers to retailers		
Presence Marketing	Boulder	largest natural foods brokerage in the U.S.		
Sterling Rice Group	Boulder	food and beverage brand building, marketing strategy, and communications		

Nonprofit organizations and industry associations supporting and promoting innovation in natural and organic foods in Colorado

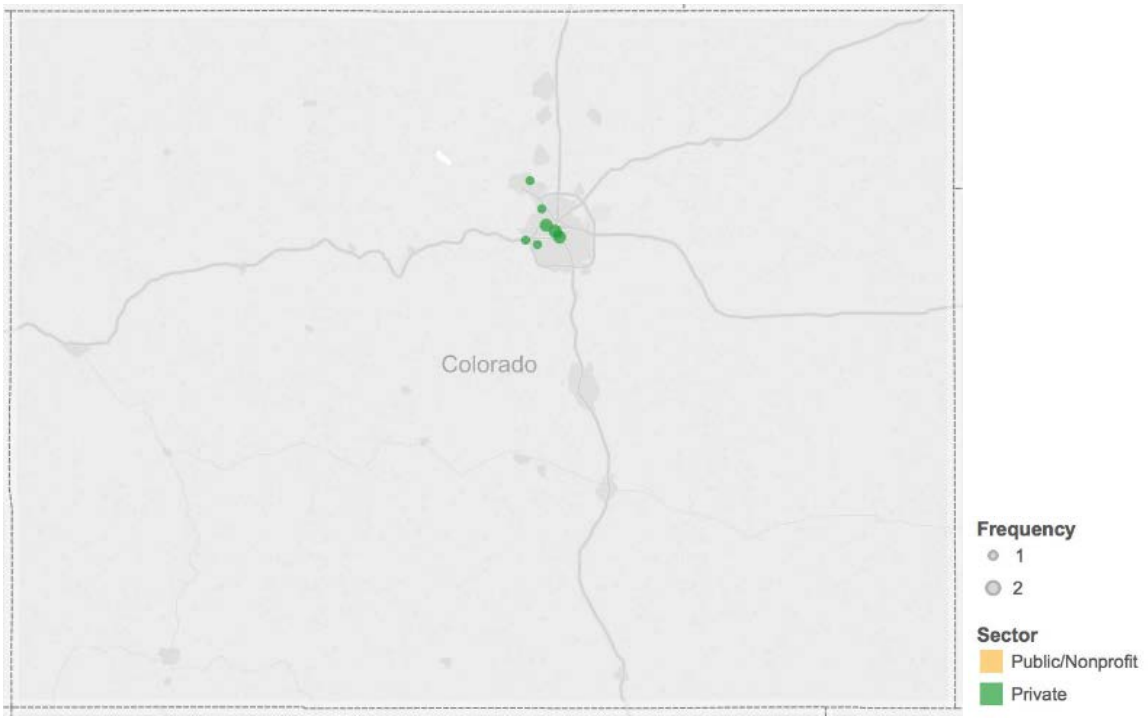
Horticultural Therapy Institute	Denver	nonprofit institute providing training to create and manage successful horticultural therapy programs	1	
Naturally Boulder	Boulder	regional natural foods industry association		

Academic research institutions and public agencies innovating in natural and organic foods in Colorado

Colorado State University	Fort Collins		7,616	59
Boulder County Extension	Boulder			

12. “FAST & FRESH” FOOD SERVICE

12. Innovators in “Fast & Fresh” food service



This category of restaurants, also known as “fast casual”, began to emerge in the 1990s as an alternative to fast food and continues to pick up market share. The main innovations in this retail model involve managing a fresh supply chain together with high levels of in-house quality control. An array of innovative marketing strategies have been developed, seeking to appeal to a range of demographics desiring fresher and healthier alternatives to established food service options, particularly fast food. Several leading national chains and a number of up-and-coming regional chains have been born, or have become based, in the Denver region.

Companies innovating in the “fast and fresh” restaurant category in Colorado

Name	Headquarters location	cuisine/ innovation	Founded	Locations
Boston Market	Golden	fast and fresh home style restaurants	1985	462
Chipotle Mexican Grill	Denver	fast and fresh Mexican restaurants; sourced meats from Neiman Ranch	1993	>1,600
Einstein Noah Restaurant Group (owns Einstein Bros Bagels, Manhattan Bagel, Chesapeake Bagel Bakery, New World Coffee)	Lakewood	fast and fresh breakfast restaurants	1995	773
Garbanzo Mediterranean Grill	Centennial	fast and fresh Mediterranean cuisine	2008	30
Good Times Burgers	Golden	fast and fresh burger restaurants; sourced from Coleman Natural Beef	1987	41
Larkburger	Arvada	fast and fresh burger restaurants	2005	13
Live Basil Pizza	Denver	fast and fresh pizza restaurants	2013	5
Mad Greens	Golden	fast and fresh salad restaurants / Mad Greens Farm in Elizabeth, CO	2004	12
ModMarket	Boulder	fast and fresh bistro restaurants	2009	13
Noodles & Co.	Broomfield	fast and fresh noodle restaurants	1995	339
Qdoba	Wheat Ridge	fast and fresh Mexican restaurants	1995	>600
Quizno’s (owned by QIP Holder LLC)	Denver	fast and fresh submarine sandwich restaurants; sourced from Mountain View Wheat Co-op	1981	>2,100
Tokyo Joe's	Denver	fast and fresh Asian restaurants	1993	28

13. OTHER EMERGENT SUBSECTORS

13. Innovators in other emergent categories

These preceding dozen categories encompass a large majority of the innovators identified to be active in Colorado's agricultural and food value chain. Yet, there remains a number of companies innovating in areas that lie outside of these categories. There are additional emergent categories that show promise but currently do not have the numbers or the diversity of innovating organizations. Since they are new, they tend to lack of supporting research at universities or public agencies. And at least one is constrained by lack of legal clarity. Their futures are largely dependent on developments in the industry and in policy.

Possibilities for greenhouse technologies

Several factors seem well aligned for the emergence of regional expertise in greenhouse technologies. Foremost is the increasing demand for locally grown fresh fruits and vegetables from consumers and restaurants. There is growing interest in urban agriculture, including use of smaller undeveloped acreages and former industrial sites interspersed within residential or light industrial zones. Off-season production requires protection from frost. High value crops, such as flowers or leaf vegetables, benefit from protection from hail damage, which is not uncommon during summer months. Readily available natural gas from extensive energy development along the Front Range, as well as advances in alternative energy sources such as wind and solar, may lower costs for greenhouse heating during colder months. Recently, demand for greenhouse space in Colorado has been very strong, likely leading to further construction and a healthy environment for adopting and testing new system designs.

Companies and research institutions innovating in greenhouse cultivation systems in Colorado

Name	Location	Company or technology description	WoS publications[42]	US patents[43]
AeroGrow International Inc.	Boulder	aeroponic growing kits for home use	**2**	**40**
Agrihouse Inc	Berthoud	hydroponics	**2**	**1**
Cherry Creek Systems	Colorado Springs	greenhouse automation		**2**
Circle Fresh Farms	Denver	local, organic Colorado produce		
Euteq Llc	Boulder	Hydroponic plant growth systems with activated carbon and/or carbonized fiber substrates		**3**
grofax	Denver	retail hydroponic supply center		
Paulino Gardens Inc.	Denver	full service nursery and garden center		**2**
Q Industries Inc.	Boulder	"pulse drip irrigation" equipment for home and small scale irrigation systems		**5**
Rachio	Denver	smart sprinkler system		
Tagawa Greenhouse Enterprises	Centennial	automated greenhouse systems		**21**
Colorado State University	Fort Collins		**7,616**	
U.S. Department of Agriculture, Agricultural Research Service (ARS)	Fort Collins		**1,080**	

[42] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[43] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Possibilities for industrial hemp

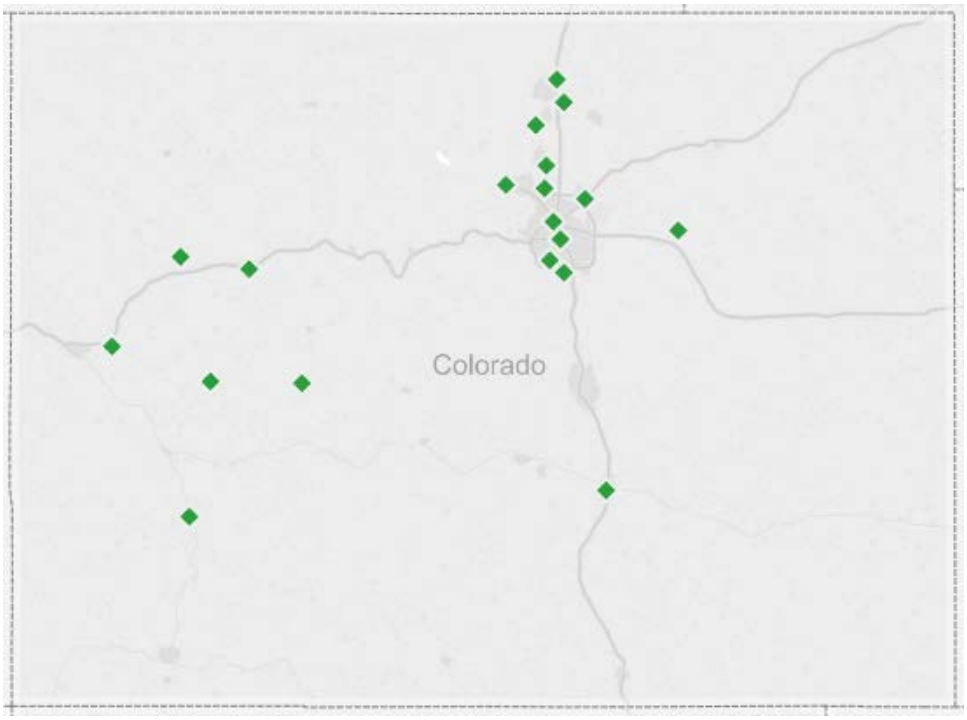
Hemp cultivation is legal in many countries around the world, including Canada, Australia, China, and much of Europe. The 2014 Farm Bill, passed by the U.S. Congress and signed into law by the president, includes a provision allowing for institutions of higher education and state departments of agriculture to conduct R&D on the agronomy and applications of industrial hemp for the possibility of future commercial production, or to license farmers and companies within the state to conduct such R&D. The federal law included conditions that such work could proceed only where state laws allow for the cultivation of industrial hemp and that cultivation is registered with the state department of agriculture. Industrial hemp is defined as those varieties of the Cannabis species lacking the narcotic psychoactive compound THC (technically, having less than 0.3 percent by dry weight). Estimates of the global market for hemp products range from the tens of millions to well over $100 million annually. Already, fifteen states have adopted laws allowing for cultivation of industrial hemp, including California, Colorado, Hawaii, Indiana, Kentucky, Maine, Montana, Nebraska, North Dakota, Oregon, South Carolina, Tennessee, Utah, Vermont, and West Virginia.

The hemp plant is capable of growing in marginal soils and with lower water requirements than many other crops. It produces fibers with a wide range of applications ranging from apparel and cordage to construction and industrial composite materials. The seeds of the plant, including both the solids and the oils, are edible and have beneficial nutritional properties, in particular high levels of omega-3 fatty acids, making it valuable as an livestock feed supplement. The plant has also been utilized for animal bedding materials, biofuels, and bioremediation of contaminated soils.

Colorado adopted a law in May of 2013, even prior to the federal Farm Bill, permitting the growing and possession of industrial hemp and charging the Colorado Department of Agriculture with developing a registration system. Colorado law also established a hemp remediation pilot program to test the ability of hemp plants to remove contaminants from polluted soils. Gaps in the current legal framework include continued restrictions on importing seed to the state and lack of clarity on the legality of industrial processing and production of final consumer products, including fiber and food products.

A number of companies have been formed by entrepreneurs seeking to exploit this emergent commercial opportunity. Under the Colorado Department of Agriculture many of these companies have applied for and been granted permits to cultivate industrial hemp for research and development purposes. Several nascent industry associations have formed, supporting, to the extent that they are able, the development of the agricultural value chain for this crop and products derived from it. In close collaboration with the Colorado Department of Agriculture, both Colorado State University and the University of Colorado have begun exploring what kinds of R&D activities researchers at the state universities can pursue within the legal space created by the 2014 Farm Bill. Limited—and largely indirect—research has already begun on topics such as indexing the Cannabis genome from data available from the National Institutes of Health gene sequence databases, and chemical characterizations of compounds found in the plant for their potential as pharmaceuticals.

13. OTHER EMERGENT SUBSECTORS



A sampling of companies innovating in industrial hemp in Colorado

Name	Location	Business or technology description	WoS publications[44]	US patents[45]
ASA Natural Industries	Ridgway	business approved by Colorado Department of Agriculture to grow industrial hemp		
CannaEnergy	Denver	hemp infused energy drink		
Centennial Seeds	Lafayette	hemp seed production; approved by Colorado Department of Agriculture to grow industrial hemp		
Colorado Botanical Distributors	Westminster	business approved by Colorado Department of Agriculture to grow industrial hemp		
Colorado Hemp Coffee / Colorado Hemp Tea	Lafayette	unique use of hemp seed for beverage manufacturing		
Colorado Hemp Company	Loveland	hemp textile products wholesaler		
Colorado Hemp Project	Littleton	business approved by Colorado Department of Agriculture to grow industrial hemp		
Delta 9 Farms	Pueblo	business approved by Colorado Department of Agriculture to grow industrial hemp		
Eagle Springs Organic	Rifle	business approved by Colorado Department of Agriculture to grow industrial hemp		
EnviroTextile	Glenwood Springs	hemp and other natural fiber products wholesale and retail		
Hemp Health	Boulder	'evo hemp' fruit, nut, and seed nutrition bar		
Green Sun Seeds	Boulder	business approved by Colorado Department of Agriculture to grow industrial hemp		

[44] Total number of Web of Science publications found by this study to be associated with this organization, regardless of category.
[45] Total number of U.S. patent applications and grants found by this study to be associated with this organization, regardless of category.

Hemp Cleans	Colorado Springs	cultivation of hemp plants for phytoremediation of contaminated soils	
HempGene	Fort Collins	Next-generation gene sequencing and genetic fingerprinting for strain identification marker assisted breeding for superior grain, fiber, and biomass production	
Hundley Hemp	Boulder	business approved by Colorado Department of Agriculture to grow industrial hemp	
Mile High Hemp	Brighton	informational and educational services; planning hemp processing services for wholesale and retail markets; business approved by Colorado Department of Agriculture to grow industrial hemp	
Native Hemp Corp	Longmont	business approved by Colorado Department of Agriculture to grow industrial hemp	
New West Genetics	Fort Collins	breeding of new varieties for industrial use; business approved by Colorado Department of Agriculture to grow industrial hemp	
Otoké Horticulture	Denver	agronomic advising for hemp producers	1
Renewal Seeds	Timnath	business approved by Colorado Department of Agriculture to grow industrial hemp	
Rocky Mountain Hemp Inc.	Springfield / Crested Butte	industrial hemp producer and processor of hemp oil, hemp protein powder, and edible hemp fiber	
Summit Plant Laboratories	Fort Collins	business approved by Colorado Department of Agriculture to grow industrial hemp	
Western Colorado Hemp	Palisade	business approved by Colorado Department of Agriculture to grow industrial hemp	

Nonprofit industry associations supporting and promoting innovation in industrial hemp

Agricultural Hemp Initiative	Denver	organization engaged in educating the public and lawmakers about the economic and environmental benefits of growing agricultural hemp as a legitimate crop for farmers in Colorado	
Colorado Industrial Hemp Coalition	Denver	dedicated to sharing information about industrial hemp, including regulations and agricultural requirements in Colorado, uses, and development	
Rocky Mountain Hemp Association	Denver	official association for Colorado hemp industry	
Western Slope Hemp Growers Association	Paonia	business approved by Colorado Department of Agriculture to grow industrial hemp	

Academic research institutions and state agencies exploring opportunities for innovation in industrial hemp

Colorado Department of Agriculture	Broomfield		
Colorado State University	Fort Collins	7,616	59
University of Colorado	Boulder	1,778	231

Section 5. Conclusions and next steps

This study accomplishes several things

This study identifies a potential innovation cluster—a geographical agglomeration of firms and research institutions engaged in interrelated innovation activities. When the constituent industries of the agricultural and food value chain are viewed as a single system, it becomes clear that there is a sizable community of innovators hard at work in Colorado that are more closely related and interdependent upon each other's presence in the region than is typically acknowledged. These organizations and their innovation activities have not traditionally all been viewed together. Identification of this potential innovation cluster requires looking at the agricultural value chain in its full scope.

Conducting a landscape analysis, this study identifies the region within which the cluster is forming, using innovation output proxies to empirically derive its geographic footprint. Contrary to views that equate agricultural innovation with rural economic activities (and policies to promote agricultural innovation with rural economic development strategy), the locus of innovation activities found in this analysis are located largely within the urban and peri-urban corridor of the northern Front Range, stretching from metro Denver to Fort Collins and encompassing the cities of Golden, Boulder, Longmont, Loveland, and Greeley.

This study explores several of the economic, demographic, and geographic fundamentals hypothesized to account for the emergence of this innovation cluster. Foremost among these is the accumulation of world class technical and entrepreneurial talent in the communities along the Front Range, which is attributed, at least in part, to the quality of life in this urban region. Also important are the history of agricultural, food, and beverage entrepreneurship in the region, the presence and research programs of several major universities and federal laboratories, the intersection of major production agriculture with the expanding urban residential and business communities in the region, and the close alignment between the challenges and opportunities that confront Colorado's industry with the challenges and opportunities that confront the industry globally.

This study inventories the companies and organizations that make up this emergent innovation cluster. In so doing, it finds a diverse ecosystem of over 500 organizations, including large corporations, small and medium sized enterprises, entrepreneurial startups, industry associations, nonprofit organizations, academic research institutions, and public agencies. The inventory finds evidence of a number of relocations to the Front Range that have occurred over the last decade. Executives of several of these relocated

firms, interviewed for this study, explained what characteristics of the region influenced their decision to locate in the Front Range of Colorado.

Finally, to organize the inventory of companies and organizations into meaningful industry categories, this study identifies a range of technical categories within which there appear to be a critical mass and diversity of innovating organizations active in Colorado. The twelve categories this study identifies, in many ways, reflect the structure of the industry's value chain, which serves to demonstrate how and why innovation within the multiple separate categories is in fact often interrelated.

Next steps

Based upon this analysis, several next steps can be recommended as helpful in cultivating and capitalizing upon this emergent economic growth opportunity.

0. As a prerequisite, recognize the economic significance and technological sophistication of innovation activities occurring in the agricultural and food value chain.

Public perceptions and conventional wisdom can take time to catch up with reality. Preconceived notions of agriculture as merely a mature, low-margins, primary employer confined to rural regions are outdated. Public discourse within the state is beginning to better reflect the importance of the agricultural-water-food-beverage-bioenergy complex, the interdependence of enterprises engaged within it, and the technological sophistication that characterizes current innovations being pursued in the industry. The global economic significant of game-changing innovations within resource-intensive industries, like agriculture food water and energy, presents enormous opportunity for Colorado.

1. First and foremost, develop and attract talent.

Talent is identified, repeatedly, as the most important factor driving growth of an innovation cluster. The availability of specialist skills is the factor most commonly cited by the executives interviewed for this study. Quality of talent is more important than quantity, but the size of the talent pool can constrain growth, leaving opportunities for new initiatives neglected. One of the main roles of state, county, and city governments is to provide high quality community services and infrastructure, and thereby create a quality of life that attracts and retains talent. Workforce training programs are important for upgrading the skills of technicians and laborers. However it falls primarily to

universities to supply the kind of high-quality professionals needed in the sciences, engineering, management, law, and finance to really drive the growth of an innovation cluster. The universities' second role is to create and transfer technologies. For the farming and ranching community, there is opportunity for younger generations coming off the farm to combine their knowledge of agriculture with specialized skills in science, engineering, or business.

One benefit of building up a critical mass of talent, and employers, within a cluster is job security. Talent is able to circulate within the region. An employee can leave one job and quickly find another at a company working in the same or a closely related field of innovation. As this dynamic becomes established, the industry and the region become even more attractive to new talent graduating from the universities and to talent moving in from out of state. Ultimately, it makes the region "a low risk environment in which to do high risk things."[46]

2. Identify and support existing activities, and connect existing companies.

For policymakers or economic developers, it is not necessary to build an economic development strategy from the ground up. There is already much going on in water, agricultural, bioenergy, and food-related innovation that has arisen in response to market forces, and thus has real market potential. It is advisable to look for existing developments and seek ways to accelerate them.

Growth of a cluster needs mechanisms to facilitate mixing and the spawning of collaborations between people and organizations. These are provided by universities, industry associations, startup incubators, and regional economic development organizations. Especially important is the development of public-private collaborations, encouraging and opening up the universities and federal laboratories to greater engagement with private-sector innovators within the region.

State government and the universities are in an excellent position to invite private sector innovators into networking events and thereby into deeper discussions. Universities can play a unique facilitating role in horizontal cooperation to support "pre-competitive" innovation among otherwise competing companies. Opportunities may exist to identify and address collective challenges or provide collective resources that firms are incapable of solving or providing individually for themselves.

[46] Attributed to Hermann Hauser, Amadeus Capital Partners, as quoted in Economist Intelligence Unit, 2011, *ibid*.

3. Exercise tolerance of different points of view.

Innovation often arises at the intersection between conflicting points of view.[47] Innovation is, by its very definition, a challenging of the status quo, and it requires a willingness to question how things are done. The agricultural and food system is very much a focus—sometimes a lightning rod—for social and political contention. And, as a state, Colorado is at the center of national debates about the control of foodborne pathogens, the labelling of foods containing genetically modified crop products, the use of antibiotics in livestock, and the legalization of industrial hemp. The Front Range is home to leaders of industrial-scale globally-oriented agricultural production and leaders of the organic and natural food movements. Innovation can solve problems common to both of these approaches to agriculture. Yet, it requires listening to one other's concerns, respecting others' intellectual and emotional responses to issues, and seeking common ground wherein solutions may lie.

4. Coordinate vertically to pilot locally, then sell globally.

Given the complexity of the value chain, vertical coordination is required for piloting many new technologies, test marketing new products, or implementing new business models. The size of the local market was the second most important factor to executives locating firms and R&D activities in the Front Range. The Denver metro market is compact enough to prove manageable for piloting, test marketing, and new product launch. Also, the necessary upstream and downstream partners can be found within the region. And, the region's market is large enough to grow within substantially, before seeking to expand nationally and even globally.

5. Develop financing mechanisms to assure access to risk capital.

Financing mechanisms have been slow to align with market opportunities in some segments of agricultural innovation. Many investors and lenders remain somewhat siloed in those market segments where they have traditionally been engaged: whether that be small business loans, commercial or agricultural real estate, farm lending backed by the farm credit cooperative (FCC) system, or venture investing in IT, software, biotech, or clean energy. Maintaining focus is understandable to the extent that smart investing requires deep expertise in the valuation of a particular class of assets or deep knowledge of a particular market. In this environment, however, some innovators in the agricultural value chain find it particularly challenging to raise capital. This may be due to the complexity of the value chain and the fact that applications of their technologies are crossovers between markets in which existing lenders or

[47] Economist Intelligence Unit, 2011, *ibid*.

investors are focused and others in which they are not. Some may simply fall through the cracks between existing markets.

Innovation in the agricultural value chain provides an opportunity to look at new financing mechanisms. Given recent increases in commodity prices and land values, some farm and ranch owners have ability to invest. Yet, when they invest, they may be more inclined to do so in familiar land- and resource-based business opportunities which today may be oversubscribed or overvalued. Traditional agricultural investors may be less familiar or may be uncertain when it comes to higher-risk venture investing, deal structures, and intellectual property valuation. At the same time, venture capital investors may be unfamiliar, uncomfortable, or out of their depth when it comes to technologies applied in agriculture, resources, or commodities. There may be new opportunities for agricultural innovation created by a financing mechanism that brings together the market knowledge of agriculturalists with the risk capital expertise of venture investors. For those in agriculture, this represents an opportunity for diversification into an additional source of revenue, an opportunity for "bringing in an additional crop".

6. Take the long view.

Changes in industry structure, such as clustering, take time. The cultivation of an innovation cluster in the agricultural and food value chain is a long term effort, measured in decades. By some measures, this emergent innovation cluster in the agricultural value chain has already been building in Colorado for at least two decades. It may take another decade of dedicated effort to bring it to a level of maturity and dynamism such that Colorado is recognized globally for creating the next-generation technologies and business models that nourish, refresh, and energize the world.

Related reports from Colorado State University:

The Value Chain of Colorado Agriculture

By Gregory Graff, Ryan Mortenson, Rebecca Goldbach Hill, Dawn Thilmany McFadden, Stephen Davies, Stephen Koontz, Geniphyr Ponce-Pore, and Kathay Rennels

Department of Agricultural and Resource Economics and the Office of Engagement, Colorado State University, February 2013

This analysis of the value chain of Colorado agriculture is intended to serve as a common starting point for new conversations about the full range of economic activities in the state of Colorado that are anchored in its agricultural sector. The analysis illustrates the web of connections amongst more than 125 separate markets and industry sub-sectors ranging from farm inputs to consumer retail that nonetheless share common resources, opportunities, and constraints. Drawing together data from multiple federal, state, and private sources, this encyclopedic reference to Colorado's agriculture, food, and beverage industries can aid in the formulation of both commercial strategy and public policy.

Available online at http://outreach.colostate.edu/econ-dev/value-chain.html

Related reports from Colorado State University:

The Agribusiness Friendliness Index

By Ryan Mortenson, Gregory M. Perry, and James G. Pritchett

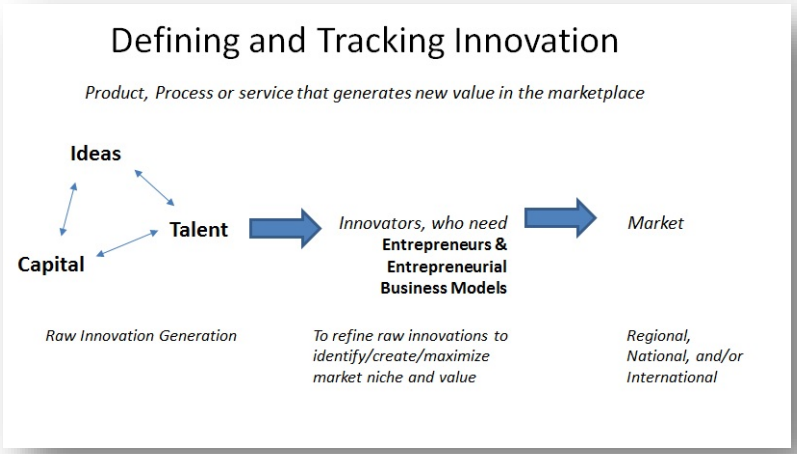
Department of Agricultural and Resource Economics, February 2014

Government fundamentally influences the economic climate of agriculture and its allied businesses. State governments play a particular role in fostering agribusiness opportunities and influencing cost structures with policies that include regulation, taxes and subsidies. Businesses are acutely aware of the role state government plays in their success; a business friendly environment will encourage business to locate or expand operations. Unfriendly polices shrink business and may even force relocation.

This study is the first known attempt to create an Agribusiness Friendliness Index focused on the agriculture sector. It is useful for describing the economic climate for the agricultural sector, which may be distinctly different from the general business climate. Such a measure can be useful for states seeking to attract more agribusinesses to their state or to retain existing businesses. It helps highlight strengths and weaknesses in policies that affect the agribusiness sector.

Available online at http://abfi.agsci.colostate.edu/

Related reports from Colorado State University:



Colorado Innovation Report 2014:

Keeping Colorado's Innovative Economy Dynamic

By Tessa Conroy and Stephan Weiler

Department of Economics, August 2014

Entrepreneurship: *Job creation comes largely from nascent small businesses. In Colorado the business sector is highly dynamic, characterized by more job creation and destruction than most other states. Dynamism produces a long-term job growth advantage.*

Talent: *Colorado is transitioning from a state where the skilled workforce was largely male to one which will become significantly more female, as male education attainment drops relative to that of women. Educated men are disproportionately older and retiring, while educated women are disproportionately younger. Hispanics and Latinos provide an additional opportunity to replace retiring educated white males with homegrown talent.*

Capital: *Small business bank lending in Colorado is above the national average. Various measures of such capital flows rank Colorado consistently in the top third among its peer state*

Available online at http://innovation.colostate.edu/ and http://www.news.colostate.edu/content/documents/ColoradoInnovationReport2014final.pdf