ROBOTICS & AUTOMATION
IN INDOOR AGRICULTURE
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Local Roots is a thought leader in indoor agriculture, dedicated to solving systemic food chain inefficiencies through innovation and technology-driven solutions. Local Roots is currently pioneering modular controlled environment agriculture technologies that enable year round crop production in any climate, in any geography. Local Roots’ Mission is to provide everyone access to fresh, healthy, and affordable locally-grown produce.

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EXECUTIVE SUMMARY

From 1948 to 2011, total factor productivity in agriculture grew by around 150%, with improvements commonly attributed to successive waves of new agricultural technology. This has especially been the case for capital-intensive indoor agriculture where cost falls seen over recent years have been almost all owing to technology, such as lower LED light prices, cheaper sensors, and better access to off-the-shelf internet of things technologies through which everyday objects can send and receive data.

A key aspect of reducing both capital and operating costs is the introduction of more automation and robotics to indoor farms, a trend which management consulting group Boston Consulting Group recently cited as the second most influential trend in agriculture. The topic is pertinent now as labor costs continue to rise, skilled professionals are ever scarcer, there are increasing pressures to minimize resource usage, food supply chains are being restructured, and consumers are increasingly demanding local food that cannot be grown outdoors year-round.

There is a wide range of automation and robotic technology deployed in indoor farms today, and a larger array of available and readily adaptable technologies that have not yet found their way into indoor farms. The vast majority of growers utilize at least some automation equipment; for instance, 60% of growers use irrigation controls. Some automation solutions have been around for thirty years – such as environmental control systems – while others are in pilot stage.

The path that indoor agriculture’s involvement in automation and robotics will take from here is primarily determined by industry adoption rates and the speed of technology commercialization. Options are plentiful in “traditional” areas of automation, such as irrigation controls, but far more limited in the more advanced robotics and data fields sought by large growers. Further, there are very few products that target mid-market and smaller growers. There’s a distinct need for simpler devices with fewer functions and intuitive user interfaces that a beginning grower can pick up in a few hours; 4 out of 5 beginning farmers did not grow up on a farm.

Thanks to the proliferation of cheap sensors and at least 54mn available plants from which to sample data, we expect a wave of analytics platforms adapted for use indoors, and of user interface products that assume minimal farming knowledge, the realization of the long-held expectation that “big data” will represent the democratization of farming. Data could turn good growers into great growers, using data on plant behavior to establish norms that growers can follow, and that smarter systems can use to automatically adjust themselves. Supply chains will tighten as grocery store inventory systems integrate into farm control ones, enabling “just in time” growing.

As potential market sizes for indoor agriculture equipment are small, we anticipate that it will be tough for “single product” technology startups to thrive in the space, and instead expect to see entrepreneurs tackle multiple industries simultaneously, develop several products in parallel, partner with firms that have established distribution, or develop proprietary technologies to improve yields at their own farms, a source of competitive advantage.

While most commentators do not expect commercial robotic and advanced automation products to play a major role for at least another decade, history tells us that such changes happen faster than most predict; the meatless stem-cell based hamburger, for instance, went from a $325,000 scientific pipedream in 2011 to a $20 product by 2015. The future may be here sooner than we know it.
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1 INTRODUCTION

On August 10, 2015, American astronauts sampled the first lettuce ever grown in space, declaring the aeroponically-grown produce “awesome”¹. The achievement was one further step in the age-old relationship between technology and agriculture, a correlation that is nowhere more obvious than in the indoor agriculture sector.

This white paper looks at one aspect of the relationship; the current state and prospects for automation and robotics in the indoor agriculture industry, which we define as growing produce in hydroponic systems in warehouses, greenhouses and containers. For the purposes of this white paper, we view automation and robotics as any process that utilizes mechanization or machine-based data interpretation to reduce farming costs or increase crop yield. This is a broad church, so we define it more closely in section two below. It is intentionally aimed at those who are specialists in neither robotics nor indoor agriculture, and its authors do not consider themselves experts in either topic. Our intent is to look at the global picture, but many of our references are based in the United States as it is our home base. We’ve assumed that readers have a general knowledge of the indoor agriculture industry, and refer those that do not to our March 2015 white paper “Indoor Crop Production: Feeding the Future”. The automation, robotics and indoor agriculture industries are jargon-rich, and we’ve attempted to define any industry terms in footnotes where relevant.

By the very nature of the exercise, there are doubtless many worthwhile projects and developments which have not been included here.

As is shown in more detail in the chart over page, from 1948 to 2011, total factor productivity in agriculture grew by around 150%²; inputs from labor meanwhile fell by an average of 2.4% annually over the same period. Much of this productivity revolution is commonly attributed to the spread of successive waves of agricultural technology, such as, modern fertilizers (1940s), genetically modified seeds (1994³), and driverless tractors (2008⁴). This has especially been the case for capital-intensive indoor agriculture where the reductions in capital costs seen over recent years have been almost exclusively owing to technology, such as lower LED prices. Leading academic Professor Kozai, formerly of Chiba University, forecasts that plant factory⁵ labor and electricity costs will halve over the next five years⁶, a necessary development if the industry is to reach ‘field parity’, the point at which produce grown in indoor systems is economically competitive with field-grown produce year-round.

A key aspect of reducing both capital and operating costs is the introduction of more automation and robotics to indoor farms, a trend which management consulting group Boston Consulting Group cited as the second most influential trend in agriculture through 2030 in recent survey⁷. The topic is pertinent now for several reasons: labor costs continue to rise, skilled professionals are ever scarcer, there are increasing pressures to minimize resource usage including water and energy, food supply chains are being restructured, and consumers are increasingly demanding local food that cannot be grown outdoors year-round. We take an overview of each of these driving forces in turn before moving on to look at current technologies and the future of the sector.

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³ Calgene’s Flavr Savr tomato introduced in 1994
⁵ Plant factories are a Japanese term for vertical farms that are entirely closed environment, so exclusively using LED lighting
⁶ Speaking at International Congress on Controlled Environment Agriculture in Panama City, Panama in May 2015
⁷ “Crop Farming 2030, the Reinvention of the Sector”, Boston Consulting Group, April 2015
Labor Issues

As for much in agriculture, the largest driver of robotics and automation adoption is the need to manage labor availability and cost; labor costs make up 26-40% of total production costs in indoor systems. The problem is not confined to the US: India is losing 2,000 farmers a day owing to drought, urbanization and debt-related suicides, and has seen its farming population fall from a third of the workforce in 2001 to just under a quarter of the workforce by 2013. Back in the US, broad demographic shifts and regulatory changes render farm labor ever more scarce, while societal changes increase scrutiny on growers. It’s important to note that farm workers are unavailable at key times, leaving crops unharvested, and this is the primary reason for adoption of automated harvesting equipment, rather than a desire to replace workers with robots.

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If 26% figure is for plant factories per Professor Kozai of Chiba University, 40% figure is for greenhouses per discussions with growers

9 “India Losing 2,000 Farmers Every Single Day”, International Business Times, May 2, 2013
Interest in manual labor as an occupation is dwindling as the number of college graduates rises. Between 2002 and 2012, the percentage of 18-24 year olds enrolled in college rose from 37% to 41%¹⁰. The National Center for Education Statistics projects that college enrollment among under 25 year olds will rise by a further 12% from 2012 to 2023¹⁰.

The undocumented workers that have traditionally made up a large part of the agricultural labor force may also be less available; the Pew Research Center, a think-tank, says that the number of illegal immigrants in the US peaked in 2007 and has since fallen owing to increased jobs in Mexico and tighter US border patrols¹¹. More stringent immigration enforcement is a significant factor in some parts of the US, with programs such as I-9 audits – which require that growers lay off undocumented workers – frequently cited by growers as a cause for concern.

With the issue of farm worker conditions now receiving attention, there is an impetus to improve health, safety and well-being of workers. Robotics and automation can play a part in these improvements. For instance, one greenhouse operation – Altman Plants – used to have 4-5 injuries per season from spacing, a physically tasking job, but now has none thanks to the incorporation of nursery robot firm Harvest Automation’s spacing robots into workflow¹².

The scarcity of experienced plant scientists – who help growers solve everything from disease outbreaks to crop yield conundrums - is a separate concern; we estimate that a plant scientist can look at 5,000 plants a day, yet a medium sized greenhouse houses approximately 250,000 plants, or 50 days’ worth¹³. As a society, we have been graduating too few plant scientists for a very long time. Academic Alan M Jones pointed out – in an opinion piece in October 2014’s edition of The Scientist¹⁴ – that over the last decade, the US minted only 800 plant scientists working in applied agriculture science annually, fewer than the 1,000 new employees required in the discipline by the six largest plant science companies alone this year. The ability to delegate simpler observation tasks to machines, and to observe plants remotely, will aid in addressing this concern.

**Resource Management**

In conversations with growers and industry suppliers, we found that – while labor remained the key motivation for automation – other resources are a growing concern. This is especially the case in areas of drought for water, and in general for energy used for heating and cooling needs. It applies to both greenhouse and field farming alike. Their interest is driven both by a desire to contain costs and to stave off criticism about resource usage in agriculture.

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¹⁰ National Center for Educational Statistics figures, most recent available
¹¹ “Robots in New Planting, Harvesting Roles”, NASDAQ, April 30, 2015
¹³ Based on 20 acre greenhouse with 3 plants per m²
Reshaping of Food Supply Chain

These advancements come in the context of wider reshaping of the global food and agriculture supply chain, primarily driven by a change in attitudes whereby consumers view food choices as a way to express their identity and represent their beliefs. In turn, this has led to a renewed focus on smaller, niche farms, on new delivery models (18% of Americans have bought groceries online\(^1\)) and on the use of technology to enable personalized food. The trend benefits indoor growers able to use technology to better meet demand for local produce.

\(\text{Ag3.0}\)

Lance Donny – CEO of agtech startup OnFarm Systems – is one of a handful of innovators who have highlighted the potential for, as he calls it, Ag 3.0, a data-rich approach to farming that utilizes inputs from diverse sources to make better farming decisions – including sensors on plants and farm equipment, weather stations and satellite images\(^2\). With cheap sensors now allowing us to connect to and understand the physical world in a way that’s been impossible on such a scale previously, far smarter commentators than us have described the “big data” movement as potentially larger than the internet revolution of the late 1990s.

According to Cisco, the 9bn devices currently connected to the Internet will rise to 50bn devices by 2020\(^3\). That’s more than six devices for every human\(^4\). The sector is in its infancy, and agriculture is but one of the numerous industries across the global economy that will be impacted; management consultant McKinsey Global Institute estimates that 25-50% of farms globally will adopt precision farming\(^5\), and in doing so increasing crop yields by 10-20%\(^6\).

While the bulk of investor and media interest in Ag3.0 has thus far accrued to the larger traditional agriculture sector, indoor agriculture is arguably better placed to capitalize on the trend. Indoor farms have far fewer uncontrolled variables than field farms. Given a uniform environment, more data can be cheaply collected on individual plants. Further, indoor growers have the ability to easily implement data-derived observations in a controlled environment. And the opportunity is large; even if we assumed that all North American greenhouses (so excluding the 20 or so commercial-scale vertical farms) planted only relatively-sparingly spaced tomatoes, there are still 54mn plants from which to capture data\(^7\).

For the commercial side of the indoor agriculture sector, we see two particular benefits from this wave of interconnectivity. We see Ag 3.0 as the democratization of farming because it offers the promise that some of the specialized knowledge that commercial farming requires today will be available to all, regardless of their farming prowess or economic situation. This is pertinent at a time when many potential growers come not from farming backgrounds, but instead transition into growing from careers as diverse as finance and the military. A National Young Farmers’ Coalition survey found that 4 of 5 farmers under 35 weren’t raised on a farm\(^8\). As a consequence, one of the most significant hurdles for new growers to overcome is that of education, something with which better access to data from sensors and other sources can help.

For established growers, there’s the promise that data could turn good growers into great growers. Using data on plant behavior to establish norms that growers can follow, and that smarter systems can use to

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\(^1\) Boston Consulting Group figure
\(^3\) “Seize New IoT Opportunities with the Cisco IoT System”
\(^4\) Based on global population forecast of 7.7bn in 2020 per Geolive
\(^5\) Defined as an information and technology based method of farm management
\(^6\) Defined as consumer surplus
\(^7\) Based on Cuesta Roble Consulting total greenhouse capacity of 4,436 acres for North America, which is 18mn m\(^2\) and with plant spacing of 3 per m\(^2\)
\(^8\) “Big Bots in Little Agriculture”, Marie Lawrence, Slate, June 1, 2012
automatically adjust themselves, is one way of maximizing plant scientists’ time. Supply chains can be tightened as grocery store inventory systems are integrated into farm control systems, enabling “just in time” produce growing. Academic research will be hastened by access to plentiful real time data.

2 STATE OF THE INDUSTRY

There is a wide range of automation and robotic technology deployed in indoor farms today, with the vast majority using at least some such equipment, for example, trade magazine Greenhouse Grower found that 60% of growers had irrigation controls. They vary in their sophistication; a complex environmental monitoring system that works well for a large mono-crop greenhouse would likely not be a fit for a small multi-crop vertical farm. With complete control over lighting conditions, vertical farms don’t necessarily need a complex monitoring systems. Some of these solutions have been around for thirty years – such as environmental control systems – while others are in pilot stage. As is shown in the chart over page, we divide the sector into eight broad stages of the growing process and briefly outline activity in each below.

A. NURSERY OPERATIONS

Nursery operations include seeding, propagating, grafting, transplanting and spacing plants. Commercial seeding machines – which place seeds such that plants have equal access to light, water and nutrients – have been available for well over a decade, and there are reliable low cost machines that breakeven at the equivalent of only 40 hours of weekly seeding labor by our calculation. Elsewhere, spacing robots – primarily supplied by Harvest Automation – have been commercial for only a few years.

Company Examples: Berry Seeder (seeding), Conic Systems (grafting), Hamilton Designer (seeding), Harvest Automation (spacing), Helper Robotech (grafting), Iseki (grafting), ISO Group (grafting), Seederman (seeding), Visser NA (seeding, propagation)

Source: Survey of 100 Growers in Late 2011, Greenhouse Grower

Image Courtesy of Newlux
Use Case: Dutch supplier Visser NA is best known for its high-precision seeding machines, but also supplies a propagator, the ‘Newlux Lighthouse’, that houses 15,000-25,000 plugs in less than 20 ft² of greenhouse floor space. The Company describes the product as ‘plug-in and grow’ as it comes fully assembled, and says that it has low power consumption, and can be used to slow down or speed up production times using adjustable controls over light intensity and power.

What’s Needed: Spacing technologies are not readily available to smaller farms. A method of continuous plant transplant that is cheap and easily installed in a vertical farm would be beneficial.
Image Courtesy of Intelligent Growth Solutions
CASE STUDY: THE COMING FULLY AUTOMATED VERTICAL FARMS

One of the holy grails of farm automation has long been the notion of a fully automated vertical farm for leafy greens and other commodity crops, a feat that has already been achieved in the biopharmaceuticals field by companies such as Kentucky BioProcessing, which was part of a group of companies that developed an experimental ZMapp serum for Ebola treatment using tobacco plants²⁴.

The vision is that – with few labor requirements – facilities should be able to reach field parity faster than more traditional vertical farms, and to scale more easily without the need for highly-skilled plant scientist and technical staff. Capital costs and the vagaries of nature – getting plants to behave uniformly is understandably difficult - have prevented such development to date, but several firms continue to work towards this goal.

Spread, Japan

In spring 2015, Japanese grower Spread announced that it will build a 1.2 acre (4,800m²) fully automated plant factory near Kyoto, Japan. The firm has developed a proprietary cultivation environment control technology that lowers production cost through efficient resource usage. For instance, 98% of water will be recycled. The facility will be fully automated, everything from seeding and watering to applying fertilizer and harvesting. It is slated for 2017 startup²⁵.

Intelligent Growth Solutions, United Kingdom

Following two years of research, Intelligent Growth Solutions has developed a commercial scale fully automated vertical farm design, for which it intends to construct a proof of concept at a research institute in Dundee, Scotland in January 2016. The Company’s focus is on competing in a commodity market, offering leafy greens that are at least as good as competitors but not assuming that consumers will consistently pay a significant premium for hydroponically grown produce.

As a consequence, its focus has been on designing a system that minimizes costs, both through economies of scale – “selling 50-100 towers to one customer rather than one at a time” – and by employing innovative ways of reducing energy and labor costs. The keys, according to the Company, are in its approach to lighting, power generation and automation. It intends to use a low cost, flexible ‘quad power’ system, through which it says it has seen savings in excess of 50% on power costs. In many cases, it has adapted technologies from other industries, for example, its tower system is modified from one originally designed at some cost for Swedish furniture retailer IKEA; plant-filled trays rotate to the bottom of the tower, so substantially reducing the labor involved in racking trays. The Company is continuing to iterate its design, seeing particular benefits in incorporating sensors into trays, which will eventually allow real-time modifications to the environmental conditions of each individual tray of plants according to their needs.

The system – like most vertical farms – is capital intensive, with the minimum commercially viable unit’s capital cost being $16mn (£10mn²⁶) according to the Company. At scale, it estimates that its capital cost per m² will be in the region of that of a greenhouse. It forecasts a five year payback period, and expects that its primary customer base will be the large European grocery retailers for whom supply chain stability is an ever-present concern.

²⁴ “Tobacco plant may be key to Ebola drugs”, Madeleine Stix, CNN, October 3, 2014
²⁵ “Entirely Robotic Lettuce Farm to be Built in Japan”, Tereza Pfitarova, Engineering & Technology Magazine, August 4, 2015
²⁶ £1 : $1.56 exchange rate as at September 17, 2015
Langmead Group, United Kingdom

While already an established growing method in the Netherlands in particular, automated greenhouses are now springing up elsewhere. In July 2015, British farmers the Langmead Group debuted a fully automated greenhouse in West Sussex, UK. The $4.7mn (£3mn) facility on a 3 acre (1.2 ha) site can produce 5mn pots of herbs – basil, parsley, mint, thyme, chives – annually, requiring minimal human intervention. It’s unique automatic potting, sowing and growing system can run 24 hours a day and enables, for example, growing benches to be sown and moved robotically. Heated by a biomass fuel system, the facility uses no tap water, instead drawing from a local reservoir and recycling all waste water27.

B. PROCESS CONTROL

Systems that monitor and control environmental conditions in greenhouses and vertical farms are longstanding mainstays of indoor farming. Environmental control systems have been commercial for thirty years, though more recent iterations naturally react more intelligently to data than did their earlier counterparts. Several suppliers have offered a remote-access version of their software since the days of dial-up. Established industry players have already captured substantial amounts of data regarding plants and operations, for example, one leading controls company told us that they have millions of pieces of data stored on servers for client use at some stage. More recent developments include enhanced data capture – whether via sensors or drones – and more granular responses to data by focusing on individual plants. As is described in section 3 below, we believe that this area will likely be most impacted by Ag 3.0.

Company Examples: Argus Control Systems, Autogrow, Climate Control Systems Inc, Nepon, Priva, Stolze

Use Case: With comparatively low costs, ease of use and higher quality images, drones have been rapidly adopted by traditional farming, and have now been trialed in greenhouse applications. The Spanish Centre for Automation and Robotics (CAR) has trialed a greenhouse drone that measures temperature, humidity, luminosity and carbon dioxide concentration, and then uses this data to improve climate control systems and monitor crops. It has a controller on-board to send data via WiFi. To date, the project is at trial stage28.

An example of technology development from established players is Dutch control company Priva’s TopCrop product, which uses an infrared camera to monitor plant temperature and then compare it to greenhouse temperature to get a measure of plant stress levels. After successful Dutch trials – one of which led to an increase in flowering in plants from 50% to 85% – the product is being trialed by five North American customers.

What’s Needed: There are several developments that would aid process control: new and cheaper sensors, better analytics and more intuitive user interfaces. In addition, one supplier noted that their software can accomplish myriad sophisticated tasks, but that there is a gap in growers’ understanding, for which they view improved education as the solution. There are currently few analytic tools adapted for use in greenhouse and vertical farm settings, a situation that could be resolved through partnerships between growers, analytics firms and control companies. Simpler user interfaces with faster learning curves would be of use to those with less experience in the greenhouse and vertical farm.

C. PLANT MANAGEMENT

Pruning, trimming and thinning plants are among the time-consuming activities in indoor farms, and there are consequently a number of research efforts aimed at creating robotic thinning and trimming machines. Companies focused on weeding and thinning, such as Blue River, have operated in traditional field agriculture for some time. Pollination is a growing concern for indoor crop production as more indoor growers produce high-value berries and fruits that require pollination.

*Company Examples: AgriNomix, Blue River, Hortiquip (staking), Logiqs*

*Use Case:* This is one of the least exotic areas of the sector; however the research bright point is robobees, bee-like micro-aerial vehicles that could conceivably be used to pollinate indoor crops in the future. A Harvard-based team believes that its work will lead to robobee swarms that can independently pollinate a crop in as soon as a decade, though the robobees will first need to be able to carry more weight, to fly unaided and to mesh network (“talk”) with one another to carry out tasks\(^29\). Robobees would be only a stopgap measure while alternate solutions are found to Colony Collapse Disorder; the phenomenon whereby no adult bees, aside from the queen bee, remain in a honeybee colony.

*What’s Needed:* Ongoing research is developing automated thinning machines that are faster, more precise, and do not damage crops. The focus of these activities should be on measuring return on investment as these tasks are performed daily, and as such draw less attention than periodic harvesting labor shortages.

D. RESOURCE MANAGEMENT

Optimizing energy, water and nutrient use is an increasingly important issue in a resource-conscious world. It is especially pressing for vertical farms, where energy-intensive LED lighting and HVAC systems account for more than a quarter of ongoing costs\(^30\). Nutrient delivery and water management solutions have been commercially available for several decades. Further technical developments were seen with the introduction and integration of alternate energy sources, primarily solar and biomass. For example, solar module company Solaria and greenhouse integrated photovoltaic provider Soliculture collaborated to create a solar integrated greenhouse that does not impact crop yields according to the joint venture. The first installation is in Northern California, and the estimated return on investment is under 6 years\(^31\). The current wave of development focuses on using data and analytics to optimize resource usage, such as, managing and cycling LED lights in response to grid sell-in rates for solar energy.

*Company Examples: Cherry Creek Systems, Dosatron Intl., DRAMM, Solaria / Soliculture*

*Use Case:* In April 2015, Dosatron Intl introduced a version of its fertilizer and chemical injector product designed specifically for controlled environment agriculture. The product allows growers to automate the “delicate science” of creating the perfect nutrient mix, so taking the guess work out of a process that is essential to maintaining yields\(^32\).

*What’s Needed:* As for process control, there are plentiful options available for larger farms and for those seeking sophisticated solutions, but few available for those seeking, low cost nutrient delivery systems or simple analytics systems for energy management.

\(^{29}\) “Tiny Flying Robots Are Being Built To Pollinate Crops Instead Of Real Bees”, Dina Spector, Business Insider, July 7, 2014

\(^{30}\) Per Professor Kozai of Chiba University


\(^{32}\) “Dosatron International Introduces the D14 MZ2 into Controlled Environment Agriculture (CEA)”, Press Release, April 27, 2015
E. HARVESTING

Finding sufficient labor for harvesting is one of the tougher challenges faced by greenhouse growers in particular, primarily as it is required intensely for a comparatively short period. For instance, one greenhouse economics study calculated tomato harvesting at 27 hours for a crop, in comparison to 21 hours for all pruning activities over a period of months\textsuperscript{33}. Consequently, there is a good deal of interest in finding robotic harvesting solutions. Some hardy row crops have been harvested mechanically for more than 50 years, but dealing with delicate produce crops is the bigger challenge that is now being tackled.

Company Examples: Agrobot, Applied Food Science, Farmers Friend, Growponics, Harvest Croo

Use Case: Ten examples of robotic harvesting projects are shown in table six over page; the bulk focus on the larger field farming opportunity at present, but we anticipate iterations of these machines eventually moving indoors. Moreover, we envisage “semi-automated” solutions proliferating, whereby a robot harvester works overnight collecting the produce that’s easiest to spot mechanically, and then skilled farm workers finish the harvest during the day.

What’s Needed: The primary developments that would make harvest robots commercially viable are better speed and accuracy. Cost is also an issue, for example, French robotics company Naio – which sold ten field harvesting robots last year – predicts returns in 5-7 years for this early generation of machines, compared to the 1-2 years considered acceptable by most growers\textsuperscript{34}.

F. POST HARVESTING

Post harvesting activities include sorting, grading and packing produce, as well as system clean down. These activities typically require conveyor systems, whether mobile or fixed, as well as grading machinery, each of which have been commercially available for some years and which have often been adapted from other industries, such as retail and warehousing. Arguably, we might also include tracking technologies in this category, such as HarvestMark’s system to trace produce from vertical farm to consumer.

Company Examples: Agemchtronix (End of Line Counter), Aweta, BTM, Cherry Creek Systems (Echo-Veyer), Greefa (Combisort), SB Machinerie (SB10), WPS (SmartFlo)

Use Case: Dutch pepper grower Duijndam recently replaced an existing twenty year old grading machine with one from Dutch grading technology company Greefa, specially designed for grading bell peppers. The new machine grades on both size and weight, an important feature in a market where peppers are often pre-packaged into containers based on weight, and allows for packages to be placed in shipping boxes semi-automatically\textsuperscript{35}. In other use cases, paybacks of under a year have been reported for conveyor systems\textsuperscript{36}.

What’s Needed: As vertical farms proliferate, there will be an increasing need for more flexible and mobile conveyor and packing solutions to accommodate the differing layouts of such facilities.

\textsuperscript{33} Figures from estimated resource use and direct costs for spring tomato crop for greenhouse production, Mississippi, 2005, from "Budget for Greenhouse Tomatoes", Mississippi State Extension, September 2007
\textsuperscript{34} "French company develops autonomous greenhouse robot", HortiDaily, June 19, 2015
\textsuperscript{35} "Greefa CombiSort sorts peppers on size and weight", HortiDaily, September 4, 2015
\textsuperscript{36} “Garden State’s Conveyors: Advanced Automation”, Kevin Yanik, Greenhouse Grower, June 17, 2009
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<td>Agrobot</td>
<td>Field, Greenhouse</td>
<td>Europe</td>
<td>Commercial</td>
<td>French company Agrobot has developed a strawberry picking machine, priced at $100,000. It uses high powered computing, color sensors and small metal baskets attached to 14 robotic arms to achieve this. A 2nd larger prototype is under development, and well-known berry growers are partially financing development.</td>
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<tr>
<td>Auto Control Systems</td>
<td>Field, Greenhouse</td>
<td>US</td>
<td>Research</td>
<td>Co has developed a robotic hand designed to work alongside humans, that can pick things up and put them down. It aims to use them for strawberry picking, and claims that a commercial system will have a return on investment of under a year.</td>
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<tr>
<td>Broccoli Harvesting Project</td>
<td>Field</td>
<td>Europe</td>
<td>Research</td>
<td>A joint project led by Prof Tom Duckett of the University of Lincoln is exploring whether 3D camera technology can be used to identify and select when broccoli, usually a hand harvested crop, is ready for harvesting. Funded by Agri-Tech Catalyst, a UK government initiative designed to develop agtech.</td>
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<td>CROPS Project</td>
<td>Greenhouse, Orchard</td>
<td>Global</td>
<td>Research</td>
<td>Begun in October 2010, the EU-funded CROPS project was a 14-university collaboration to develop “scientific know-how for a highly configurable, modular and clever carrier platform that includes modular parallel manipulators and intelligent tools (sensors, algorithms, sprayers, grippers) that can be easily installed onto the carrier and are capable of adapting to new tasks and conditions”. Of particular interest is the sweet pepper harvesting robot that is capable of “selective harvesting of fruit (detects the fruit, determines its ripeness, moves towards the fruit, grasps it and softly detaches it)”</td>
</tr>
<tr>
<td>Energrid Tech</td>
<td>Orchard</td>
<td>US</td>
<td>Prototype</td>
<td>Energrid Tech has developed a robotic citrus harvesting machine that picks at 2-3 seconds per orange and has 80% thoroughness in recent trials. It uses a heavy base, that contains cameras, with a boom, that houses “frog tongues” that strike the tree to detach fruit. It is expected to retail for $200,000-300,000 per Patti Orton Kuma white paper. Project is funded by the USDA.</td>
</tr>
<tr>
<td>Harvest Croo Robotics</td>
<td>Field, Greenhouse</td>
<td>US</td>
<td>Research</td>
<td>Established in 2013, Harvest Croo has raised $1mn from backers to develop an automated strawberry picker. It expects to raise a further $1.5mn round before reaching a commercial model.</td>
</tr>
<tr>
<td>Naio Tech</td>
<td>Field</td>
<td>Europe</td>
<td>Commercial</td>
<td>Co that is aiming to fully automate way that growers plant, maintain &amp; harvest row crops. Has released a robot that can weed a field unaided, based on row length and no of rows in field. Working on additional features.</td>
</tr>
<tr>
<td>RoboticsPlus</td>
<td>Orchard</td>
<td>New Zealand</td>
<td>Research</td>
<td>A collaboration between Robotics Plus Ltd, University of Auckland, University of Waikato and Plant and Food Research aiming to automate harvesting &amp; pollination of kiwifruit &amp; apples. Team has secured $10mn+ in funding. The Autonomous Mobile Modular Platform (AMMP) will be capable of driving around an orchard by itself, stopping at the appropriate spots for tasks to be performed. The system is modular &amp; can support operations such as, sensing systems, custom robotic arms or spraying systems, so allowing it to multi-task.</td>
</tr>
<tr>
<td>Vineland Research &amp; Innovation Center</td>
<td>Field, Greenhouse</td>
<td>Canada</td>
<td>Research</td>
<td>Vineland Research &amp; Innovation Center is developing an autonomous machine that can choose which mushroom to pick, process and move it gently to its packaging case. It’s backed by an algorithm that decides when to pick based on a range of variables. Cycle to select and pick one mushroom takes 6 seconds, and uses a propriety gripper to pick mushroom, cut stem and put it in packaging.</td>
</tr>
<tr>
<td>Washington State University</td>
<td>Orchard</td>
<td>US</td>
<td>Research</td>
<td>A USDA-funded collaboration at Washington State University is focused on developing a robotic hand to be tested for speed &amp; effectiveness in detaching apples. Expects it be ready for testing in 5-7 years, and for commercialization in 15 years.</td>
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Sources: Company Websites, News Reports, Discussions with Researchers, Newbean Capital
3 WHAT COMES NEXT

The path that indoor agriculture’s involvement in automation and robotics will take from here is, in our opinion, primarily determined by industry adoption rates and the speed of technology commercialization.

It’s no secret that agriculture is a necessarily conservative industry, and as a consequence, adoption rates for new technologies are significantly lower than in internet or other technology industries. One industry commentator noted that successive generations of robots have been adopted with too little testing, leading to disappointment\(^\text{37}\). Such skepticism will be a barrier for those seeking to introduce new hardware in particular, where, lacking in economies of scale, payback periods are almost always well in excess of those considered acceptable by growers.

A further concern is security, especially for systems that require cloud access. This may be partially mitigated by the integration of technologies such as blockchain\(^\text{38}\) that enable more secure distributed databases with no WiFi or cell reception.

As was outlined above, options are plentiful in “traditional” areas of automation, such as irrigation controls, but far more limited in the more advanced robotics and data fields sought by large growers, and extremely curtailed when it comes to hardware and data services that target mid-market and smaller growers. For this end of the market, devices are sometimes over-engineered; they’re made too complicated and too feature-rich. As one industry consultant pointed out to us: “many of my clients only ever end up using 20% of the functions of the better systems”. There’s a distinct need for simpler devices with fewer functions, the kind that a beginning farmer can pick up in a few hours, and that include intuitive user interfaces.

Yet, much of the technology, funding and innovation that’s required to meet these needs already exists in other industries, and agriculture has a storied history of repurposing technology. For example, a group at IBM created 30% more accurate solar energy forecasts than the next best conventional system by using a deep machine learning technology that combines data from sensor networks, local weather stations, cloud motion physics derived from sky cameras and satellite observations, and multiple weather prediction models. This approach could equally be adapted to greenhouse control systems\(^\text{39}\).

Perhaps the largest barrier to technology commercialization will be economics, both of the equipment itself and of the businesses that will bring them to market. If we take harvesting robots, for instance, a generous calculation of the current North American greenhouse potential market size would be $60mn, which is respectable, but insufficient to sustain an industry alone. As a general rule of thumb, investors tend to look at market sizes of at least $300mn as viable. This calculation assumes that each of the 325 North American greenhouses in excess of 5 acres have one robotic harvester at the maximum viable price calculated by the European CROPs project of $200,000 per unit\(^\text{40}\).

Consequently, we anticipate that it will be tough for “single product” technology startups to thrive in the space, and instead we expect to see entrepreneurs partnering with those who have established distribution in the industry, are tackling numerous industries simultaneously, or are already using proprietary technology to create a competitive advantage by improving yields at their own farms.

\(^{37}\) Abe Van Wingerden of Metrolina Greenhouses quoted in “What’s the Next Industry Game Changer?”, Growertalks, July 2015

\(^{38}\) Typically associated with cryptocurrencies, blockchain is a distributed database that maintains an expanding list of data records that are protected against revision and security, even from owners of portions of the records, called nodes


\(^{40}\) Greenhouse market data from Cuesta Roble Consulting, CROPs figures from Dr. Jochen Hemming of Wageningen UR
Two bright spots in this evolution are the adoption of technology from outside the industry for use in indoor farms and the rise of readily available plant data. For instance, in traditional hardware, Visser NA and auto firm Toyota collaborated on an electric forklift, the Visser Vitoy, designed specifically for greenhouse applications.

Historically, there’s been an information asymmetry in that established control companies and growers have a quorum of data on plant behavior available to them that less experienced players do not. One control company told us that they are holding millions of pieces of data for their customers. It is only in the past few years that cheap sensors have allowed nearly all growers to easily capture plant behavior data. In the short run, established growers will likely still retain a competitive advantage from their backlog of data, and will naturally be loath to share it with others. It remains to be seen how fast – and whether – plentifully available data will level the playing field, primarily because we do not yet know if and when low cost, simple analytics platforms and user interfaces will enable smaller growers to translate “big data” into usable information.

4 CONCLUSION

We anticipate that future indoor farms will take a wide range of forms, much as they do today. For clarity, none of the scenarios that we examined in the preparation of this report result in labor-free farms, even in the long run. There are tasks that humans just do better than the most sophisticated machines. Instead, we expect large scale automated commercial farms that use feedback from sensors to optimize everything from farm inputs to timing harvest with data-connected grocery store and distributor customers. Others will choose to use basic analytics programs that translate data into actions for them, and alert them only when human intervention is required, a low tech response to high tech prompts.

For sure, these changes cannot be achieved through the application of robotics and automation technology alone. Plenty of technology advances will not be in automation. They will instead be design-led, such as, an elegant stacking system or a better way of handling heat in a controlled environment. There will be important developments in seeds and in the ways that we understand and utilize LED lighting. Progress in other disciplines, such as, biomanipulation – the ability to manipulate individual plants, or parts of them – would reduce the need for thinning and pruning, and render automation easier to implement. Given the capital intensity of indoor agriculture, better financing vehicles and methods will also play a part.

While most commentators, do not expect commercial products for at least another decade, history tells us that such changes happen a good deal faster than most predict: the meatless stem-cell based hamburger, for instance, went from being a $325,000 scientific pipedream in 2011 to a $20 product by 2015⁴¹. The future may be here faster than we know it.

⁴¹ “How Will We Buy Food in 2065”, Brian Halweil, Edible Brooklyn, December 11, 2014
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