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Research universities, incubators of (urban) innovation

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Abstract The intellectual might and the creative and innovative spirit of the faculty and students at our research universities play a key role in providing the basis for many inventions and innovations that address pressing problems of today's society. Many universities have built the vibrant culture and the nurturing environment that supports academic innovation and entrepreneurship and they have developed mechanisms that encourage and incentivize the translation of research breakthroughs into new products and processes. Urban environments, particularly big cities, face unprecedented challenges to address the needs of its citizens as more and more people move from rural parts of the world to cities in search of a better life and more economic opportunities. Securing reliable transportation of people and goods, adequate electrical power and water to satisfy the needs of the growing urban population, addressing the ever increasing waste disposal needs, maintaining the health and wellness of the general population, but especially of older adults and people with disabilities require a new paradigm for urban science, engineering, and innovation. Many universities have responded to this challenge and have developed research pillars around the challenges and opportunities that complex urban systems pose.

1 Introduction

The rapid trend of urbanization that will see 68% of the world's population living in cities by 2050 [1] poses enormous challenges to our cities and to the local governments that bear responsibility for addressing the needs of its citizens. Science, technology, and innovation play a key role in providing solutions to the complex urban challenges, from facilitating the reliable transportation of people and goods, to securing the availability of electrical power and water that meet the needs of the growing population as well as addressing the ever increasing waste disposal needs, to ensuring the health and wellness of the urban populations, in particular of older adults and people with disabilities, to making our cities more accessible and inclusive, to supporting local governments to be more responsive to the needs of its citizens. Moreover, none of these challenges can be addressed in isolation. Urban environments represent complex, intertwined social–economic–technical–environmental systems that require a new inter-/cross-disciplinary paradigm of innovative scientific and technological approaches combined with a path to translate the science and engineering breakthroughs into new products and processes.

The research university of the twenty-first century serves primarily three functions, (1) dissemination of existing knowledge or teaching, (2) creating new knowledge or research, and (3) exploiting new knowledge or technology transfer, i.e. the commercialization of research breakthroughs. The latter function is relatively new, but has gained importance in recent years, particularly after the passage of the Bayh–Dole act of 1980 by Congress [2], which gave universities the right to control the intellectual property (IP) derived from federally funded research. In response to Bayh–Dole, universities started to accumulate significant portfolios of IP, especially patents, developed incentives for faculty, Postdocs, and students to consider the potential of their research breakthroughs to lead to protectable IP, and created institutional environments and support mechanisms that would promote innovation and academic entrepreneurship To date, there is hardly any major research university in the world that does not claim to be innovative and/or entrepreneurial.

Many universities have responded to the multifaceted challenges that complex urban systems pose by developing research and innovation pillars in this area. New York University (NYU) has a university-wide "Urban Initiative" that engages the faculty, students, and staff of its Schools and Colleges [3]. Much of NYU's urban research is carried out under the auspices of its "Center for Urban Science and Progress (CUSP)" [4], which is anchored in its Tandon School of Engineering (NYU Tandon). In this article we use five case studies of startup companies whose innovations either originated at New York City's research universities and/or were developed and brought to market in close collab-

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oration with university faculty, and showcase how they responded to the challenges and issues that impact, but are not limited to urban environments.

2 Research universities, innovation, and start-ups

2.1 Background

Technology transfer at research universities can follow different pathways. We assume a science or engineering breakthrough at a university has been patented and the rights to the IP have been assigned to the university. In addition to the traditional tech transfer routes, (1) selling the IP to a third party, often an entity that buys up patents wholesale, (2) identifying a licensee to license the IP, or (3) engaging with a partner to jointly develop the technology further towards commercialization, the creation of spin-out companies has become the fourth path. Spin-out companies will license the IP from the university and develop the technology, very often with active participation of university personnel that was involved in creating the IP in the first place. The last 20 years or so have seen an increasing trend towards start-up formation as the preferred route to IP commercialization at many research universities. Even though the rate of failure for start-up is very high, by some estimates above 80% [5], however, if a start-up succeeds, the return on investment is much higher than what can be realized from the more traditional commercialization routes, perhaps with the exception of Medical Schools and the development of new drugs, where the "patent and license" approach still seems to be prevalent.

Many successful and prominent innovation and entrepreneurship or start-up hubs are located in the proximity of major research universities. Silicon Valley is close to Stanford, UC Berkeley and other universities of the UC system. Boston's Route 128 is in the backyard of MIT, Harvard, and others. The rapidly growing entrepreneurship ecosystem in New York City is supported by Columbia, NYU, CUNY, and Cornell Tech—to mention only the 4 big research universities in the city. Similar observations are true in other parts of the world, e.g. in Berlin, Munich, Paris, Prague, Innsbruck, London as well as in China, Korea, and India, among others. The reasons for these symbiotic relationships are (1) the strong basic science activities that serve as the foundation of new inventions and innovations, (2) broad expertise in all fields of engineering, applied science and technology, (3) a well-educated and trained human resource base (faculty, students, Postdocs, etc.), and (4) the presence of major tech companies in the area.

Following the examples of the early creators of an academic entrepreneurial culture, such as Stanford and MIT—to mention just the two most frequently cited examples, many institutions in the US have by now developed their own local culture that allows both internal stakeholders (faculty, students, Postdocs, staff) and external stakeholders (funders, industry partners, investors, representatives of federal, state, and local governments) to benefit from these entrepreneurial activities. At NYU, faculty can participate in their own startup company as e.g. Chief Technology Officer (CTO) or Chief Operating Officer (COO) (but not as Chief Executive Officer, CEO), while maintaining their faculty position, subject, of course, to a properly crafted conflict-of-interest management plan. University employees may also hold equity positions in startups that commercialize IP created by the employee and owned by the university. Lastly, annual faculty activity reports at NYU Tandon have a section for faculty to describe activities and accomplishments relating to innovation and entrepreneurship. Such activities may include, but are not limited to invention disclosures, patent filings, patents granted, and startups formed. Faculty compensation and decisions regarding tenure and promotion also value these activities and take them into consideration in addition to the traditional academic values of scholarship, teaching, and service.

2.2 Innovation, entrepreneurship, and support for start-ups at the New York University Tandon School of Engineering

Many research universities have set up the infrastructure and the support mechanisms that will support start-ups in their early stage when they are most vulnerable to failure. At NYU Tandon, the Institute for Invention, Innovation, and Entrepreneurship (IIIE@Tandon) [6] serves as the focal point of all research, educational, and service activities in support of NYU Tandon's goal to integrate invention, innovation, and entrepreneurship into its academic culture and to advance student and faculty appreciation of and skills in inventiveness, innovation, creativity, and entrepreneurial thinking. The IIIE draws its strengths from the contributions of faculty from multiple departments, a structure that facilitates the integration of inventions and innovations emerging from the departmental faculty and students and linking them to entrepreneurship, i.e. the proactive consideration and realization of commercialization opportunities through various institutional pathways. The IIIE

- serves as a one-stop shop for all school-wide activities that promote invention, innovation, and entrepreneurship.
- creates and supports a nurturing environment for the translation of science and engineering breakthroughs into new technologies, products, and processes in service to society.
- explores new learning opportunities that will provide every student with the basic knowledge and experience of entrepreneurial thinking.
- connects faculty and students with the NYU Tandon Future Labs [7], a network of technology acceleration and commercialization hub for start-ups as

well as with other innovation and entrepreneurship activities across the entire university.
- promotes student participation in NYU Tandon and other NYU innovation and entrepreneurship competitions.
- links the NYU Tandon community to the broader NYC technology scene through hackathons, workshops, competitions, guest lectures and tech talks.
- creates and supports the infrastructure for faculty and students to turn their ideas into successful ventures

The NYU Tandon Future Labs [7] are a cornerstone of the NYU Tandon innovation and entrepreneurship activities. The purpose of the Future Labs is to support start-up companies that commercialize new technologies and products in areas such as data-driven and data-intensive solutions, augmented and virtual reality, digitalization, cleantech, and smart cities and urban tech. Many of these start-up companies have their origin in basic and applied research carried out at NYC's major research universities or the start-ups collaborated with faculty researchers on the further development of their product. The technologies developed by many of the start-ups address problems that arise from complex urban systems and present challenges for the people who live there, but have also more far reaching applications.

3 Case studies of start-ups urban innovation

3.1 Motivation

In this section, case studies involving a few selected start-ups addressing problems of impact in, but not limited to, urban environments are discussed. They are meant to be illustrative case studies addressing a specific issue or problem and highlighting a case-specific solution that has the potential to be more widely applicable. Specifically, the case studies below address the charging of electric vehicles, data collection and surveillance using unmanned, autonomous vehicles, energy management in multi-dwelling buildings, waste-to-food conversion, and peak energy demand management in urban settings.

3.2 Specific case studies

3.2.1 HEVO wireless charging

HEVO [8], which stands for Hybrid & Electric Vehicle Optimization, addresses the challenge to charge electric vehicles (EVs) wirelessly. The company offers a safe and effective method of charging EVs that eliminates the hazards and inconvenience associated with plug-in charging, which is especially problematic in dense urban areas. HEVO's vision is to create the global wireless charging standard for EVs that provides users with a convenient charging experience, namely the ability to simply park and power up. The company has built a fast, safe and affordable wireless charging network that delivers locally resourced, sustainable energy wirelessly to customers with electric vehicles. HEVO is part of the transportation evolution, which aims to achieve greater energy independence and protect the environment and security interests of future generations.

Fig. 1 A HEVO power station seamlessly integrated into a New York City manhole cover (Picture courtesy of HEVO)

The company is a Service Disabled Veteran Owned Small Business. Founder and former U.S. Army Captain, Jeremy McCool, launched HEVO in November 2011, while finishing his graduate degree at Columbia University. HEVO subsequently took up residence in NYU Tandon's Urban Future Lab (UFL) [9], which supports start-ups in the cleantech, smart city, smart grid, and energy efficiency domains. The main technical challenge for the company was to scale up the power requirements needed to charge EV batteries wirelessly. Wireless charging of small electronic devices such as cell phone is ubiquitous and easy to accomplish, because the needed power is very low. The traditional wireless charging in low-power applications is inductive requiring a primary coil to generate an electromagnetic field that is picked up by a secondary coil. This is not very efficient in high-power applications because a significant fraction of the energy is dissipated through the coils. Charging a typical EV battery in a reasonable time, so-called "fast charging" requires a technology capable of providing more than 50 kW reliably for up to 2 h [10]. By contrast, "slow charging" a typical EV battery at power levels below 10 kW takes up to 10 h [10]. Tapping into the expertise of the NYU Tandon Power Engineering faculty allowed HEVO to develop a resonance-based system as an alternative to inductive charging. Here both coils are connected with a capacitor that creates a resonance circuit. This reduces the energy loss dramatically at a specific resonance frequency and one can transmit more energy at a faster rate over a larger distance.

HEVO's system has three parts, a power station that can either be bolted on the street or embedded in the surface, a vehicle receiver that transmits the power to the EV's battery via a rectifier, and a smartphone app that controls the entire charging process including vehicle alignment, provides communication between the hardware components, and serves as the sole interface with the end user. HEVO's power station can be integrated into manhole covers that are found all over New York City, see Fig. 1. HEVO's technology is particularly attractive in situations where a vehicle is parked in a particular spot for an extended period of time such as a parking lot or a parking garage or for charging delivery vehicles that follow the same delivery route day after day and make extended stops at pre-determined locations.

HEVO left the UFL after a few years and embarked on a remarkable growth trajectory. Today, HEVO's team spans across North America and Europe, with offices in Brooklyn, Amsterdam and Silicon Valley. Collectively, they have launched more than 10 other spin-out companies and have continued to develop innovative new products that are being sold and used around the world.

Manifold Robotics

Manifold Robotics [11] is a start-up company that uses specialized drones for data collection in a variety of aquatic and aerial applications. The company's technology grew out of a citizen science project that started in 2013 and was called Brooklyn Atlantis [12]. This new initiative was aimed at getting residents involved in cleaning up the highly polluted Gowanus Canal. Developed in the research lab of Professor Maurizio Profiri at the NYU Tandon School of Engineering, the project used autonomous robotic boats to collect water-quality data and capture images of the polluted canal, which citizen scientists would then view and help classify. Those robotic boats or unmanned surface vehicles (USVs), see Fig. 2, formed the core technology of the start-up company Manifold Robotics founded in 2017 by Porfiri and his PhD student Jeffrey Laut, who now serves as the company's CEO and chief engineer. Already in 2016, before the founding of Manifold Robotics, the USV technology of Porfiri and Laut with its ability to collect data on water quality, thus eliminating the need for a full-sized boat and dedicated crew and making the process much more efficient and cost-effective, caught the attention of PowerBridgeNY (a proof-of-concept center at NYU Tandon funded by the New York State Energy Research and Development Authority, NYSERDA) [13]. Using PowerBridgeNY funding, they engaged in customer discovery, talked to potential customers, assessed the competitive landscape, refined their prototype, and developed a go-to-market strategy. In early 2018, they received a second round of PowerBridgeNY funding, a so-called "Ignition Grant", which provided them with the means to take their start-up to the next level. The key differentiators of their technology are (i) the high degree of customizability, which allows the user to outfit the USV with their own sensors, (ii) the robustness of the USV, no matter what the payload (within reasonable weight limits), which is very important when a customer is equipping it with expensive sonar and other devices and (iii) the addition of computer vision algorithms that enable the craft to navigate efficiently in narrow water ways, which the company developed with an Small Business Innovation Research (SBIR) award from the National Science Foundation in 2019.

Fig. 2 Manifold Robotic' USV operating on the Gowanus canal in Brooklyn, NY (Picture courtesy of Manifold Robotics)

Universities have many ways to provide direct financial as well as non-financial support to innovative and entrepreneurial faculty, Postdocs, and students through, e.g. monetary prizes and awards, access to facilities and faculty/student expertise, grants, mentorship, access to external advisors and potential funding sources, etc. At NYU Tandon, this support structure is coordinated by the IIIE@Tandon. However, the above described level of support is only available to teams of inventors before they form a start-up company. Once a start-up company has been formed, the relationship between the university, as a not-for-profit and tax-exempt entity and the start-up, which is now a commercial for-profit entity, is fundamentally different. The university can no longer provide the start-up company with pro bono or discounted services to which a monetary value can be assigned, and must charge market rates for all such services. Of course, university spin-out companies can still benefit from many non-financial services and support that the university can provide.

A few years back, Manifold Robotics branched out to develop a mobile data collection platform that allows unmanned aerial vehicles (UAVs) to operate safely in the sky near power lines, see Fig. 3. In New York City, only the power lines in Manhattan are largely underground, where the vast majority of power lines in the outer boroughs (Brooklyn, Queens, Staten Island, and the Bronx) as well as essentially all power lines in neighboring Long Island and in suburban New Jersey and Connecticut are above ground. Traditionally, power companies have relied on the use of helicopters to inspect these power lines, which is noisy, risky, expensive, and highly problematic in densely populated areas. Despite their advantages, however, the use of UAVs still faces challenges, e.g. the high electromagnetic fields near power lines can destabilize conventional UAV nav-

Fig. 3 Manifold Robotic' UAV operating near a high-voltage power line (Picture courtesy of Manifold Robotics)

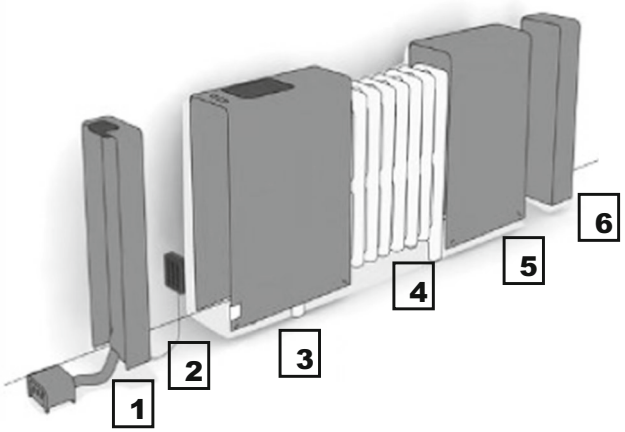

Fig. 4 Conceptual sketch of the cozy. The various components are: 1—Fan cover, 2—removable fan, 3—Air pipe cover, 4—Radiator, 5—sliding cover, 6—Back cover. (Picture courtesy of Radiator Labs)

igation systems, and low visibility can greatly increase the chances that a UAV will collide with either a line or a transmission tower.

With partial support from NYSERDA and the New York Power Authority (NYPA), the nation's largest state public power utility, the company is now developing a UAV that is capable of operating safely near power lines using new sensing technologies and algorithms [14]. This development uses technology licensed from the US Army Research Labs, which enables the UAV to sense the electromagnetic field from transmission lines at a distance and counteract its deleterious effect on the UAV's navigation system. The commercial/technological feasibility of this technology was established with support from the National Security Innovation Network, NSIN [15], which is funded by the U.S. Department of Defense.

The use of autonomous aquatic vehicle remains a core business thrust of Manifold Robotics. The company is intent on making a significant impact in the world of water-quality data collection, help its customers meet their specific measurement and monitoring needs, and ultimately contributing to the health of our planet.

Radiator Labs

The mission of Radiator Labs [16] is to eliminate overheating in steam heated buildings, a 100-year-old problem, which results in a lack of comfort for the residents and wastes energy. Many of the more than 1 million buildings in New York City were built before 1940. The vast majority of these "pre-war" buildings employ steam heating systems. Water is heated by a gas or oil-fired burner which turns it into steam. The steam travels through pipes to radiators, which give off heat and warm the room. As the steam cools, it condenses back into water, and returns to the boiler.

Common complaints in steam heated pre-war buildings are overheating and the lack of temperature control. Quite often radiators are either on or off, and sometimes even in the off position, the valves do not completely shut off the hot steam. It is not uncommon to see open windows in buildings on cold days in New York City. It is the only way to maintain a comfortable temperature by balancing the uncontrollable heat from the radiator with the cold air from the outside, arguably an incredible waste of energy and money. By incorporating radiator-level control with real-time data collection and visualization, the company's product, the "Cozy", a smart, internet-connected, thermostatic cover for radiators (Fig. 4), achieves significant savings while maximizing comfort and temperature control for the residents.

The idea for the Cozy dates back to 2011, when Marshall Cox, then a PhD student at Columbia University, was living in overheated graduate student housing. Together with his advisor he developed the basic concept of the Cozy. After a year of initial testing in Mr. Cox's apartment, he competed in—and won—the Grand Prize at the MIT Clean Energy Prize [17]. The $220,000 in prize money helped launch Radiator Labs. After he graduated with a PhD degree in Electrical Engineering in 2013, Dr. Cox and Radiator Labs took up residence in NYU Tandon's Urban Future Lab [9], where they stayed for several years. During that time, and continuing to collaborate with faculty, Radiator Labs refined its technology, maximized product-market fit, solicited feedback from potential customer, and started several pilot projects.

The full benefit of the technology is realized when an entire building is outfitted with Cozys, in which case building-wide savings of up to 45% in fuel use and on heating costs can be realized as independently verified by NYSERDA. In that case, the product, which now accommodates many types of radiators (cast iron, baseboard, wall mounts, convectors), allows the real-time monitoring of the building-wide temperature balance and the status of the building's entire steam delivery system.

Figure 5 shows the temperature fluctuations over a period of 72 h in a room before and after the Cozy was installed for three cases, a hot room (top diagram), a very warm room (middle diagram), and a cold room (lower diagrams). In all cases, temperature fluctuations are reduced to a very narrow interval of only a few degrees, which allows the room to maintain a more or

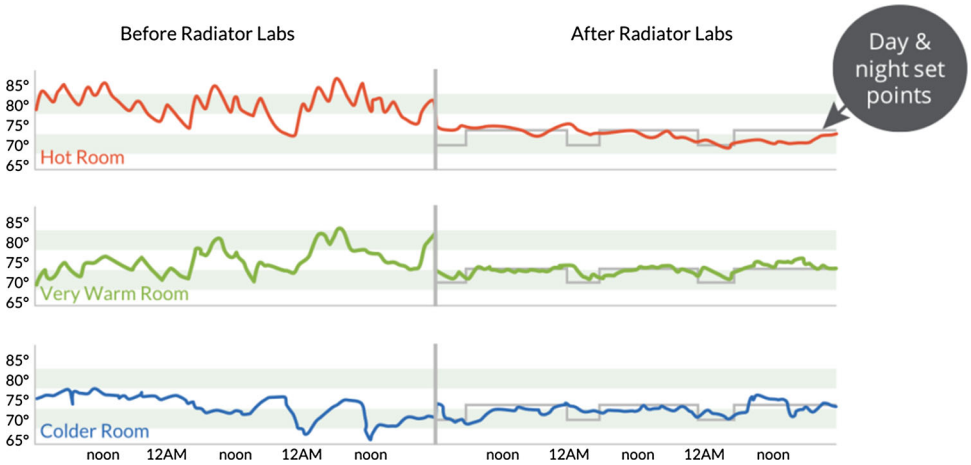

Fig. 5 Impact of the Cozy on temperature fluctuations in a steam-heated hot room (top), very warm room (middle), and cold room (bottom) over a period of 72 h. (Picture courtesy of Radiator Labs)

less constant and easily controllable temperature. Large and somewhat erratic temperature swings are avoided and, in the case of the hot room, there is a noticeable reduction in the time-averaged temperature over the 72-h period, which translates to a reduction in heating costs.

The technology that is being commercialized by Radiator Labs provides a clear pathway to compliance with New York City Local Law 97 [18] (see Sect. 4 below).

Rise Products, from waste to food

Rise Products ("RISE") [19] was co-founded about 5 years ago by 2 PhD students in NYU Tandon's Department of Technology Management and Innovation, Bertha Jimenez and Ashwin Gobi. The basic idea of recycling beer waste and turn it into value products first came into the cross hairs of Ms. Jimenez in 2015, while she was working towards her PhD degree. Intent on finding ways to reduce industrial waste, she started a side project with like-minded friends. Artisanal breweries in Brooklyn, of which there were more than 20 at the time, were the initial target. Brewing relies on grains, typically malted barley, which is first soaked in hot water, a step that releases sugars crucial to the later production of alcohol. Once those sugars are released into the liquid, the spent grain, referred to as Brewers' Spent Grain (BSG), which is still rich in in fiber and protein [20], is usually discarded (Fig. 6). Annually, breweries around the world discard 40 million tons of BSG [21]. While a small fraction of the BSG is repurposed as animal feed, compostable products or heating fuel, little has been exploited for its value as food.

In 2016, after Ms. Jimenez received her doctorate, RISE joined Food-X, an accelerator in New York City [22], and completed plans for a mechanical process that could speed flour production. RISE uses a patent-pending process to convert organic by-products into food-grade ingredients. Currently, RISE is focusing primarily on turning the by-product of the beer into an ultra-nutritious artisanal flour that has 12× the fiber, 2× the protein, and only 1/3 of the carbohydrates of all-purpose flour.

Fig. 6 Collecting Brewers' Spent Grain at an artisanal brewery in Brooklyn, NY. (Picture courtesy of RISE Products)

Their product has found its way into sustainable bakeries and kitchens in New York City and as far away as Italy. The company works very closely with the large craft-beer network in the city and helps them divert tons of food-waste away from landfills. The team's expertise in upcycled ingredients allows them to consult with food brands to help them develop, market, and launch sustainable products. Current products include Brownies, Brownie Mixes, Granola, and Flour [19].

Today, the RISE Products team makes its flour in a commercial kitchen in Long Island City in Queens (Fig. 7). The grains are dried in an oven, then ground, milled and sifted into flour. RISE has also broadened its portfolio. Its team of engineers, innovation consultants, chefs, and food scientists helps food and beverage companies across the value chain by identifying other opportunities for upcycling and recycling, creating financial rewards, and introducing new sustainable processes. The company's technology can easily be adapted to other organic by-products.

Fig. 7 Turning BSG into a ultra-nutritious flour (Picture courtesy of RISE Products)

Fig. 8 ThinkEco's first product, the Modlet Smart AC kit. (Picture courtesy of ThinkEco)

Currently, the company is exploring upcycling (1) grape pomace, a by-product of wine, which is rich in vitamin A and natural antioxidants, (2) okara, a by-product of soy milk, which is rich in prebiotic fiber and plant based protein, and (3) juice pulp from citrus, which is rich in vitamin C, minerals (calcium, magnesium, and potassium), and high in fiber.

As a student at NYU Tandon, Ms. Jimenez developed a keen interest in understanding the role of higher education in developing entrepreneurs and supporting them on their path from taking a lab discovery to a market-ready product. This research, in turn, helped the university augment and improve their co-curricular entrepreneurship training programs. She became a frequent participant in the New York City entrepreneurship ecosystem in different roles, as student, presenter, coach, mentor, and founder. She still using her research and startup experience to help students understand, analyze and develop technology and she is actively leveraging her experience and skills to create a better community, especially for minority and female entrepreneurs. In the US (and across the globe), female entrepreneurs represent only a small percentage of all entrepreneurs [23] and there are many programs in existence that aim to support and encourage female entrepreneurs [24,25]. Similarly, entrepreneurs from traditionally underrepresented groups in the STEM (Science, Technology, Engineering, Mathematics) disciplines (African Americans, Latinx, Native Americans, and others) make up only a small fraction of start-up founders and entrepreneurs in the US.

ThinkEco and Essense Partners

The stories of ThinkEco [26] and Essense Partners [27] are inextricably linked to Mei Shibata [28] and her passion to help transform the energy industry. Before founding ThinkEco in 2008, Ms. Shibata earned a BS in Physics and a MS in Engineering from Harvard, and subsequently also a MBA from the Harvard Business School. The unique combination of science, engineering, and business training formed the basis for her success. The idea behind ThinkEco was to find a way to reduce the energy consumption of window air conditioners in New York City during the hot summer season, when power used by AC units makes up a significant fraction of the power demand, particularly during the late afternoon hours when the peak power needed reaches the limit of what the utilities can deliver [29]. This often results in requests to the public to reduce power consumption during these times by e.g. shutting off some elevators in office buildings or raising the temperature setting on the AC units. In 2015, there were close to 7 million window AC units in the city according to data provided by Consolidated Edison (ConEd) [29]. That number has probably not changed much in the past 5 years as new buildings that are being constructed tend to have central AC rather than window units. To better manage peak power demand in the summer, ConEd in 2015 partnered with ThinkEco, when the company was a resident of NYU Tandon's Urban Future Lab [9], to launch the coolNYC program, which was subsequently renamed the Smart AC Program [30].

This program made ThinkEco's first product, the "Smart AC Kit" (Fig. 8), a combination of its "Modlet", short for "modern outlet", and the ability to control an AC unit that is plugged into it wirelessly, available to many of ConEd's residential customers in the city. Customers can use their smartphone to set the AC's temperature and turn it on and off remotely, thus taking the stress off the grid. Even when only the AC's fan is running, it uses about 100 W, so putting the unit remotely into the energy saver mode reduces the power demand considerably given the large number of AC units in the city. The purpose of ThinkEco's technology is not to effect or control comfort, but to reduce the load, particularly during peak hours.

Today, the company is based in New York City, but operates across the nation. ThinkEco's modlet platform is being used by many utilities and their customers and a wide range of devices can be controlled (Fig. 9). In essence, the company offers a portfolio of full-service, turnkey demand response and energy effi-

Fig. 9 Kitchen devices controlled by the Modlet. (Picture courtesy of Think Eco)

ciency solutions by developing and implementing customized offerings around residential and commercial customer engagement, demand response, and energy efficiency.

While still at ThinkEco, Ms. Shibata set her sight on broader global issues. In 2014, she created Essense Partners [27] leveraging her experiences at ThinkEco. Essense Partners is a vertically-integrated global strategic marketing and technology implementation firm focused exclusively on the evolving energy sector. The company now supports about 50 clients internationally helping them navigate and maximize growth towards a cleaner, more customer-centric, and technology-enabled energy future. Change in energy is all encompassing, from technology development to business models and operational changes, thus fundamentally changing many aspects of the customer-supplier relationship in the energy sector.

4 New York City's local law 97, a challenge for building owners and operators and an opportunity for innovation

In May of 2019, the City Council in New York City passed Local Law 97 [18] as part of the Climate Mobilization Act. It is arguably one of the most ambitious and far reaching laws passed by any locality in the world to reduce greenhouse gas (GHG) emissions from existing buildings. GHG emissions from buildings account for close to 1/3 of the total GHG emissions in New York State [31] (Fig. 10). In New York City, that percentage is even higher.

The law impacts close to 60,000 buildings in New York City, of which 60% are residential and 40% are commercial buildings. The main objective of this law is to reduce building-based GHG emissions by 40% by 2030 from a 2005 baseline. Local Law 97 sets limits for two initial compliance periods: 2024-2029 and 2030-2034 (and requires the city to set future goals through 2050 when the objective is to reduce emissions by 80% over the 2005 baseline). Buildings over 25,000 square feet must meet annual whole-building carbon intensity limits during each compliance period based on building type or prorated for mixed-use buildings. To comply, building owners must submit an emissions intensity report stamped by a registered design professional every year starting in 2025 or pay substantial fines. Currently, the vast majority of buildings that are subject to this law are significantly above the emissions limits. They will require comprehensive retrofits and/or the implementation of new and innovative technologies to achieve compliance by 2030 or face progressively increasing fines over time.

Exceptions exist for hospitals, assisted living facilities, houses of worship, and certain categories of low-income housing. Local Law 97 also requires that the city perform a study regarding the feasibility of carbon trading among the city's buildings as a potential compliance mechanism. The study must include methods to ensure equitable investment in and benefits for environmental justice communities. Led by New York University, the study will be reporting its findings in late 2021.

Compliance with Local Law 97 presents an enormous challenge for building owners and building operators. At the same time, satisfying the requirements of the law has the potential to stimulate the creativity and the innovative spirit of the faculty and students at our research universities. Academic researchers may join forces with the private sector and government to conceive, reduce to practice, test, and deploy inventions and innovations around new materials and more efficient manufacturing protocols, novel multipurpose smart sensors and monitoring/control systems combined with artificial intelligence and machine learning, other hardware solutions and software platforms that we are not yet able to think of, and innovative financial models to pay for improvements to building and to amortize the costs of implementing the new solutions—to name only a few.

5 Conclusions

In this article, five selected case studies were used to showcase how start-ups can respond to the challenges and issues that impact, but are not limited to urban environments using New York City as a testbed. The focus was on start-ups, whose innovations either originated at New York City's research universities and/or were developed and brought to market in close collaboration with university faculty and students.

In mid-2019, New York City was home to about 170 incubators, accelerators, and co-working spaces according to Tracxn [32]. Today, the number may well be above 200. They are spread over a wide range of technologies and sectors. While not exclusively focusing on advancing technologies that address urban challenges, many provide a home for at least some start-ups operat-

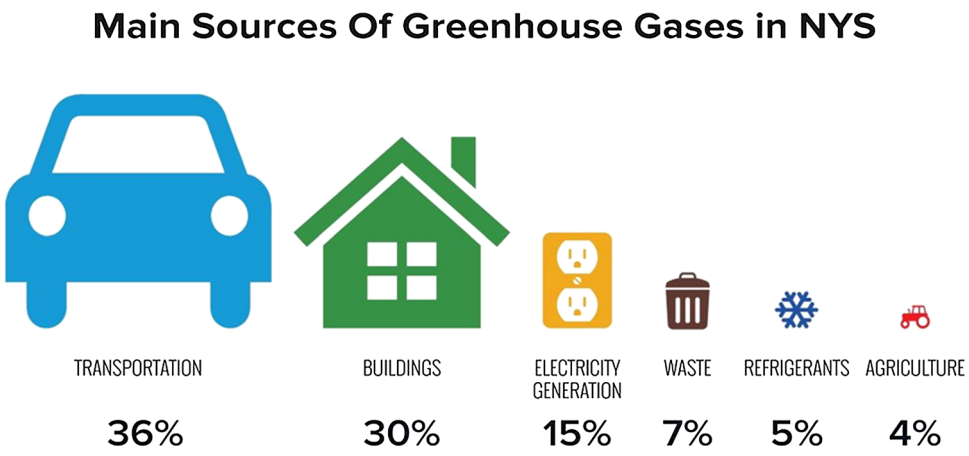

Fig. 10 Sources of GHG Emission in New York State in 2018. (Picture courtesy of the NYS Department of Environmental Protection)

ing in that domain. There are far fewer incubators that focus exclusively on supporting start-ups in the urban technology area. An even smaller number of those are directly affiliated or collaborate with near-by research universities to take advantage of (1) the basic science activities at these institutions that fuel new inventions and innovation, (2) the technical expertise in engineering, applied science and technology, (3) the highly educated and well-trained human resource base (faculty, students, Postdocs, etc.), and (4) the presence of major technology companies in the area attracted by the innovative and creative spirit found at these premier research institutions. One such example is the Urban-X Accelerator [33] that provides 20 immersive weeks of customer development, product development, network-building and expert guidance for startups exclusively focused on urban technology twice a year. The New York City Economic Development Corporation (NYC EDC) has a program with a focus on "Urban Tech New York City" [34]. They support, among other initiatives, the "Urban Tech Hub" with 2 locations, one in mid-town Manhattan [35] and another one in the Brooklyn Navy Yard [36].

The challenges of the intertwined social–economic–technical–environmental urban systems for its citizens and for local governments will only become more pressing in the future. Solutions require a close collaboration between academia, the private sector, and government. Research universities, leveraging the creative and innovative spirit of its faculty and students, will play a key role in in providing the basis for many inventions and innovations that will address the pressing problems posed by complex urban systems.

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