US011856902B2

(12) **United States Patent**
Coffin et al.

(10) **Patent No.: US 11,856,902 B2**
(45) **Date of Patent: Jan. 2, 2024**

(54) **PRODUCTION FACILITY LAYOUTS FOR AUTOMATED CONTROLLED ENVIRONMENT AGRICULTURE**

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(73) Assignee: **MJNN LLC**, South San Francisco, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 141 days.

(21) Appl. No.: **17/639,893**

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(86) PCT No.: **PCT/US2020/050593**
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(2) Date: **Mar. 2, 2022**

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PCT Pub. Date: **Mar. 25, 2021**

(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Provisional application No. 62/987,149, filed on Mar. 9, 2020, provisional application No. 62/903,573, filed on Sep. 20, 2019.

(51) **Int. Cl.**
A01G 9/029 (2018.01)
A01G 31/04 (2006.01)
A01G 31/06 (2006.01)

(52) **U.S. Cl.**
CPC ***A01G 31/06*** (2013.01); ***A01G 31/045*** (2013.01)

(58) **Field of Classification Search**
CPC A01G 9/0299; A01G 31/00; A01G 31/04; A01G 31/042; A01G 31/045; A01G 9/024; B65G 17/20; B65G 23/14; B65G 33/02
See application file for complete search history.

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Primary Examiner — Kristen C Hayes
(74) *Attorney, Agent, or Firm* — Almanac IP Advisors LLP

(57) **ABSTRACT**

Facility layouts and configurations for an automated crop production system for controlled environment agriculture. In particular implementations, the core of the facility comprises a controlled growth environment and a central processing system. The controlled growth environment includes systems for exposing crops housed in modules, such as grow towers, to controlled environmental conditions. The central processing system may include various stations and functionality both for preparing crop-bearing modules to be inserted in the controlled growth environment, for harvest-

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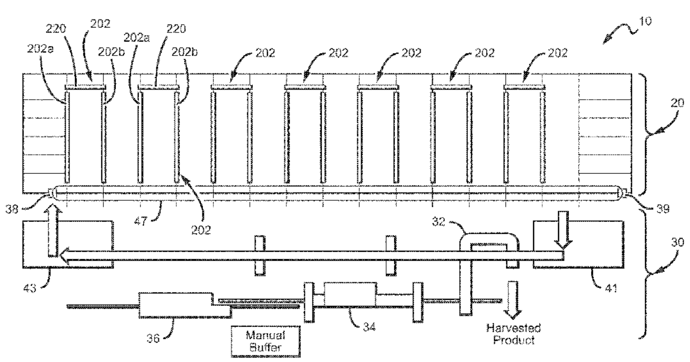

ing crops from the crop-bearing modules after they have been extracted from the controlled growth environment, and for cleaning or washing crop-bearing modules for re-use. The controlled growth environment may include vertical farming structure having vertical grow towers and associated conveyance mechanisms for moving the vertical grow towers along one or more grow lines. The conveyance mechanisms may include a return transfer mechanism that creates a return or u-shaped path for each grow line.

7 Claims, 25 Drawing Sheets

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International Application No. PCT/US2020/050593, Search Report dated Feb. 1, 2021, 6 pgs.
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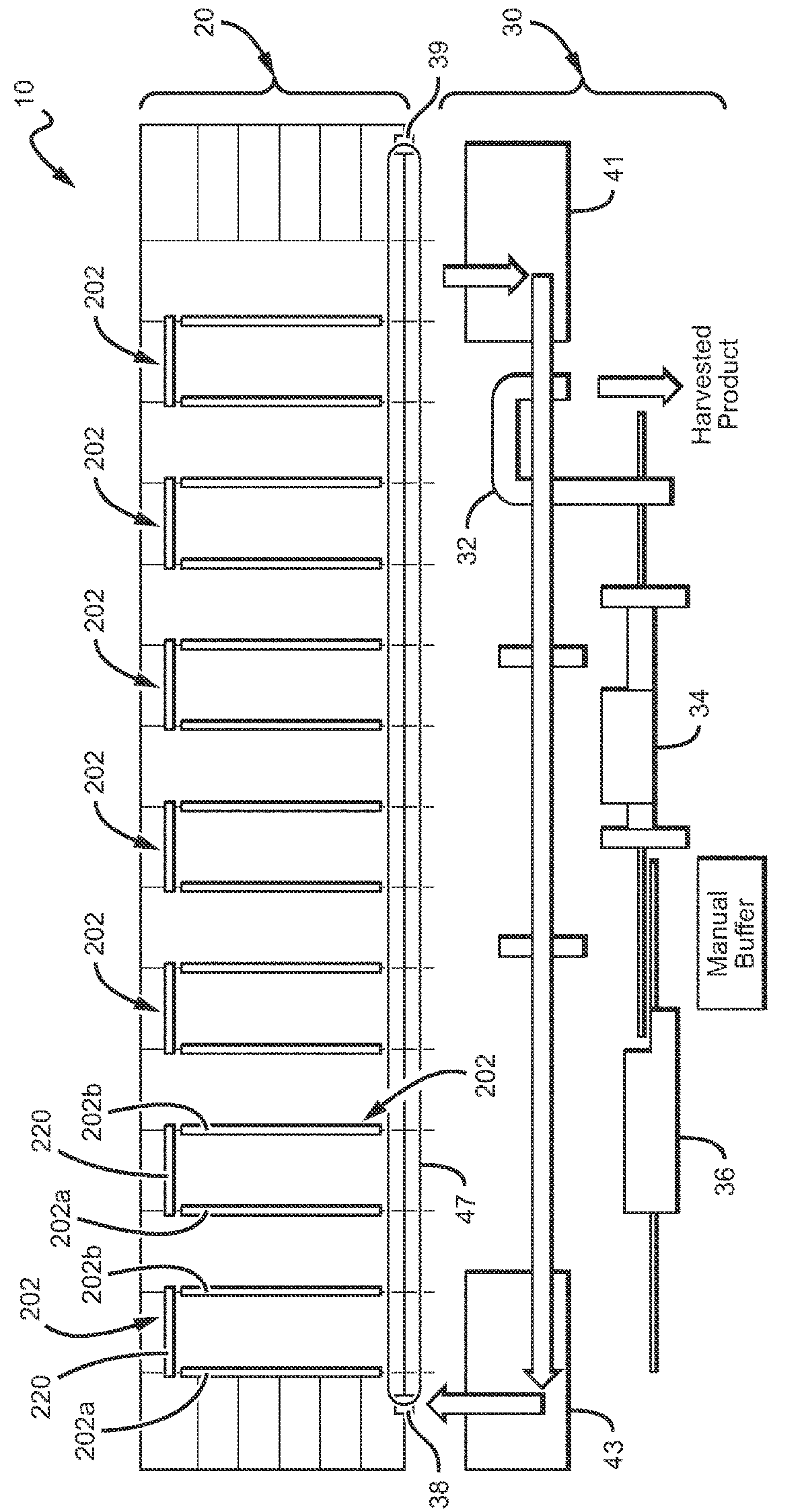
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202
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Harvested Product
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Manual Buffer
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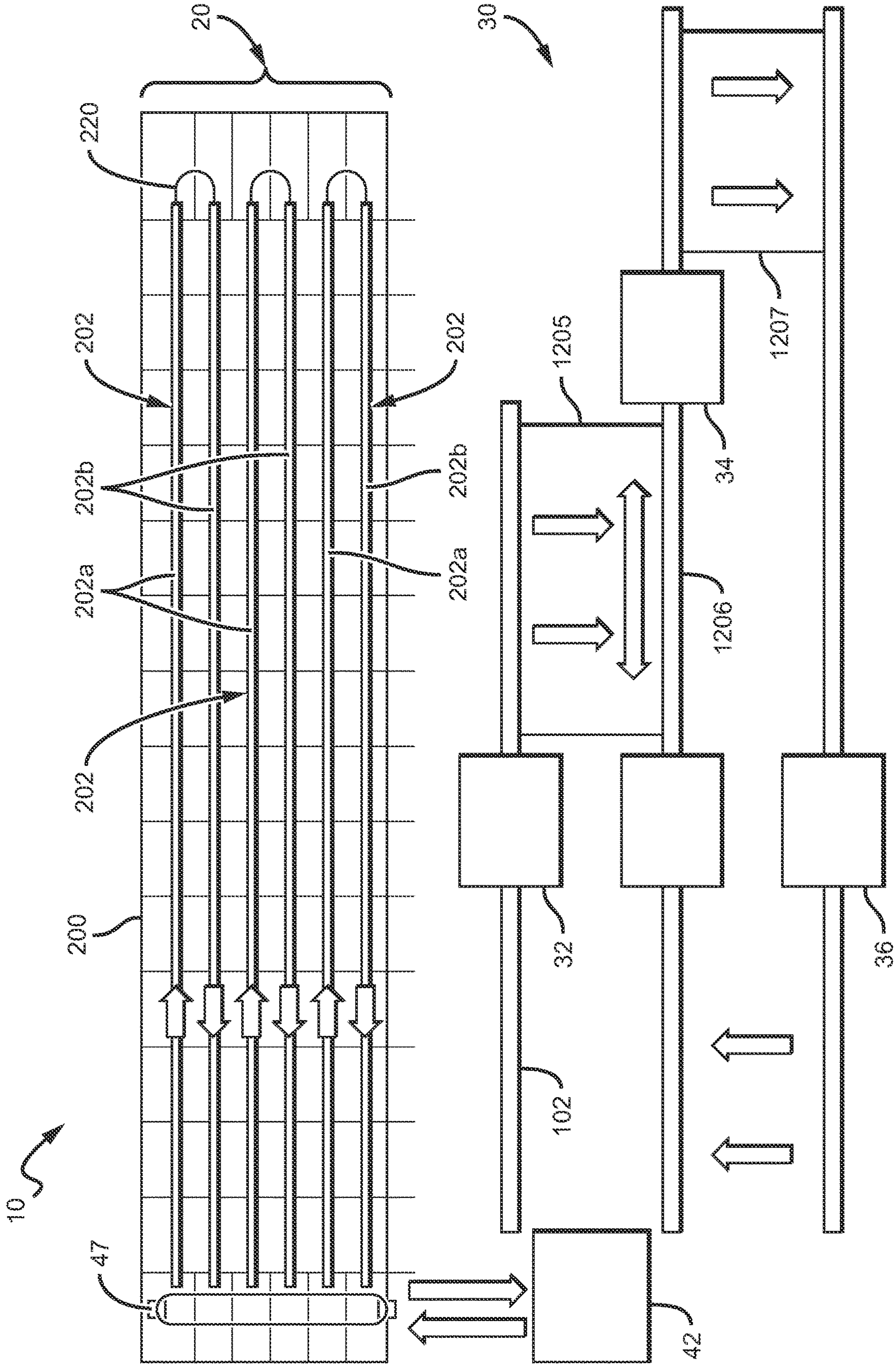
FIG. 1A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102
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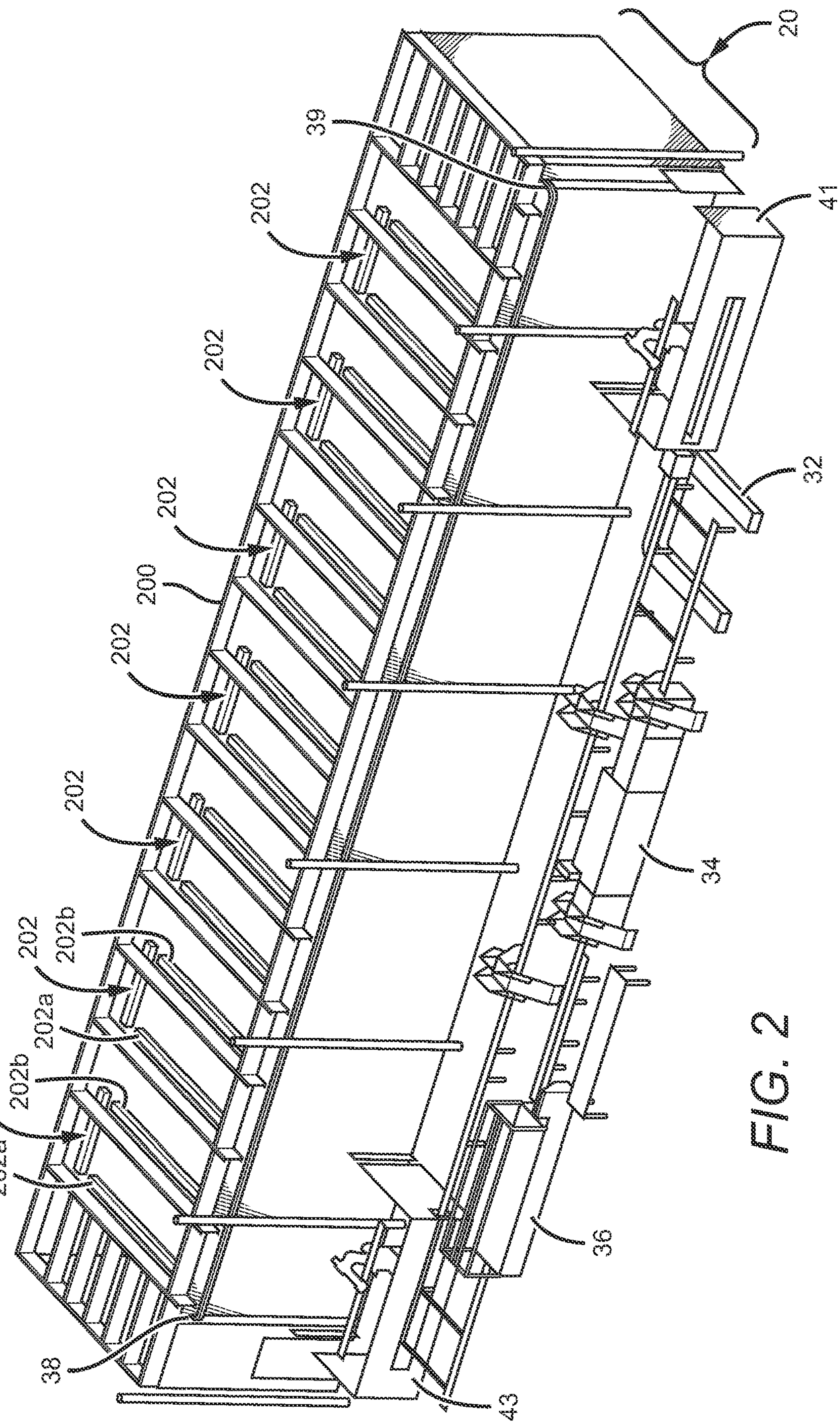
FIG. 1B



20
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FIG. 2

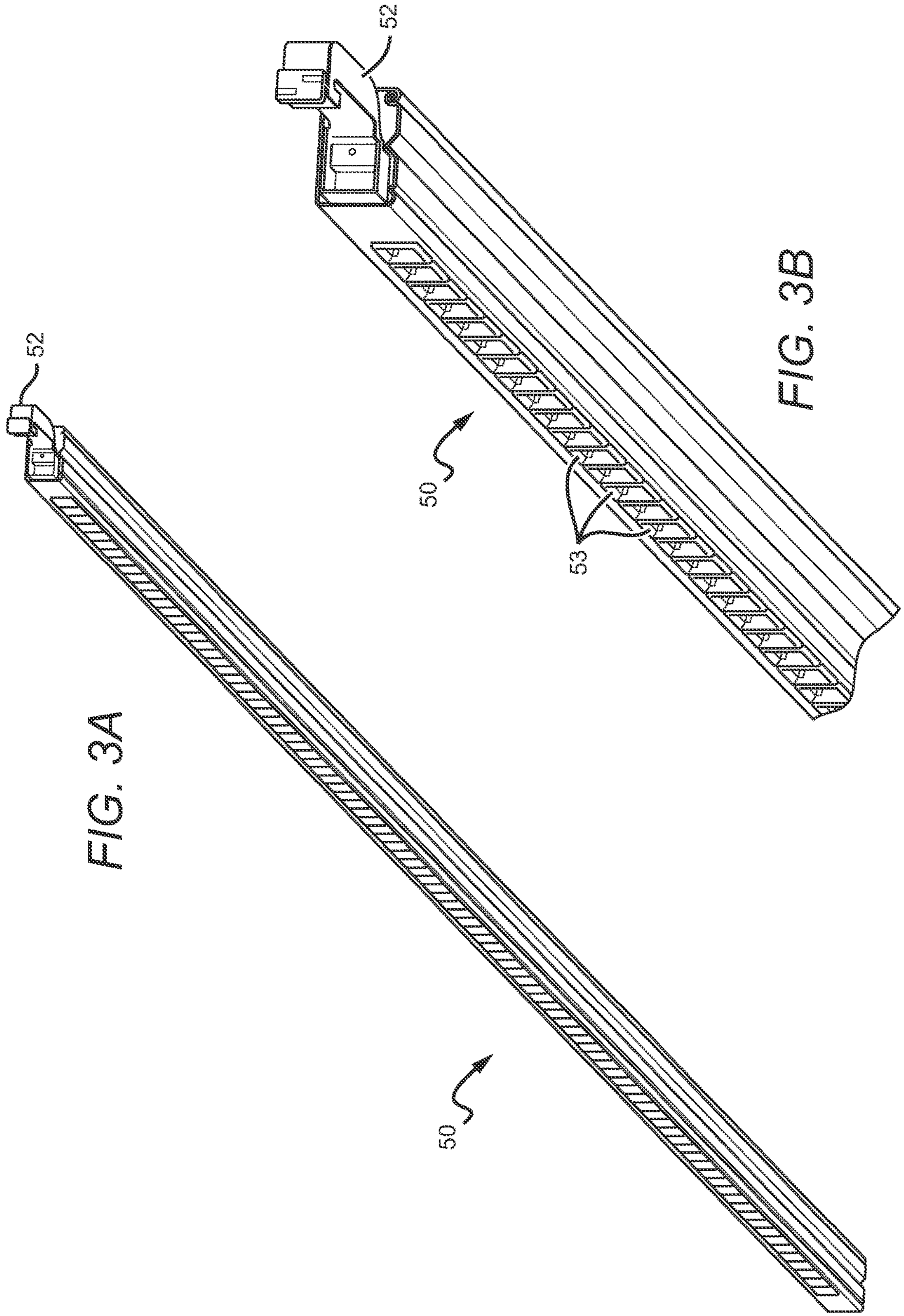


FIG. 3B

FIG. 3A

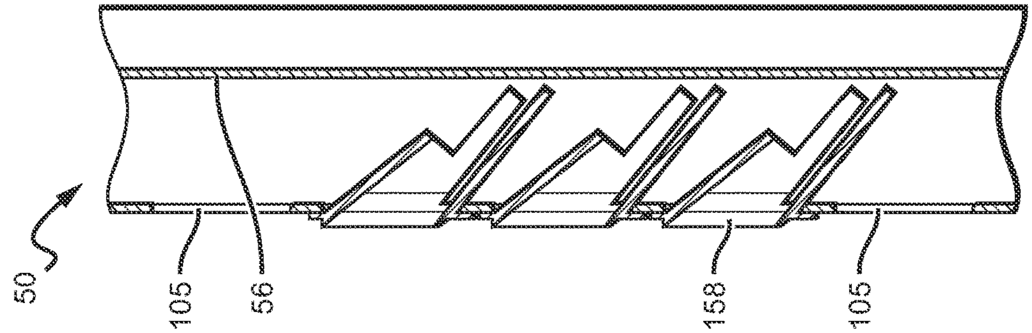


FIG. 4D

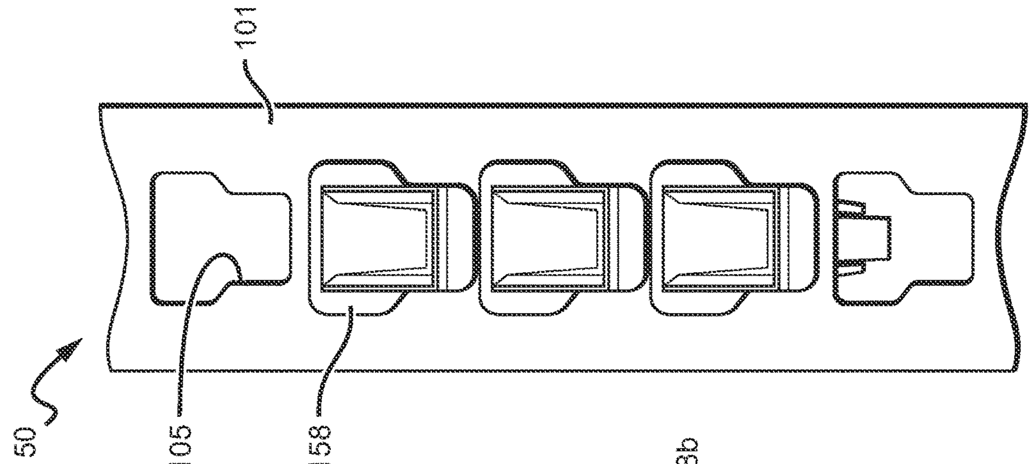


FIG. 4C

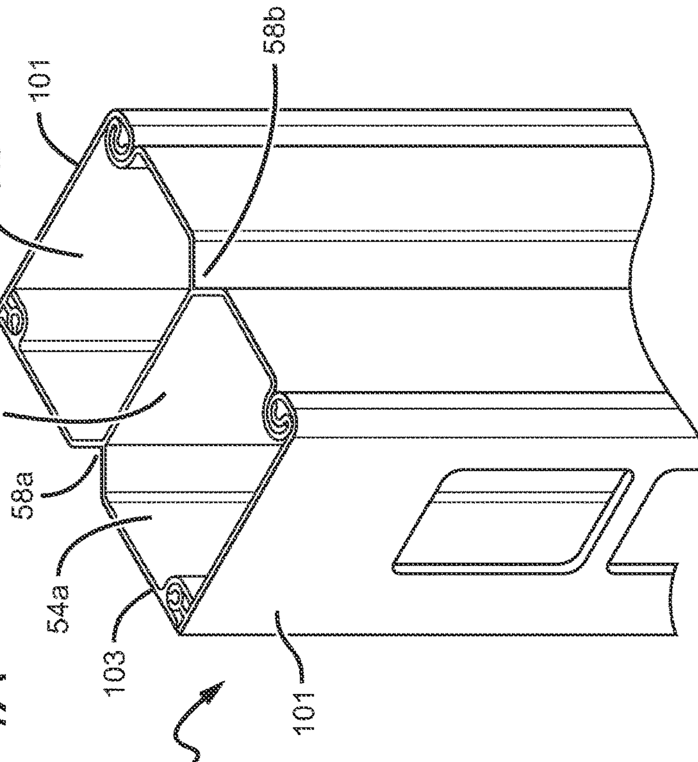


FIG. 4B

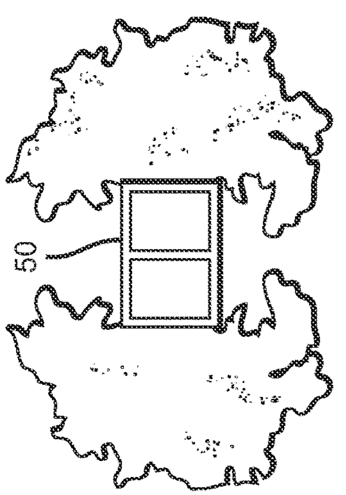


FIG. 4A

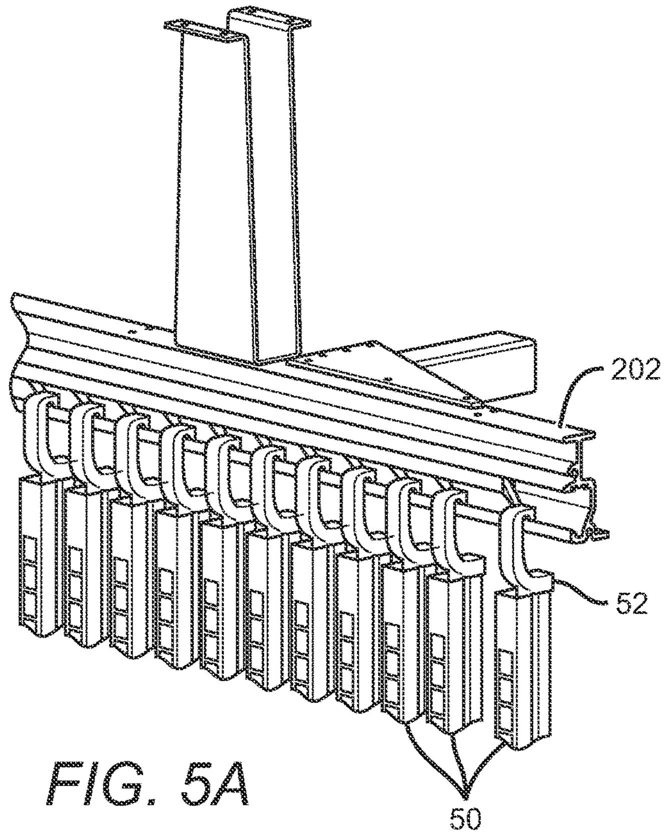


FIG. 5A

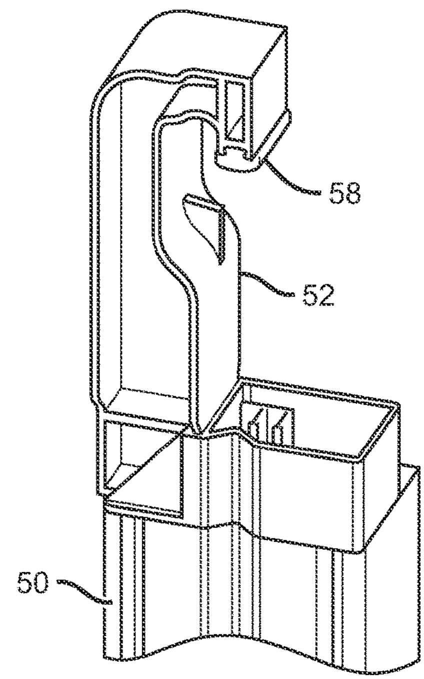


FIG. 5B

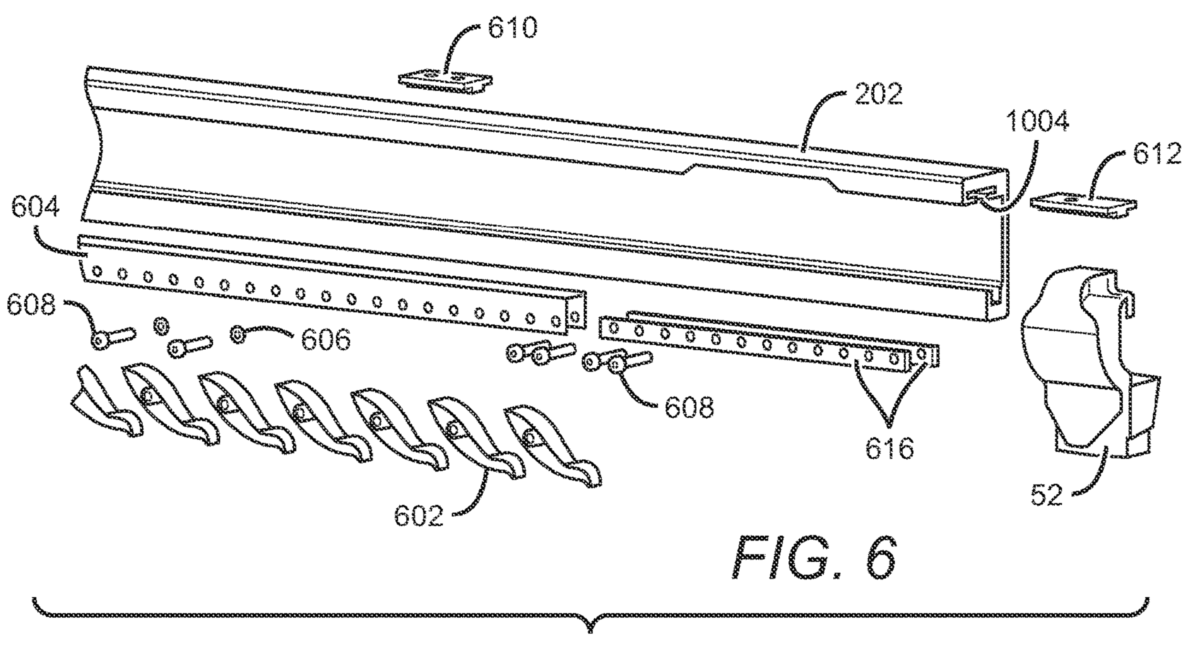


FIG. 6

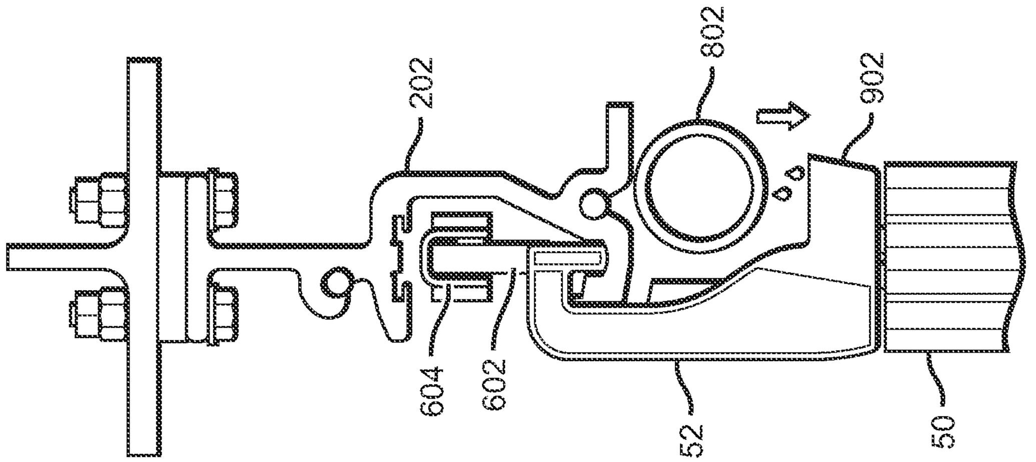
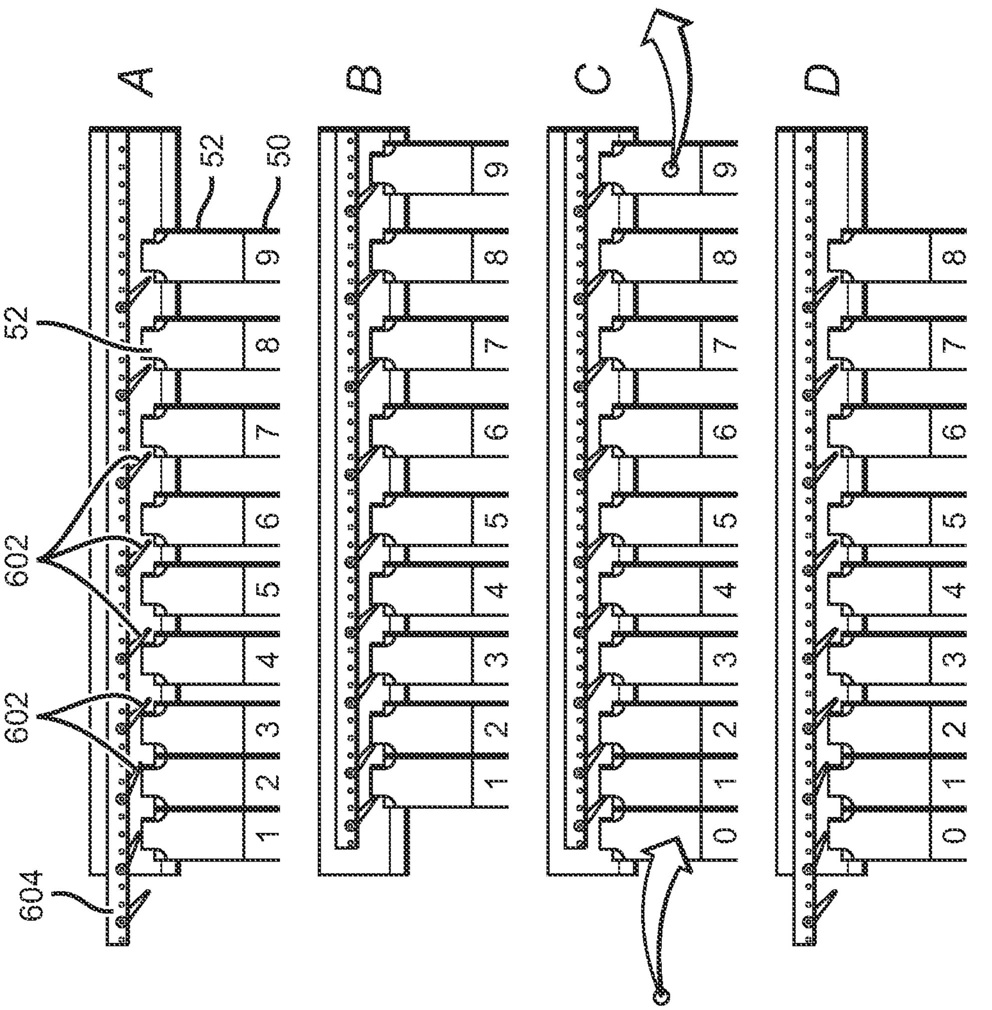

202
802
902
604
602
52
50

FIG. 8


A
B
C
D
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602
602
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0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 5 6 7 8

FIG. 7A

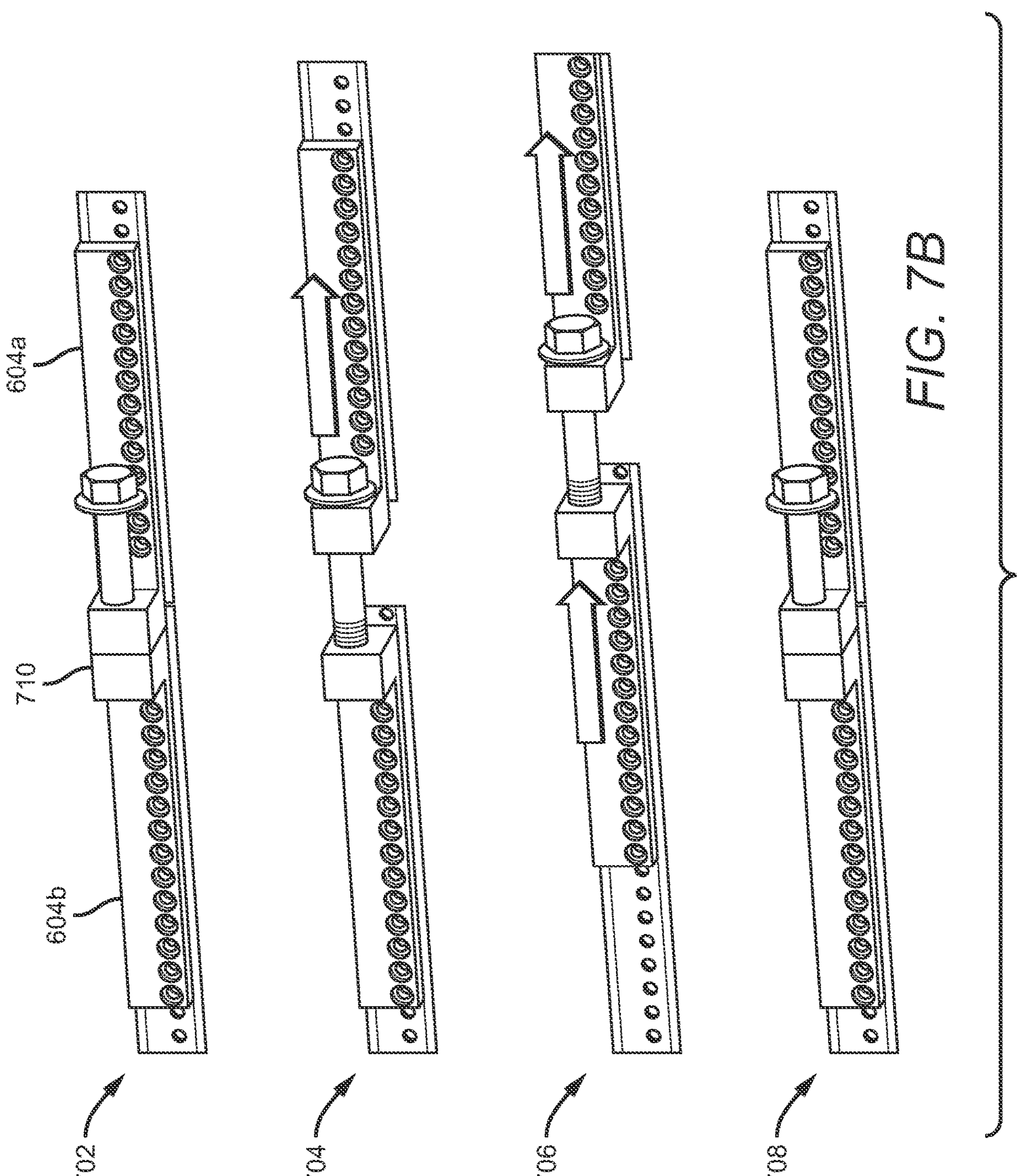


FIG. 7B

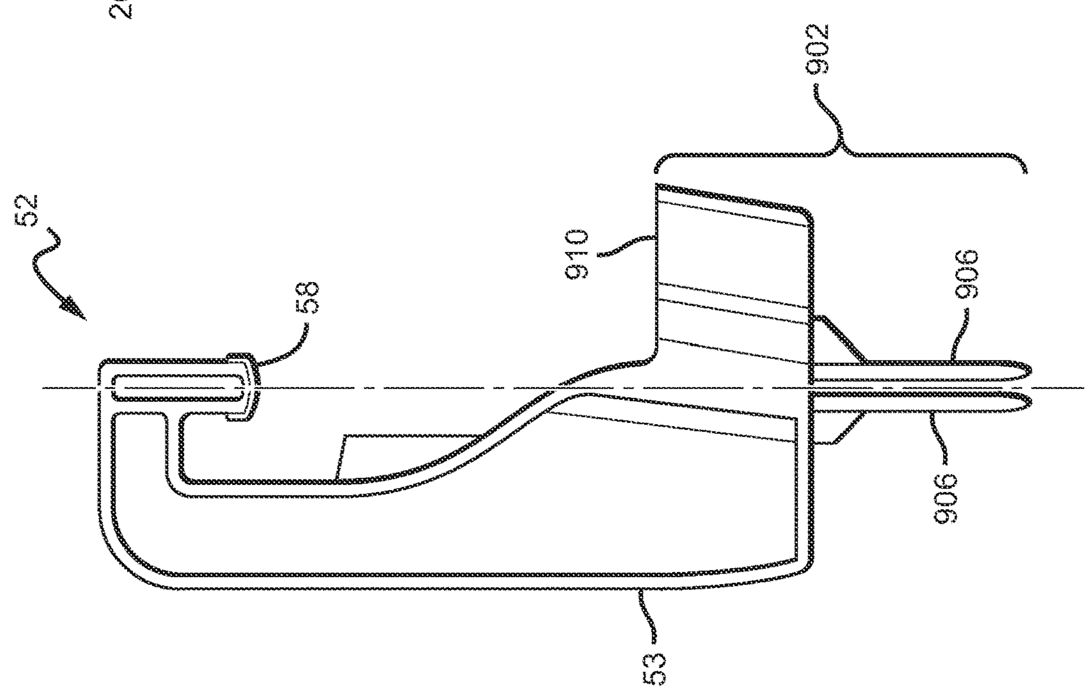


FIG. 9

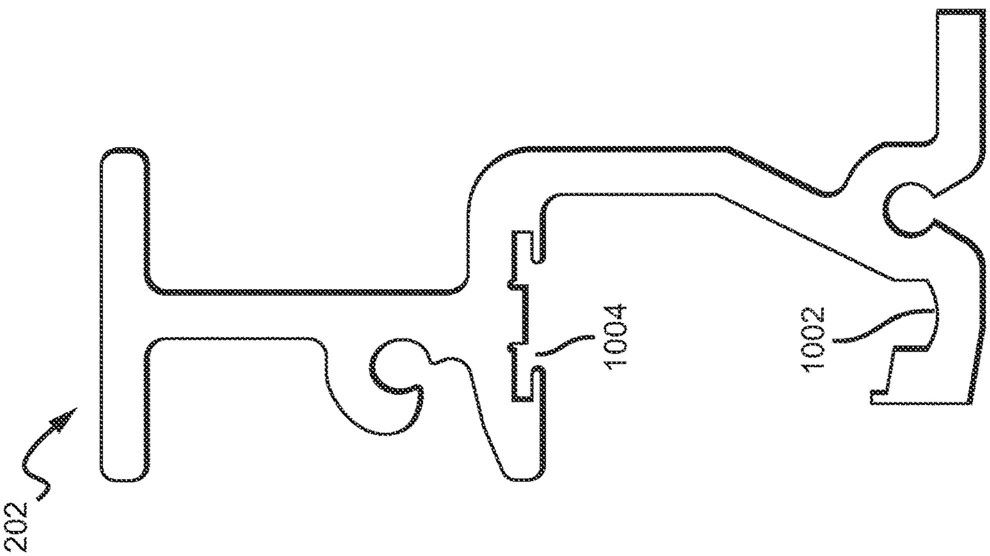


FIG. 10

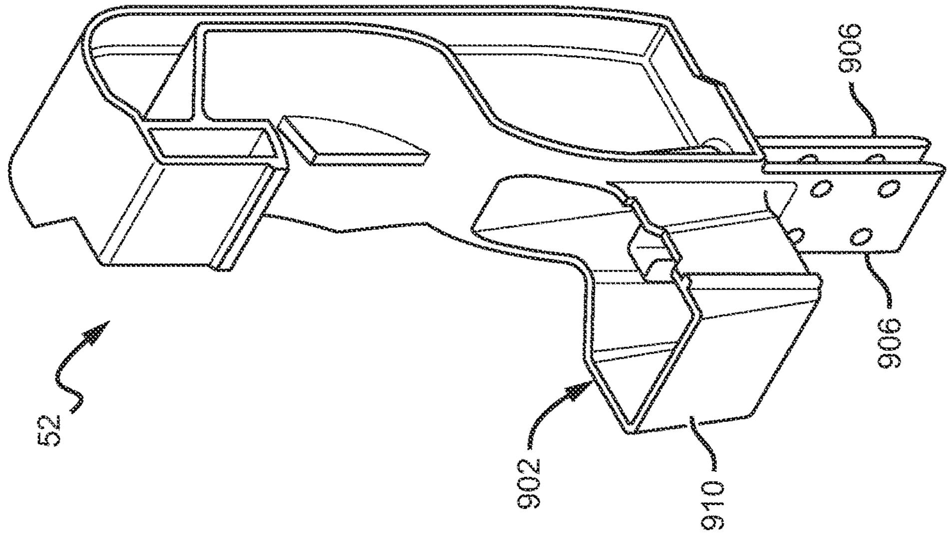


FIG. 11A

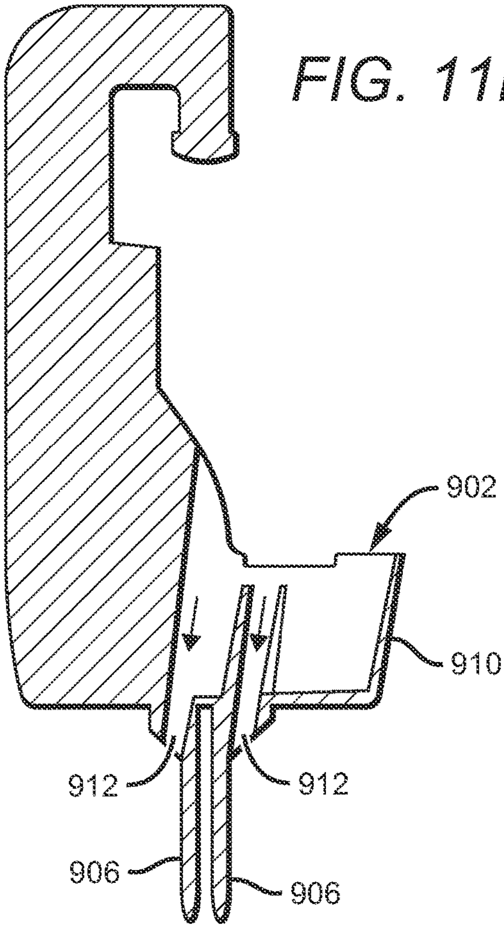


FIG. 11B

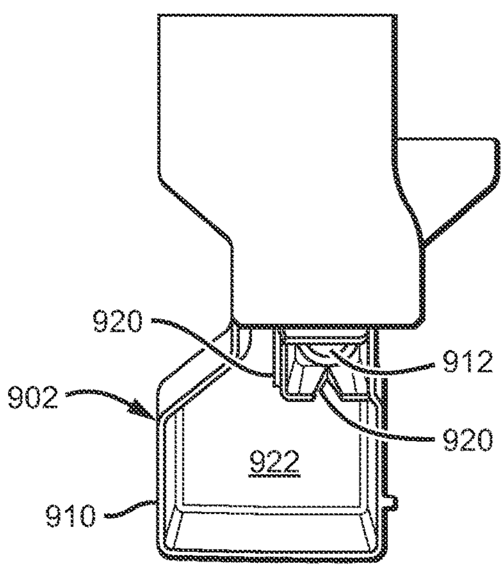


FIG. 11C

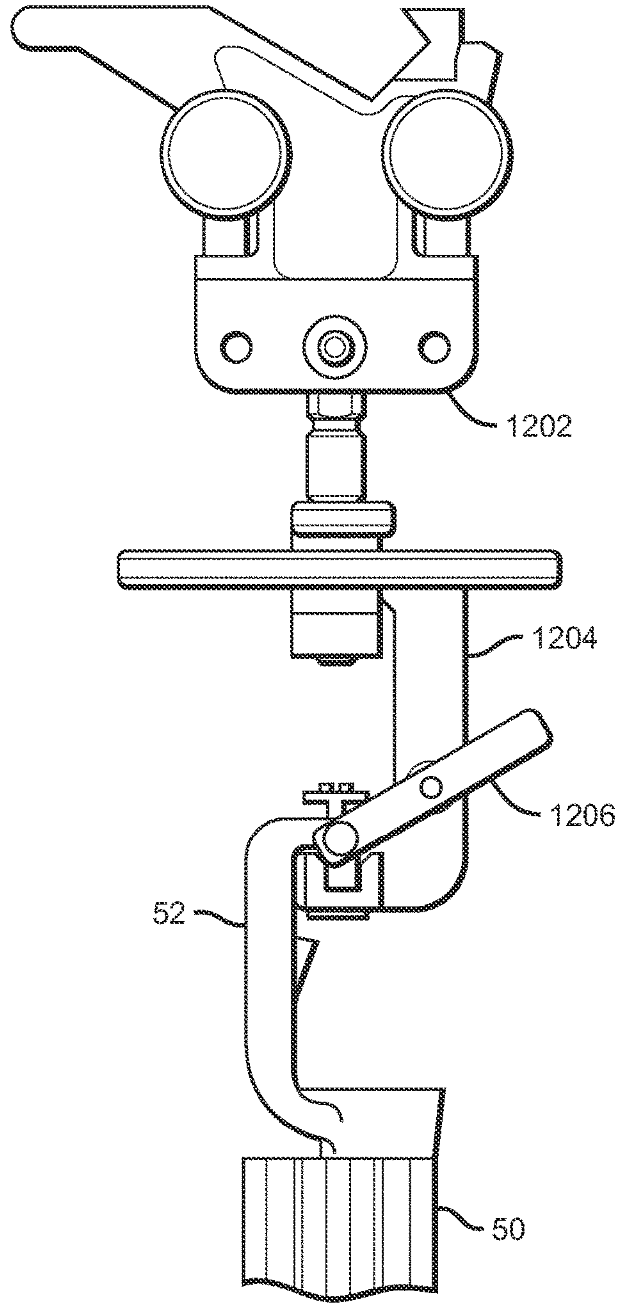


FIG. 12

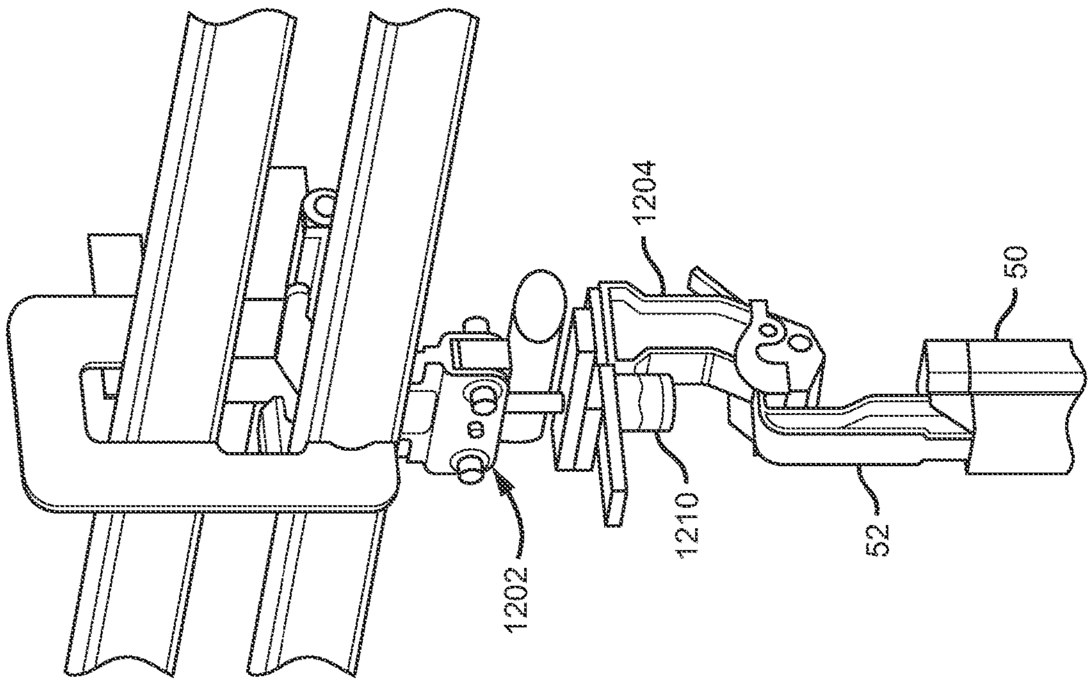


FIG. 13B

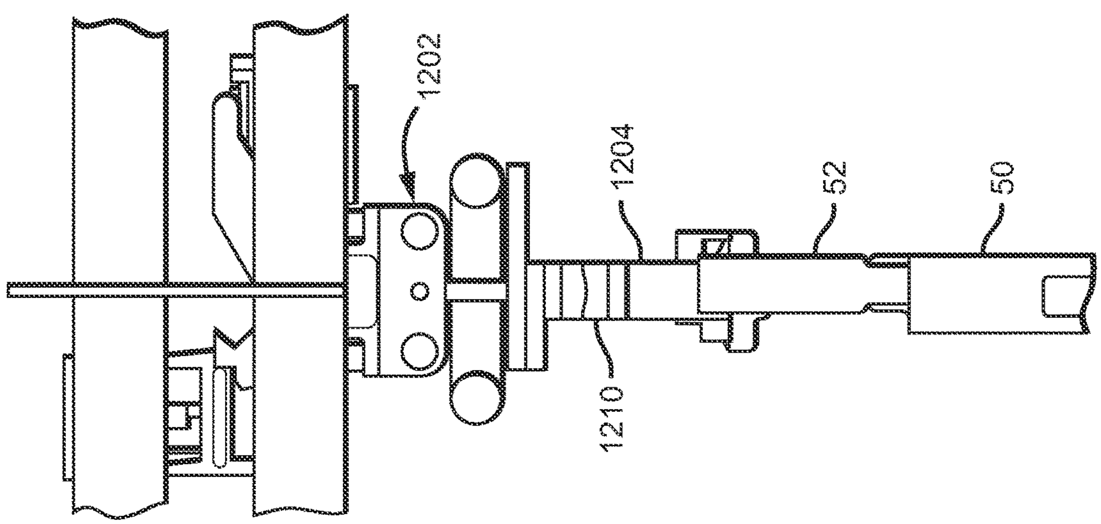


FIG. 13A

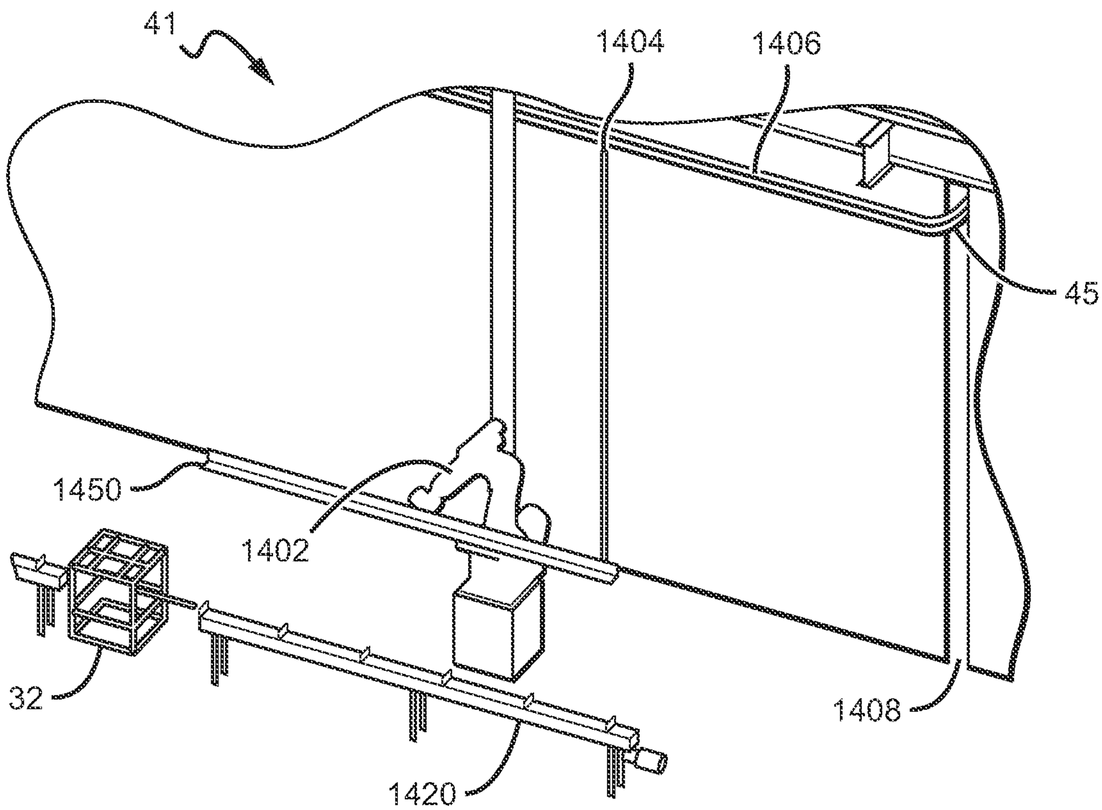


FIG. 14

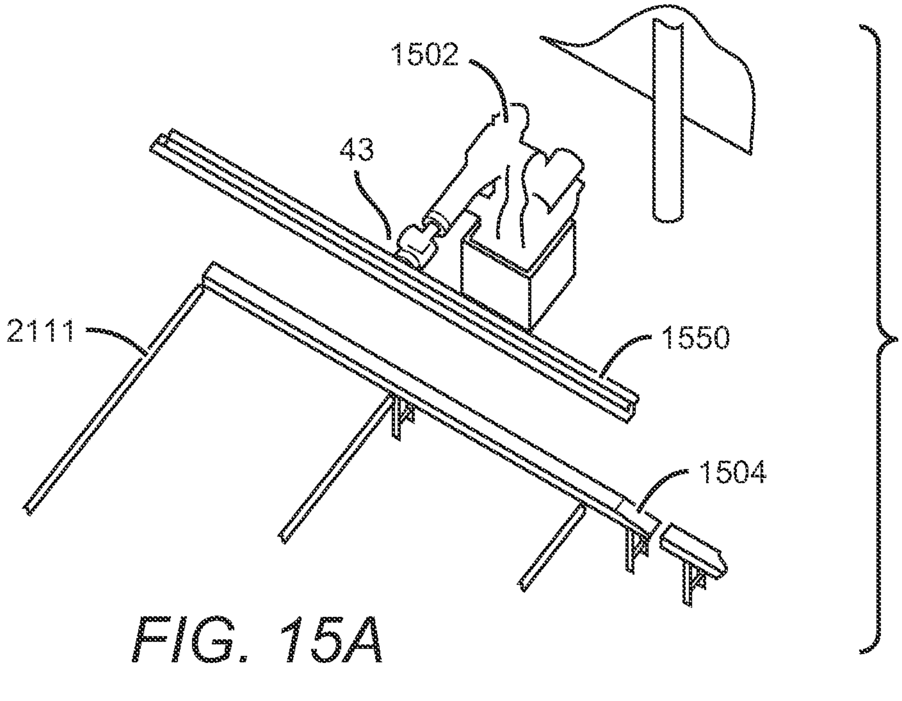


FIG. 15A

FIG. 15B

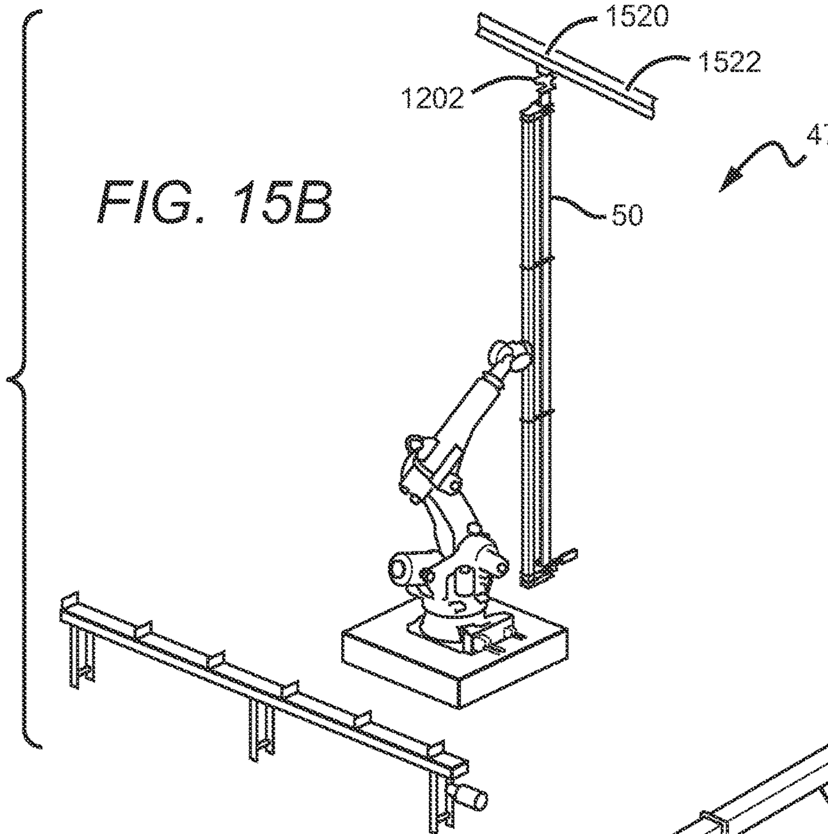


FIG. 16

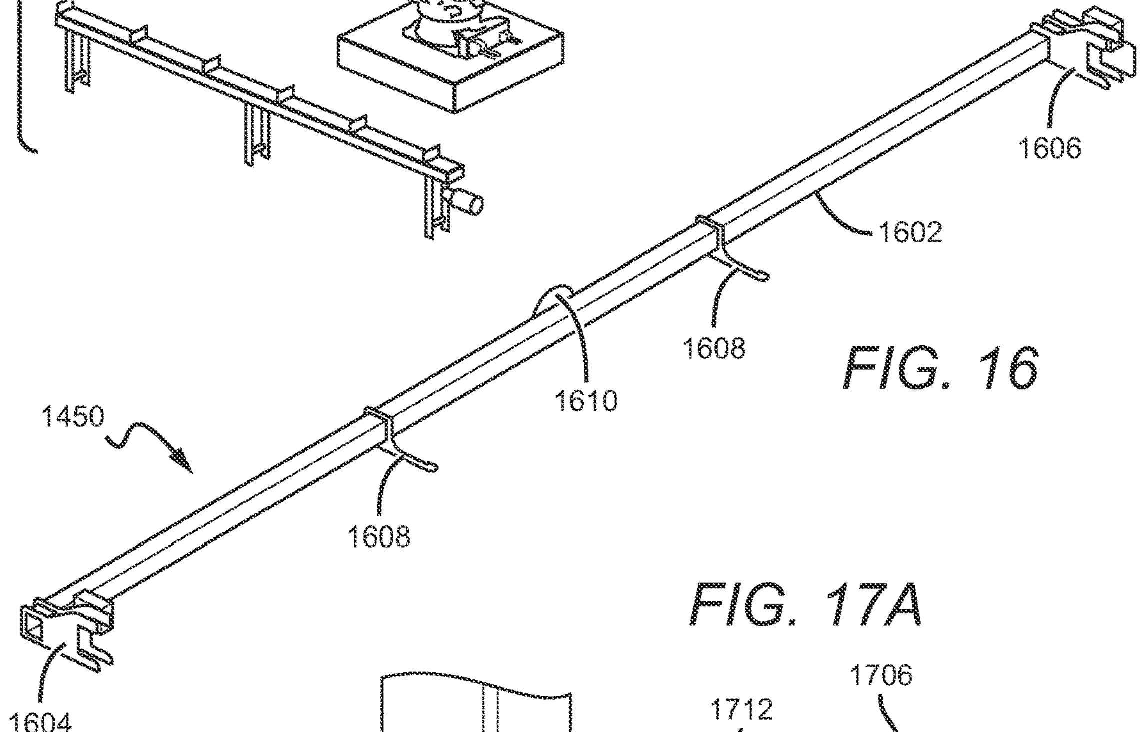
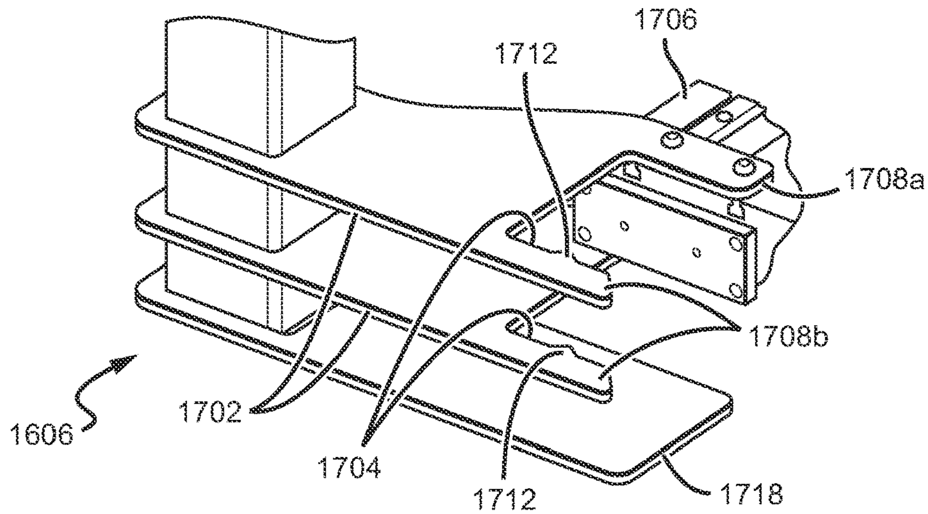


FIG. 17A



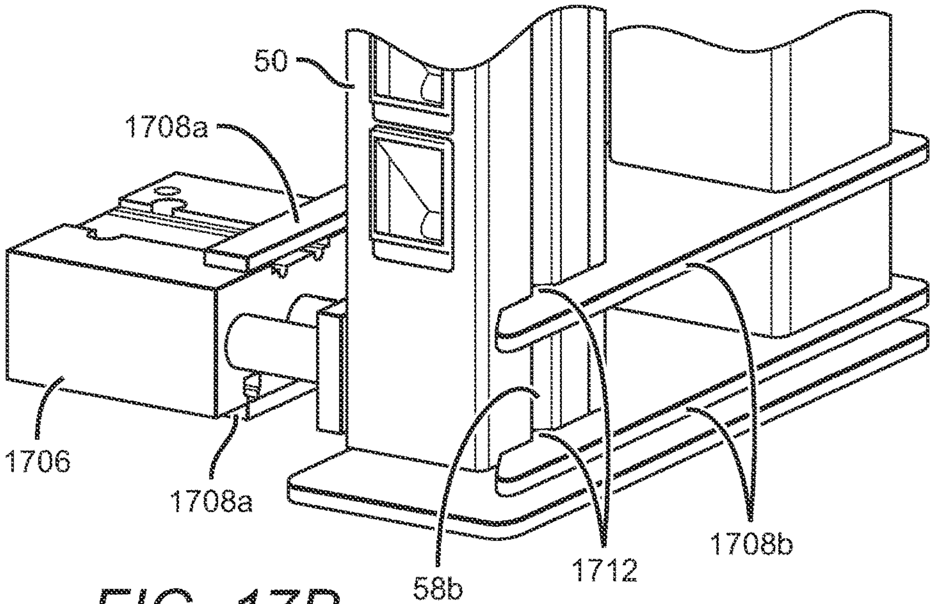


FIG. 17B

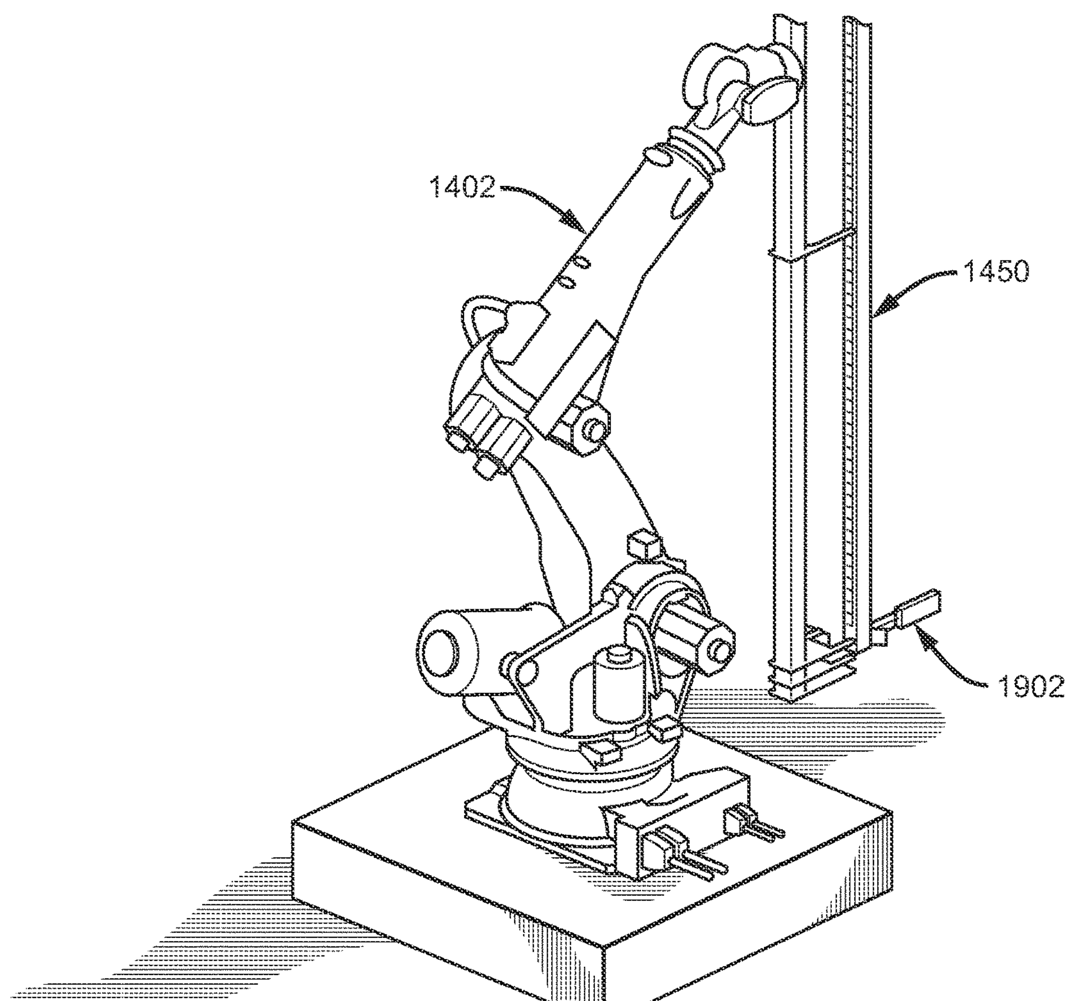


FIG. 18

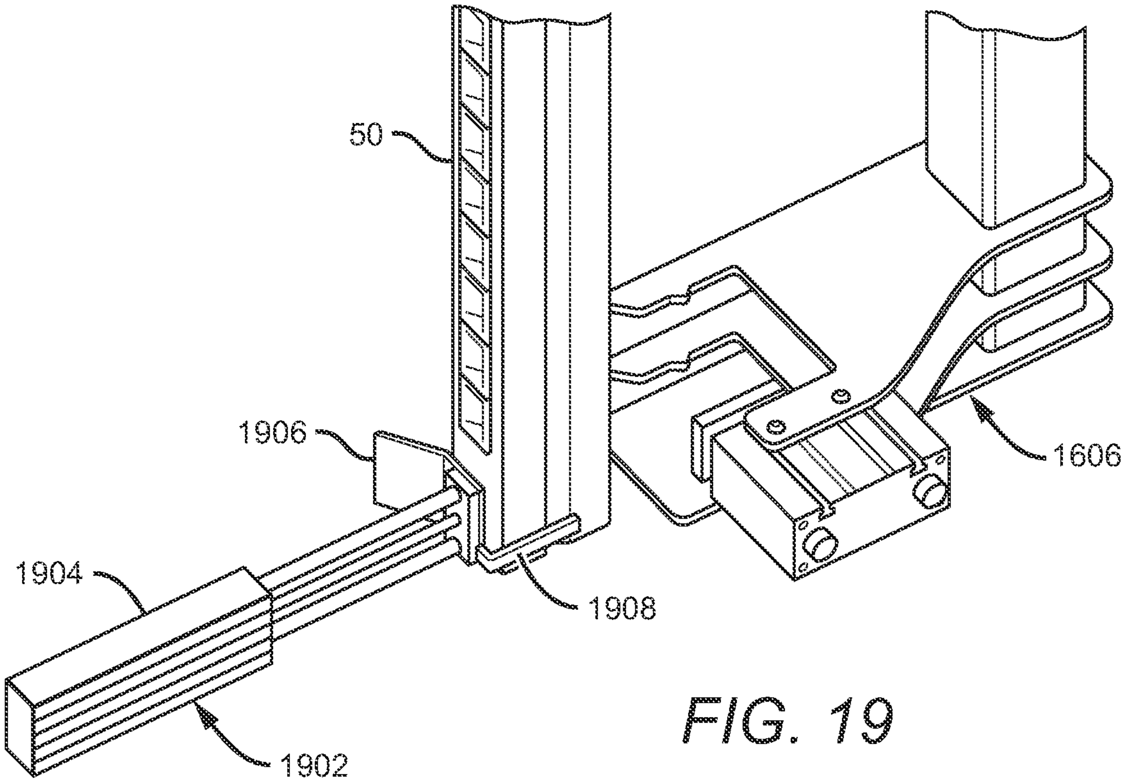


FIG. 19

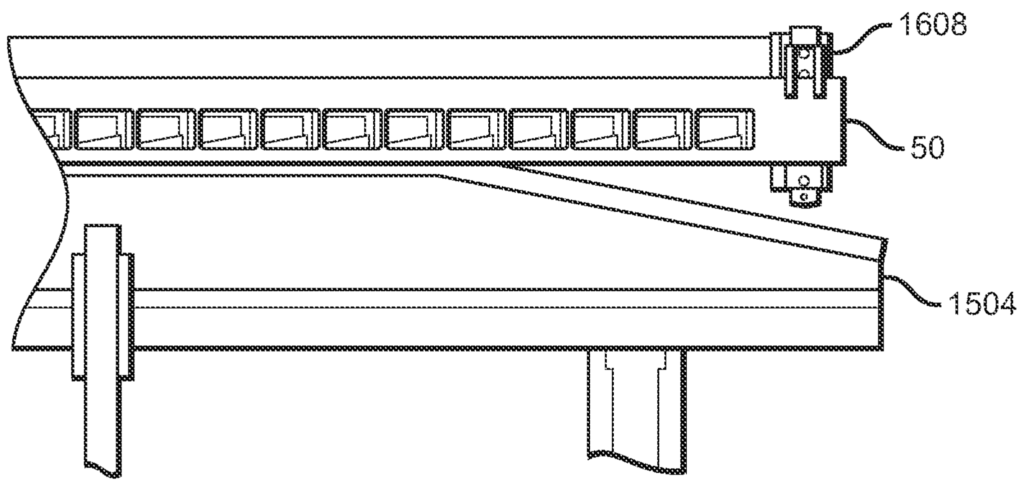
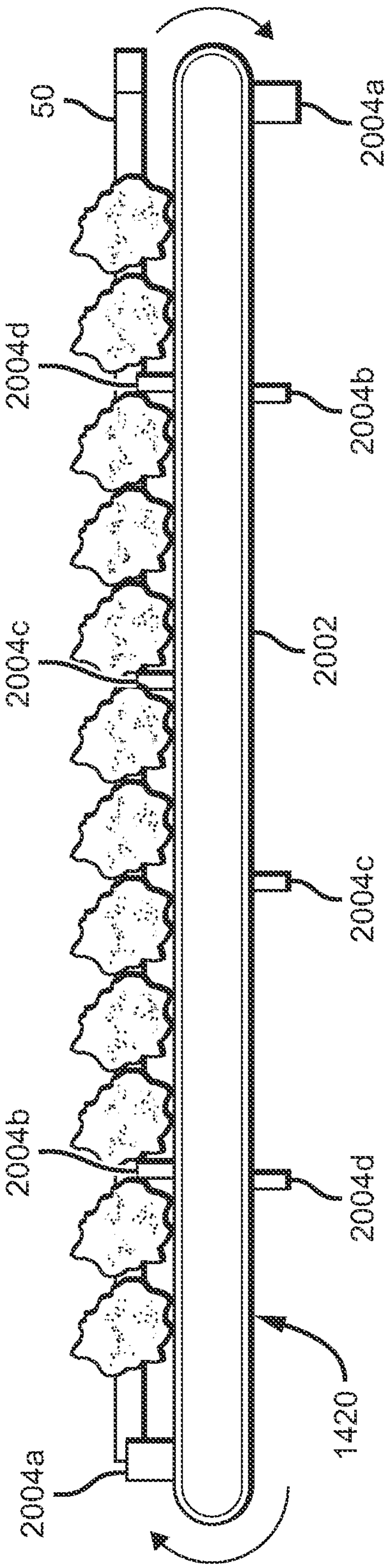


FIG. 22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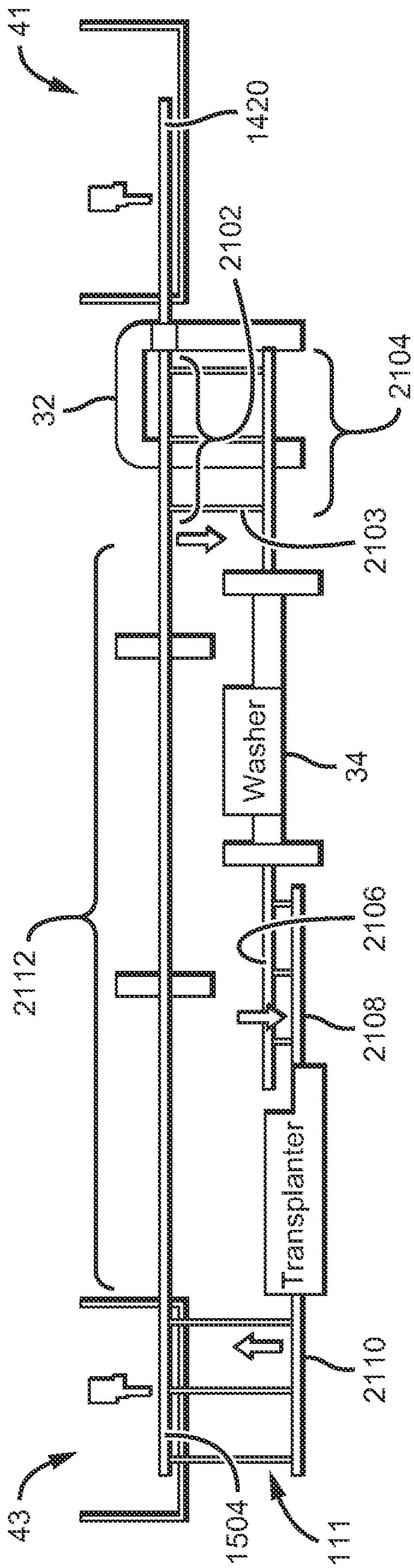
2004b
2004d
2004a
1420

FIG. 20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Transplanter
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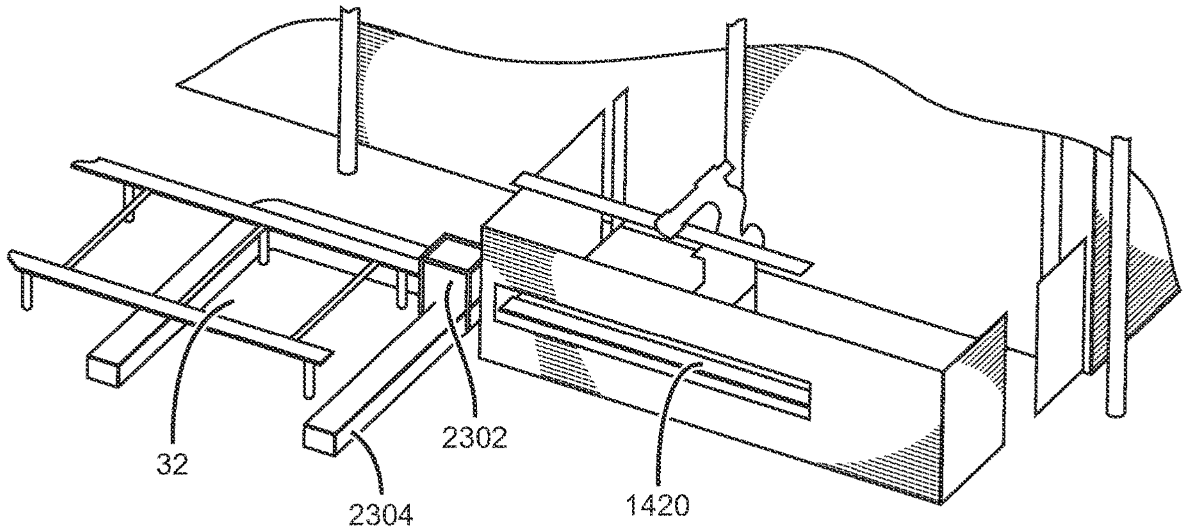
1504
2111

FIG. 21

FIG. 23A



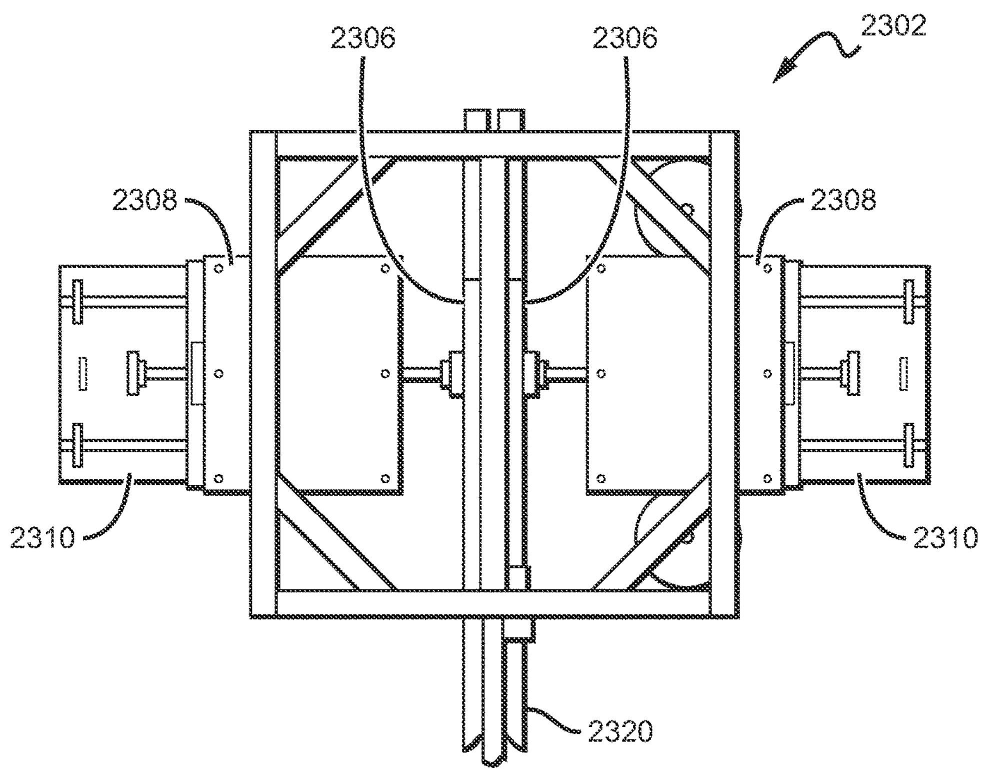


FIG. 23B

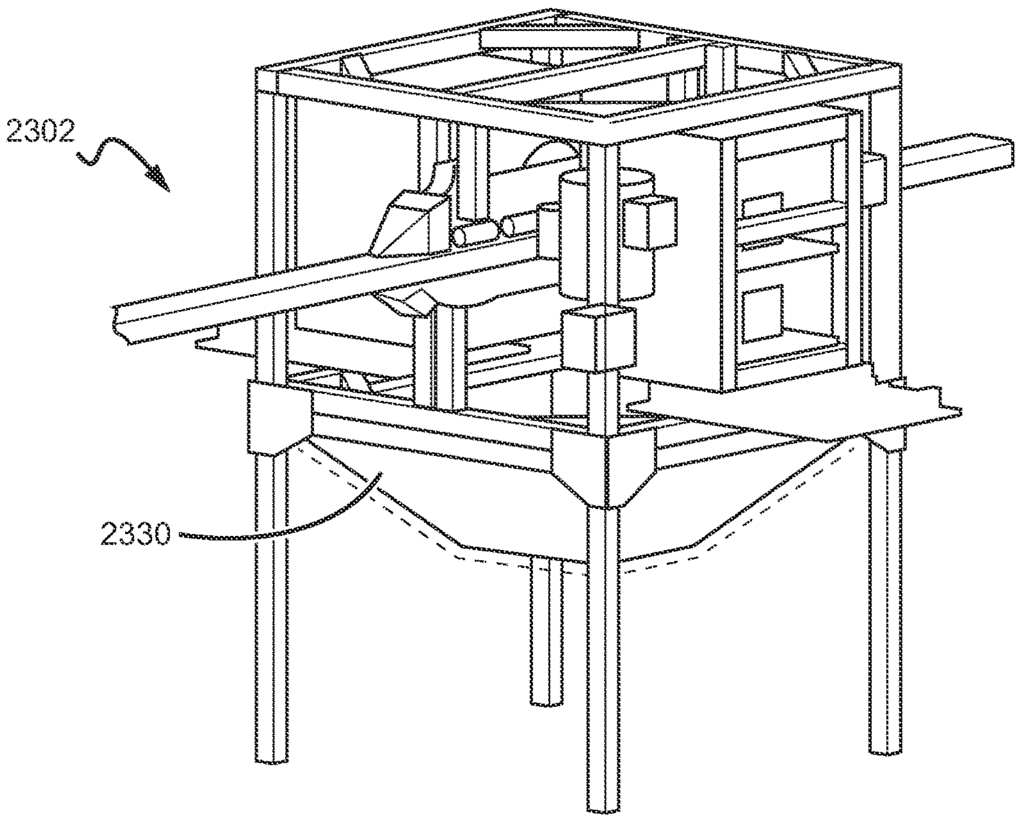


FIG. 23C

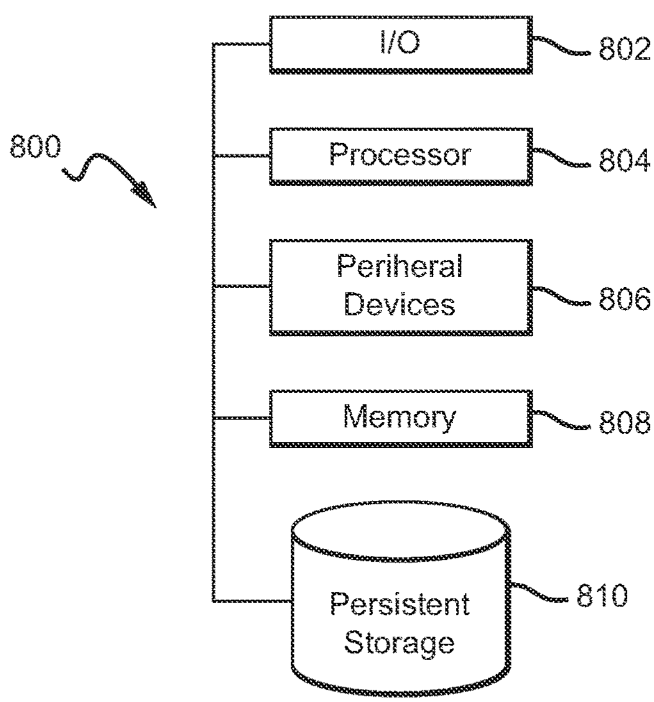


FIG. 25

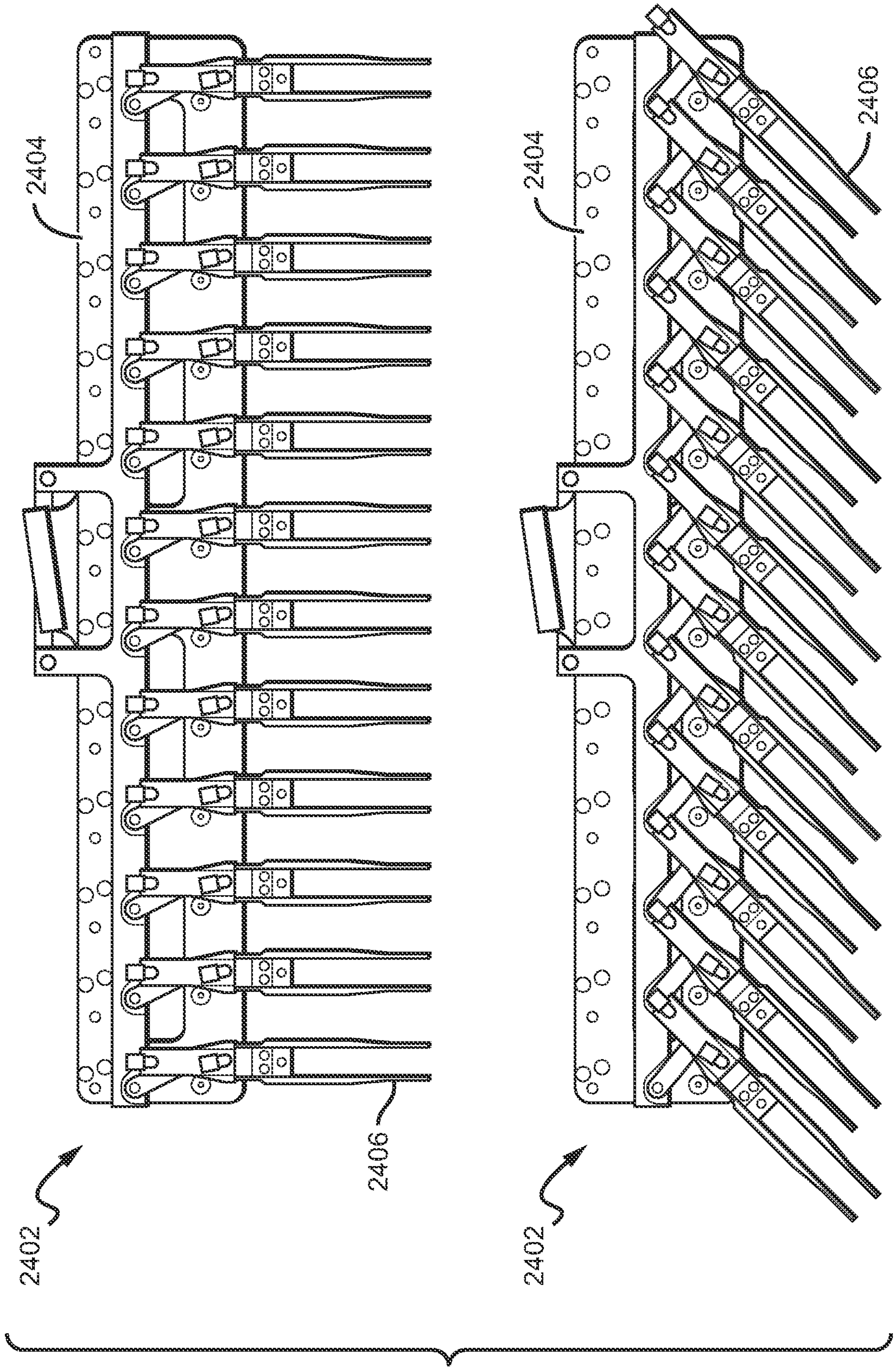


FIG. 24A

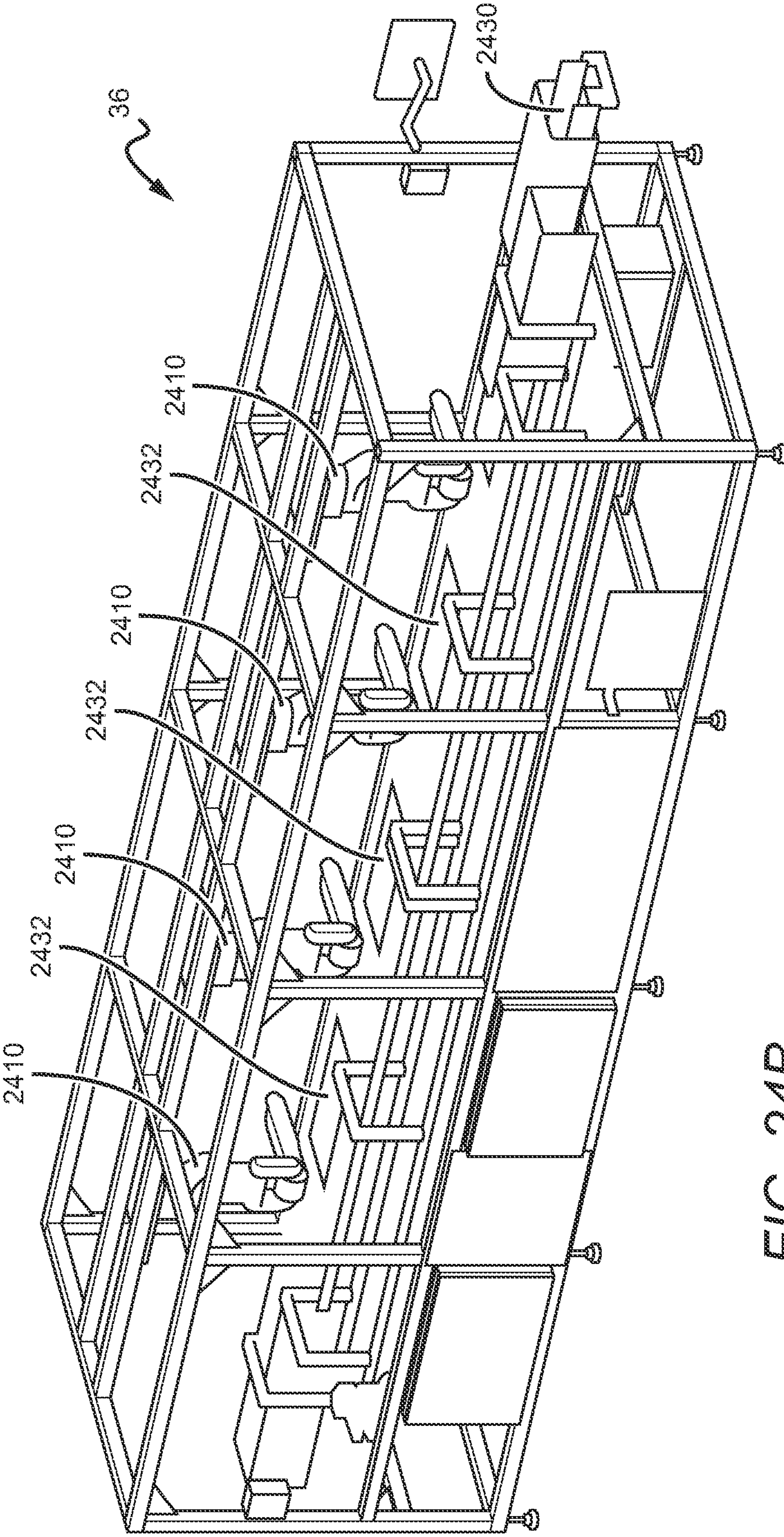


FIG. 24B

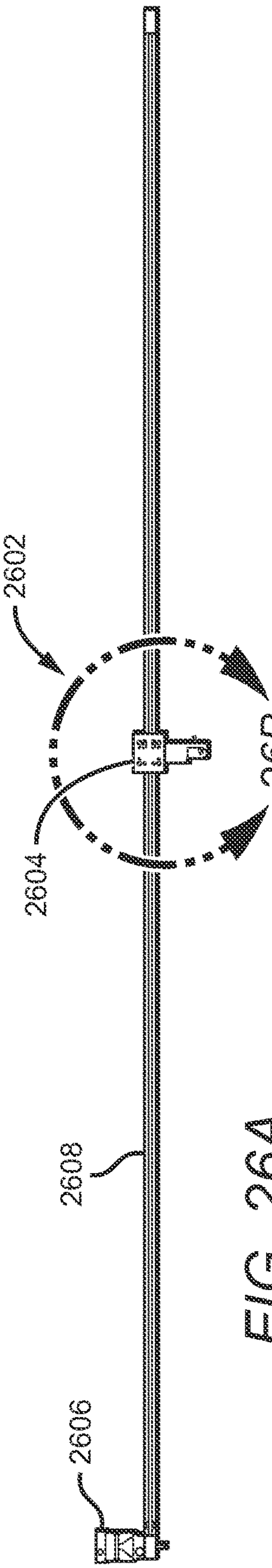


FIG. 26A

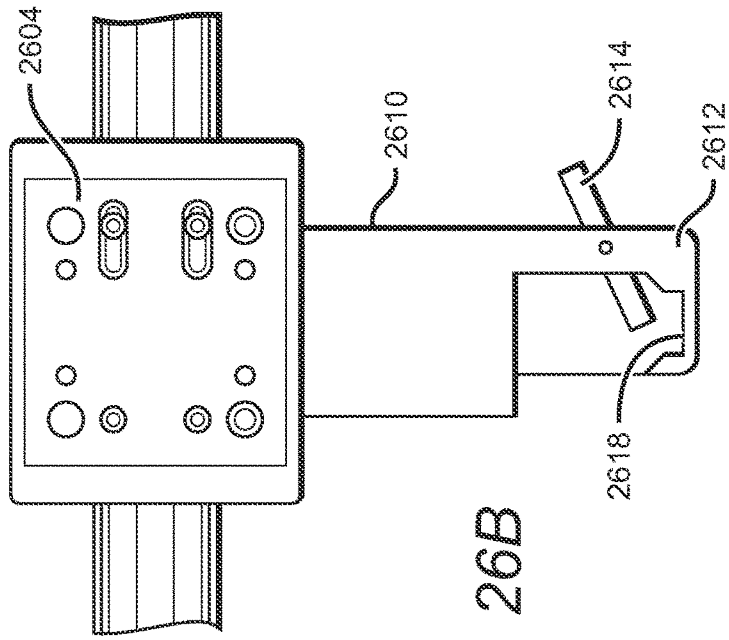


FIG. 26B

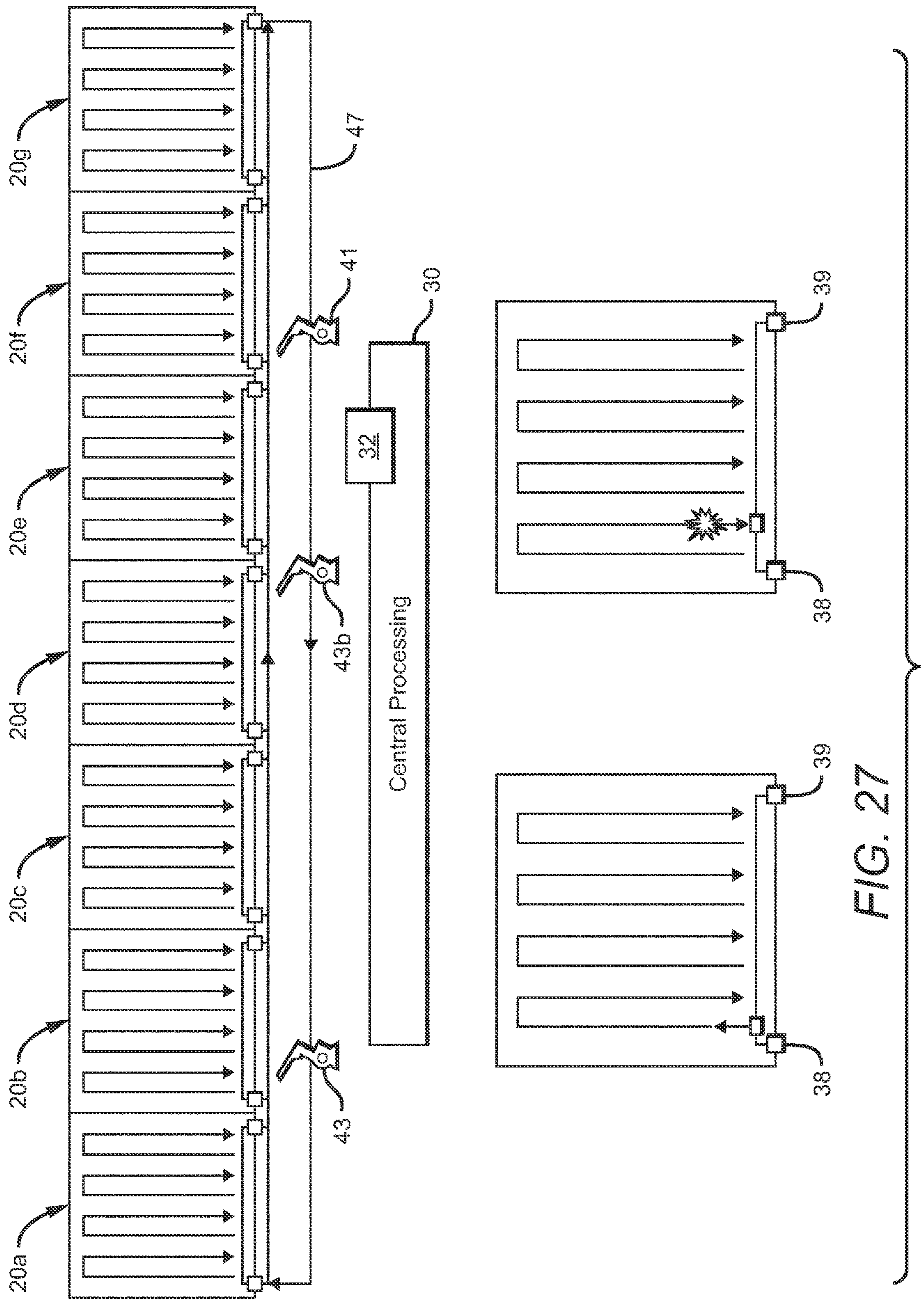

20g
20f
20e
20d
20c
20b
20a
47
41
30
32
Central Processing
43b
43
39
38
39
38

FIG. 27

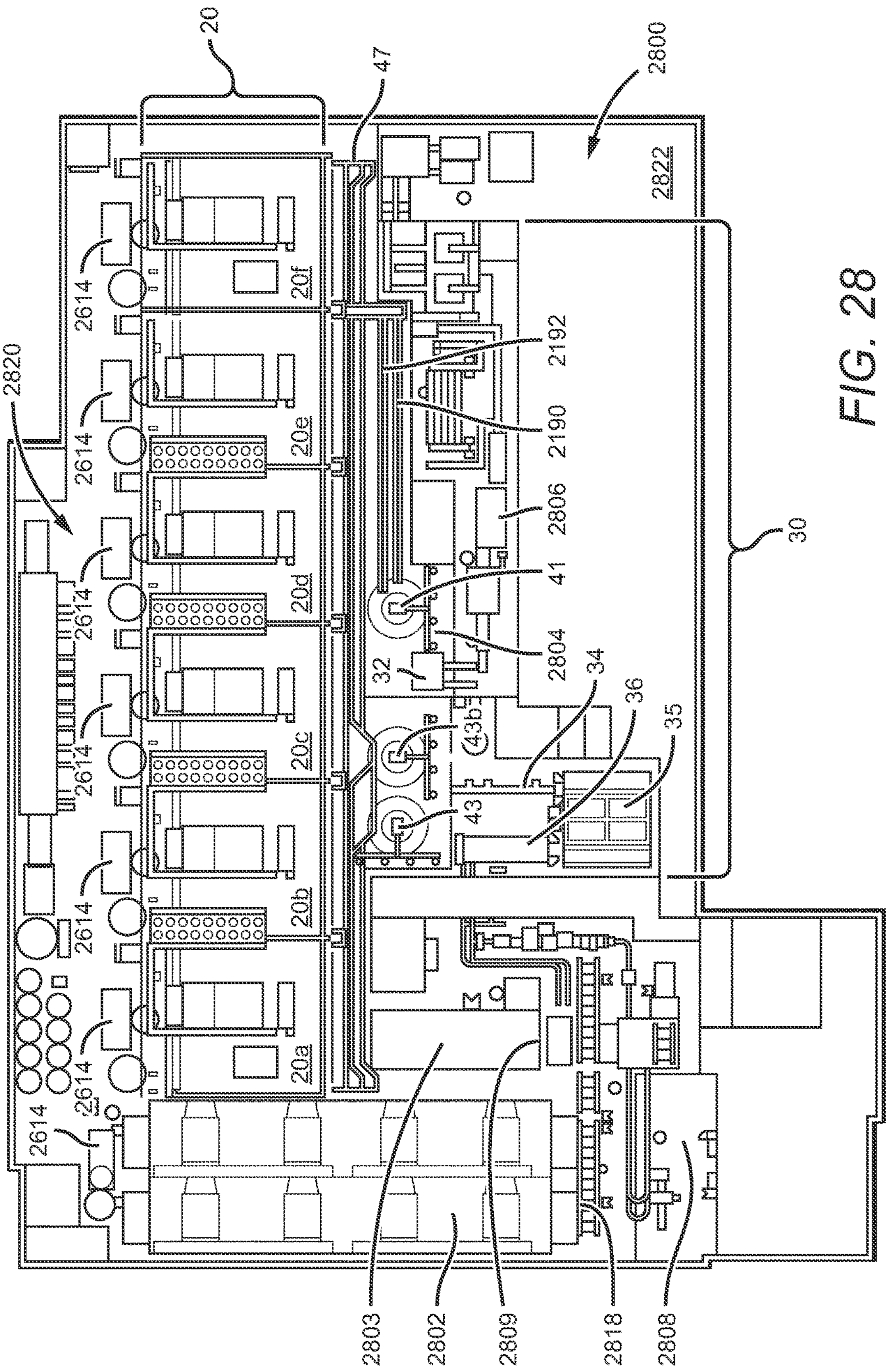

20
2800
47
2822
2820
2614
2614
2614
2614
2614
2614
2614
20f
20e
20d
20c
20b
20a
2192
2190
2806
30
41
2804
32
34
36
35
43b
43
2803
2802
2809
2818
2808

FIG. 28

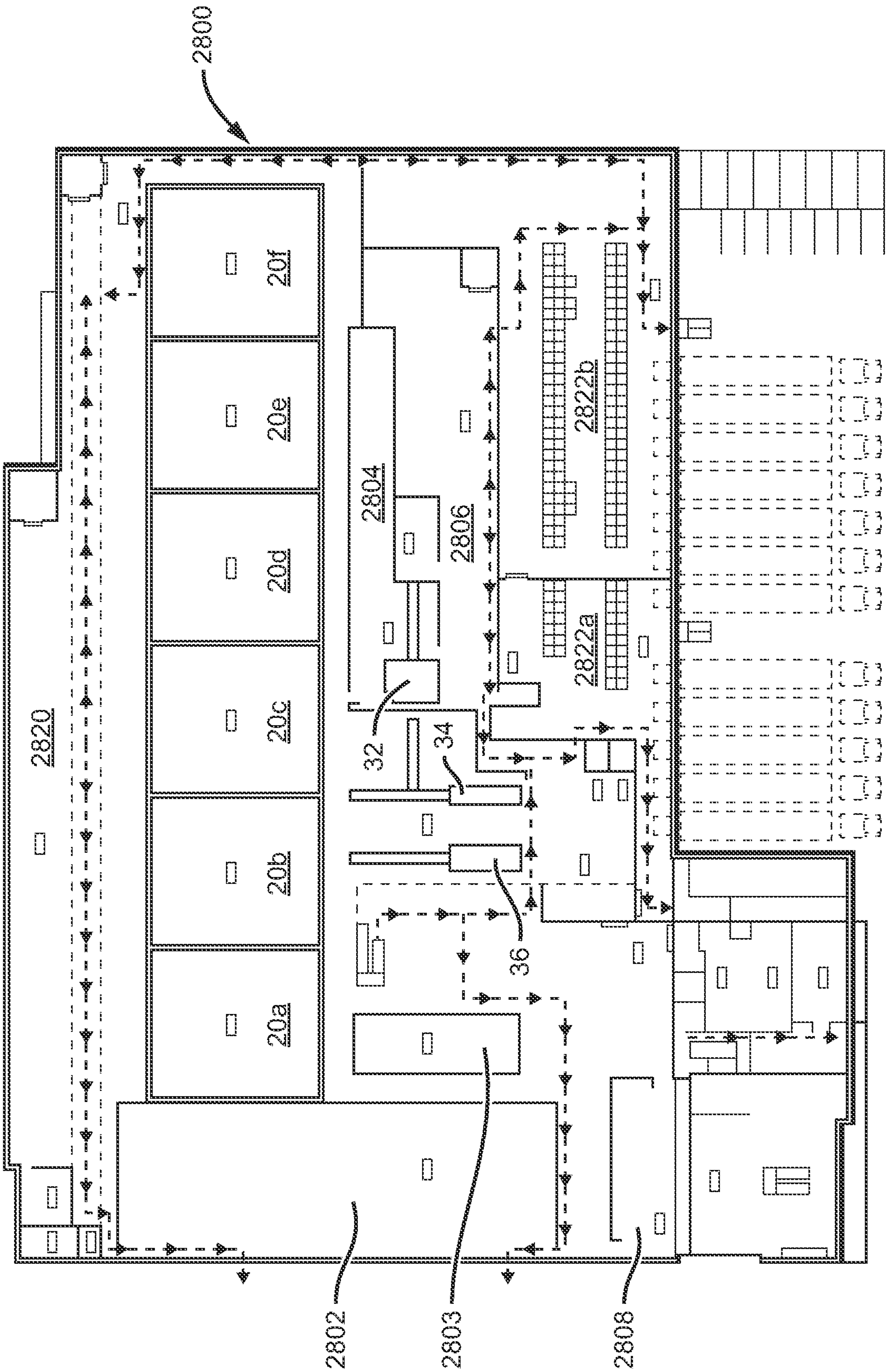

2800
2820
20a
20b
20c
20d
20e
20f
2804
2806
2822a
2822b
32
34
36
2802
2803
2808

FIG. 29

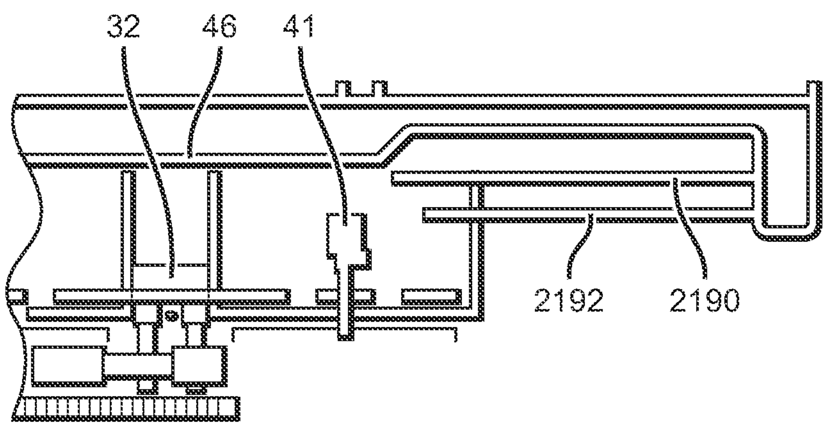


FIG. 30

PRODUCTION FACILITY LAYOUTS FOR AUTOMATED CONTROLLED ENVIRONMENT AGRICULTURE

CROSS-REFERENCE TO RELATED APPLICATION

The present application is the National Stage of International Application No. PCT/US2020/050593, filed Sep. 12, 2020, which claims priority to U.S. provisional application Ser. No. 62/903,573 filed Sep. 20, 2019 and 62/987,149 filed Mar. 9, 2020, both of which are incorporated herein by reference for all purposes.

BACKGROUND

Field of the Disclosure

The disclosure relates generally to controlled environment agriculture and, more particularly, to production facility layouts and configurations for automated controlled environment crop production systems.

Description of Related Art

The subject matter discussed in the background section should not be assumed to be prior art merely as a result of its mention in the background section. Similarly, a problem mentioned in the background section or associated with the subject matter of the background section should not be assumed to have been previously recognized in the prior art. The subject matter in the background section merely represents different approaches, which in and of themselves may also correspond to implementations of the claimed technology.

During the twentieth century, agriculture slowly began to evolve from a conservative industry to a fast-moving high-tech industry. Global food shortages, climate change and societal changes drove a move away from manually-implemented agriculture techniques toward computer-implemented technologies. In the past, and in many cases still today, farmers only had one growing season to produce the crops that would determine their revenue and food production for the entire year. However, this is changing. With indoor growing as an option and with better access to data processing technologies, the science of agriculture has become more agile. It is adapting and learning as new data is collected and insights are generated.

Advancements in technology are making it feasible to control the effects of nature with the advent of "controlled environment agriculture." Improved efficiencies in space utilization, lighting, and a better understanding of hydroponics, aeroponics, crop cycles, and advancements in environmental control systems have allowed humans to better recreate environments conducive for agriculture crop growth with the goals of greater yield per square foot, better nutrition and lower cost.

US Patent Publication Nos. 2018/0014485 and 2018/0014486, both assigned to the assignee of the present disclosure and incorporated by reference in their entirety herein, describe environmentally controlled vertical farming systems. The vertical farming structure (e.g., a vertical column) may be moved about an automated conveyance system in an open or closed-loop fashion, exposed to precision-controlled lighting, airflow and humidity, with ideal nutritional support.

US Patent Pub. No. US 2017/0055460 ("Brusatore") describes a system for continuous automated growing of plants. A vertical array of plant supporting arms extends radially from a central axis. Each arm includes pot receptacles which receive the plant seedling, and liquid nutrients and water. The potting arms are rotated beneath grow lamps and pollinating arms.

U.S. Pat. No. 2,244,677 to Cornell describes a plant production system that conveys vertical box-shaped frame within a greenhouse structure. A chain-drive mechanism conveys the vertical box-like frames in a track where they are exposed to controlled environmental conditions. Cornell, however, does not contemplate automated processing or harvesting of the crops grown in the box-like frames.

SUMMARY OF THE DISCLOSURE

The present disclosure is directed to facility layouts and configurations for an automated crop production system for controlled environment agriculture. In some implementations, the facility layouts establish consolidated utility and plant production zones that achieve a variety of operational and cost efficiencies. In particular implementations, the core of the facility comprises a controlled growth environment and a central processing system. The controlled growth environment includes systems for exposing crops housed in modules, such as grow towers, to controlled environmental conditions. The central processing system may include various stations and functionality both for preparing crop-bearing modules to be inserted in the controlled growth environment, for harvesting crops from the crop-bearing modules after they have been extracted from the controlled growth environment, and for cleaning or washing crop-bearing modules for re-use. The remaining aspects of the crop production facility—such as seeding stations, propagation facilities, packaging stations and storage facilities—are arranged to achieve one or more desired efficiencies relating to capital expenditures or operating costs associated with an automated crop production facility.

The present disclosure is also directed to a vertical farming structure having vertical grow towers and associated conveyance mechanisms for moving the vertical grow towers along one or more grow lines through a controlled environment, while being exposed to controlled conditions, such as lighting, airflow, humidity and nutritional support. The present disclosure describes a return transfer mechanism that creates a return or u-shaped path for each grow line. The present disclosure also describes an automated crop production system for controlled environment agriculture that selectively routes grow towers through various processing stages of an automated crop production system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a functional block diagram illustrating an example controlled environment agriculture system; and FIG. **1**B is a functional block diagram illustrating a second example controlled environment agriculture system.

FIG. **2** is a perspective view of an example controlled environment agriculture system.

FIGS. **3**A and **3**B are perspective views of an example grow tower.

FIG. **4**A is a top view of an example grow tower; FIG. **4**B is a perspective, top view of an example grow tower; FIG. **4**C is an elevation view of a section of an example grow tower; and FIG. **4**D is a sectional, elevation view of a portion of an example grow tower.

FIG. 5A is a perspective view of a portion of an example grow line; and FIG. 5B is a perspective view of an example tower hook.

FIG. 6 is an exploded, perspective view of a portion of an example grow line and reciprocating cam mechanism.

FIG. 7A is a sequence diagram illustrating operation of an example reciprocating cam mechanism; and FIG. 7B illustrates an alternative cam channel including an expansion joint.

FIG. 8 is a profile view of an example grow line and irrigation supply line.

FIG. 9 is a side view of an example tower hook and integrated funnel structure.

FIG. 10 is a profile view of an example grow line.

FIG. 11A is perspective view of an example tower hook and integrated funnel structure; FIG. 11B is a section view of an example tower hook and integrated funnel structure; and FIG. 11C is a top view of an example tower hook and integrated funnel structure.

FIG. 12 is an elevation view of an example carriage assembly.

FIG. 13A is an elevation view of the example carriage assembly from an alternative angle to FIG. 12; and FIG. 13B is a perspective view of the example carriage assembly.

FIG. 14 is a partial perspective view of an example automated laydown station.

FIG. 15A is a partial perspective view of an example automated pickup station; and

FIG. 15B is an alternative partial perspective view of the example automated pickup station.

FIG. 16 is a perspective view of an example end effector for use in an automated pickup or laydown station.

FIGS. 17A and 17B are partial, perspective views of an example gripper assembly mounted to an end effector for releasably grasping grow towers.

FIG. 18 is a partial perspective view of the example automated pickup station.

FIG. 19 is partial perspective view of the example automated pickup station that illustrates an example constraining mechanism that facilitates location of grow towers.

FIG. 20 is a side view of an example inbound harvester conveyor.

FIG. 21 is a functional block diagram of the stations and conveyance mechanisms of an example central processing system.

FIG. 22 is a partial perspective view of an example pickup conveyor.

FIG. 23A is a perspective view of an example harvester station; FIG. 23B is a top view of an example harvester machine; and FIG. 23C is a perspective view of an example harvester machine.

FIG. 24A is an elevation view of an example end effector for use in a transplanter station; and FIG. 24B is a perspective view of a transplanter station.

FIG. 25 illustrates an example of a computer system that may be used to execute instructions stored in a non-transitory computer readable medium (e.g., memory) in accordance with embodiments of the disclosure.

FIG. 26A is an elevation view of an example return transfer mechanism; and FIG. 26B is an enlarged view of an example carriage for the return transfer mechanism.

FIG. 27 is a schematic diagram illustrating an example controlled environment agriculture system that includes multiple growth environments.

FIG. 28 is a functional block diagram illustrating an example crop production facility layout.

FIG. 29 is a schematic diagram illustrating an alternative view of the production facility layout of FIG. 28.

FIG. 30 is an enlarged view of pre-harvest buffers contained within a pre-harvest space of the production facility depicted in FIGS. 28 and 29.

DETAILED DESCRIPTION

The present description is made with reference to the accompanying drawings, in which various example embodiments are shown. However, many different example embodiments may be used, and thus the description should not be construed as limited to the example embodiments set forth herein. Rather, these example embodiments are provided so that this disclosure will be thorough and complete. Various modifications to the exemplary embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the disclosure. Thus, this disclosure is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

Operating cost and capital expenditure concerns are key drivers to commercial implementation of large-scale controlled environment agriculture. Commercial scale, indoor crop production facilities include a large array of processing stations and equipment. For example, indoor crop production facilities may include stations and related equipment to: fill plug trays with soil and seed them; grow crops from seed to a stage ready for transplant; transplant the seedlings to a crop-holding module; transfer the crop-holding module to a growth environment; harvest crops in the crop-holding module; clean and package the harvested crop; and store the harvested crop. Commercial scale facilities may also include loading bays and inventory handling mechanisms to receive inbound supplies used in operating the facility and to ship out the resulting crop. Arranging these stations and equipment in an efficient manner can be a complex task and is extremely important to the success of a commercial-scale facility. Factors that this disclosure considers to increase cost efficiency include space utilization and total flow distance of product from seed stage to harvest and packaging. Other factors considered include the total length of materials required to construction the facility (such as total length of walls, HVAC ducting and the like), and the distances that facility workers are required to travel during standard processing operations. These factors, as well as equipment layout clearances and local fire and building regulations, may combine to yield a crop production facility layout.

FIGS. 28 and 29 set forth an example production facility layout that achieves a variety of operational and cost efficiencies. For didactic purposes, the following describes a vertical farm production system configured for high density growth and crop yield that can be included in the production facility layout described herein. FIGS. 1A and 2 illustrate a controlled environment agriculture system 10 according to one possible embodiment of the invention. At a high level, the system 10 may include an environmentally-controlled growing chamber 20 and a central processing facility 30. The central processing facility 30 may be a clean room environment to keep contaminants and pollutants within acceptable limits. Air filtration, transfer and other systems may be employed to effect a clean room environment to meet required food safety standards.

The growing chamber 20 may contain one to a plurality of vertical grow lines 202 that include conveyance systems to translate grow towers **50** along the grow lines **202** within the growing chamber **20**. The crops or plants species that may be grown may be gravitropic, geotropic and/or phototropic, or some combination thereof. The crops or plant species may vary considerably and include various leaf vegetables, fruiting vegetables, flowering crops, fruits and the like. The controlled environment agriculture system **10** may be configured to grow a single crop type at a time or to grow multiple crop types concurrently.

The system **10** may also include conveyance systems for moving the grow towers **50** in a circuit throughout the crop's growth and processing cycle, the circuit comprising a staging area configured for loading the grow towers **50** into and out a grow line **202**. The central processing system **30** may include one or more conveyance mechanisms for directing grow towers **50** to stations in the central processing system **30**—e.g., stations for loading plants into, and harvesting crops from, the grow towers **50**.

Each grow tower **50** is configured for containing plant growth media that supports a root structure of at least one crop plant growing therein. Each grow tower **50** is also configured to releasably attach to a grow line **202** in a vertical orientation and move along the grow line **202** within growth environment **20** during a growth phase. Together, the grow lines **202** contained within the growth environment **20** and the stations of the central processing system **30** (including associated conveyance mechanisms) can be arranged in a production circuit under control of one or more computing systems.

The growth environment **20** may include light emitting sources positioned at various locations between and along the grow lines **202** of the vertical tower conveyance system **200**. The light emitting sources can be positioned laterally relative to the grow towers **50** in the grow line **202** and configured to emit light toward the lateral faces of the grow towers **50** that include openings from which crops grow. The light emitting sources may be incorporated into a water-cooled, LED lighting system as described in U.S. Publ. No. 2017/0146226A1, the disclosure of which is incorporated by reference herein. In such an embodiment, the LED lights may be arranged in a bar-like structure. The bar-like structure may be placed in a vertical orientation to emit light laterally to substantially the entire length of adjacent grow towers **50**. Multiple light bar structures may be arranged in the growth environment **20** along and between the grow lines **202**. Other lighting systems and configurations may be employed. For example, the light bars may be arranged horizontally between grow lines **202**.

The growth environment **20** may also include a nutrient supply system configured to supply an aqueous nutrient solution to the crops as they translate through the growth chamber **20**. As discussed in more detail below, the nutrient supply system may apply aqueous nutrient solution to the top of the grow towers **50**. Gravity may cause the solution to travel down the vertically-oriented grow tower **50** and through the length thereof to supply solution to the crops disposed along the length of the grow tower **50**. The growth environment **20** may also include an airflow source configured to, when a tower is mounted to a grow line **202**, direct airflow in the lateral growth direction of growth and through an under-canopy of the growing plant, so as to disturb the boundary layer of the under-canopy of the growing plant. In other implementations, airflow may come from the top of the canopy or orthogonal to the direction of plant growth. The growth environment **20** may also include a control system, and associated sensors, for regulating at least one growing condition, such as air temperature, airflow speed, relative air humidity, and ambient carbon dioxide gas content. The control system may for example include such sub-systems as HVAC units, chillers, fans and associated ducting and air handling equipment. Grow towers **50** may have identifying attributes (such as bar codes or RFID tags). The controlled environment agriculture system **10** may include corresponding sensors and programming logic for tracking the grow towers **50** during various stages of the farm production cycle and/or for controlling one or more conditions of the growth environment. The operation of control system and the length of time towers remain in growth environment can vary considerably depending on a variety of factors, such as crop type and other factors.

As discussed above, grow towers **50** with newly transplanted crops or seedlings are transferred from the central processing system **30** into the vertical tower conveyance system **200**. Conveyance mechanisms move the grow towers **50** along respective grow lines **202** in growth environment **20** in a controlled fashion, as discussed in more detail below. Crops disposed in grow towers **50** are exposed to the controlled conditions of growth environment (e.g., light, temperature, humidity, air flow, aqueous nutrient supply, etc.). The control system is capable of automated adjustments to optimize growing conditions within the growth chamber **20** to make continuous improvements to various attributes, such as crop yields, visual appeal and nutrient content. In addition, US Patent Publication Nos. 2018/0014485 and 2018/0014486 describe application of machine learning and other operations to optimize grow conditions in a vertical farming system. In some implementations, environmental condition sensors may be disposed on grow towers **50** or at various locations in growth environment **20**. When crops are ready for harvesting, grow towers **50** with crops to be harvested are transferred from the growth environment **20** to the central processing system **30** for harvesting and other processing operations.

Central processing system **30**, as discussed in more detail below, may include processing stations directed to injecting seedlings into grow sites located in the towers **50**, harvesting crops from towers **50**, and cleaning towers **50** that have been harvested. Central processing system **30** may also include conveyance mechanisms that move towers **50** between such processing stations. For example, as FIG. **1**A illustrates, central processing system **30** may include harvester station **32**, washing station **34**, and transplanter station **36**. Harvester station **32** may deposit harvested crops into food-safe containers and may include a conveyance mechanism for conveying the containers to post-harvesting facilities (e.g., preparation, washing, packaging and storage) that are beyond the scope of this disclosure.

Controlled environment agriculture system **10** may also include one or more conveyance mechanisms for transferring grow towers **50** between growth environment **20** and central processing system **30**. In the implementation shown, the stations of central processing system **30** operate on grow towers **50** in a horizontal orientation. In one implementation, an automated pickup station **43**, and associated control logic, may be operative to releasably grasp a tower in a horizontal orientation from a loading location, rotate the tower to a vertical orientation and attach the tower to a transfer station for insertion into a selected grow line **202** of the growth environment **20**. On the other end of growth environment **20**, automated laydown station **41**, and associated control logic, may be operative to releasably grasp and move a vertically-oriented grow tower **50** from a buffer location, rotate the grow tower **50** to a horizontal orientation and place it on a conveyance system for loading into harvester station

32. In some implementations, if a grow tower **50** is rejected due to quality control concerns, the conveyance system may bypass the harvester station **32** and carry the grow tower to washing station **34** (or some other station). The automated laydown and pickup stations **41** and **43** may each comprise a six-degrees of freedom robotic arm, such as a FANUC robot. The stations **41** and **43** may also include end effectors for releasably grasping grow towers **50** at opposing ends.

In one implementation, a transfer conveyance mechanism **47** may include a power-and-free conveyor system including a plurality of carriages, a track system and a drive system that conveys the carriages, each loaded with a grow tower **50**, from the automated pickup station **43** to a selected grow line **202**. In one implementation, growth environment **20** includes a tower injection interface **38** to allow a carriage **1202** of the transfer conveyance mechanism **47** to pass through the physical barrier of growth environment **20**. In one implementation, tower injection interface **38** comprises a vertical slot (sufficient in length to accommodate a grow tower **50**) and a sliding door that opens to permit a grow tower **50** to pass through the vertical slot. System **10** may include sensors (such as RFID or bar code sensors) to identify a given grow tower **50** and, under control logic, select a grow line **202** for the grow tower **50**. The transfer conveyance mechanism **47** may also convey a grow tower **50** from a grow line **202** to the automated laydown station **41**. Tower extraction interface **39** includes a vertical slot in growth environment and a sliding door to permit transfer conveyance mechanism **47** to convey a tower **50** from growth environment. Particular algorithms for grow line selection can vary considerably depending on a number of factors and is beyond the scope of this disclosure.

Growth environment **20** may also include automated loading and unloading mechanisms for inserting grow towers **50** into selected grow lines **202** and unloading grow towers **50** from the grow lines **202**. For example, after the transfer conveyance mechanism **47** has transported a grow tower **50** to a selected grow line **202**, one or more linear actuators may push (or otherwise transfer) the grow tower **50** onto the grow line **202**. Similarly, one or more linear actuators that push or pull (or otherwise transfer) grow towers from a grow line **202** onto a carriage of transfer conveyance mechanism **47**, which conveys the carriages **1202** from the grow line **202** to the automated laydown station **41**.

FIG. **12** illustrates a carriage **1202** that may be used in a powered and free conveyor mechanism. In the implementation shown, carriage **1202** includes hook **1204** that engages hook **52** attached to a grow tower **50**. A latch assembly **1206** may secure the grow tower **50** while it is being conveyed to and from various locations in the system. In one implementation, transfer conveyance mechanism **47** may be configured with a sufficient track distance to establish a zone where grow towers **50** may be buffered. For example, transfer conveyance mechanism **47** may be controlled such that it unloads a set of towers **50** to be harvested unto carriages **1202** that are moved to a buffer region of the track. On the other end, automated pickup station **43** may load a set of towers to be inserted into growth environment **20** onto carriages **1202** disposed in another buffer region of the track.

Grow Towers

Grow towers **50** provide the sites for individual crops to grow in the system. As FIGS. **3**A and **3**B illustrate, a hook **52** attaches to the top of grow tower **50**. Hook **52** allows grow tower **50** to be supported by a grow line **202** when it is inserted into the vertical tower conveyance system **200**. In one implementation, a grow tower **50** measures 5.172 meters long, where the extruded length of the tower is 5.0 meters, and the hook is 0.172 meters long. The extruded rectangular profile of the grow tower **50**, in one implementation, measures 57 mm×93 mm (2.25"×3.67"). The hook **52** can be designed such that its exterior overall dimensions are not greater than the extruded profile of the grow tower **50**. The foregoing dimensions are for didactic purposes. The dimensions of grow tower **50** can be varied depending on a number of factors, such as desired throughput, overall size of the system, and the like. For example, a grow tower **50** may be 8 to 10 meters in length or longer.

Grow towers **50** may include a set of grow sites **53** arrayed along at least one face of the grow tower **50**. In the implementation shown in FIG. **4**A, grow towers **50** include grow sites **53** on opposing faces such that plants protrude from opposing sides of the grow tower **50**. Transplanter station **36** may transplant seedlings into empty grow sites **53** of grow towers **50**, where they remain in place until they are fully mature and ready to be harvested. In one implementation, the orientation of the grow sites **53** are perpendicular to the direction of travel of the grow towers **50** along grow line **202**. In other words, when a grow tower **50** is inserted into a grow line **202**, plants extend from opposing faces of the grow tower **50**, where the opposing faces are parallel to the direction of travel. Although a dual-sided configuration is preferred, the invention may also be utilized in a single-sided configuration where plants grow along a single face of a grow tower **50**.

U.S. application Ser. No. 15/968,425 filed on May 1, 2018 which is incorporated by reference herein for all purposes, discloses an example tower structure configuration that can be used in connection with various embodiments of the invention. In the implementation shown, grow towers **50** may each consist of three extrusions which snap together to form one structure. As shown, the grow tower **50** may be a dual-sided hydroponic tower, where the tower body **103** includes a central wall **56** that defines a first tower cavity **54***a* and a second tower cavity **54***b*. FIG. **4**B provides a perspective view of an exemplary dual-sided, multi-piece hydroponic grow tower **50** in which each front face plate **101** is hingeably coupled to the tower body **103**. In FIG. **4**B, each front face plate **101** is in the closed position. The cross-section of the tower cavities **54***a*, **54***b* may be in the range of 1.5 inches by 1.5 inches to 3 inches by 3 inches, where the term "tower cavity" refers to the region within the body of the tower and behind the tower face plate. The wall thickness of the grow towers **50** maybe within the range of 0.065 to 0.075 inches. A dual-sided hydroponic tower, such as that shown in FIGS. **4**A and **4**B, has two back-to-back cavities **54***a* and **54***b*, each preferably within the noted size range. In the configuration shown, the grow tower **50** may include (i) a first V-shaped groove **58***a* running along the length of a first side of the tower body **103**, where the first V-shaped groove is centered between the first tower cavity and the second tower cavity; and (ii) a second V-shaped groove **58***b* running along the length of a second side of the tower body **103**, where the second V-shaped groove is centered between the first tower cavity and the second tower cavity. The V-shaped grooves **58***a*, **58***b* may facilitate registration, alignment and/or feeding of the towers **50** by one or more of the stations in central processing system **30**. U.S. application Ser. No. 15/968,425 discloses additional details regarding the construction and use of towers that may be used in embodiments of the invention. Another attribute of V-shaped grooves **58***a*, **58***b* is that they effectively narrow the central wall **56** to promote the flow of aqueous nutrient solution centrally where the plant's roots are located. Other implementations are possible. For example, a grow tower **50** may be formed as a unitary, single extrusion, where the material at the side walls flex to provide a hinge and allow the cavities to be opened for cleaning. U.S. application Ser. No. 16/577,322 filed on Sep. 20, 2019 which is incorporated by reference herein for all purposes, discloses an example grow tower **50** formed by a single extrusion.

As FIGS. **4**C and **4**D illustrate, grow towers **50** may each include a plurality of cut-outs **105** for use with a compatible plug holder **158**, such as the plug holder disclosed in any one of co-assigned and co-pending U.S. patent application Ser. Nos. 15/910,308, 15/910,445 and 15/910,796, each filed on 2 Mar. 2018, the disclosures of which is incorporated herein for any and all purposes. As shown, the plug holders **158** may be oriented at a 45-degree angle relative to the front face plate **101** and the vertical axis of the grow tower **50**. It should be understood, however, that tower design disclosed in the present application is not limited to use with this particular plug holder or orientation, rather, the towers disclosed herein may be used with any suitably sized and/or oriented plug holder. As such, cut-outs **105** are only meant to illustrate, not limit, the present tower design and it should be understood that the present invention is equally applicable to towers with other cut-out designs. Plug Holder **158** may be ultrasonically welded, bonded, or otherwise attached to tower face **101**.

The use of a hinged front face plate simplifies manufacturing of grow towers, as well as tower maintenance in general and tower cleaning in particular. For example, to clean a grow tower **50** the face plates **101** are opened from the body **103** to allow easy access to the body cavity **54***a* or **54***b*. After cleaning, the face plates **101** are closed. Since the face plates remain attached to the tower body **103** throughout the cleaning process, it is easier to maintain part alignment and to insure that each face plate is properly associated with the appropriate tower body and, assuming a double-sided tower body, that each face plate **101** is properly associated with the appropriate side of a specific tower body **103**. Additionally, if the planting and/or harvesting operations are performed with the face plate **101** in the open position, for the dual-sided configuration both face plates can be opened and simultaneously planted and/or harvested, thus eliminating the step of planting and/or harvesting one side and then rotating the tower and planting and/or harvesting the other side. In other embodiments, planting and/or harvesting operations are performed with the face plate **101** in the closed position.

Other implementations are possible. For example, grow tower **50** can comprise any tower body that includes a volume of medium or wicking medium extending into the tower interior from the face of the tower (either a portion or individual portions of the tower or the entirety of the tower length. For example, U.S. Pat. No. 8,327,582, which is incorporated by reference herein, discloses a grow tube having a slot extending from a face of the tube and a grow medium contained in the tube. The tube illustrated therein may be modified to include a hook **52** at the top thereof and to have slots on opposing faces, or one slot on a single face.

Vertical Tower Conveyance System & Return Path Grow Lines

FIG. **5**A illustrates a portion of a grow line **202** disposed within growth environment **20**. In one implementation, the growth environment **20** may contain a plurality of grow lines **202** arranged in a parallel configuration. As FIG. **1**A illustrates, each grow line **202** may have a substantially u-shaped travel path including a first path section **202***a* and a second return path section **202***b*. As discussed below, a return transfer mechanism **220** transfers grow towers **50** from the end of the first path section **202***a* to the second return path section **202***b*. As discussed above, transfer conveyance mechanism **47** may selectively load a grow tower on a first path section **202***a* of a selected grow line **202**, and unload grow towers **50** from the end of a return path section **202***b* of a grow line **202** under automated control systems. As FIG. **5**A shows, each path section **202***a*, **202***b* of a grow line **202** supports a plurality of grow towers **50**. In one implementation, a grow line **202** may be mounted to the ceiling (or other support) of the grow structure by a bracket for support purposes. As FIGS. **5**A and **5**B show, hook **52** hooks into, and attaches, a grow tower **50** to a grow line **202**, thereby supporting the tower **50** in a vertical orientation as it is translated through the growth environment **20**.

FIG. **10** illustrates the cross section or extrusion profile of a grow line **202**, according to one possible implementation of the invention. The grow line **202** may be an aluminum extrusion. The bottom section of the extrusion profile of the grow line **202** includes an upward facing groove **1002**. As FIG. **9** shows, hook **52** of a grow tower **50** includes a main body **53** and corresponding member **58** that engages groove **1002** as shown in FIGS. **5**A and **8**. These hooks allow the grow towers **50** to hook into the groove **1002** and slide along the grow line **202** as discussed below. Conversely, grow towers **50** can be manually unhooked from a grow line **202** and removed from production. This ability may be necessary if a crop in a grow tower **50** becomes diseased so that it does not infect other towers. In one possible implementation, the width of groove **1002** (for example, 13 mm) is an optimization between two different factors. First, the narrower the groove the more favorable the binding rate and the less likely grow tower hooks **52** are to bind. Conversely, the wider the groove the slower the grow tower hooks wear due to having a greater contact patch. Similarly, the depth of the groove, for example 10 mm, may be an optimization between space savings and accidental fallout of tower hooks.

Hooks **52** may be injection-molded plastic parts. In one implementation, the plastic may be polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), or an Acetyl Homopolymer (e.g., Delrin® sold by DuPont Company). The hook **52** may be solvent bonded to the top of the grow tower **50** and/or attached using rivets or other mechanical fasteners. The groove-engaging member **58** which rides in the rectangular groove **1002** of the grow line **202** may be a separate part or integrally formed with hook **52**. If separate, this part can be made from a different material with lower friction and better wear properties than the rest of the hook, such as ultra-high-molecular weight polyethylene or acetal. To keep assembly costs low, this separate part may snap onto the main body of the hook **52**. Alternatively, the separate part also be over-molded onto the main body of hook **52**.

As FIGS. **6** and **10** illustrate, the top section of the extrusion profile of grow line **202** contains a downward facing t-slot **1004**. Linear guide carriages **610** (described below) ride within the t-slot **1004**. The center portion of the t-slot **1004** may be recessed to provide clearance from screws or over-molded inserts which may protrude from the carriages **610**. Each grow line **202** can be assembled from a number of separately fabricated sections. In one implementation, sections of grow line **202** are currently modeled in 6-meter lengths. Longer sections reduce the number of junctions but are more susceptible to thermal expansion issues and may significantly increase shipping costs. Additional features not captured by the Figures include intermittent mounting holes to attach the grow line **202** to the ceiling structure and to attach irrigation lines. Interruptions to the t-slot **1004** may also be machined into the conveyor body. These interruptions allow the linear guide carriages **610** to be removed without having to slide them all the way out the end of a grow line **202**.

At the junction between two sections of a grow line **202**, a block **612** may be located in the t-slots **1004** of both conveyor bodies. This block serves to align the two grow line sections so that grow towers **50** may slide smoothly between them. Alternative methods for aligning sections of a grow line **202** include the use of dowel pins that fit into dowel holes in the extrusion profile of the section. The block **612** may be clamped to one of the grow line sections via a set screw, so that the grow line sections can still come together and move apart as the result of thermal expansion. Based on the relatively tight tolerances and small amount of material required, these blocks may be machined. Bronze may be used as the material for such blocks due to its strength, corrosion resistance, and wear properties.

In one implementation, the vertical tower conveyance system **200** utilizes a reciprocating linear ratchet and pawl structure (hereinafter referred to as a "reciprocating cam structure or mechanism") to move grow towers **50** along a path section **202***a*, **202***b* of a grow line **202**. In one implementation, each path section **202***a*, **202***b* includes a separate reciprocating cam structure and associated actuators. FIGS. **5**A, **6** and **7** illustrate one possible reciprocating cam mechanism that can be used to move grow towers **50** across grow lines **202**. Pawls or "cams" **602** physically push grow towers **50** along grow line **202**. Cams **602** are attached to cam channel **604** (see below) and rotate about one axis. On the forward stroke, the rotation is limited by the top of the cam channel **604**, causing the cams **602** to push grow towers **50** forward. On the reserve or back stroke, the rotation is unconstrained, thereby allowing the cams to ratchet over the top of the grow towers **50**. In this way, the cam mechanism can stroke a relatively short distance back and forth, yet grow towers **50** always progress forward along the entire length of a grow line **202**. A control system, in one implementation, controls the operation of the reciprocating cam mechanism of each grow line **202** to move the grow towers **50** according to a programmed growing sequence. In between movement cycles, the actuator and reciprocating cam mechanism remain idle.

The pivot point of the cams **602** and the means of attachment to the cam channel **604** consists of a binding post **606** and a hex head bolt **608**; alternatively, detent clevis pins may be used. The hex head bolt **608** is positioned on the inner side of the cam channel **604** where there is no tool access in the axial direction. Being a hex head, it can be accessed radially with a wrench for removal. Given the large number of cams needed for a full-scale farm, a high-volume manufacturing process such as injection molding is suitable. ABS is suitable material given its stiffness and relatively low cost. All the cams **602** for a corresponding grow line **202** are attached to the cam channel **604**. When connected to an actuator, this common beam structure allows all cams **602** to stroke back and forth in unison. The structure of the cam channel **604**, in one implementation, is a downward facing u-channel constructed from sheet metal. Holes in the downward facing walls of cam channel **604** provide mounting points for cams **602** using binding posts **606**.

Holes of the cam channel **604**, in one implementation, are spaced at 12.7 mm intervals. Therefore, cams **602** can be spaced relative to one another at any integer multiple of 12.7 mm, allowing for variable grow tower spacing with only one cam channel. The base of the cam channel **604** limits rotation of the cams during the forward stroke. All degrees of freedom of the cam channel **604**, except for translation in the axial direction, are constrained by linear guide carriages **610** (described below) which mount to the base of the cam channel **604** and ride in the t-slot **1004** of the grow line **202**. Cam channel **604** may be assembled from separately formed sections, such as sections in 6-meter lengths. Longer sections reduce the number of junctions but may significantly increase shipping costs. Thermal expansion is generally not a concern because the cam channel is only fixed at the end connected to the actuator. Given the simple profile, thin wall thickness, and long length needed, sheet metal rolling is a suitable manufacturing process for the cam channel. Galvanized steel is a suitable material for this application.

Linear guide carriages **610** are bolted to the base of the cam channels **604** and ride within the t-slots **1004** of the grow lines **202**. In some implementations, one carriage **610** is used per 6-meter section of cam channel. Carriages **610** may be injection molded plastic for low friction and wear resistance. Bolts attach the carriages **610** to the cam channel **604** by threading into over molded threaded inserts. If select cams **602** are removed, these bolts are accessible so that a section of cam channel **604** can be detached from the carriage and removed.

Sections of cam channel **604** are joined together with pairs of connectors **616** at each joint; alternatively, detent clevis pins may be used. Connectors **616** may be galvanized steel bars with machined holes at 20 mm spacing (the same hole spacing as the cam channel **604**). Shoulder bolts **618** pass through holes in the outer connector, through the cam channel **604**, and thread into holes in the inner connector. If the shoulder bolts fall in the same position as a cam **602**, they can be used in place of a binding post. The heads of the shoulder bolts **618** are accessible so that connectors and sections of cam channel can be removed.

In one implementation, cam channel **604** attaches to a linear actuator, which operates in a forward and a back stroke. A suitable linear actuator may be the T13-B4010MS053-62 actuator offered by Thomson, Inc. of Redford, Virginia; however, the reciprocating cam mechanism described herein can be operated with a variety of different actuators. The linear actuator may be attached to cam channel **604** at the off-loading end of a path section **202***a*, **202***b* of a grow line **202**, rather than the on-boarding end. In such a configuration, cam channel **604** is under tension when loaded by the towers **50** during a forward stroke of the actuator (which pulls the cam channel **604**) which reduces risks of buckling. FIG. **7**A illustrates operation of the reciprocating cam mechanism according to one implementation of the invention. In step A, the linear actuator has completed a full back stroke; as FIG. **7**A illustrates, one or more cams **602** may ratchet over the hooks **52** of a grow tower **50**. Step B of FIG. **7**A illustrates the position of cam channel **604** and cams **602** at the end of a forward stroke. During the forward stroke, cams **602** engage corresponding grow towers **50** and move them in the forward direction along grow line **202** as shown. Step C of FIG. **7**A illustrates how a new grow tower **50** (Tower 0) may be inserted onto a grow line **202** and how the last tower (Tower 9) may be removed. Step D illustrates how cams **602** ratchet over the grow towers **50** during a back stroke, in the same manner as Step A. The basic principle of this reciprocating cam mechanism is that reciprocating motion from a relatively short stroke of the actuator transports towers **50** in one direction along the entire length of the grow line **202**. More specifically, on the forward stroke, all grow towers **50** on a grow line **202** are pushed forward one position. On the back stroke, the cams **602** ratchet over an adjacent tower one position back; the grow towers remain in the same location. As shown, when a grow line **202** is full, a new grow tower **50** may be loaded and a last tower unloaded after each forward stroke of the linear actuator. In some implementations, the top portion of the hook **52** (the portion on which the cams push), is slightly narrower than the width of a grow tower **50**. As a result, cams **602** can still engage with the hooks **52** when grow towers **50** are spaced immediately adjacent to each other. FIG. **7**A shows 9 grow towers for didactic purposes. A grow line **202** can be configured to be quite long (for example, 40 meters) allowing for a much greater number of towers **50** on a grow line **202** (such as 400-450). Other implementations are possible. For example, the minimum tower spacing can be set equal to or slightly greater than two times the side-to-side distance of a grow tower **50** to allow more than one grow tower **50** to be loaded onto a grow line **202** in each cycle.

Still further, as shown in FIG. **7**A, the spacing of cams **602** along the cam channel **604** can be arranged to effect one-dimensional plant indexing along the grow line **202**. In other words, the cams **602** of the reciprocating cam mechanism can be configured such that spacing between towers **50** increases as they travel along a grow line **202**. For example, spacing between cams **602** may gradually increase from a minimum spacing at the beginning of a grow line to a maximum spacing at the end of the grow line **202**. This may be useful for spacing plants apart as they grow to increase light interception and provide spacing, and, through variable spacing or indexing, increasing efficient usage of the growth chamber **20** and associated components, such as lighting. In one implementation, the forward and back stroke distance of the linear actuator is equal to (or slightly greater than) the maximum tower spacing. During the back stroke of the linear actuator, cams **602** at the beginning of a grow line **202** may ratchet and overshoot a grow tower **50**. On the forward stroke, such cams **602** may travel respective distances before engaging a tower, whereas cams located further along the grow line **202** may travel shorter distances before engaging a tower or engage substantially immediately. In such an arrangement, the maximum tower spacing cannot be two times greater than the minimum tower spacing; otherwise, a cam **602** may ratchet over and engaging two or more grow towers **50**. If greater maximum tower spacing is desired, an expansion joint may be used, as illustrated in FIG. **7**B. An expansion joint allows the leading section of the cam channel **604** to begin traveling before the trailing end of the cam channel **604**, thereby achieving a long stroke. In particular, as FIG. **7**B shows, expansion joint **710** may attach to sections **604***a* and **604***b* of cam channel **604**. In the initial position (**702**), the expansion joint **710** is collapsed. At the beginning of a forward stroke (**704**), the leading section **604***a* of cam channel **604** moves forward (as the actuator pulls on cam channel **604**), while the trailing section **604***b* remains stationary. Once the bolt bottoms out on the expansion joint **710** (**706**), the trailing section **604** of cam channel **604** begins to move forward as well. On the back stroke (**708**), the expansion joint **710** collapses to its initial position.

Other implementations for moving vertical grow towers **50** may be employed. For example, a lead screw mechanism may be employed. In such an implementation, the threads of the lead screw engage hooks **52** disposed on grow line **202** and move grow towers **50** as the shaft rotates. The pitch of the thread may be varied to achieve one-dimensional plant indexing. In another implementation, a belt conveyor include paddles along the belt may be employed to move grow towers **50** along a grow line **202**. In such an implementation, a series of belt conveyors arranged along a grow line **202**, where each belt conveyor includes a different spacing distance among the paddles to achieve one-dimensional plant indexing. In yet other implementations, a power-and-free conveyor may be employed to move grow towers **50** along a grow line **202**.

A return transfer mechanism **220** transfers grow towers **50** from a first path section **202***a* to the second return path section **202***b*, causing grow towers **50** to travel in a substantially u-shaped path. In the implementation shown in FIG. **1**A, each grow line **202** includes a separate return transfer mechanism **220**. In other implementations, a single return transfer mechanism **220** can be configured to span across and serve multiple grow lines **202**. As FIG. **26**A illustrates, in one implementation, the return transfer mechanism **220** comprises a belt-driven actuator **2602** that drives a carriage **2604** along a track **2608** using a servo motor **2606**. The MSA series of actuators offered by Macron Dynamics, Inc. of Croydon, PA are examples of belt-driven actuators suitable for use in various implementations disclosed herein. Carriage **2604** includes a lower section **2610** that includes a hook receiver section **2612** including a groove **2618** that engages hook **52** attached to a grow tower **50**. Receiver section **2612** may also have a latch **2614** which closes down on the outer side of the grow tower **50** to prevent a grow tower **50** from sliding off during acceleration or deceleration associated with return transfer conveyance. In one implementation, a controller may control return transfer mechanism **220** to move carriage **2604** such that groove **2618** aligns with the track of a first path section **202***a* of a select grow line **202**. A linear actuator attached proximally to the offload end of the first path section **202***a* can push a grow tower **50** onto receiver section **2612**. Alternatively, the reciprocating cam mechanism associated with first path section **202***a* can be configured to push the grow tower **50** onto receiver section **2612**. When hook **52** of grow tower **50** is engaged in receiver section **2612**, a controller may cause servo motor **2606** to move carriage **2604** to the onload end of return path section **202***b* of the grow line **202** such that the hook **52** is aligned with the track. A second linear actuator attached proximally to the onload end of the return path section **202***b* may slide the grow tower **50** from receive section **2612** onto the track. Alternatively, the reciprocating cam mechanism associated with return path section **202***b* can be configured to transfer the grow tower **50** from receiver section **2612**. An advantage associated with the return transfer mechanism described above is that the orientation of hook **52** does not change. This allows for carriage **1202** of transfer conveyance mechanism **47** to load a grow tower **50** onto a grow line **202** and extract a grow tower **50** from the grow line without having to rotate the receive section **1204** of the carriage **1202**.

As discussed above, the length of the track **2608** is configured to span either a first path section **202***a* and a return path section **202***b*, or to span across multiple grow lines **202** to allow a single return transfer mechanism **220** to operate in connection with these grow lines **202** (schematically, this can be envisioned by extending the individual elements **220** into a return transfer mechanism with a single contiguous track). In other implementations, other types of return transfer mechanisms **220** may be configured for each grow line **202**. For example, pneumatic actuators can be employed to move a carriage similar to carriage **2604** above along a track back and forth as required to perform the transfer operations described herein. Other return transfer mechanisms can also be employed. For example, the return transfer mechanism may comprise a swinging arm that engages a grow tower **50** at the offload end of first path section **202***a* and swings 180 degrees to translate the grow tower **50** to the onload end of the return path section **202***b*. In another implementation, return transfer mechanism **220** may include a semi-circular track section spanning the first and second path sections **202***a*, **202***b* of grow line **202**. In such an implementation, a wheel including paddles can push grow towers around the semi-circular track section with each movement cycle of the grow line **202**. These two foregoing implementations, however, switch the orientation of hook **52**, requiring carriage **1202** to include a swivel mechanism.

FIGS. **1**A and **21** schematically illustrates how central processing system **30** may be configured to work in connection with a system that includes a return path grow line **202**. For example, automated transfer station **41** may extract a grow tower **50** from conveyance mechanism **47** and place the grow tower horizontally on infeed conveyor **1420**. Harvesting station **32** may process the grow tower **50**. The processed grow tower **50** may be routed back to growth environment **20** or to other stations of the central processing system, such as washing station **34** or back to automated transfer station **42**. In either case, automated pickup station **43** may place the grow tower **50** onto a carriage **1202** of transfer conveyance mechanism **47**, as discussed below. In the implementations discussed above, using a return path in the grow line **202** means that grow towers **50** can be injected into, and extracted from, the same side of the growth environment **20**. This configuration allows for potential reductions in system cost by eliminating certain components, such as separate transfer mechanisms for loading and unloading grow towers from the grow lines **202**. In some implementations, path sections **202***a* and **202***b* are substantially horizontal. In other implementations, one or both of path sections **202***a* and **202***b* may be downwardly sloped in their respective directions of travel.

FIG. **1**B illustrates another example farm system layout. In the system illustrated in FIG. **1**B, one automated pickup and laydown station **42** is used instead of separate stations **41** and **43**. Similar to the system illustrated in FIG. **1**A, transfer conveyance mechanism **47** transfers grow towers **50** between growth environment **20** and station **42**. The orientation of the various components of central processing system **30** may also change. For example, conveyor **102** may transfer a horizontally-oriented tower to harvester **32** for processing. Conveyor **104** in connection with transfer station **105** may transfer the processed grow tower to conveyor **106**. Conveyor **106** may feed the grow tower **50** into washing station **34** or, in a cut-again workflow, transfer the grow tower **50** back to station **42** for insertion into the growth environment. Transfer conveyor **107** may transfer a grow tower **50** from washing station **34** to a conveyor that feeds transplanter station **36**. Otherwise, the central processing system **30** operates in a substantially similar manner to the system described in connection with FIG. **1**A.

FIGS. **1**A and **1**B illustrate systems where all grow lines **202** of system **10** are contained within a single growth environment **20**. FIG. **27** illustrates how a single central processing system **30** may operate in connection with multiple growth environments **20***a*-*g*. Each of the growth environments **20***a*-*g* may be separately controlled to support optimized growing for a variety of different crop types. In the implementation shown, transfer conveyance mechanism **47** may be configured to include track sections that loop into each growth environment **20***a*-**20***g*. A control system can cause transfer conveyance mechanism **47** to route carriages **1202** to select grow lines **202** within a select growth environment. As discussed above, each growth environment **20***a*-**20***g* includes a tower injection interface **38** and a tower extraction interface **39**. As FIG. **27** illustrates, injection and extraction interfaces **38** and **39** are configured on the sides of growth environments **20***a*-*g* that face central processing system **30**. This configuration allows for reductions to the overall size of the clean room space required outside of the growth environments **20***a*-*g* for central processing system **30** and the conveyance systems that transfer grow towers to and from it.

FIG. **27** also illustrates that the system **10** may also include a second automated pickup station **43***b*. As discussed below, grow towers **50** may be inserted back into a select grow environment **20***a*-*g* as so-called "cut-agains" after an initial processing by harvester station **32**. The grow tower **50** may be horizontally conveyed to automated pickup station **43**. In an alternative embodiment, however, a second automated pickup station **43***b* located more proximally to harvester station **32** may pick up a "cut-again" grow tower **50** and load it onto a carriage **1202** of transfer conveyance mechanism **47**.

Irrigation & Aqueous Nutrient Supply

FIG. **8** illustrates how an irrigation line **802** may be attached to grow line **202** to supply an aqueous nutrient solution to crops disposed in grow towers **50** as they translate through the vertical tower conveyance system **200**. Irrigation line **802**, in one implementation, is a pressurized line with spaced-apart holes or apertures disposed at the expected locations of the towers **50** as they advance along grow line **202** with each movement cycle. For example, the irrigation line **802** may be a PVC pipe having an inner diameter of 1.5 inches and holes having diameters of 0.125 inches. The irrigation line **802** may be approximately 40 meters in length spanning the entire length of a grow line **202**. To ensure adequate pressure across the entire line, irrigation line **802** may be broken into shorter sections, each connected to a manifold, so that pressure drop is reduced.

As FIG. **8** shows, a funnel structure **902** collects aqueous nutrient solution from irrigation line **802** and distributes the aqueous nutrient solution to the cavity(ies) **54***a*, **54***b* of the grow tower **50** as discussed in more detail below. FIGS. **9** and **11**A illustrate that the funnel structure **902** may be integrated into hook **52**. For example, the funnel structure **902** may include a collector **910**, first and second passageways **912** and first and second slots **920**. As FIG. **9** illustrates, the groove-engaging member **58** of the hook may disposed at a centerline of the overall hook structure. The funnel structure **902** may include flange sections **906** extending downwardly opposite the collector **910** and on opposing sides of the centerline. The outlets of the first and second passageways are oriented substantially adjacent to and at opposing sides of the flange sections **906**, as shown. Flange sections **906** register with central wall **56** of grow tower **50** to center the hook **52** and provides additional sites to adhere or otherwise attach hook **52** to grow tower **50**. In other words, when hook **52** is inserted into the top of grow tower **50**, central wall **56** is disposed between flange sections **906**. In the implementation shown, collector **910** extends laterally from the main body **53** of hook **52**.

As FIG. **11**B shows, funnel structure **902** includes a collector **910** that collects nutrient fluid and distributes the fluid evenly to the inner cavities **54***a* and **54***b* of tower through passageways **912**. Passageways **912** are configured to distribute aqueous nutrient solution near the central wall **56** and to the center back of each cavity **54***a*, **54***b* over the ends of the plug holders **158** and where the roots of a planted crop are expected. As FIG. **11**C illustrates, in one implementation, the funnel structure **902** includes slots **920** that promote the even distribution of nutrient fluid to both passageways **912**. For nutrient fluid to reach passageways **912**, it must flow through one of the slots **920**. Each slot **920** may have a V-like configuration where the width of the slot opening increases as it extends from the substantially flat bottom surface **922** of collector **910**. For example, each slot **920** may have a width of 1 millimeter at the bottom surface **922**. The width of slot **920** may increase to 5 millimeters over a height of 25 millimeters. The configuration of the slots **920** causes nutrient fluid supplied at a sufficient flow rate by irrigation line **802** to accumulate in collector **910**, as opposed to flowing directly to a particular passageway **912**, and flow through slots **920** to promote even distribution of nutrient fluid to both passageways **912**.

In operation, irrigation line **802** provides aqueous nutrient solution to funnel structure **902** that even distributes the water to respective cavities **54***a*, **54***b* of grow tower **50**. The aqueous nutrient solution supplied from the funnel structure **902** irrigates crops contained in respective plug containers **158** as it trickles down. In one implementation, a gutter disposed under each grow line **202** collects excess water from the grow towers **50** for recycling.

Other implementations are possible. For example, the funnel structure may be configured with two separate collectors that operate separately to distribute aqueous nutrient solution to a corresponding cavity **54***a*, **54***b* of a grow tower **50**. In such a configuration, the irrigation supply line can be configured with one hole for each collector. In other implementations, the towers may only include a single cavity and include plug containers only on a single face **101** of the towers. Such a configuration still calls for a use of a funnel structure that directs aqueous nutrient solution to a desired portion of the tower cavity, but obviates the need for separate collectors or other structures facilitating even distribution.

Automated Pickup & Laydown Stations

As discussed above, the stations of central processing system **30** operate on grow towers **50** in a horizontal orientation, while the vertical tower conveyance system **200** conveys grow towers in the growth environment **20** in a vertical orientation. In one implementation, an automated pickup station **43**, and associated control logic, may be operative to releasably grasp a horizontal grow tower from a loading location, rotate the tower to a vertical orientation and attach the tower to a carriage of transfer conveyance mechanism **47** for insertion into a selected grow line **202** of a growth environment **20**. On the other end of central processing system **30**, automated laydown station **41**, and associated control logic, may be operative to releasably grasp and move a vertically-oriented grow tower **50** from a buffer location, rotate the grow tower **50** to a horizontal orientation and place it on a conveyance system for processing by one or more stations of central processing system **30**. For example, automated laydown station **41** may place grow towers **50** on a conveyance system for loading into harvester station **32**. The automated laydown station **41** and pickup station **43** may each comprise a six-degrees of freedom (six axes) robotic arm, such as a FANUC robot. The stations **41** and **43** may also include end effectors for releasably grasping grow towers **50** at opposing ends. Automated pick up and laydown station **42** may be configured to perform both functions implemented by stations **41** and **43**.

FIG. **14** illustrates an automated laydown station **41** according to one implementation of the invention. As shown, automated laydown station **41** includes robot **1402** and end effector **1450**. As discussed above, transfer conveyance mechanism **47**, which may be a power and free conveyor, delivers grow towers **50** from growth environment **20**. In one implementation, the track system **1406** of transfer conveyance mechanism **47** extends through a vertical slot **1408** of tower extraction interface **39** in growth environment **20**, allowing mechanism **45** to convey grow towers **50** attached to carriages **1202** outside of growth environment **20** and towards pick location **1404**. Transfer conveyance mechanism **47** may use a controlled stop blade to stop the carriage **1202** at the pick location **1404**. The transfer conveyance mechanism **47** may include an anti-roll back mechanism, bounding the carriage **1202** between the stop blade and the anti-roll back mechanism.

As FIG. **12** illustrates, receiver **1204** may be attached to a swivel mechanism **1210** allowing rotation of grow towers **50** when attached to carriages **1202** for closer buffering in unload transfer conveyance mechanism **45** and/or to facilitate the correct orientation for loading or unloading grow towers **50**. In some implementations, for the laydown location and pick location **1404**, grow towers **50** may be oriented such that hook **52** faces away from the automated laydown and pickup stations **41**, **43** for ease of transferring towers on/off the swiveled carriage receiver **1204**. Hook **52** may rest in a groove in the receiver **1204** of carriage **1202**. Receiver **1204** may also have a latch **1206** which closes down on either side of the grow tower **50** to prevent a grow tower **50** from sliding off during acceleration or deceleration associated with transfer conveyance. In other implementations, however, the return transfer mechanism **220** may be configured to obviate the need for swivel mechanism **1210**, given that the transfer of grow towers into and from a carriage **1202** can occur on the same side for all operations.

FIG. **16** illustrates an end effector **1450**, according to one implementation of the invention, that provides a pneumatic gripping solution for releasably grasping a grow tower **50** at opposing ends. End effector **1450** may include a beam **1602** and a mounting plate **1610** for attachment to a robot, such as robotic arm **1402**. A top gripper assembly **1604** and a bottom gripper assembly **1606** are attached to opposite ends of beam **1602**. End effector **1450** may also include support arms **1608** to support a grow tower **50** when held in a horizontal orientation. For example, support arms **1608** extending from a central section of beam **1602** mitigate tower deflection. Support arms **1608** may be spaced ~1.6 meters from either gripper assembly **1604**, **1606**, and may be nominally 30 mm offset from a tower face, allowing 30 mm of tower deflection before the support arms **1608** catch the tower.

Bottom gripper assembly **1606**, as shown in FIGS. **17**A and 17B, may include plates **1702** extending perpendicularly from an end of beam **1602** and each having a cut-out section **1704** defining arms **1708***a* and **1708***b*. A pneumatic cylinder mechanism **1706**, such as a guided pneumatic cylinder sold by SMC Pneumatics under the designation MGPM40-40Z, attaches to arms **1708***a* of plates **1702**. Arms **1708***b* may include projections **1712** that engage groove **58***b* of grow tower **50** when grasped therein to locate the grow tower **50** in the gripper assembly **1606** and/or to prevent slippage. The gripper assembly **1606**, in the implementation shown, operates like a lobster claw—i.e., one side of the gripper (the pneumatic cylinder mechanism **1706**) moves, while the other side (arms **1708***b*) remain static. On the static side of the gripper assembly **1606**, the pneumatic cylinder mechanism **1706** drives the grow tower **50** into the arms **1708**, registering the tower **50** with projections **1712**. Friction between a grow tower **50** and arms **1708***b* and pneumatic cylinder mechanism **1706** holds the tower **50** in place during operation of an automated laydown or pick up station **41**, **43**. To grasp a grow tower **50**, the pneumatic cylinder mechanism **1706** may extend. In such an implementation, pneumatic cylinder mechanism **1706** is retracted to a release position during a transfer operation involving the grow towers **50**. In one implementation, the solenoid of pneumatic cylinder mechanism **1706** is center-closed in that, whether extended or retracted, the valve locks even if air pressure is lost. In such an implementation, loss of air pressure will not cause a grow tower **50** to fall out of end effector **1450** while the pneumatic cylinder mechanism **1706** is extended.

Top gripper assembly **1604**, in one implementation, is essentially a mirror image of bottom gripper assembly **1606**, as it includes the same components and operates in the same manner described above. Catch plate **1718**, in one implementation, may attach only to bottom gripper assembly **1606**. Catch plate **1718** may act as a safety catch in case the gripper assemblies fail or the grow tower **50** slips. Other implementations are possible. For example, the gripper assemblies may be parallel gripper assemblies where both opposing arms of each gripper move when actuated to grasp a grow tower **50**.

Robot **1402** may be a 6-axis robotic arm including a base, a lower arm attached to the base, an upper arm attached to the lower arm, and a wrist mechanism disposed between the end of the upper arm and an end effector **1450**. For example, robot **1402** may 1) rotate about Its base; 2) rotate a lower arm to extend forward and backward; 3) rotate an upper arm, Relative to the lower arm, upward and downward; 4) rotate the upper arm and attached wrist Mechanism in a circular motion; 5) tilt a wrist mechanism attached to the end of the upper Arm up and down; and/or 6) rotate the wrist mechanism clockwise or counter-clockwise. However, modifications to end effector **1450** (and/or other elements, such as conveyance mechanisms and the like) may permit different types of robots and mechanisms, as well as use of robots with fewer axes of movement. As FIG. **18** illustrates, robot **1402** may be floor mounted and installed on a pedestal. Inputs to the robot **1402** may include power, a data connection to a control system, and an air line connecting the pneumatic cylinder mechanism **1706** to a pressurized air supply. On pneumatic cylinder mechanism **1706**, sensors may be used to detect when the cylinder is in its open state or its closed state. The control system may execute one or more programs or sub-routines to control operation of the robot **1402** to effect conveyance of grow towers **50** from growth environment **20** to central processing system **20**.

When a grow tower **50** accelerates/decelerates in unload transfer conveyance mechanism **45**, the grow tower **50** may swing slightly. FIGS. **18** and **19** illustrate a tower constraining mechanism **1902** to stop possible swinging, and to accurately locate, a grow tower **50** during a laydown operation of automated laydown station **41**. In the implementation shown, mechanism **1902** is a floor-mounted unit that includes a guided pneumatic cylinder **1904** and a bracket assembly including a guide plate **1906** that guides a tower **50** and a bracket arm **1908** that catches the bottom of the grow tower **50**, holding it at a slight angle to better enable registration of the grow tower **50** to the bottom gripper assembly **1606**. A control system may control operation of mechanism **1902** to engage the bottom of a grow tower **50**, thereby holding it in place for gripper assembly **1606**.

The end state of the laydown operation is to have a grow tower **50** laying on the projections **2004** of the harvester infeed conveyor **1420**, as centered as possible. In one implementation, a grow tower **50** is oriented such that hook **52** points towards harvester station **32** and, in implementations having hinged side walls, and hinge side down. The following summarizes the decisional steps that a controller for robot **1402** may execute during a laydown operation, according to one possible implementation of the invention.

Laydown Procedure Description

The Main program for the robot controller may work as follows:

- A control system associated with central processing system **30** may activate the robot controller's Main program.
- Within the Main program, the robot controller may check if robot **1402** is in its home position.
- If robot **1402** is not in its home position, it enters its Home program to move to the home position.
- The Main program then calls the reset I/O program to reset all the I/O parameters on robot **1402** to default values.
- Next, the Main program runs the handshake program with the central processing controller to make sure a grow tower **50** is present at the pickup location **1404** and ready to be picked up.
- The Main program may run an enter zone program to indicate it is about to enter the transfer conveyance zone.
- The Main program may run a Pick Tower program to grasp a grow tower **50** and lift it off of carriage **1202**.
- The Main program may then call the exit zone program to indicate it has left the transfer conveyance zone.
- Next the Main program runs the handshake program with the central processing controller to check whether the harvester infeed conveyor **1420** is clear and in position to receive a grow tower **50**.
- The Main program may then run the enter zone program to indicate it is about to enter the harvester infeed conveyor zone.
- The Main program runs a Place Tower program to move and place the picked tower onto the infeed conveyor **1420**.
- The Main program then calls an exit zone program to indicate it has left the harvester infeed conveyor zone.
- The Home program may then run to return robot **1402** to its home position.
- Lastly, the Main program may run the handshake program with the central processing controller to indicate robot **1402** has returned to its home position and is ready to pick the next grow tower **50**.

The Pick Tower program may work as follows:

- Robot **1402** checks to make sure the grippers **1604**, **1606** are in the open position. If the grippers are not open, robot **1402** will throw an alarm.
- Robot **1402** may then begin to move straight ahead which will push the end effector **1450** into the tower face so that the grow tower is fully seated against the back wall of the grippers **1604**, **1606**.
- Robot **1402** may then move sideways to push the rigid fingers **1712** against the tower walls to engage groove **58***b*.
- Robot **1402** may activate robot outputs to close the grippers **1604**, **1606**.
- Robot **1402** may wait until sensors indicate that the grippers **1604**, **1606** are closed. If robot **1402** waits too long, robot **1402** may throw an alarm.
- Once grip is confirmed, robot **1402** may then move vertically to lift grow tower **50** off of the receiver **1204**.
- Next, robot **1402** may then pull back away from pick location **1404**.

The Place Tower program may work as follows:

Robot **1402** may move through two waypoints that act as intermediary points to properly align grow tower **50** during the motion.

Robot **1402** continues on to position end effector **1450** and grow tower **50** just above the center of the harvester in-feed conveyor **1450**, such that the tower is in the correct orientation (e.g., hinge down on the rigid fingers, hook **52** towards harvester station **32**).

Once the conveyor position is confirmed, robot **1402** may then activate the outputs to open grippers **1604**, **1606** so that grow tower **50** is just resting on the rigid fingers **1712** and support arms **1608**.

Robot **1402** may wait until the sensors indicate that grippers **1604**, **1606** have opened. If robot **1402** waits too long, robot **1402** may throw an alarm.

After grippers **1604**, **1606** are released, robot **1402** may then move vertically down. On the way down the projections **2004** of harvester infeed conveyor **1420** take the weight of grow tower **50** and the rigid fingers **1712** and support arms **1608** of end effector **1450** end up under grow tower and not in contact.

Lastly, robot **1402** may then pull end effector **1450** towards robot **1402**, away from harvester infeed conveyor **1420**, and slides rigid fingers **1712** of end effector **1450** out from under grow tower **50**.

FIGS. **15**A and **15**B illustrate an automated pickup station **43** according to one implementation of the invention. As shown, automated pickup station **43** includes robot **1502** and pickup conveyor **1504**. Similar to automated laydown station **41**, robot **1502** includes end effector **1550** for releasably grasping grow towers **50**. In one implementation, end effector **1550** is substantially the same as end effector **1450** attached to robot **1402** of automated laydown station **41**. In one implementation, end effector **1550** may omit support arms **1608**. As described herein, robot **1502**, using end effector **1550**, may grasp a grow tower **50** resting on pickup conveyor **1504**, rotate the grow tower **50** to a vertical orientation and attach the grow tower **50** to a carriage **1202** of transfer conveyance mechanism **47**. As discussed above, loading transfer conveyance mechanism **47**, which may include be a power and free conveyor, delivers grow towers **50** to growth environment **20**. In one implementation, the track system **1522** of transfer conveyance mechanism **47** extends through a vertical slot of tower injection interface **38** in growth environment **20**, allowing mechanism **47** to convey grow towers **50** attached to carriages **1202** into growth environment **20** from stop location **1520**. Transfer conveyance mechanism **47** may use a controlled stop blade to stop the carriage **1202** at the stop location **1520**. Transfer conveyance mechanism **47** may include an anti-roll back mechanism, bounding the carriage **1202** between the stop blade and the anti-roll back mechanism.

The following summarizes the decisional steps that a controller for robot **1502** may execute during a pickup operation, according to one possible implementation of the invention.

Pickup Procedure Description

The Main program for the robot controller may work as follows for robot **1502**:

The central processing controller may activate the Main program.

Within the Main program, robot **1502** controller will check if robot **1502** is in its home position.

If robot **1502** is not in its home position, robot **1502** will enter its home program to move to the home position of the robot **1502**.

The Main program may then call the reset IO program to reset I/O values on robot **1502** to their default values.

Next, the Main program may run the handshake program with the central processing controller to request a decision code indicating which station (pickup conveyor **1504** or the transplanter transfer conveyor **2111**) has a grow tower **50** ready for pickup.

The Main program may run the enter zone program to indicate it is about to enter the pickup location based on the decision code from above.

The Main program may then run the Pick Tower program to grab a tower and lift it from the specified conveyor based on the decision code from above.

The Main program may then call the exit zone program to indicate it has left the pickup location based on the decision code from above.

Next the Main program may run the handshake program with the central processing controller to check whether loading transfer conveyance mechanism **47** has a carriage **1202** in place and is ready to receive a grow tower **50**.

The Main program may then run the enter zone program to indicate it is about to enter the transfer conveyance zone.

The Main program may run the Place Tower program to move and place the picked grow tower onto receiver **1204** of carriage **1202**.

The Main program may then call the exit zone program to indicate it has left the transfer conveyance zone.

Robot **1502** then run the go to Home program to return robot **1502** to its home position.

Lastly, the Main program may run the handshake program with the central processing controller to indicate robot **1502** has returned to its home position and is ready to pick up the next grow tower **50**.

The Pick Tower program may work as follows:

Robot **1502** may check to make sure the grippers are in the open position. If they are not open, robot **1502** will throw an alarm.

If the decision location resolves to the transplanter transfer conveyor **2111**, robot **1502** will move vertically to align with the grow tower **50** on the transplanter transfer conveyor **2111**.

Robot **1502** may then begin to move straight ahead to push end effector **1550** into the tower face so that the grow tower **50** is fully seated against the back wall of the grippers.

Robot **1502** moves upwards to lift grow tower **50** to rest the tower on the rigid fingers of the grippers.

Robot **1502** may then activate robot **1502** outputs to close the grippers.

Robot **1502** may wait until the sensors indicate that the grippers are closed. If robot **1502** waits too long, robot **1502** will throw an alarm.

Once grip is confirmed, robot **1502** moves vertically and pulls back away from the pickup conveyor **1504** or the transplanter transfer conveyor **2111**.

The Place Tower program may work as follows:

Robot **1502** may move through two waypoints that act as intermediary points to properly align grow tower **50** during the motion.

Robot **1502** continues on to position end effector **1550** and grow tower **50** in line with receiver **1204** of carriage **1202**.

Robot **1502** may then move forward to point **1520** which will position the tower hook **52** above the channel in receiver **1204**.

Robot **1502** may then move down which will position the tower hook **52** to be slightly above (e.g., ~10 millimeters) above the channel of receiver **1204**.

Robot **1502** may activate the outputs to open the grippers so that the hook **52** of tower **50** falls into the channel of receiver **1204**.

Robot **1502** may wait until the sensors indicate that the grippers have opened. If robot **1502** waits too long, robot **1502** will throw an alarm.

Once the grippers are released, robot **1502** may move straight back away from the tower.

Central Processing System

As discussed above, central processing system **30** may include harvester station **32**, washing station **34** and transplanter station **36**. Central processing system **30** may also include one or more conveyors to transfer towers to or from a given station. For example, central processing system **30** may include harvester outfeed conveyor **2102**, washer infeed conveyor **2104**, washer outfeed conveyor **2106**, transplanter infeed conveyor **2108**, and transplanter outfeed conveyor **2110**. These conveyors can be belt or roller conveyors adapted to convey grow towers **50** laying horizontally thereon. As described herein, central processing system **30** may also include one or more sensors for identifying grow towers **50** and one or more controllers for coordinating and controlling the operation of various stations and conveyors.

FIG. **21** illustrates an example processing pathway for central processing system **30**. As discussed above, a robotic laydown station **41** may lower a grow tower **50** with mature crops onto a harvester infeed conveyor **1420**, which conveys the grow tower **50** to harvester station **32**. FIG. **20** illustrates a harvester infeed conveyor **1420** according to one implementation of the invention. Harvester infeed conveyor **1420** may be a belt conveyor having a belt **2002** including projections **2004** extending outwardly from belt **2002**. Projections **2004** provide for a gap between belt **2002** and crops extending from grow tower **50**, helping to avoid or reduce damage to the crops. In one implementation, the size the projections **2004** can be varied cyclically at lengths of grow tower **50**. For example, projection **2004***a* may be configured to engage the end of grow tower **50**; top projection **2004***d* may engage the opposite end of grow tower **50**; and middle projections **2004***b, c* may be positioned to contact grow tower **50** at a lateral face where the length of projections **2004***b, c* are lower and engage grow tower **50** when the tower deflects beyond a threshold amount. The length of belt **2002**, as shown in FIG. **20** can be configured to provide for two movement cycles for a grow tower **50** for each full travel cycle of the belt **2002**. In other implementations, however, all projections **2004** are uniform in length.

As FIG. **21** shows, harvester outfeed conveyor **2102** conveys grow towers **50** that are processed from harvester station **32**. In the implementation shown, central processing system **30** is configured to handle two types of grow towers: "cut-again" and "final cut." As used herein, a "cut-again" tower refers to a grow tower **50** that has been processed by harvester station **32** (i.e., the crops have been harvested from the plants growing in the grow tower **50**, but the root structure of the plant(s) remain in place) and is to be re-inserted in growth environment **20** for crops to grow again. As used herein, a "final cut" tower refers to a grow tower **50** where the crops are harvested and where the grow tower **50** is to be cleared of root structure and growth medium and re-planted. Cut-again and final cut grow towers **50** may take different processing paths through central processing system **30**. To facilitate routing of grow towers **50**, central processing system **30** includes sensors (e.g., RFID, barcode, or infrared) at various locations to track grow towers **50**. Control logic implemented by a controller of central processing system **30** tracks whether a given grow tower **50** is a cut-again or final cut grow tower and causes the various conveyors to route such grow towers accordingly. For example, sensors may be located at pick position **1404** and/or harvester infeed conveyor **1420**, as well as at other locations. The various conveyors described herein can be controlled to route identified grow towers **50** along different processing paths of central processing system **30**. As shown in FIG. **21**, a cut-again conveyor **2112** transports a cut-again grow tower **50** toward the work envelope of automated pickup station **43** for insertion into grow environment **20**. Cut-again conveyor **2112** may consist of either a single accumulating conveyor or a series of conveyors. Cut-again conveyor **2112** may convey a grow tower **50** to pickup conveyor **1504**. In one implementation, pickup conveyor **1504** is configured to accommodate end effector **1450** of automated pickup station **43** that reaches under grow tower **50**. Methods of accommodating the end effector **1450** include either using a conveyor section that is shorter than grow tower **50** or using a conveyor angled at both ends as shown in FIG. **22**.

Final cut grow towers **50**, on the other hand, travel through harvester station **32**, washing station **34** and transplanter **36** before reentering growth environment **20**. With reference to FIG. **21**, a harvested grow tower **50** may be transferred from harvester outfeed conveyor **2102** to a washer transfer conveyor **2103**. The washer transfer conveyor **2103** moves the grow tower onto washer infeed conveyor **2104**, which feeds grow tower **50** to washing station **34**. In one implementation, pneumatic slides may push a grow tower **50** from harvester outfeed conveyor **2102** to washer transfer conveyor **2103**. Washer transfer conveyor **2103** may be a three-strand conveyor that transfers the tow to washer infeed conveyor **2104**. Additional pusher cylinders may push the grow tower **50** off washer transfer conveyor **2103** and onto washer infeed conveyor **2104**. A grow tower **50** exits washing station **34** on washer outfeed conveyor **2106** and, by way of a push mechanism, is transferred to transplanter infeed conveyor **2108**. The cleaned grow tower **50** is then processed in transplanter station **36**, which inserts seedlings into grow sites **53** of the grow tower. Transplanter outfeed conveyor **2110** transfers the grow tower **50** to final transfer conveyor **2111**, which conveys the grow tower **50** to the work envelope of automated pickup station **43**.

In the implementation shown in FIG. **23**A, harvester station **34** comprises crop harvester machine **2302** and bin conveyor **2304**. Harvester machine **2302** may include a rigid frame to which various components, such as cutters and feed assemblies, are mounted. Harvester machine **2302**, in one implementation, includes its own feeder mechanism that engages a grow tower **50** and feeds it through the machine. In one implementation, harvester machine **2302** engages a grow tower on the faces that do not include grow sites **53** and may employ a mechanism that registers with grooves **58***a*, **58***b* to accurately locate the grow tower and grow sites **53** relative to harvesting blades or other actuators. In one implementation, harvester machine **2302** includes a first set of rotating blades that are oriented near a first face **101** of a grow tower **50** and a second set of rotating blades on an opposing face **101** of the grow tower **50**. As the grow tower **50** is fed through the harvester machine **2302**, crop extending from the grow sites **53** is cut or otherwise removed, where it falls into a bin placed under harvester machine **2302** by bin conveyor **2304**. Harvester machine **2302** may include a grouping mechanism, such as a physical or air grouper, to group the crops at a grow site **53** away from the face plates **101** of the grow towers **50** in order to facilitate the harvesting process. Bin conveyor **2304** may be a u-shaped conveyor that transports empty bins the harvester station **34** and filled bins from harvester station **32**. In one implementation, a bin can be sized to carry at least one load of crop harvested from a single grow tower **50**. In such an implementation, a new bin is moved in place for each grow tower that is harvested. In one implementation, grow towers **50** enter the harvester machine **2302** full of mature plants and leave the harvester machine **2302** with remaining stalks and soil plugs to be sent to the next processing station.

FIG. **23**B is a top view of an example harvester machine **2302**. Circular blades **2306** extending from a rotary drive system **2308** harvest plants on opposing faces **101***a* of grow towers **50**. In one implementation, rotary drive system **2308** is mounted to a linear drive system **2310** to move the circular blades **2306** closer to and farther away from the opposing faces **101***a* of the grow towers **50** to optimize cut height for different types of plants. In one implementation, each rotary drive system **2308** has an upper circular blade and a lower circular blade (and associated motors) that intersect at the central axis of the grow sites of the grow towers **50**. Harvester machine **2302** may also include an alignment track **2320** that includes a set of rollers that engage groove **58** of the grow tower **50** as it is fed through the machine. Harvester machine **2302** may also include a tower drive system that feeds grow towers through the machine at a constant rate. In one implementation, the tower drive system includes a two drive wheel and motor assemblies located at opposite ends of harvester machine **2302**. Each drive wheel and motor assembly may include a friction drive roller on the bottom and a pneumatically actuated alignment wheel on the top. As FIG. **23**C illustrates, harvester machine **2302** may also include a gathering chute **2330** that collects harvested crops cut by blades **2306** as it falls and guides it into bins located under the machine **2302**.

Washing station **34** may employ a variety of mechanisms to clean crop debris (such as roots and base or stem structures) from grow towers **50**. To clean a grow tower **50**, washing station **34** may employ pressurized water systems, pressurized air systems, mechanical means (such as scrubbers, scrub wheels, scrapers, etc.), or any combination of the foregoing systems. In implementations that use hinged grow towers (such as those discussed above), the washing station **34** may include a plurality of substations including a substation to open the front faces **101** of grow towers **50** prior to one or more cleaning operations, and a second substation to close the front faces **101** of grow towers after one or more cleaning operations.

Transplanter station **36**, in one implementation, includes an automated mechanism to inject seedlings into grow sites **53** of grow towers **50**. In one implementation, the transplanter station **36** receives plug trays containing seedlings to be transplanted into the grow sites **53**. In one implementation, transplanter station **36** includes a robotic arm and an end effector that includes one or more gripper or picking heads that grasps root-bound plugs from a plug tray and inserts them into grow sites **53** of grow tower **53**. For implementations where grow sites **53** extend along a single face of a grow tower, the grow tower may be oriented such that the single face faces upwardly. For implementations where grow sites **53** extend along opposing faces of a grow tower **50**, the grow tower **50** may be oriented such that the opposing faces having the grow sites face laterally. FIGS. **24**A and **24**B illustrate an example transplanter station. Transplanter station **36** may include a plug tray conveyor **2430** that positions plug trays **2432** in the working envelope of a robotic arm **2410**. Transplanter station **36** may also include a feed mechanism that loads a grow tower **50** into place for transplanting. Transplanter station **36** may include one or more robotic arms **2410** (such as a six-axis robotic arm), each having an end effector **2402** that is adapted to grasp a root-bound plug from a plug tray and inject the root bound plug into a grow site **53** of a grow tower. FIG. **24**A illustrates an example end effector **2402** that includes a base **2404** and multiple picking heads **2406** extending from the base **2404**. The picking heads **2406** are each pivotable from a first position to a second position. In a first position (top illustration of FIG. **24**A), a picking head **2406** extends perpendicularly relative to the base. In the second position shown in FIG. **24**A, each picking head **2406** extends at a 45-degree angle relative to the base **2404**. The 45-degree angle may be useful for injecting plugs into the plug containers **158** of grow towers that, as discussed above, extend at a 45-degree angle. A pneumatic system may control the pivoting of the picking heads between the first position and the second position. In operation, the picking heads **2406** may be in the first position when picking up root-bound plugs from a plug tray, and then may be moved to the second position prior to insertion of the plugs into plug containers **158**. In such an insertion operation, the robotic arm **2410** can be programmed to insert in a direction of motion parallel with the orientation of the plug container **158**. Using the end effector illustrated in FIG. **24**A, multiple plug containers **158** may be filled in a single operation. In addition, the robotic arm **2410** may be configured to perform the same operation at other regions on one or both sides of a grow tower **50**. As FIG. **24**B shows, in one implementation, several robotic assemblies, each having an end effector **2402** are used to lower processing time. After all grow sites **53** are filled, the grow tower **50** is ultimately conveyed to automated pickup station **43**, as described herein.

One or more of the controllers discussed above, such as the one or more controllers for central processing system **30**, may be implemented as follows. FIG. **25** illustrates an example of a computer system **800** that may be used to execute program code stored in a non-transitory computer readable medium (e.g., memory) in accordance with embodiments of the disclosure. The computer system includes an input/output subsystem **802**, which may be used to interface with human users or other computer systems depending upon the application. The I/O subsystem **802** may include, e.g., a keyboard, mouse, graphical user interface, touchscreen, or other interfaces for input, and, e.g., a LED or other flat screen display, or other interfaces for output, including application program interfaces (APIs). Other elements of embodiments of the disclosure, such as the controller, may be implemented with a computer system like that of computer system **800**.

Program code may be stored in non-transitory media such as persistent storage in secondary memory **810** or main memory **808** or both. Main memory **808** may include volatile memory such as random-access memory (RAM) or non-volatile memory such as read only memory (ROM), as well as different levels of cache memory for faster access to instructions and data. Secondary memory may include persistent storage such as solid-state drives, hard disk drives or optical disks. One or more processors **804** reads program code from one or more non-transitory media and executes the code to enable the computer system to accomplish the methods performed by the embodiments herein. Those skilled in the art will understand that the processor(s) may ingest source code, and interpret or compile the source code into machine code that is understandable at the hardware gate level of the processor(s) **804**. The processor(s) **804** may include graphics processing units (GPUs) for handling computationally intensive tasks.

The processor(s) **804** may communicate with external networks via one or more communications interfaces **807**, such as a network interface card, WiFi transceiver, etc. A bus **805** communicatively couples the I/O subsystem **802**, the processor(s) **804**, peripheral devices **806**, communications interfaces **807**, memory **808**, and persistent storage **810**. Embodiments of the disclosure are not limited to this representative architecture. Alternative embodiments may employ different arrangements and types of components, e.g., separate buses for input-output components and memory subsystems.

Those skilled in the art will understand that some or all of the elements of embodiments of the disclosure, and their accompanying operations, may be implemented wholly or partially by one or more computer systems including one or more processors and one or more memory systems like those of computer system **800**. In particular, the elements of automated systems or devices described herein may be computer-implemented. Some elements and functionality may be implemented locally and others may be implemented in a distributed fashion over a network through different servers, e.g., in client-server fashion, for example.

Facility Layout & Arrangement

FIGS. **28** and **29** are a functional block diagrams illustrating an example controlled-environment agriculture production facility **2800**. In some implementations, the layout illustrated in FIGS. **28** and **29** incorporate the configuration of the growth environments and central processing illustrated in FIG. **27**, adding to it the selection and arrangement of other spaces and functionality of the facility **2800**. In other implementations, the configuration illustrate in FIG. **1**A can be incorporated. As FIG. **28** illustrates, production facility **2800** includes growth environment **20**, central processing system **30**, nutrient and thermal corridor **2820**, propagation space **2802**, pre-harvest processing space **2804**, and post-harvest processing space **2806**. Production facility **2800** also includes seeding space **2808**, germination space **2803**, and materials or product supply handling space **2822**. One or more space or area components of production facility **2800** may be housed within a warehouse building or any other suitable building structure.

As discussed above, growth environment **20** may be a substantially-encapsulated space to facilitate control of one or more environmental conditions to which crops are exposed and to reduce risk of potential contaminants and pests. Growth environment **20** may comprise an array of multiple growth environments **20***a-f*, as illustrated in FIG. **27** and as discussed above. Each of the growth environments **20***a-f* may be separately controlled to support optimized growing for a variety of different crop types. As discussed above, the growth environments **20***a-f* may each contain one or more grow lines **202** that have a substantially u-shaped travel path including a first path section **202***a* and a second return path section **202***b* (see above). In the implementation shown, transfer conveyance mechanism **47** may be configured to include track sections that loop into each growth environment **20***a*-**20***f* A control system can cause transfer conveyance mechanism **47** to route carriages **1202** to select grow lines **202** within a select growth environment **20***a*-**20***f*. The control system may also cause transfer conveyance mechanism **47** to route carriages **1202** to a select pre-harvest buffer **2190**, **2192** within pre-harvesting processing space **2804**.

In the implementation of central processing system **30** shown in FIG. **28**, the processing path associated with harvesting station **32** is perpendicular to the processing paths associated with washing station **34** and transplanter station **36**. Pre-harvest processing space **2804** may contain harvester station **32** and one or more pre-harvesting buffers **2190**, **2192**, as discussed above. Automated laydown station **41** may engage a grow tower **50** from one of buffers **2190**, **2192**, rotate the grow tower **50** to a horizontal orientation and place it on a conveyance mechanism that feeds the grow tower **50** through harvester station **32**. For so-called "cut-again" towers, automated pick up station **43***b* may place the harvested grow tower **50** back onto transfer conveyance mechanism **47**, which routes the tower to a select growth environment **20***a-f*. Otherwise, automated pickup station **43***b* may rotate the grow tower 90 degrees and place it horizontally onto a conveyance mechanism that feeds the grow tower to washing station **34**. A washed grow tower **50** may be buffered in buffering mechanism **35** with other grow towers **50** and ultimately fed into transplanter station **36**. Automated pickup station **43** may engage a grow tower **50** that has been transplanted and transfer it to transfer conveyance mechanism **47**, which routes the tower to a select growth environment **20***a-f*.

Nutrient and thermal corridor **2820** contains one or more fluid tanks, nutrient supply and mixing equipment, fluid pumps, filtration equipment, sanitation equipment, manifolds, plumbing and related equipment to provide aqueous nutrients to grow lines **202** within the growth environments **20***a-f*. Nutrient and thermal corridor **2820** also includes equipment for controlling thermal conditions as well including, for example, chillers and hydronic piping that run to air handling units and fluid coolers. In one implementation, modular aqueous nutrient supply systems **2614** can supply aqueous nutrient solution to the grow lines **202** within the growth environments **20***a-f*. The plumbing (not shown) delivering nutrient solution from the aqueous nutrient supply system **2614** can extend over growth environment **20** and/or grow lines **202**. Furthermore, HVAC systems, such as chillers, air handlers and other equipment bay be housed between sections of growth environment **20***a-f* and/or placed on the top of the structure that contains each growth environment **20***a-f*. Nutrient and thermal corridor **2820** is environmentally separated from growth environments **20***a-f*, propagation space **2802** and central processing system **30**. Given that corridor **2820** does not contain agricultural product, it may be subject to looser environmental controls (e.g., heat, humidity, insulation, cleanliness, etc.) than other spaces in facility **2800**. For example, corridor **2820** may be classified as a Group U (Utility and Miscellaneous) space pursuant to Title 24 of the California Code of Regulations. As such, implementers of the facility **2800** can reduce costs by building to the lower requirements of corridor **2820**, while building to higher requirements in other spaces of facility **2800**.

Propagation space **2802** includes equipment for growing young plants in stacked horizontal beds (or plug trays) for later transplant into grow towers **50**. Propagation space **2802** may include a rack system for vertically stacking the horizontal beds or plug trays. In one implementation, propagation space **2802** is a substantially encapsulated growth environment that includes air handling, lighting, climate control, irrigation and other equipment to grow plants from seed stage to transplant stage. The grow lights used in propagation space **2802** may be air-cooled and located above each horizontal bed. In the implementation shown in FIG. **28**, plug trays are inserted into and extracted from a single side **2818** (opposing corridor **2820**) of propagation space **2802**. In one implementation, the location of propagation space **2802** adjacent to the end of array of growth environments **20***a-f* allows for a modular aqueous nutrient supply system **2614** located in corridor **2820** to be the irrigation supply for the space **2802**.

Seeding area **2808** is a space including one or more stations and associated equipment for filling plug trays with growth medium, seeds, and other nutrient or water solutions to meet the nutritional requirements for ideal growth per crop variety. In addition to a seeding line, the seeding space **2808** may also include media/soil storage, storage for seeds in a controlled temperature environment (e.g., a refrigerator) depending on requirements, and potentially media/soil mixing equipment. Seeding area **2808** may also include ventilation equipment. Germination space **2803** is an encapsulated space including one or more tables where the newly seeded plug trays are contained during plant germination. In the implementation shown in FIG. **28**, plug trays are inserted into and extracted from a single side **2809** (opposing corridor **2820**) of germination space **2803**. After the germination phase, the plug trays may be transferred to propagation space **2802**. In the implementation shown, germination area **2803** and seeding area **2808** are adjacent to propagation space **2802**.

In one embodiment, plants are initially grown in so-called plug trays, where each tray include multiple plugs that are ultimately transferred to transplanter station **36** when ready. As FIG. **28** demonstrates, propagation space **2802** is located adjacent to central processing system and proximal to transplanter station **36**. Such a configuration minimizes the distance plug trays are required to travel from propagation space **2802** to transplanter station **36**. In one implementation, a conveyor may transfer loaded plug trays from propagation area **2802** to transplanter station **36**.

The spaces associated with central processing system **30** may also be divided into separate environments to achieve various objectives. For example, pre-harvesting space **2804** may be a cooled environment separate from the spaces that contain washing station **34** and transplanter station **36**. Post harvesting space **2806** may also be a separate space. In one implementation, pre-harvesting space **2804** includes environmental controls for providing a cooled space to cool the crop in grow towers **50** to a target temperature prior to harvesting and irrigation to supply water or aqueous nutrient solution to grow towers **50** as they hang from vertical buffers **2190**, **2192**. In one implementation, the irrigation supply is a chilled water supply to further induce cooling of crop to a target temperature prior to harvesting. For certain crops, such as leafy greens, the cooling of the crop facilitates cleaner harvesting operations, as the crop is slightly more rigid, providing for cleaner cuts by the blades of harvester station **32**.

As discussed above, the vertical tower conveyance system **47** includes a track system that routes carriages **1202** to various destinations along the system **10**. As FIGS. **28** and **30** illustrate, the track system may include a first pre-harvest (cut-again) vertical buffer **2190** and a second pre-harvest (final-cut) vertical buffer **2192**, both contained in pre-harvesting space **2804**. As discussed above, central processing system **30** may be configured to selectively process certain grow towers **50** for so-called cut-again processing. FIG. **28** illustrates that the system **10** may also include a second automated pickup station **43***b*. In particular, after processing by harvester station **32**, automated pickup station **43***b* may pick up a grow tower **50** from the outfeed conveyor of harvester station **32** rotate the grow tower **50** to vertical and place it on a carriage **1202** of tower conveyance mechanism **47** for reinsertion into a grow line **202**. A grow tower **50** that undergoes "final-cut" processing is routed to washing station **34** and transplanter station **36** as described herein. Pre-harvesting space **2804** may also include additional buffer lines for other purposes, such as a buffer line to place grow towers with damaged or otherwise rejected crops.

Towers designated as "cut-agains" take less time to process than towers **50** designated as final cuts, as cut-again towers need not pass through cleaning station **34** and transplanter station **36**. Pre-harvest buffers **2190**, **2192** provide a space to buffer grow towers **50** prior to initiating harvester station **32** in order to ensure an adequate supply of grow towers **50** for efficient processing. A controller selectively routes grow towers **50**, as appropriate, to either the cut-again buffer **2190** or final cut buffer **2192**. Automated laydown station **41** can selectively access grow towers **50** from either buffer **2190** or **2192** under control of a control system as may be required. The use of separate vertical tower buffers allows the farm system **10** to alternate between cut-again and final-cut towers and maintain a consistent mix of final-cut and cut-again grow towers **50** for processing, despite such types of grow towers arriving in batches from growth environment. The use of separate buffers also allows system **10** to accommodate for the different cycle times of the cut-again and final-cut towers, increasing the total number of towers than can be processed within a given time span and improving the average cycle time of overall tower processing. In one implementation, automated laydown station **41** can alternate 1:1 between final-cut and cut-again pre-harvest buffers **2190**, **2192** provided that both tower types are available. In other implementations, however, differences in cycle times between such tower types may suggest a ratio of 2 cut-again towers for every 1 final-cut tower. Other implementations are possible. For example, the system **10** may also include a vertical reject buffer (not shown) to provide a space to temporarily store grow towers that have failed a quality inspection. The reject buffer allows a rejected tower to simply be routed out of the processing pathway and stored for later handling.

Post-harvest processing space **2806** may be an encapsulated environment that includes equipment for processing crops after they have been harvested from grow towers **50** at harvester station **32**. In some implementations, post-harvest processing space **2806** is a substantially encapsulated space subject to controlled environmental conditions; for example, post-harvesting space **2806** may be a cooled or refrigerated environment, or a warmed environment to accommodate other types of crops. In some implementations, the equipment included in post-harvest processing space **2806** may include crop washing and drying equipment, product quality equipment, product cooling equipment, product packaging equipment, and food safety equipment. Other equipment may include process isolation equipment for sanitation purposes. Post-harvest processing space **2806** is arranged adjacent to central processing system **30** and proximal to harvester station **32** to minimize or reduce the distance that harvested crop travels from harvester station **32**. In one implementation, a bin conveyor can extend directly into post-harvest processing space **2806** to convey bins loaded with harvested crop into the space. In one implementation, harvested product can be harvested directly onto conveyance without bins, and transported to the post-harvest processing space **2806**. In addition, harvested product (whether in bins or conveyed directly on a conveyor) may also be subject to cooling systems (such as vacuum cooling, a cooling tunnel, etc.) as it is conveyed to post-harvest processing space **2806**. Similarly, facility **2800** may also include a cold storage space to provide a controlled, refrigerated environment adapted for storing packaged crops for shipment depending on the specific crop storage environmental requirements. In some implementations, the equipment included in the cold storage space may include package palletizing equipment, case erecting equipment, and other inventory storage equipment or infrastructure. In the implementation shown, the cold storage space is adjacent to post-harvest processing space **2806**.

Implementations of production facility **2800** are also arranged to optimize efficiency. In some implementations, production facility **2800** may be configured to reduce or minimize total product flow distance from seed stage to post-harvest processing and cold storage. Minimizing or reducing this metric increases cost efficiencies by, for example, reducing the total length of conveyors used in the facility. The layout of production facility **2800** may also be configured to reduce or minimize other attributes, such as the percentage of unutilized space, the distance of employee travel, the maximum distance between any two stations in the facility **2800**, length of cabling, plumbing and/or HVAC ducting, and total wall length.

As FIG. **28** illustrates, total product flow from seed to packaging is both direct and efficient, reducing operating time, operating cost and capital expenditure. In particular, the product flow starts at seed station **2808** where plug trays are filled with soil and seeded. The product flow proceeds to the propagation space **2802** where plants germinate and are ready for transplant. The plug trays are then conveyed to transplant station **36** of central processing system **30**, where the plugs are inserted in crop-bearing modules, such as the plug containers of grow towers **50**. The grow towers **50** are inserted into growth environment **20** where they proceed from one end to another of the space along grow lines **202**. Grow towers **50** are then transferred to harvesting station **32** where the crop is harvested and conveyed to post-harvest processing space **2806**. The packaged product is ultimately stored in a cold storage facility from where it may be ultimately shipped out of the facility **2800**.

The configuration illustrated in FIG. **28** achieves a variety of operational and cost efficiencies and advantages. The configuration set forth in FIGS. **28** and **29** essentially bifurcate the system **2800** into a utility zone for housing thermal and irrigation equipment, and a plant production zone for growing crops. For example, locating propagation space **2802** and the array of growth environments as shown, allows for most of the thermal, irrigation and nutrient supply equipment to be located in a single corridor **2800**. Growth environments **20***a-f* and the spaces associated with central processing system **30** have different requirements relative to environmental controls, requiring more precise controls for temperature, humidity, air filtration, process isolation, and/or lighting. In addition, given that growth environments **20***a-f* and the spaces associated with central processing system **30** contain agricultural product, various food safety requirements may also require additional controls, such as process isolation or clean room equipment to create a space suitable for food/crop production. The layout set forth in FIG. **28** essentially creates a utility zone (nutrient corridor) where it is less expensive to achieve the required controls and a production zone where food safety and other requirements mandate tighter environmental controls. For example, nutrient and thermal corridor **2820** and space **2822** may not be subject to environmental controls and have be subject to ambient temperature and air conditions. In other implementations, nutrient and thermal corridor **2820** and space **2822** are contained in a controlled environment. In addition, the configuration of FIG. **28** is scalable from both a design standpoint and in connection with expansion of an existing facility. To build out capacity of the system, additional growth environments can be added to the end of the array of growth environments **20***a-f*. Similarly, propagation space **2802** can be expanded outwardly relative to FIG. **28**.

Materials handling space **2822** is an area of facility **2800** adapted for receiving supplies and shipping product. As FIG. **29** illustrates, space **2822** may be divided into an inbound area **2822***a* and outbound area **2822***b*. Additionally, space **2822** may house any additional electrical or mechanical equipment that does not need to be installed within the clean or controlled environment of the production facility. In one implementation, space **2822** is connected to loading bays including one or more dock doors for receiving supplies shipped by truck. Receiving space **2822***a* may be located more proximally to propagation space **2802** and seeding space **2808** in order to reduce the distance traveled for seeds, soil and other supplies consumed by such spaces. Similarly, outbound space **2822***b* may be located more proximally to post-harvest processing space **2806** and/or the cold storage area to facilitate loading of crops for shipment out of the facility. Similarly, the cold storage space may include dock doors allowing for flow of product out of a loading bay.

Although the disclosure may not expressly disclose that some embodiments or features described herein may be combined with other embodiments or features described herein, this disclosure should be read to describe any such combinations that would be practicable by one of ordinary skill in the art. Unless otherwise indicated herein, the term “include” shall mean “include, without limitation,” and the term “or” shall mean non-exclusive “or” in the manner of “and/or.”

Those skilled in the art will recognize that, in some embodiments, some of the operations described herein may be performed by human implementation, or through a combination of automated and manual means. When an operation is not fully automated, appropriate components of embodiments of the disclosure may, for example, receive the results of human performance of the operations rather than generate results through its own operational capabilities.

All references, articles, publications, patents, patent publications, and patent applications cited herein are incorporated by reference in their entireties for all purposes to the extent they are not inconsistent with embodiments of the disclosure expressly described herein. However, mention of any reference, article, publication, patent, patent publication, and patent application cited herein is not, and should not be taken as an acknowledgment or any form of suggestion that they constitute valid prior art or form part of the common general knowledge in any country in the world, or that they are disclose essential matter.

Several features and aspects of the present invention have been illustrated and described in detail with reference to particular embodiments by way of example only, and not by way of limitation. Those of skill in the art will appreciate that alternative implementations and various modifications to the disclosed embodiments are within the scope and contemplation of the present disclosure. Therefore, it is intended that the invention be considered as limited only by the scope of the appended claims.

What is claimed is:

1. A crop production facility for controlled environment agriculture, comprising:

a nutrient and thermal corridor;

an array of one or more grow rooms adjacent to the nutrient and thermal corridor, the array having a first end and a second end, the array extending substantially parallel to the nutrient and thermal corridor; wherein each of the grow rooms comprises

one or more grow lines, each of the one or more grow lines comprising a grow conveyance mechanism; and

a plurality of grow towers, each of the plurality of grow towers vertically attached to, and moveable along, a respective one of the one or more grow lines;

wherein each of the one or more grow lines comprises a first path section, a second path section, and a return mechanism operative to transfer grow towers from the first path section to the second path section;

wherein the grow conveyance mechanism conveys grow towers along the first path section in a first direction, and along the second path section in a second direction opposite the first direction;

a conveyance mechanism that injects and ejects grow structures from a side of the one or more grow rooms opposite the nutrient and thermal corridor;

a propagation space adjacent to the first end of the array and interfacing with the nutrient and thermal corridor; and

a central processing system comprising one or more grow structure processing systems adjacent to the array of grow rooms and opposite the nutrient and thermal corridor;

wherein one of the one or more grow structure processing systems is a harvester station, and wherein the crop production facility further comprises a post-harvest processing facility located adjacent to the central processing system and proximal to the harvester station;

wherein the harvester station comprises a crop harvesting machine, and a feeder mechanism to receive a grow tower in a horizontal orientation and feed the grow tower through the crop harvesting machine in a horizontal orientation; and wherein the crop production facility further comprises

an automated laydown station comprising a first robot including an end effector adapted to releasably grasp a grow tower, and control logic operative to cause the first robot to pick the grow tower from a pick location in a vertical orientation, rotate the grow tower to a horizontal orientation and place the grow tower on a conveyor for loading into the harvester station.

2. The crop production facility of claim 1 further comprising a seeding area adjacent to the propagation space.

3. The crop production facility of claim 1 further comprising a cold storage facility adjacent to the post-harvest processing facility.

4. The crop production facility of claim 3 further comprising a loading bay adjacent to the cold storage facility.

5. The crop production facility of claim 1 further comprising a conveyor configured to carry bins or harvested product directly on the belt from the harvester station to the post-harvest processing facility.

6. The crop production facility of claim 1 wherein each of the grow rooms is substantially encapsulated and comprises one or more control systems for controlling one or more environmental variables.

7. A crop production facility for controlled environment agriculture, comprising:

a nutrient and thermal corridor;

an array of one or more grow rooms adjacent to the nutrient and thermal corridor, the array having a first end and a second end, the array extending substantially parallel to the nutrient and thermal corridor; wherein each of the grow rooms comprises a substantially encapsulated growth environment containing a vertical grow tower conveyance system comprising

one or more grow lines, wherein each of the one or more grow lines comprises a first path section, a second path section, and a return mechanism operative to transfer grow towers from the first path section to the second path section;

a plurality of grow towers, each of the plurality of grow towers vertically attached to, and moveable along, a respective one of the one or more grow lines, wherein each of the plurality of grow towers includes a plurality of grow sites extending at least along one face thereof; and

a grow tower conveyance mechanism operative to convey grow towers along the first path section in a first direction, and along the second path section in a second direction opposite the first direction;

a central processing system, arranged adjacent to the array of one or more grow rooms and opposite the nutrient and thermal corridor, comprising

a harvester station comprising a crop harvesting machine, and a feeder mechanism to receive a grow tower in a horizontal orientation and feed the grow tower through the crop harvesting machine in a horizontal orientation;

a washing station comprising a second feeder mechanism to receive a grow tower in a horizontal orientation and feed the grow tower through the washing station in a horizontal orientation;

a transplanter station comprising a third feeder mechanism to receive a grow tower in a horizontal orientation and feed the grow tower through the transplanter station in a horizontal orientation;

a plurality of conveyors arranged to convey grow towers to and from respective ones of the harvester station, the washing station and the transplanter station, wherein the plurality of conveyors include a first conveyor arranged to feed a grow tower to the harvester station, a second conveyor arranged to feed a grow tower to the washing station, a third conveyor arranged to feed a grow tower to the transplanter station, and a fourth conveyor arranged to feed a grow tower from the transplanter station to a pickup location; and

an automated laydown station comprising a first robot including an end effector adapted to releasably grasp a grow tower, and control logic operative to cause the first robot to pick the grow tower from a pick location in a vertical orientation, rotate the grow tower to a horizontal orientation and place the tower on a conveyor for loading into the harvester station;

an automated pickup station comprising a second robot including an end effector adapted to releasably grasp a grow tower, and control logic operative to cause the second robot to grasp a grow tower from the pickup location in a horizontal orientation, rotate the grow tower to a vertical orientation for transfer to a select grow line of the plurality of grow lines; and a propagation space adjacent to the first end of the array and interfacing with the nutrient and thermal corridor.

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