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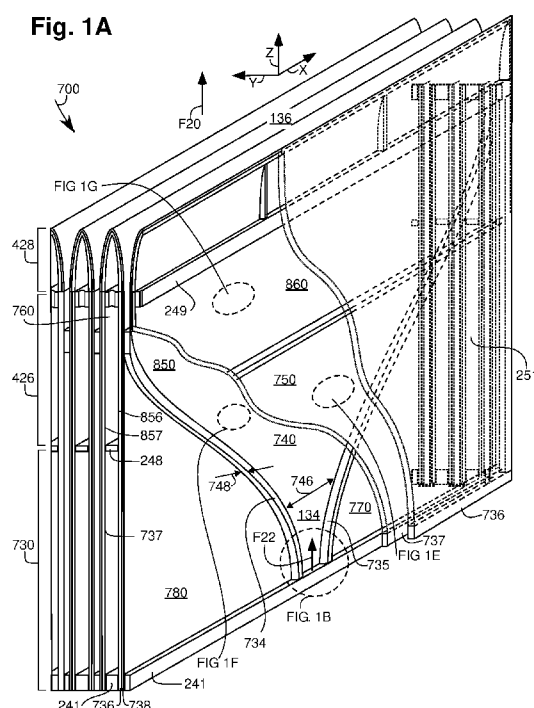
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(54) Title: SYSTEMS AND METHODS FOR SCALABLE COMBUSTORS

Fig. 1A



(57) Abstract: Systems and methods for scalable combustion are provided. A scalable combustor system includes a fluid delivery system configured to deliver a fuel fluid comprising a fuel, an oxidant fluid comprising an oxidant; and a diluent fluid comprising a diluent; into a combustor, in fluid communication with the fluid delivery system. The combustor includes a combustor chamber having a first combustor wall and a second combustor wall opposite the first combustor wall. The combustor additionally includes a plurality of orifices in at least one of the first and second combustor walls and a combustor outlet. The first and second combustor walls are transversely elongated relative to a shallow spacing between the first and second combustor walls, along directions transverse and perpendicular to a streamwise flow direction through the combustor.

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SYSTEMS AND METHODS FOR SCALABLE COMBUSTORS

CLAIM OF PRIORITY

This application claims the priority benefit of U.S. provisional patent application serial
5 number 63/547,814 filed on November 8, 2023 and entitled “SYSTEMS AND
METHODS FOR SCALABLE COMBUSTORS,” which is hereby incorporated by
reference in its entirety.

FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

[0001] This invention was made with U.S. Department of Energy High Performance For
10 Manufacturing (HPC4Mfg) grants with the Argonne National Laboratory, ANL No.
A18179 and A21020, and with the Lawrence Livermore National Laboratory, LLNL
No. TC02306 and TC02380.

JOINT RESEARCH AGREEMENT

[0002] This invention was made with government support under a Cooperative Research
15 and Development Agreement (CRADA) No. TC02380 between the Department of
Energy (DOE), Lawrence Livermore National Security LLC, University of Chicago
Argonne LLC, and VAST Power Systems, LLC. The government has rights in the
invention.

TECHNICAL FIELD

[0003] The present disclosure relates to combustor or reactor systems, and more
20 specifically, to scalable combustor systems.

BACKGROUND OF THE INVENTION

[0004] In certain combustion and power generation systems, such as conventional,
green, renewable, and/or sustainable energy systems, combustors are used to combust
25 or otherwise react fuels useful in generating thermal energy. For example, a combustor
can deliver and mix a fuel fluid comprising a fuel, an oxidizer fluid comprising an
oxidizer, and a diluent fluid comprising a diluent, to combust a fluid mixture comprising
fuel, oxidant, and a diluent, resulting in a working fluid having useful thermal energy.
The working fluid can then be used, for example, to produce heat and/or power via
30 direct and/or indirect energy transfers, such as rotating a gas turbine system, heating, or
cooling. It would be beneficial to improve on such combustor systems, processes, and
controls.

BRIEF DESCRIPTION OF DRAWINGS

[0005] Fig. 1A is an elevation view of a transversely elongated vertical Cuboidal “Scalable Combustor” with fluid manifolds feeding opposed combustor walls, according to some examples.

5 [0006] Fig. 1B is a schematic detail of an upstream flame authority in the Cuboidal Scalable Combustor, according to some examples.

[0007] Fig. 1C is an elevation view of a combusting chamber and Blend-Trim region in the Cuboidal Scalable Combustor, according to some examples.

10 [0008] Fig. 1D is an elevation view of upstream diluted oxidant, and downstream diluted oxidant fluid manifolds feeding a first side of an adjacent combusting chamber and Blend-Trim region of the Cuboidal Scalable Combustor, according to some examples.

[0009] Fig. 1E is a detail section of an insulated combusting chamber wall with diluted fuel delivery orifices in the Cuboidal Scalable Combustor, according to some examples.

15 [0010] Fig. 1F is a detail section of an insulated combusting chamber wall with diluted oxidant delivery orifices in the Cuboidal Scalable Combustor, according to some examples.

[0011] Fig. 1G is a detail section of an insulated wall in a downstream Blend-Trim region with diluted oxidant and diluent delivery orifices in the Cuboidal Scalable Combustor, according to some examples.

20 [0012] Fig. 1H is an elevation view of upstream diluted fuel and downstream diluted oxidant fluid manifolds in the vertical Cuboidal Scalable Combustor feeding a second side of the adjacent combusting chamber and Blend-Trim region, according to some examples.

25 [0013] Fig. 1I is a plan view of the vertical Cuboidal Scalable Combustor through plane A-A', according to some examples.

[0014] Fig. 2A is a schematic of a scalable combustor with a blower and diluent delivery, according to some examples.

30 [0015] Fig. 2B is a perspective view of a horizontal Cuboidal Scalable Combustor with diluent spray and common ignition authority, according to some examples.

[0016] Fig. 2C is a detailed section view of an insulated combusting chamber wall with fluid delivery orifices, according to some examples.

[0017] Fig. 2D is a perspective view of a vertically oriented Cuboidal Scalable Combustor section with downstream diluent delivery, according to some examples.

[0018] Fig. 2E is a perspective view of a vertically oriented Cuboidal Scalable Segmented Combustor section with multiple rich combusting delivery, and intermediate diluent delivery, according to some examples.

[0019] Fig. 3A An axial transverse schematic view of a Scalable Gas Turbine Combustor, according to some examples.

[0020] Fig. 3B A perspective upstream view of a cylindrical Scalable Gas Turbine Combustor with a common pilot, according to some examples.

[0021] Fig. 3C Detail of an insulated wall with fluid delivery orifices in a Scalable Gas Turbine Combustor, according to some examples.

[0022] Fig. 3D A Radial Circumferential Outer Cross Section of the Scalable Gas Turbine Combustor, according to some examples.

[0023] Fig. 3E A Circumferential Axial Unrolled Perspective of Symmetric Adjacent Gas Turbine Combusting Shell Sections, according to some examples.

[0024] Fig. 3F Graph of Axial Combustor Temperature, Ammonia Fuel, and NO_x, according to some examples.

[0025] Fig. 3G A Circumferential Axial Unrolled Perspective of a Symmetric Gas Turbine Feeder Manifold Section, according to some examples.

[0026] Fig. 3H A Circumferential Axial Unrolled Perspective of Adjacent Asymmetric Gas Turbine Combusting Shell Sections with common adjacent oxidant and Fuel Manifolds, according to some examples.

[0027] Fig. 3I A Circumferential Axial Unrolled Perspective of an Outer Asymmetric Combusting Blend-Trim Feeder, according to some examples.

[0028] Fig. 3J An axial-circumferential detail view of axially and circumferentially offset fuel and oxidant orifices from outer feeders into a combusting chamber, according to some examples.

[0029] Fig. 3K An axial-circumferential detail view of axially and circumferentially offset fuel and oxidant orifices from inner feeders into a combusting chamber axially and/or radially offset from opposed feeder orifices, according to some examples.

[0030] Fig. 3L An axial-circumferential detail view of axially and circumferentially offset diluent and/or oxidant orifices from outer feeder(s) into a downstream combustor Blend-Trim region, according to some examples.

[0031] Fig. 3M An axial-circumferential detail view of axially and circumferentially offset diluent and/or oxidant orifices from inner feeder(s) into a combustor Blend-Trim region axially and/or radially offset from radially opposed feeder orifices, according to some examples.

5 [0032] Fig. 3N A radial-axial elevation view of a CounterClockWise wall outer side of a radially outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

[0033] Fig. 3O A radial-axial elevation view inwardly adjacent to a CounterClockWise outer wall of an outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

[0034] Fig. 3P A radial-axial elevation view inwardly adjacent to a clockwise outer wall of an outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

15 [0035] Fig. 3Q A radial-axial elevation view of a clockwise wall outer side of a radially outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

[0036] Fig. 3R An axial-circumferential detail view of Fuel and offset oxidant delivery orifice spacing in fuel and oxidant feeders radially adjacent to a Scalable Combusting Region, according to some examples.

20 [0037] Fig. 3S An axial-circumferential detail view of fuel and aligned oxidant orifices in feeders adjacent a combusting region, according to some examples.

[0038] Fig. 3T A radial-circumferential detail view of fuel and oxidant orifice orientations into a combusting chamber from adjacent feeders, according to some examples.

25 [0039] Fig. 3U A radial-axial elevation detail view of fuel and oxidant channels and orifices in outer and inner feeders adjacent a radially outward combusting region, according to some examples.

[0040] Fig. 3V A radial-circumferential detail view of an oxidant orifice in a combusting chamber wall, according to some examples.

30 [0041] Fig. 3W A radial-circumferential detail view of an angled oxidant orifice in a combusting chamber wall, according to some examples.

[0042] Fig. 3X A radial-circumferential detail view of an oxidant feeder closed end, according to some examples.

[0043] Fig. 3Y A radial-circumferential detail view of a fuel feeder closed end, according to some examples.

[0044] Fig. 4A is an axial radial schematic view of a Gas Turbine System with a Scalable Combustor, according to some examples, according to some examples.

5 [0045] Fig. 4B is a perspective view of the upstream section of an Annular Scalable Gas Turbine Combustor with a feeder comprising multiple ignition authorities, according to some examples, according to some examples.

10 [0046] Fig. 4C is a detailed perspective view of an insulated wall with fluid delivery orifices in a Scalable Gas Turbine Combustor, according to some examples, according to some examples.

[0047] Fig. 4D is a Radial Circumferential Outer Cross Section of the Scalable Gas Turbine Combustor, according to some examples, according to some examples.

[0048] Fig. 4E is a Radial Axial Unrolled Perspective of Symmetric Adjacent Gas Turbine Combusting Shell Sections, according to some examples.

15 [0049] Fig. 4F is a Graph of Axial Combustor Temperature, Ammonia Fuel, and NO_x, according to some examples.

[0050] Fig. 4G is a Radial Axial view of a Symmetric Gas Turbine Feeder Manifold Section, according to some examples.

20 [0051] Fig. 4H is a Radial Axial view of Adjacent Asymmetric Gas Turbine Combusting Shell Sections with common adjacent oxidant and Fuel Manifolds, according to some examples.

[0052] Fig. 4I is a Radial Axial view of an Outer Asymmetric Combusting Blend-Trim Feeder, according to some examples.

25 [0053] Fig. 4J is a Radial Axial detail view of axially and circumferentially offset fuel and oxidant orifices from outer feeders into a combustor chamber, according to some examples.

[0054] Fig. 4K is a Radial Axial detail view of axially and circumferentially offset fuel and oxidant orifices from inner feeders into a combustor chamber axially and/or radially offset from opposed feeder orifices, according to some examples.

30 [0055] Fig. 4L is a Radial Axial detail view of axially and circumferentially offset diluent and/or oxidant orifices from outer feeder(s) into a downstream combustor Blend-Trim region, according to some examples.

[0056] Fig. 4M is a Radial Axial detail view of axially and circumferentially offset diluent and/or oxidant orifices from inner feeder(s) into a combustor Blend-Trim region

axially and/or radially offset from radially opposed feeder orifices, according to some examples.

[0057] Fig. 4N is a Radial Axial elevation view of a CounterClockWise wall outer side of a radially outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

[0058] Fig. 4O is a Radial Axial elevation view inwardly adjacent to a CounterClockWise outer wall of an outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

[0059] Fig. 4P is a Radial Axial elevation view inwardly adjacent to a clockwise outer wall of an outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

[0060] Fig. 4Q is a Radial Axial elevation view of a clockwise wall outer side of a radially outer combusting region of a Gas Turbine Scalable Combustor, according to some examples.

[0061] Fig. 4R is a Radial Axial detail view of Fuel and offset oXidant delivery orifice spacing in fuel and oxidant feeders radially adjacent to a Scalable Combusting Region, according to some examples.

[0062] Fig. 4S is a Radial Axial detail view of fuel and aligned oxidant orifices in feeders adjacent a combusting region.

[0063] Fig. 4T is a Radial Circumferential detail view of fuel and oxidant orifice orientations into a combusting chamber from adjacent feeders, according to some examples.

[0064] Fig. 4U is a Radial Circumferential elevation detail view of fuel and oxidant channels and orifices in outer and inner feeders adjacent a radially outward combusting region, according to some examples.

[0065] Fig. 4V is a Radial Circumferential detail view of an oxidant orifice in a combusting chamber wall, according to some examples.

[0066] Fig. 4W is a Radial Circumferential detail view of an angled oxidant orifice in a combusting chamber wall, according to some examples.

[0067] Fig. 4X is a Radial Axial detail view of an oxidant feeder closed end, according to some examples.

[0068] Fig. 4Y is a Radial Axial detail view of a fuel feeder closed end, according to some examples, according to some examples.

[0069] Fig. 5A is a Circumferential-Radial Cross-section of Combusting Chamber With Radial Combusting Regions, according to some examples.

[0070] Fig. 5B is a Circumferential-Radial Cross-section of Combusting Chamber With Combusting Regions at a Skew Angle to the Radial Axis, according to some examples.

5 [0071] Fig. 5C is a Close-Up Perspective View of The Combusting Regions at a Skew Angle to the Radial Axis, according to some examples.

[0072] Fig. 5D is a Graph of hot gas temperature T_{35} versus combustor radius R , from temperature T_{35i} at an inner radius R_i , to temperature T_{35o} at an outer radius R_o , at the downstream end of the fuel delivery region at the axial location CZ_{35} , according to some
10 examples.

[0073] Fig. 5E is a Graph of hot gas temperature T_4 versus combustor radius R , from temperature T_{4i} at inner radius R_i to temperature T_{4o} at outer radius R_o , at the combustor outlet CZ_4 , according to some examples.

[0074] Fig. 5F is a Graph of hot Wall Temperature TW versus combustor axial length Z ,
15 from a wall temperature TW_{35} at the downstream end of the fuel delivery region CZ_{35} , to a wall temperature TW_4 the combustor outlet at CZ_4 , according to some examples.

[0075] Fig. 5G is a Graph of hot gas mean Velocity V_{4M} versus combustor radius R at the combustor outlet CZ_4 , from inner velocity V_{4i} at inner radius R_{4i} to outer velocity V_{4o} at outer radius R_o , according to some examples.

20 [0076] Fig. 5H is a Graph of hot gas temperature T versus combustor circumferential angle Θ , cooled near downstream stators, with Inner Temperature T_i at combustor inner radius R_i , and Outer Temperature T_o at outer radius R_o , from a first combustion section Θ_1 to a second clockwise combustion section Θ_2 , according to some examples.

25 [0077] Fig. 5I is a Graph of hot gas temperature T versus combustor circumferential angle Θ , heated near downstream stators, with Inner Temperature T_i at combustor inner radius R_i , and Outer Temperature T_o at outer radius R_o , from a first combustion section Θ_1 to a second clockwise combustion section Θ_2 , according to some examples.

30 [0078] Fig. 5J is a Graph of hot gas velocity V versus combustor circumferential angle Θ , for Inner Velocities V_i at combustor inner radius R_i , and Outer Velocities V_o , at outer radius R_o , with a cooled counterclockwise first combustion section at Θ_1 and a clockwise second combustion section at Θ_2 , according to some examples.

[0079] Fig. 5K is a Scalable Omega Combustor Equilibrating Region Radial-Axial Cross-Section Elevation View, according to some examples.

[0080] Fig. 5L is a Premixed Scalable Combustor Premixing of Fuel, Oxidant and Diluent, Radial-Axial Plan View, according to some examples.

5 [0081] Fig. 5M is a Plan View of an Ignition Authority Outer Fuel and Oxidant Feeders with Fuel and Oxidant Orifices into the middle Combusting Region, according to some examples.

10 [0082] Fig. 5N is a Perspective View of an Ignition Authority Outer Fuel and Oxidant Feeders with Fuel and Oxidant Orifices into the middle Combusting Region, according to some examples.

[0083] Fig. 5O is a Schematic Plan View of an Ignition Authority Outer Fuel and Oxidant Feeders with Fuel and Oxidant Orifices into the middle Combusting Region, according to some examples.

15 [0084] Fig. 5P illustrates Fuel/Oxidant Orifices in Ignition Authority Upper Inner Wall Plan View, according to some examples.

[0085] Fig. 5Q is a Ignition Authority Mid-Section Plan View, according to some examples.

[0086] Fig. 5R illustrates Fuel/Oxidant Orifices in Ignition Authority Lower Inner Wall Plan View, according to some examples.

20 [0087] Fig. 5S is a Schematic Plan View of an Ignition Authority Inner Fuel and Oxidant Feeders with Fuel and Oxidant Orifices into the middle Combusting Region, according to some examples.

[0088] Fig. 5T is a Close-up schematic of Igniter in Wall of the Pilot Combusting Region, according to some examples.

25 [0089] Fig. 5U is a Radial-Axial Cross Section of Combustor Wall Fluid Cooling Capable of Ammonia Cracking, according to some examples.

[0090] Fig. 5V is a Radial Inner to Outer Temperature Profile (T vs R) of Equilibrating Zone Flow Temperature Upstream at CZ39 and Downstream at CZ4, according to some examples.

30 [0091] Fig. 6A is a Power Versus Temperature Graph of Brayton Cycle and VAST Cycles, according to some examples.

[0092] Fig. 6B is a Schematic of Control System Configuration of Controller Subsystems, according to some examples.

[0093] Fig. 6C is a Schematic Graph of Control System with Control Sections, according to some examples.

[0094] Fig. 6D is a Schematic Graph of Control System with Sensors, according to some examples.

5 [0095] Fig. 6E is a Schematic Graph of Low Pilot and Combustor Temperatures, Expander-Generator Speeds, and Power Generation versus Time Showing Flexible Operations, according to some examples.

[0096] Fig. 6F is a Schematic Graph of High Pilot and Emergency Combustor Temperatures, Expander-Generator Speeds, and Power Generation versus Time Showing
10 Flexible Operations, according to some examples.

[0097] Fig. 6G is a Combined Schematic Graph of Flexible & Emergency Low and High Pilot and Combustor Temperatures, Expander-Generator Speeds, and Power Generation versus Time, according to some examples.

15

DETAILED DESCRIPTION

[0098] A conventional combustor's delivery of fluids is impacted by the ability of combustor systems and processes used to spatially and/or temporally control the delivery of fuel (or reactant), oxidant (or co-reactant), and diluent fluids. Combustion and emissions (or reaction and byproducts) are often impacted by the distribution and rates of conventional fluid delivery and mixing. These are typically limited by physical, thermal, and temporal apparatus, fluid design, delivery, cooling systems, control processes, and material thermal and strength constraints.

[0099] Micro- to large Brayton gas turbines nominally use about 420% to 280% excess air to cool combustion to tolerable Turbine Inlet Temperatures (herein "TIT") over a range of about 1,000°C (1,832°F) to 1,500°C (2,732°F). Such large excess air flows increase the size and cost of compressors which are typically the most expensive component in Simple Cycle gas turbines. Compressing and re-expanding such large excess air fractions cause system losses in Brayton turbines. Large gas flows cause uncertainties in measuring TIT.

[0100] Combustor systems (or reactor systems) deliver fluids through relatively few passageways or orifices. Increasing fluid mixing typically incurs substantial pressure drops with associated power losses to achieve turbulence of injected fluids. E.g., gas turbine combustors may have fluid flow pressure drops of 2.5% to 5% of combustor inlet pressures, thus increasing compressor size and cost, while reducing system power and efficiency.

[0101] Reducing gas turbine emissions to certain levels (e.g., regulatory-imposed levels) in hot lean air diluted flames increases complexity and cost. Brayton gas turbine emissions such as nitrogen oxides (NO, N₂O, and NO₂, referred to herein collectively as "NO_x") and carbon monoxide (referred to herein as "CO") are typically substantially higher than international and other jurisdictionally legislated limits. Certain large gas turbines may be limited to operating above 50% of design power to constrain NO_x generation, and to enable NO_x emission catalytic cleanup to below legislatively prescribed levels.

[0102] Commercial combustion ranges over nine orders of magnitude from <1 Watt to >1,000 MW turbine systems. However, combustor systems generally do not scale well. Combustion systems are more difficult to design over widely different temperatures, pressures, power levels, and over rapid ramp-up rates, with frequent shutdowns.

[0103] Conventional or non-scaling combustors typically mix volumes of disparate fluids at pressures ranging from atmospheric to over 4.5 MPa (44 atmospheres). High performance gas turbines have TIT limited by material strength and cooling capabilities. E.g., often below 1,500°C (2,732°F). Higher combustion temperatures typically increase NO_x emissions. Conventional large Simple Cycle (Brayton) gas turbine generate emissions typically an order of magnitude higher than stringent legislated emissions. e.g., above typical ~2.4 parts per million by volume diluted to 15% Oxygen (referred to herein as “ppmvd” and O₂) NO_x legislated limits, for example in the state of California in the United States.

[0104] Combusting methane (referred to herein as “CH₄”) or natural gas at higher temperatures typically increases CO and Unburned Hydrocarbon (referred to herein as “UHC”) emissions. NO_x emissions generally increasing exponentially with temperature. Some gas turbines are being designed with the TIT approaching 1,700°C (3,092°F) which will likely amplify NO_x emissions and increase CO emissions. Reducing NO_x and CO emissions typically involves catalytic reduction systems that increase system complexity and may cost from 4% to 7% of installed capital cost. Reducing chemicals such as ammonia (referred to herein as “NH₃”), plus pumping, maintenance, and catalyst replacement commonly add cleanup operating costs over life of power production systems.

[0105] Very “lean” oxidant mixtures with high excess oxidant (e.g., air) concentrations have been used to reduce NO_x emissions. However, such lean operation may cause difficulties in maintaining combustion stability bordering on flameout. Combustion stability may constrain the lower turndown ratio and minimum power of gas turbines. Operational variations in commercial natural gas delivery (e.g., differing in chemical makeups and/or heating values) have reportedly even caused flameouts with shutdown of large gas turbines.

[0106] Conventional turbine combustion noise typically results in certain acoustic enclosures to meet legislated workspace or urban noise limits. Conventional concentrated fuel delivery can generate intense combustion dynamics in combustion systems, especially with low pressure gaseous fuel delivery. Highly diluted diffusion flames operating near combustion stability limits can cause and amplify self-excited thermoacoustic instabilities. Such factors make “noise” more difficult to control. Strong combustion acoustic resonance has been known to increase scheduled and/or

unscheduled maintenance activity for combustor liners, fatigue combustor sides, and mechanically distort combustor “cans”.

[0107] Certain gas turbines may use a “Rich Quench Lean” combustion methodology, with an initial fuel-rich combustion zone, a middle quenching zone, and a final lean-burn zone. Conventional inlet water injection, “fogging”, or “humid” combustion has had limited success in reducing gas turbine NO_x emissions. Injecting water mixed with liquid kerosene has caused quenching for mixtures with water/kerosene mass ratio (Omega) greater than 0.4 to 1.1 depending on equivalence ratio.

[0108] Certain water and steam delivery efforts have worsened combustion performance, increasing CO and UHC emissions. For example, water injection may use ultrapure water to reduce hot section deposits and corrosion, but may increase maintenance. It reportedly increases system complexity, and fuel consumption. Such conventional water purification costs alone may be high.

[0109] Injecting diluent in from outer walls of a cylindrical “can” combustor can cause poor mixing and circulation, limiting reductions in NO_x. Higher steam fractions increase ignition delay and reduce laminar flame speed. Quenching combustion can constrain water and steam delivery in typical Brayton gas turbines. Premixed fuel and oxidant delivery raises the possibility of combustion “flashback.” Likewise, higher flame speed of hydrogen (referred to herein as “H₂”) may amplify the flashback.

[0110] Efforts to transition to renewable fuels raise challenges of cost-effective power generation, delivery, storage, and use. Rising use of renewable (“sustainable” or “green”) fuels, such as hydrogen, ammonia (referred to herein as “NH₃”), methanol (referred to herein as “CH₃OH”), and ethanol (referred to herein as “CH₅OH”), may raise combustor design, control, and durability issues. For example, hydrogen use can increase intra-combustion temperatures, extend flammability limits, and increase emissions, such as of CO and NO_x.

[0111] Ammonia (NH₃) is generally available for agriculture and is a leading candidate for renewable fuels. However, conventional ammonia combustion commonly generates higher NO_x than legislated emission levels. Ammonia low flame speed may further impact combustion operating regimes. Cracking ammonia back to hydrogen and nitrogen typically requires more equipment, heat, catalysts, and operating effort.

[0112] Increasing non-dispatchable renewable power use is rapidly increasing the frequency of backup power use to sustain grid power frequency, and for minimizing or preventing grid blackouts. Frequent large thermal cycling with high temperatures can

lead to lessening the life of insulating tiles in cylindrical “can” combustors and additionally fatigue combustor sides.

[0113] Increasing ambient temperatures typically reduce conventional gas turbine power. This causes reductions in backup power capacity when it is most needed for cooling in hot climates. E.g., Brayton cycle “peaker” gas turbines may lose ~13% in peak power and a further ~2.5% in efficiency for a 25 kelvin (Celsius deg) increase in ambient temperature from rated power at 15 deg C up to 40 deg C (59 deg F to 104 deg F) hot ambient conditions.

[0114] Higher combustion temperature at peak power typically rapidly increases blade creep that reduces a gas turbine’s useful life. E.g., just increasing temperature as power increases from 70% to 100% in conventional Brayton “peaker” gas turbines may cause about a 300-fold reduction in life, due to rapidly increasing creep with higher temperature. A ten kelvin increase or decrease in TIT may halve or double the life of some gas turbines. Yet such high temperatures are difficult to accurately measure or control in conventional gas turbines.

[0115] Cycling power in conventional Brayton cycle turbines further causes thermal creep, with higher cyclic strain fatigue. High TIT temperature sensors may be adversely affected, leading to more frequent maintenance. Combustor failure results in unwanted maintenance of power systems. Discrete fuel injectors and combustor liner cooling can cause combustor hot streaks that vary TIT and temperature distribution. Conventional combustion, its variations, and higher TIT make it more difficult to accurately sense TIT temperatures.

[0116] Legislation requiring higher renewable energy is increasing the retirement of dispatchable coal fired power systems. Higher renewable energy use is increasing the use of standby power and backup gas turbines, with more frequent starts and faster power ramps. Higher renewable energy use is further forcing combined cycle turbines to operate at lower annual capacity factors with more frequent power cycling. Such trends are degrading grid resilience and reliability.

[0117] California’s “100 Percent Clean Energy Act of 2018” mandated a Renewable Power Standard (RPS) with targeting 60% of electricity from eligible renewable energy sources and zero-carbon resources by 2030, and 100% by 2045. Such legislated increases in renewable power are reducing the average annual usage of combined cycle base load power. Reduced usage with more frequent cycling is making

combined cycle turbines more maintenance prone, and reducing availability, despite their higher efficiency. Increased cycling is similarly degrading peaker gas turbines and increasing backup costs.

5 [0118] Legislated increases in renewable power are projected to increase California Independent System Operator (CAISO)'s "Duck Curve" of rapid backup power demand ramp. This ramp from an afternoon peak solar to an evening peak demand is projected to reach ~7,400 MW/hr (~26,000 MW rise/3.5 hours) on weekdays by 2030. Solar and wind supplied about 36% California Independent System Operator (CIASO's) power in 2019.

10 [0119] Non-dispatchable solar plus wind power have already exceeded 97% of CIASO's demand. Declining reliable dispatchable generation needed left CIASO with a 1,700 MW shortfall in its 2022 planned capacity. CIASO was forced to implement rolling ("rotating") blackouts during heat waves in August 2020 and September 2022.

15 [0120] Besides rapid 15-minute dispatches, CIASO has now added faster 5-minute dispatches. CIASO has even introduced 1 minute interval emergency dispatches to stabilize grid voltage and control grid frequency. Ramp up rates for major combined cycle and industrial gas turbines were up to 8 hours to avoid turbine fatigue. Now, ramp rates may be reduced from 30-minute startups to about 10 minutes for combined cycles, 5 minutes for industrial turbines, and even 2 minutes for aeroderivative turbines.

20 [0121] CAISO's increasingly frequent dispatches may be causing higher thermal cyclic fatigue that can lead to shortening the life of gas turbines and turbine blades. This requires more frequent inspections, and refurbishments, with a markedly shorter useful life. Consequently, higher non-dispatchable solar and wind use have increased California's retail power costs to about twice that in other US western states.

25 [0122] The 2021 winter storm Uri triggered blackouts in the Electric Reliability Council of Texas' (ERCOT) grid. Renewables could not compensate for power generation and natural gas supply failures. In 2023, ERCOT warned: "On the hottest days of summer, there is no longer enough on-demand dispatchable power generation to meet demand..."

30 [0123] The North American Electric Reliability Corp. (NERC), in its 2023 Summer Reliability Assessment, warns that 2/3rds of North America risks energy shortfalls with rolling blackouts, during periods of extreme demand at peak summer temperatures with low winds. i.e., in the seven power regions of SPP and MISO (US West), ERCOT

(Texas), SERC Central (particularly North & South Carolina), and NPCC (New England and Ontario).

[0124] Current trends of increasing non-dispatchable renewable power while reducing adequate rapid backup power generation or storage capacity is increasing the likelihood of blackouts. The US Energy Information Agency (EIA) (2020) projected 46.5 GW loss in Reliable Electricity Capacity from 2022-2030 (with 72.3 GW reductions and only 25.8 GW of additions).

[0125] The US Environmental Protection Agency's (EPA) 2023 "Greenhouse Gas Standards and Guidelines for Fossil Fuel-Fired Power Plants Proposed Rule" seeks to reduce or sequester 90% of CO₂ emissions by 2030 from coal and natural gas power plants that now supply 20% and 40% of US electricity. That could further reduce US Reliable Electricity Capacity.

[0126] Extended periods of low solar and wind can lead to increased use of non-renewable power and/or energy storage to ensure grid reliability. E.g., During Germany's dark cold winter doldrums ("Dunkelflaute") it experienced a shortage of 18 days of average load (27 TWh) equivalent of wind and solar availability in 1996-1997. Germany's maximum wind plus solar power generation often drop below 3% of total demand in such doldrum periods.

[0127] These trends may increase operating, maintenance, and refurbishment requirements, reduce availability, shorten system life, increase NO_x and CO emissions, in both simple Brayton cycle gas turbines, and of combined cycle (base load) gas turbines. These trends may increase the need for cleaner reliable power with rapid response rates, particularly for intermediate usage above peaking power and below conventional base load.

Scalable Combustor Design and Operation

[0128] Accordingly, several technical features in this disclosure lead to reactors that deliver and more cleanly burn reactant, oxidant, and, in some examples, add diluent fluids. The techniques described herein include combustors that combust fuel with an oxidant (e.g., air or oxygen), and that may add a diluent such as water, carbon dioxide, nitrogen or excess oxygen, in any phase and/or combination, in ways that are more scalable across broader ranges of commercial combustor pressures, temperatures, and/or power levels, therein improving power system capabilities and economics.

[0129] The techniques described further scalably design combustors for wider operating ranges in gas turbine systems, with fuel, oxidant, and diluent types, combinations, and

loads, therein enabling more reliable grid operation and backup with major intermittent non-dispatchable renewable power penetration.

[0130] The techniques enable widely scaling combustor designs with power; e.g., providing a greater than a 10:1, or a 25:1 or wider range in power per combusting shell from their mean, and using multiple shells, therein increasing design capability and economics.

Diffusing Region

[0131] Diffusing region techniques include varying delivery of liquid and/or gaseous diluent through multiple orifices into the upstream fluid delivery region, therein improving fluid delivery rates, liquid evaporation, and/or combustion.

Pilot Ignition

[0132] Techniques include providing a diluted fuel rich pilot to more cleanly provide ignition of downstream fluid delivery, therein initiating reliable combustion while reducing the generation of NO_x emissions.

Combusting Region Manifolds and Feeders

[0133] Techniques further include providing an oxidant rich manifold, and a fuel rich manifold transversely adjacent to one or more combusting chambers, therein improving scalability, mixing, combustion, and economics.

[0134] Techniques include providing a diluent manifold or duct adjacent to an oxidant or fuel manifold, mixing gaseous and/or liquid diluent with oxidant and/or fuel, and delivering mixed fluid through orifices, therein facilitating fluid mixing and delivery.

[0135] Techniques include providing a diluted oxidant rich manifold between perpendicularly or transversely adjacent combusting chambers, therein reducing the number of oxidant manifolds, and improving manufacturability and economics.

[0136] Techniques include providing a diluted fuel rich manifold between perpendicularly or transversely adjacent combusting chambers, therein reducing the number of fuel manifolds, and improving manufacturability and economics.

Combusting Chamber

[0137] Techniques include providing the upstream combusting chamber in a transversely elongated distribution having a transverse width to perpendicular (or radial) depth ratio normal to the flow axis greater than 1.15, and with fuel, oxidant, and diluent fluid delivery through the elongated walls, therein improving fluid mixing into and/or in the combusting chamber.

[0138] Techniques include adjusting the angle orifices transverse to the fluid flow relative to the combustor chamber wall surface normal, therein improving combustor fluid mixing.

5 [0139] Techniques include adjusting the number of transversely distributed fuel and oxidant fluid delivery orifices through opposing shallowly displaced sides of the combustor, as a function of axial distance upstream to downstream, therein improving combustor fluid mixing and combustion reliability.

[0140] Techniques include transversely offsetting oxidant rich fluid orifices relative to fuel rich fluid orifices, therein improving fluid mixing.

10 [0141] Techniques include changing or reducing upstream diluent/oxidant and/or diluent/fuel ratios, relative to hot pilot fluid delivery and/or to downstream combustor orifices, therein improving upstream combustibility and extending combustion delivery limits.

Combustion Quenching, Stability, and Flashback

15 [0142] Techniques include delivering fuel rich fluid through adjacent transverse fuel feeders, and oxidant rich fluid through separate adjacent transverse oxidant feeders, through respective orifices into the combustor chamber, therein improving combustor fluid mixing, and reducing quenching or flashback risks.

20 [0143] Techniques provide configuring combustor upstream transverse width versus axial length profiles, of one or more combustor chambers, within combustion stability, manufacturability, and aerodynamic flow efficiency objectives, therein improving reliability and competitiveness.

Blend Trim Region

25 [0144] Techniques include controlling remaining diluent delivery and mixing in the blend trim region, to axially control cumulative diluent to fuel mass ratios Ω , therein configuring axial combustor and equilibrating temperature profiles and reducing emissions to below prescribed regulatory levels.

30 [0145] Techniques include controlling remaining oxidant delivery and mixing in the blend trim region, to axially and/or transversely control cumulative relative oxidant to fuel mass stoichiometric ratios Λ , therein configuring axial and/or transverse combustor and equilibrating oxidant profiles and reducing emissions to below prescribed regulatory levels.

Scalable Pilot Combustor

[0146] Techniques further provide controlling upstream pilot combusting region temperature equal to or greater than downstream combusting chamber diluted fuel oxidant mixture standby ignition temperature, therein improving pilot reliability;

[0147] Techniques may provide multiple upstream pilot chambers feeding respective scalable combusting chambers or regions, therein improving combustion scalability, range, ramp rate, and/or reliability.

Combustor Outlet Temperature Control and Scaling

[0148] Techniques may further improve control of Combustor Outlet Temperature (COT), or Turbine inlet Temperature (TIT), reduce outlet temperature variation, and/or reduce outlet temperature uncertainty.

[0149] Techniques may include configuring fluid delivery to control diluent to fuel mass ratio Omega with the relative oxidant to fuel ratio Lambda across a plurality of orifices, therein scaling combustor designs across wide temperature ranges, e.g., between about 700°C to 2,500°C for commercial combustors and/or gas turbines.

[0150] Techniques may control fuel, oxidant, and/or diluent fluid delivery rate per combustor volume, (MW/m³-atm) and provide predominantly axial laminar flow within the combustor, therein improving transverse combustor outlet or turbine inlet temperature (TIT) control, expander durability, and economics.

Scalable Control of NO_x and CO Emissions

[0151] Techniques provide for designing combustor fuel, and/or oxidant spatial fluid delivery rates to substantially reduce NO_x and CO emissions relative to conventional combustors. In some configurations these may deliver NO_x and CO emissions below legislated emission limits; e.g., NO_x and/or CO below 75 ppmvd.

[0152] Techniques further include reducing NO_x and/or CO emissions while controlling combustor outlet temperature within a range from 500°C to 2,500°C, by using thermal diluent spatial fluid delivery rates, therein increasing applications, thermal efficiency, and/or economics; e.g., by controlling the H₂O, CO₂, N₂, O₂ and/or other diluent to fuel mass delivery ratio Omega, for an Omega greater than about 1.15, (or the corresponding enthalpy delivery ratio) and with lower catalyst and reductant usage than with Brayton turbines.

[0153] Further techniques and advantages of the invention will become apparent from consideration of the drawings and ensuing description.

SUMMARY OF THE DISCLOSURE

[0154] The techniques described herein include scalable ultraclean combustion (or chemical reaction) and equilibration equipment, configurations, and processes. These may progressively deliver and combust mixtures of fuel, oxidant, and thermal diluent along the axial flow direction. These techniques may deliver fluids via one or more fuel, oxidant, and diluent fluid manifolds, through numerous fuel, oxidant, and/or diluent orifices into one or more upstream combusting chambers, and downstream Blend-Trim regions.

[0155] Such techniques described herein may comprise one or more upstream transversely elongated combusting chambers with shallowly separated combusting chamber walls relative to the axial flow direction, (referred to herein as “transversely elongated”). Combusting techniques may configure enclosed transverse cross-sectional combusting areas that generally increase along the axial flow direction. Such techniques may configure fluid compositions in combusting regions preferably provide upstream fuel rich conditions, while maintaining combusting temperatures above quench limits.

[0156] These techniques may distribute numerous fuel fluid (or reactive fluid) orifices and oxidant fluid (such as air, or co-reactant fluid such as oxygen) orifices across the transversely elongated shallowly separated combusting chamber sides. Fuel and/or oxidant fluids may be fed into the fuel and oxidant fluid orifices from respective fuel and/or oxidant manifolds.

[0157] Further techniques may configure downstream Blend-Trim regions with similar transversely elongated walls with shallow spacing, configured transversely and normal to the axial fluid flow axis. Blend-Trim techniques may similarly configure oxidant and/or diluent delivery through numerous orifices in transversely elongated shallowly spaced walls about the combusting flow. These techniques may further combustion, control combustor axial and outlet temperature(s), and control emissions (or minor products).

[0158] Techniques may further mix diluent fluid with fuel fluid, oxidant fluid, and/or Blend-Trim oxidant fluids to deliver them into the combusting chamber, and/or Blend-Trim region, through respective fuel, oxidant, and/or Blend-Trim orifices. Similar techniques may use upstream flame authorities comprising fuel, oxidant, and diluent with rich primary combustion and downstream oxidant and diluent trim, wherein

similarly constraining combustion temperatures to provide reliable combustion while constraining emissions.

[0159] Such techniques may vary the composition of fuel, oxidant, and/or diluent delivered into upstream versus downstream combustors and/or Blend-Trim regions. Such combustors and Blend-Trim regions may be replicated to scale the combustor (or reactor) to provide the combustor power (or reacting rate) desired while achieving improved mixing and low emissions (or byproducts).

[0160] Referring Fig. 1A and Fig. 1B, combustor fluid temperature in an upstream combustor chamber 740 and/or a downstream Blend-Trim region 850 may be controlled by controlling one or more of the ratios of diluent fluid F7 to fuel fluid F1, diluent fluid F7 to oxidant fluid F4, and/or diluent fluid F7 to Blend-Trim oxidant fluid F4, in diluted fuel fluid delivery F2, upstream diluted oxidant fluid delivery F5, and/or downstream Blend-Trim diluted oxidant fluid delivery F15, and diluent fluid F7, and/or liquid diluent fluid F14 delivered into the Blend-Trim region. The transverse cross-sectional area (X-Y axes) of the combustor chamber 740 may be progressively increased along the axial fluid flow direction (Z axis) to progressively increase the combustor chamber volume, and to accommodate gas expansion from increasing temperature. This may beneficially reduce axial fluid acceleration and fluid pressure drop across the combustor.

[0161] An upstream diluted ignition authority or pilot 720 may be configured to provide a diluted pilot flame F22 to reliably ignite downstream fuel fluid F2 and diluted oxidant fluid F5. This may include controlling a pilot combustor temperature and pilot combustor emissions resulting in pilot fluid F22. A downstream diffuser 429 may be used to reduce an axial combustor fluid pressure drop while providing additional combustor (or reacting) residence time to reduce unburned fuel and combustor (or reacting) emissions such as carbon monoxide and oxides of nitrogen.

[0162] Referring to Fig. 2A through Fig. 2E, combustor fluid oxidant concentration (or oxidant to fuel ratio) in the combustor region 740 may be varied between an upstream combustor region 742 and a downstream combustor region 744. The order and magnitude of residual oxidant fluid and/or of residual diluent fluid may be varied in the Blend-Trim region 850. E.g., they may be varied between an upstream Blend-Trim region 852, and a downstream Blend-Trim region 854.

DETAILED DESCRIPTION

Scalable Combustor Design and Operation

[0163] Certain embodiments of a scalable reactor or scalable combustor 700 are depicted in Fig. 1A, as further detailed in Fig. 1B through Fig. 1I. These embodiments exhibit one or more transversely elongated shallow combusting chambers 740 in a combustion section 730, disposed between combusting chamber near and far side feeder walls and 737 spaced shallowly apart (along the Y axis), and bounded transversely (along an X axis) to a longitudinal axial flow direction (along a Z axis) by combusting chamber near end walls 734 and far end walls 735 perpendicular to the longitudinal axial flow direction (along the Z axis) from an upstream inlet region 134 to a downstream outlet 136.

[0164] Further embodiments of a scalable reactor or scalable combustor 706 with a combusting section 730 are shown in Fig. 2A as further detailed in Fig. 2B through Fig. 2E. A blower 406 (BLW) may be used to compress an intake air or oxidant mass flow WX2, comprising optional liquid diluent F7, to a pressurized oxidant mass flow WX3 and deliver it to the inlet of a diffuser 420 at axial location CZ31. Such configurations may include an upstream diluent delivery section 710 comprising diluent delivery spray system 24, an ignition section 720 comprising an ignition authority or pilot 100, the combusting region 740, the Blend – Trim region 850 for further oxidant and diluent delivery, and an equilibration zone 750. These may deliver a hot fluid flow W4 exiting the combustor 706 after the end of the equilibrating zone 750 at CZ 394.

Transversely Elongated Perforated Combustor Side Walls

[0165] Certain embodiments of a cuboidal configuration of the scalable reactor or combustor 700 are depicted in Fig. 1A, as further detailed in Fig. 1B through Fig. 1I. In one embodiment, the cuboidal scalable reactor or combustor 700 may be formed by creating one or more transversely elongated shallow reacting regions or combusting chambers 740 in an upstream combustion section 730 of the scalable reactor or combustor. The embodiment of Fig. 1A, including detail in Fig. 1B, displays the scalable combustor 700 oriented with an upstream inlet region 134, near an upstream combustor end wall 241, with an upstream pilot chamber 720. Said scalable combustor 700 has a downstream combustor outlet 136 at the downstream combustor end (or top in the Z direction).

[0166] In this embodiment, the scalable combustor 700 is configured with a flow direction from an upstream pilot fluid F22 flow at the upstream inlet 134, to an energetic fluid F20 exiting the combustor outlet 136, along a generally upward vertical direction (similar to the vertical Z axis). In other embodiments, the flow axis of the scalable combustor 700 may be oriented horizontally, or downwards, or at some intermediate angle.

[0167] Per Fig. 1A, in this embodiment, the upstream combustion section 730 may comprise one or more elongated shallow reacting or combusting chambers 740 generally elongated in a transverse direction (X axis). In this embodiment, this is depicted as generally perpendicular to the primary axial flow direction (along the Z direction). Correspondingly, such one or more combusting chambers 740 may be generally shallowly displaced in a normal direction (Y axis) perpendicular to the transverse elongation direction, (typically normal to both the axial flow in the Z axis and to the transverse X direction).

[0168] Correspondingly, Figs. 2B, Fig. 2D, and Fig. 2E detail such scalable reactor configurations 706, depicted here in a similar cuboidal configuration. Fig. 2B, Fig. 2D, and Fig. 2E similarly show the combusting section 730 with the combusting chamber 740 bounded by transversely elongated (“far” side) oxidant feeder perforated wall 737, and an opposing combusting chamber transversely elongated (“near” side) fuel feeder perforated wall 736.

[0169] Similarly, per Fig. 2D and Fig. 2E, the combusting chamber 740 may further be configured into an upstream combusting chamber 742, and a downstream combusting chamber 744. Upstream combusting chamber 742 may be bounded by upstream perforated fuel feeder 805 with orifices 81 and upstream perforated oxidant feeders 815 with orifices 82. Downstream combusting chamber 744 may be bounded by downstream perforated fuel feeder 806 with orifices 81 through fuel feeder walls 736, and downstream perforated oxidant feeders 816 with orifices 82 through oxidant feeder walls 737.

Combusting Chamber Transverse End Walls

[0170] Further per Fig. 1A, such transversely elongated shallow combusting chambers 740 may generally be configured between correspondingly sized combusting chamber side fuel feeder walls 736 and oxidant feeder walls 737 similarly transversely elongated along the X direction. The combusting chamber 740 between such elongated combusting side fuel feeder walls 736 and oxidant feeder 737 may be transversely

bounded along the transverse X direction by combustor chamber bounding end walls. These transverse end bounds typically include a combustor chamber near end wall 734 (in the negative X direction), and a combustor chamber far end wall 735 (in the positive X direction).

5 [0171] Further per perspective views Fig. 2D, and Fig. 2E, transversely elongated shallow combustor chambers 740 with combustor chamber side feeder perforated walls 736 and 737, may be transversely bounded by combustor chamber bounding end walls such as end walls 734, similar to that shown in Fig. 1A, Fig. 1C, and elevation view Fig. 1D.

10 Shallowly Separated Combustor Chamber Side Walls

[0172] Per Fig. 1A, the elongated far side feeder wall 737 and near side feeder wall 736 may be spaced shallowly apart with a shallow spacing depth 748 in the Y direction perpendicular (normal) to both the axial flow and the transverse X direction. Such shallow spacing depth 748 may separate near side feeder walls 736 and far side feeder walls 737 relatively closer, in the perpendicular Y direction, than the transverse elongated width 746 separating the near end wall 734 from the far end wall 735 and bounding the elongated combustor chamber 740 along the transverse X direction. Such shallow separation spacing 748 or perpendicular (normal) combustor chamber depth, between elongated side feeder walls 736 and 737 bounding the combustor chamber 740, may be provided by a corresponding shallow separation depth of the near side bounding walls 734 and far side bounding walls 735 separating elongated nearside feeder walls 736 and elongated far side feeder wall 737 along the Y axis perpendicular to the Z flow axis.

Combustor Section Manifolds and Ducts

25 Opposed Fuel and Oxidant Ducts

[0173] With reference to Fuel Fluid Delivery Elevation View Fig. 1D, Fuel Fluid Wall Section View Fig. 1E, Oxidant Fluid Wall Section view Fig. 1F, and Oxidant Manifold Elevation View Fig. 1H, in one embodiment, a separated fuel-oxidant scalable combustor may be formed having at least one first fluid or fuel manifold 770 configured to deliver first fuel fluid F1, comprising fuel fluid (and/or reactant fluid), to one or more perforated fuel feeders 750 (or first fluid reactant perforated delivery ducts) such as shown in Fig. 1D and Fig. 1I. As shown in Fig. 1A, 1C, 1H and Fig. 1I, this embodiment may comprise at least one second fluid or oxidant manifold 780 configured to deliver second oxidant fluid F4 comprising oxidant fluid (or second co-reactant) through

oxidant manifolds 780 to one or more perforated second fluid or oxidant delivery ducts or oxidant feeders 760 having a plurality of oxidant orifices 82 to deliver second oxidant fluid F4 into the combustor chamber 740.

[0174] Referring further to Fuel Fluid Delivery Elevation View Fig. 1D and Fig. 1E, in some configurations, the first fuel fluid F1 may be mixed with third diluent fluid F7 to form and deliver a diluted fuel fluid F2 for delivery into fuel manifold 770, and thence into perforated fuel feeders 750 (or perforated reactant delivery duct). The second oxidant fluid F4 comprising oxidant fluid and/or co-reactant fluid may be diluted with diluent fluid F7 to form diluted oxidant (and/or co-reacting) fluid F5 for delivery into oxidant manifold 760.

[0175] As depicted in combustor perspective view Fig 1A, Fuel Fluid Delivery Elevation View Fig. 1D, Oxidant Fluid Delivery Elevation View Fig. 1H and Combustor Plan View Fig. 1I, diluted first fluid or fuel fluid F2 may similarly be delivered from fuel manifold 770 into perforated fuel feeders 750 adjacent to the combustor chamber(s) 740. Similarly, diluted second fluid, diluted oxidant (or co-reactant) fluid F5 may be delivered from oxidant manifold(s) 780 into oxidant fluid feeder (perforated duct(s)) 760 adjacent to combustor chamber(s) 740.

[0176] As depicted in Combustor Plan View Fig. 1I, a central combustor/feeder region 739 may comprise one or more fuel feeders 750 having perforated near side fuel feeder wall(s) 736, and one or more oxidant feeders 760 (perforated second fluid ducts) having perforated far side oxidant feeder wall(s) 737. These fuel feeders 750 and oxidant feeders 760, may form proximate combustor chambers (or zone(s)) 740 between opposing fuel feeders 750 and oxidant feeders 760, and bounded by perforated fuel feeder walls 736 and oxidant feeder walls 737, and combustor chamber end walls 734 and 735.

[0177] Referring to Fig. 1E, Fig. 1F, Fig. 1G, and Fig. 1I, fuel fluid orifices 81, oxidant fluid orifices 82, and Blend-Trim oxidant ports or orifices 83 in the respective near side fuel feeder walls 736, and far side oxidant feeder walls 737, Blend-Trim oxidant near side feeder walls 856 and Blend-Trim oxidant far side feeder walls 857 may be configured to provide respective distributions of one or more of fluid port diameters and port spacings along the streamwise flow direction. These may be configured to provide desired streamwise distributions of fuel fluid and oxidant fluid delivery to achieve desired streamwise composition distributions in the energetic fluids within a plurality of streamwise reaction zones.

[0178] Similarly, as depicted in Combustor Perspective View Fig. 2D, fuel fluid orifices 81, and oxidant fluid orifices 82 may be configured in fuel feeder walls 736, and oxidant feeder walls 737. These deliver fuel fluid F2 through diluted fuel feeder 804, and oxidant fluid F5 through diluted oxidant feeder 814 into the combustor chamber or region 740.

[0179] As depicted in Segmented Combustor Perspective View Fig. 2E upstream and downstream fuel and oxidant fluid delivery feeders may be configured to feed fuel and oxidant fluids with different diluent compositions into upstream combustor regions 742 and downstream combustor regions 744. E.g., fuel fluid F1 may be delivered through perforated fluid delivery feeder 805 via fuel orifices 81 into upstream combustor chamber(s) 742. Similarly diluted fuel fluid F2 may be delivered through downstream fuel fluid delivery feeder 806 via fuel orifices 81 into downstream combustor chamber(s) 744.

[0180] Correspondingly, oxidant fluid F4 may be delivered through upstream perforated oxidant fluid delivery feeder 815 via oxidant orifices 82 into the upstream combustor chamber 742. Similarly diluted oxidant fluid F5 may be delivered through downstream oxidant fluid delivery feeder 816 via oxidant orifices 82 into a downstream combustor chamber 744.

[0181] Further in Fig. 2E, in similar configurations, upstream and downstream fuel fluids F1 and F2 may comprise differing diluent compositions. E.g., the diluent to fuel ratio Ω_1 and Ω_2 of fuel fluids F1 and F2 may be configured differently in the upstream perforated fuel feeder 805 versus the downstream perforated fuel feeder 806. This enables controlling the temperature differently upstream combustor region 742 versus downstream combustor region 744 degrees of diluent to fluid composition.

[0182] Similarly upstream and downstream oxidant fluids F4 and F5 may comprise differing degrees of diluent to oxidant composition. These fluids may be configured to control the relative oxidant to fuel ratio to stoichiometric oxidant to fuel ratio Λ of F4 in the upstream oxidant feeder 815 into the upstream combustor region 742 differently from the relative oxidant to fuel ratio Λ of diluted oxidant fluid F5 in the downstream oxidant feeder 816 into the downstream combustor region 744. This enables controlling combustor region richness (relative oxidant to fuel ratio) and thus the fuel combustor or oxidizing rate in the upstream combustor region 742 differently from that the downstream combustor region 744.

[0183] The separated fuel-oxidant combustor may be configured in generally transversely elongated shallow combusting chambers 740, (such as rectangular-like configurations) between opposed perforated duct sides (or liners) and in an axial direction along the fluid flow.

5 [0184] With further reference to Fig. 1A, Fig. 1C, Fig. 1D, and Fig. 1H, the scalable combustor 700 may be configured with a downstream transversely expanding (or hand “fan”) shape combusting chamber 740, between transversely bounding end walls 734 and 735 (in the X direction), (between shallowly separated side feeder walls 736 and 737) that generally increases transversely (in the X direction) to the fluid flow, along
10 the streamwise flow direction (along the Z axis) and with progressively increasing fluid flow.

[0185] This scalable combustor may be configured such that the cross-sectional area of the combusting (or reacting) zones increases with increasing axial distance along the flow direction. The opposed fuel fluid and oxidant fluid delivery through perforated
15 fuel and oxidant feeders may comprise individually mixed proportions of diluent as desired to achieve a desired axial temperature distribution. The effectiveness of the Thermal Barrier Coating (TBC) may be adjusted (or the TBC removed) to configure the heat transfer rate from the reaction zone to the fluid within one or both adjacent ducts.

20 Downstream Blend-Trim Region

[0186] Per Fig. 1A, and Fig. 1C, a Blend-Trim section 426 comprising a Blend-Trim region 850 may be configured downstream of the combustion section 730 comprising the combusting chamber 740. This Blend-Trim region 860 may deliver one or both of further oxidant fluid F4 and/or further diluent fluid F7. These oxidant fluids F4 and
25 diluent fluids F7 may be mixed such as by delivering diluted second reactant fluid or diluted oxidant fluid F5 into the Blend-Trim region 860.

[0187] Per Fig. 1D and Fig. 1H, the Blend-Trim region may axially begin at an adjacent upstream Blend-Trim manifold bounding wall 248 separating fluid delivery into the upstream combusting chamber (or region) 740 from diluted oxidant fluid delivery into
30 the downstream Blend-Trim region 850. The Blend-Trim region 850 may extend to a downstream Blend-Trim Manifold and Blend-Trim feeder bounding wall 249.

[0188] The Blend-Trim region of Fig. 1A further depicts a portion of the transversely elongated downstream Blend-Trim region near side wall 856 and Blend-Trim region far side wall 857 between transversely bounding near end wall 734 and transversely

bounding far end wall 735, (or between counterclockwise walls 250 and clockwise walls 251) such as shown in Fig. 1D and Fig. 1H. The downstream Blend-Trim region side wall 856 and side wall 857 may further extend between axial boundaries of Blend-Trim region upstream wall 248 and Blend-Trim region downstream wall 249.

[0189] Referring to Fig. 1A, Fig. 1G, and Fig. 1I, Blend-Trim oxidant ports or orifices 83 in the Blend-Trim oxidant near side feeder walls 856 and equivalent Blend-Trim oxidant far side feeder walls 857 may be configured to provide respective distributions of one or more of fluid port diameters and port spacings along the streamwise flow direction. These may be configured to provide desired streamwise distributions of oxidant fluid delivery and/or optional diluent fluid delivery to achieve desired streamwise composition distributions in the energetic fluids within a plurality of streamwise reaction zones.

Bounding Distance Between Transverse End Walls

[0190] In the upstream combustion section 730, as shown in Fig. 1A, Fig. 1C, Fig. 1D, and Fig. 1H, the combustor chamber 740 has a transverse width 746 along the transverse X direction, between transverse near end walls 734 and transverse far end walls 735 bounding the combustor chamber 740. Such combustor chamber transverse width 746 may generally increase along the Z axial flow direction in the combustion section 730 from an upstream combustor inlet (or pilot outlet) 134, near an upstream combustor end wall 241, and progressively increasing with downstream distance along the Z flow direction.

[0191] In the downstream Blend-Trim region 426, as shown in Fig. 1A, Fig. 1C, Fig. 1D, and Fig. 1H, the Blend-Trim flow region 850 has a transverse bounding separation or combustor transverse width 746 between near bounding end wall 734 and far bounding end wall 735. Such transverse bounding width 746 may further increase in the transverse X direction within the Blend-Trim fluid delivery region 426 between the upstream Blend-Trim region manifold boundary 248 and a corresponding downstream Blend-Trim region boundary 249, and downstream of the combustor chamber 740. In other configurations, the transverse bounding width 746 may be fairly uniform in the Blend-Trim region 426.

[0192] As further shown in Fig. 1C, and Fig. 1I, in some configurations of the combustion section 730, the transverse end walls 734 and 735 may be configured with an upstream convex wall section 731, providing a non-linearly increasing bounding separation width 746 between those transverse bounding walls. Similarly, per Fig. 2D

and Fig. 2E, the upstream transverse end walls 734 (and 735 not shown), may be configured with upstream curved convex end wall sections 731 with radial to axial slopes increasing with downstream axial distance.

[0193] As further shown in Fig. 1C, the convex end wall section 731 bounding combustion section 730, may be followed downstream by an end wall section 732 with a maximum slope (or low curvature) of transverse increase with axial distance. Similarly, per Fig. 2D, and Fig. 2E, the combustion section 740 may be bounded axially midway by an end wall section 732 having a maximum slope of transverse increase with axial distance, or similar section with low radial to axial curvature.

[0194] Such a maximum slope end wall section 732 in one or both bounding end walls 735 and/or 734 may be configured to provide a low curvature (or fairly linear) increase in the transverse bounding separation between those bounding end walls. Such maximum slope (low curvature or fairly linear) sections may be utilized to accommodate overhang slope limitations in 3D printing manufacturing of such bounding end walls. E.g., such as when 3D printing may be used to form the bounding end walls 735 and/or 735 with the combusting Z axis in the vertical gravitational direction.

[0195] Similarly, per Fig. 2D and Fig. 2E, the bounding end walls 734 (and similarly bounding end walls 735) of the combusting section 740 may similarly have maximum radial to axial slopes 732 with fairly linear radial to axial slopes (or low curvature).

[0196] Further to Fig. 1C, in some configurations of the combustion section 730, the transverse bounding end walls 734 and 735 may further be configured with a downstream concave wall section 733 downstream of the fairly linear bounding end wall section 732. This downstream generally concave transversely bounding end wall section 733, providing a non-linear section with the bounding separation width 746 between those transverse bounding walls further increasing along the axial Z flow direction.

[0197] Such concave nonlinear bounding end wall sections 733 in one or both bounding end walls 735 and/or 734 may be configured to provide a declining rate of increase along the axial Z flow direction. This declining rate of increase in bounding separation with 746 between bounding end walls 735 and 734 may beneficially improve the expansion fluid dynamics in one or both of the combusting chamber 740 and the Blend-Trim transition region 850.

[0198] Similarly, per Fig. 2D and Fig. 2E, the bounding end walls 734 (and similar end walls 735) of the combustor section 740 may similarly be configured with downstream concave radial to axial sloped wall sections 733 downstream of the transition bounding end wall section 732 with maximum slope. Radial to axial slopes of bounding sections 733 may decline towards zero curvature bounding the downstream Blend-Trim section 852 and thence to connect with downstream equilibrating section 750. This beneficially reduces transition turbulence and combustor pressure drop from the upstream combustor inlet at CZ31 to the combustor outlet CZ394 per Fig. 2A.

[0199] As depicted in Fig. 2B, the diluent delivery section 710 near the inlet 134 may comprise delivering oxidant fluid F4 through an upstream oxidant manifold 242 and out through a plurality of perforated oxidant feeders 11 distributed across the upstream region. Similarly, a distributed fuel delivery system may inject diluent F7 through a downstream fuel manifold 244 and out through distributed perforated oxidant feeders 14 into incoming oxidant fluid F4.

Pilot Light or Ignition Authority

[0200] As schematically depicted in the upstream closeup Fig. 1B, the combustor chamber 740 may have an upstream pilot light, ignition source or flame authority 720, such as near the combustor upstream end wall 241. Ignition source 720 may form a diluted hot pilot flow F22 at the pilot outlet flowing into the adjacent combustor chamber 740.

[0201] Per schematic Fig. 2A, the combustor chamber 740 may have an upstream Flame Holder or Ignition Authority 100 comprising a Pilot P with an inlet axially at CZ33 and an outlet axially at CZ34. Perspective Fig. 2B depicts diluted pilot fuel F10 being delivered to ignition authority or flame holder 100 downstream of the diluted oxidant delivery section 720. Combusting diluted pilot fuel may be delivered via hot gas delivery flame tubes 116 to one or more combustor chambers in Combustion Section 730 where the chambers may have Combustion Chamber Radially Outer Side Walls 736.

Fluid Delivery Orifices

[0202] Per Fig. 1A, as detailed in combustor wall sections Fig. 1E, Fig. 1F, and Fig. 1G, at least one of the scalable combustor region's transversely elongated near side feeder wall (or "fan" wall) 736 and elongated far side feeder wall 737, bounding the adjacent combustor chamber 740, may comprise a plurality of fuel fluid orifices 81, or oxidant fluid orifices 82. Such orifices may be configured about the one or more perforated

combustor side (or liner) far side oxidant feeder walls 737 and near side fuel feeder walls 736 adjacent to at least one combusting chamber 740.

[0203] Per Fig. 1A (and Fig. 1B) such transversely elongated combustor near side fuel feeder walls 736 and far side oxidant feeder walls 737 may be generally shallowly opposed to each other about reacting or combusting chambers 740.

[0204] As further detailed in Fig. 1E, and Fig. 1F, one or more diluted fuel fluids F2 (or fuel fluid F1 not shown) and/or diluted oxidant fluids F5 (or oxidant fluid F4 not shown) may be delivered through a plurality of perforated wall orifices 81 and 82 (in the Y, or negative Y direction) configured in the combusting region side fuel feeder (or liner) walls 736, and oxidant feeder (or liner) walls 737 adjacent to and into transversely flow combusting fluid F12 flowing axially (Z direction) along the combusting chamber 740. For example, Oxidant Wall Section Detail Fig. 1F depicts a Diluted Oxidant Delivery Combusting Wall Section 745 having multiple oxidant fluid orifices 82 configured to deliver diluted co-reactant or oxidant fluid F5 (or oxidant fluid F4 not shown), and may be configured about fluid duct feeder wall 737 section of the combusting chamber 740 of Fig. 1A. The near side oxidant fluid duct feeder wall 737 may have an optional thermal barrier coating (TBC) or insulating coating 738 protecting the fluid duct wall 132 from hot reacting or combusting fluid F12 flowing axially (Z direction) along the combusting chamber 740.

[0205] Fig. 1E depicts a Diluted Fuel Delivery Wall Section 743 enlarged from the combusting chamber wall of Fig. 1A. Fig. 1E depicts a portion of the transversely elongated upstream combusting chamber near side fuel feeder wall 736 between axial (Z axis) boundaries of the upstream end wall 241 and the downstream wall 248. Combusting chamber wall section detail Fig. 1E, is further located between transverse near bounding wall 734 and far bounding wall 735 (along X axis), such as further detailed in Fig. 1C, Fig. 1D, and Fig. 1H.

[0206] Fig. 1E details how some configurations may configure multiple fuel fluid orifices 81, to deliver diluted first reacting fluid or fuel fluid F2 (or fuel fluid F1 not shown) through a perforated duct wall section 132 in the combusting near side fuel feeder wall 737 into the adjacent combusting chamber 740 per Fig. 1A and Fig. 1C. Per detail Fig. 1E, fluid duct feeder wall section 736 may optionally have a thermal barrier coating (TBC) or insulating coating 738 adjacent to the hot combusting fluid F12 flowing axially through the combusting chamber 740.

[0207] Similarly, Blend-Trim Wall Section Detail Fig. 1G depicts detail of an enlarged wall section 747 of the Blend-Trim Region 850 in the Blend-Trim section 426 downstream of the combustor chamber 740. This Blend-Trim region wall section 747 of Fig. 1G may comprise one or more Blend-Trim orifices 83. These Blend-Trim orifices 83 may be configured to deliver Blend-Trim diluted oxidant fluid F5 (and/or optionally diluent fluid F7 not shown) into an axially flowing Rich Reacting or Combusting Fluid F12 coming from the upstream combustor chamber into the Blend-Trim region 860 shown in Fig. 1A.

[0208] Per Blend-Trim Wall Section Detail Fig. 1G, such blend-trim orifices 83 may be distributed across the Blend-Trim region wall section 856 to deliver Blend-Trim fluid F7 from Blend-Trim feeder 860 into the Blend-Trim region 850 within the downstream Blend-Trim section 426, as depicted in Fig. 1A. Such delivery of oxidant F5 in Blend-Trim diluted oxidant fluid F5 may increase the oxidant concentration of transversely flowing fuel rich combustor fluid F12 from the upstream combustor chamber 740. Adding diluted oxidant fluid F5 (or oxidant fluid F7 not shown) then forms an oxidant rich Blend-Trim fuel lean reacting fluid F13 flowing downstream in the Blend-Trim region 850.

[0209] Per Blend-Trim Wall Section Detail Fig. 1G, fluid duct wall section 856 may have an optional thermal barrier coating (TBC) or insulating coating 738 protecting the Blend-Trim wall section 856 from the adjacent hot fuel rich (oxidant lean) energetic fluid F12 flowing downstream into the Blend-Trim region 850. Delivering further oxidant fluid F4 in diluted fluid F5 increases oxidant in the Blend-Trim region, furthers combustion of the fuel rich energetic fluid F12, and forms an oxidant rich energetic fluid F13 within the Blend-Trim region 850.

[0210] Similarly, detailed Fig. 2C details a Diluted Fluid Delivery Wall Section, comprising fluid orifices 80 extending through fluid duct / combustor chamber walls 132, and adjacent thermal insulating coating 150 on combustor chamber wall, to deliver fuel, oxidant, and/or diluent fluids such as further depicted in Fig. 2D, and Fig. 2E.

[0211] Per Fig. 2B, In some configurations, Pilot Fuel Fluid F3 delivery may be controlled by Fuel Control Valve 232 and delivered through Pilot Fuel Fluid Tube or Passage 101 to Flame Holder 100. Similarly, Pilot Oxidant Fluid F6 may be controlled by Pilot Oxidant Valve 232 and delivered through Pilot Oxidant Fluid Tube or Passage 102 to Flame Holder 100. Correspondingly, Pilot Diluent Fluid F8 may be controlled

by Pilot Oxidant Valve 232 and delivered through peripheral Diluent Fluid Tube or Passage 103 to Flame Holder 100.

[0212] Further to Fig. 2B, one or more of the Pilot Fuel Fluid Tube 101, Pilot Oxidant Fluid Tube 102, and/or Pilot Diluent Fluid Tube 103 may be used as electrical conductors to connect excitation or Ignition Voltage Source(s) 308 to the Ignition Authority 720, along with Ground 302. Such Pilot Fluid Tubes 101, 102, and/or 103 may be positioned along the Transverse End Walls 734 (and/or 735) and/or Pilot Hot Fluid Feeder Passages 116.

Orifice Sizing

[0213] Referring to Fig. 1A, Fig. 1E, and Fig. 1I, the perpendicular (normal) separation distance 748 (along the Y axis) between opposing transversely elongated combustor near side (or liner) fuel feeder walls 736, and combustor far side oxidant feeder wall 737 may be configured together with the size of the fuel fluid orifices 81 and the respective fuel fluid pressure to generally provide a combusting fuel fluid jet (or “fuel jet”) mean penetration distance F71 of the diluted fuel fluid F2 delivered through the combustor side or feeder wall orifices 81 into the inter side wall combusting chamber 740.

[0214] Referring to Fig. 1A, Fig. 1F, and Fig. 1I, the perpendicular (normal) separation distance between combustor side walls 746 (along the Y axis) between one or more opposing transversely elongated combustor near side (or liner) feeder walls 736, and combustor far side feeder walls 737, may be configured together with one or both of the size of the oxidant fluid orifices 82 and the respective fluid delivery pressure to generally provide combusting oxidant fluid jet (or “oxidant jet”) mean penetration distance F72 of the diluted oxidant fluid F5 delivered through the combustor chamber side wall orifices 82 into the inter side wall combusting chamber 740.

[0215] Referring to Fig. 1A, Fig. 1G, and Fig. 1I, the perpendicular (normal) Blend Trim perpendicular (normal) separation distance 748 (along the Y axis) between opposing transversely elongated combustor near side (or liner) feeder walls 736, and combustor far side feeder walls 737, may be configured together with one or both of the size of the Blend-Trim diluted oxidant fluid orifices 83, and the respective fluid delivery pressure of Blend-Trim diluted oxidant fluid F15, to generally provide a Blend-Trim Diluted oXidant fluid (or “oxidant jet”) mean penetration distance F73 of the Blend-Trim diluted oxidant fluid F15 delivered through the combustor side wall orifices 83 into the inter side wall Blend-Trim region 850. As depicted in

Fig. 1G, in some configurations diluent fluid F7 comprising liquid and/or gaseous diluent, may similarly be delivered through orifices 78 into reacting fluid F12 to form diluted combustng (or reacting) fluid F13.

[0216] For example, such side wall separation distance, orifice diameter (or area), and fluid pressure may generally be configured to deliver fuel fluid jets of diluted fuel fluid F2, oxidant fluid jets of diluted oxidant fluid F5, and/or Blend-Trim diluted oxidant fluid fluid jets F15, with about 0.1 to 10 times the equivalent fluid penetration distance under similar conditions without an opposing impinging wall. Such design of the jet penetration distance F72 and/or F71 may use configurations of one or more of the combustor side wall spacing 748, fuel orifice size 81, oxidant orifice size 82, Blend-Trim diluted oxidant fluid orifice size 83, and/or controlling the delivery pressure of fuel fluid F2, oxidant fluid F5 and/or Blend-Trim oxidant fluid F14. This fluid penetration distance F71, oxidant fluid penetration distance F72 and/or Blend-trim diluted oxidant fluid penetration distance F73 may be configured for about 20% to 200% of the shallow combustng wall separation 748. The fuel, oxidant, and trim oxidant fluid penetration distances F71, F72 and/or F73, may further be configured to between 40% to 100% of the shallow combustng wall separation distance 748.

Combusting Chamber Transverse End Walls

[0217] Per Fig. 1A, Fig. 1C, Fig. 1D, Fig. 1H, and Fig. 1I, the combusting chamber outer (far) side (liner) feeder wall 737 and the shallowly displaced inner (near) side feeder wall 736 adjacent to combusting chambers 740 may be joined or abutted together along their elongated transverse ends along the X axis perpendicular to the axial fluid flow Z axis. This joining may be achieved by forming near end walls 734 and/or far end walls 735 of a fluid delivery duct between adjacent combusting side feeder (or liner) walls 736 and 737.

[0218] These combusting chamber transverse near end walls 734 and transverse far end walls 735 may be generally convex (outwardly) curved facing downstream. These form one or more reacting or combusting zones between adjacent shallowly opposed near combusting chamber side feeder wall(s) 736 and far side feeder wall(s) 737. The upstream combusting chamber 740 may generally increase in cross sectional area perpendicular to the axial combusting flow direction with increasing axial distance downstream towards the reactor or combustor outlet 136. This increasing combustor cross section may beneficially accommodate an increasing temperature and an increasing volume of the hot combustion gas formed. This increasing area with increasing combusting gas mass may beneficially reduce the fluid flow pressure drop across the scalable combustor 700 from the combustor inlet 134 to the combustor outlet 136.

[0219] The transversely elongated and opposed combusting section's near side feeder wall 736 may comprise a generally increasing number of fuel fluid orifices 81 to deliver fluid comprising fuel fluid F1 into the reacting or combusting chamber 740 between the opposed combusting chamber near side wall 736 and combusting chamber far side wall 737. The transversely elongated combusting chamber far side feeder wall 737 may comprise a generally increasing number of oxidant fluid orifices 82 to deliver fluid comprising oxidant fluid F4 into the reacting or combusting chamber between the opposed combustor side walls.

[0220] The corresponding configuration of shallowly displaced transversely elongated perforated combustor near and far side feeder walls 736 and 737, with transverse combustor end walls 734 and 735, may form an upstream to downstream expanding combusting chamber 740 having a generally downstream scalable expanding (hand "fan") shape.

Thermal Resistance & Insulation

[0221] The combustor chamber near and far side feeder walls 736 and 737, and combustor chamber transversely bounding near end wall 734 and far end wall 735 may be formed from a high temperature material sufficient to withstand elevated combustion gas temperatures in the reacting or combusting chamber 740.

5 [0222] One or more of these combusting chamber near side feeder walls 736, and/or combusting chamber far side feeder walls 737, may be covered by a thermal barrier coating (TBC) or insulating layer 738. Such TBC insulating layers 738 may be used to protect the structural material of combustor near and far side feeder walls 736 and 737 from the hot adjacent reacting fluid or energetic fluid and any corresponding radiation.
10 Such TBC insulating layers 738 may comprise chemical protecting materials such as to protect combustor side feeder walls 736 and 737 from elevated steam and/or oxygen with their corrosive or oxidizing characteristics.

[0223] At least one reactive fluid or fuel fluid F1 may typically be delivered through the fuel fluid duct 770 and through the perforated near side (or liner) feeder walls 736 into
15 the reacting or combusting chamber (or zone) 740.

[0224] In some configurations, the reactive fluid or fuel fluid F1 may be a premixed fuel fluid comprising a fuel and one or both of oxidant and diluent therein forming a diluted reactive fluid or fuel fluid F2 (not shown). For example, Fuel fluid F2 may comprise a mixture of natural gas, air, and a diluent comprising one or more of water vapor, steam
20 formed from heated water, and/or a water mist. The diluted reactive fluid or diluted fuel F2 may similarly comprise chemical reactants with one or more other diluents such as carbon dioxide (CO₂) and/or nitrogen (N₂).

[0225] The combustor far side (or “liner”) oxidant feeder wall 737, and combustor near side fuel feeder wall 736 may be configured between outermost enclosure walls of the combustor (not shown), similar to unperforated versions of oxidant side feeder wall 737
25 and fuel side feeder wall 736.

[0226] The embodiment depicted in Fig. 1A and Fig. 1I enables using a moderate differential pressure between the fluid supply duct on one side of the combustor side (or liner) wall and the fluid in the reacting or combusting zone between the opposed combustor oxidant side feeder wall(s) 737 and combustor fuel side feeder wall(s) 736
30 (each optionally coated with insulating coatings 738). The fluid jets may then penetrate a portion of the way into the fluid between the combustor walls.

[0227] Per Fig. 1A, Fig. 1I and as further detailed in Fig. 1E, Fig. 1F, and Fig. 1G, numerous fuel fluid ports 81 and oxidant fluid ports 82 supplied with pressurized fluid

to form fluid jets may be configured to provide substantial penetration of 33% to 67% into the shallow combustor depth under a substantial combustion power level. The fuel and oxidant fluid jet orifices 81 and 82 and corresponding fluid delivery pressures may similarly be configured to provide major penetration of 40% to 100% of the distance across the shallow combustor while achieving major portion of combustion power. This generally provides good mixing of the injected fluid(s) F2 and F5 with the transverse distribution of axially flowing combustor (or reacting) fluid F12 in the transversely extended shallow combustor 740 between the combustor fuel side feeder wall 736 and oxidant side feeder walls 737.

[0228] In some configurations, the scalable configurations may be operated as a chemical reactor. In such configurations, numerous jets may form an effective mixing system to mix reacting fluid with co-reacting fluid to form a product fluid or energetic fluid. Such configurations may facilitate bringing injected reactive and co-reactive fluid rapidly up to a desired reacting temperature and to begin reacting.

[0229] Per Fig. 1E and Fig. 1G, in further configurations, thermal diluent may be delivered with one or both of the reacting fluid and/or co-reacting fluid to form first diluted reacting fluid F2 and second diluted co-reacting fluid F5 for delivery through ports 81 and/or ports 82 respectively. For example, a premixed humid fuel F2 and air-mist oxidant fluid F5 may be injected into axially flowing reacting or combustor fluid F22 or into hot or energetic fluid. Similarly, diluent fluid F7 may be delivered separately through diluent orifices 78 into reacting fluid F12.

[0230] When using the scalable (“Fan”) combustor 700, multiple fuel orifices 81 and oxidant orifices 82 may be configured to provide an axial distribution of net orifice area sufficient to deliver the flow rate of reactive or fuel fluid F1 and co-reactive or oxidant fluid F4 with the desired axial flow rate distribution. For example, this may include an increasing number of orifices of similar size about the reaction zone transverse to the combustor flow axis.

Downstream Transition or Diffuser Region

[0231] With reference to Fig. 1A, a downstream end transition or end diffuser 428 may be provided downstream of the combustion section 730, and the blend-trim equilibration region 426 where present. This may provide further fluid residence time which may beneficially increase the degree of reaction or combustion. Such an end diffuser 428 may reduce the pressure drop of delivering the energetic fluid F20 out from the downstream combustor outlet 136 of the scalable combustor 700.

Ignition System or Flame Authority

[0232] With reference to Fig. 1B, in some embodiments, an ignition system or flame authority 720 may be provided near the upstream end wall 241 of the combustor chamber 740. This flame authority 720 may deliver hot igniting fluid F22 into an upstream reacting zone or pilot region or chamber 720 between one or more of the perforated opposed pilot chamber side walls 722.

Pilot Igniter

[0233] With further reference to Fig. 1B, an igniter 124 may be provided near the upstream end of the flame authority 720. The igniter 124 may comprise one or more of a spark igniter, a pilot light, a hot gas jet, a plasma jet, a laser beam, a light pipe, a glow plug, a heated surface, a microwave heater, or other igniters such as may be used to ignite combustion or initiate chemical reactions.

[0234] Combustion may also be initiated by providing a starter fuel or reactant fluid flow F3 and second reactant or oxidant fluid flow F6, which together may comprise two or more hypergolic fluids that ignite on mutual contact.

Pilot Diluent Delivery

[0235] With reference to Figure 1B, in some embodiments, further diluent F8 may be delivered through a pilot thermal diluent delivery system 373. In some configurations, an outlet of the Pilot diluent delivery system 373 may be positioned downstream of a pilot reactant or fuel delivery system 372 outlet delivering pilot reactive fluid or fuel fluid F3 to an upstream Combustor Inlet (or pilot outlet) 134 to the combustor chamber 740. Pilot diluent delivery system 373 may be located downstream of a co-reactant or oxidant pilot fluid F6 delivery through an Oxidant Pilot Delivery port 371. Such configurations may reduce the likelihood of quenching the pilot reaction or flame.

[0236] Further to Fig. 1B, the energetic pilot fluid F22 formed by the pilot reaction may be cooled by using one or both of more pilot diluent fluid, and/or cooler pilot diluent fluid F8 through pilot fluid delivery port 373. For example, this enables conducting an upstream primary reaction at a hotter temperature and/or with less oxidant fluid F6 present. e.g., with fuel rich, (and oxygen or air lean) fluid mixture of Pilot Fuel/First Fluid F3 and Pilot oXidant/Second Fluid F6.

[0237] Such diluent delivery cooling the pilot may beneficially lower byproduct combustion emissions such as NO_x. It may further enable operating the reaction or combustion at hotter temperatures. This may beneficially more rapidly consume the

primary reactants and optionally shorten the residence time required to achieve desired emissions of unburnt reactants or fuel. E.g., such as residual unburned hydrocarbons, alcohols, or ammonia.

[0238] For example, one or more perforated direct contactor perforated wall sections such as depicted in Fig. 1E, Fig. 1G, and/or Fig. 1F, may be used to deliver one or more diluent fluids comprising one or more of cold water, hot water, superheated water, saturated steam, superheated steam, air, carbon dioxide, nitrogen, an inert gas, or one or more reacted fluids. These may use one or more of the processes variously described in VAST Patent Applications appended or incorporated by reference. i.e., the VAST.001 (Direct Contactor), VAST.002 (Trifluid), VAST.003 (Cycle), and/or the Campbell (VAST.014) patent.

[0239] Referring to Fig. 1I, Fig. 1E, Fig. 1G, (and correspondingly to Fig. 1F) orifices 81 and/or 82 in such perforated wall sections may be further configured to orient the diluent jets at an angle transverse to the fuel-rich combusting fluid flow such as F12 in the upstream combusting chamber 740 generally flowing axially along the Z axial direction. Similarly, orifices 83 may be oriented at an angle transverse to the Blend-Trim fuel rich (oxidant lean) fluid flow F12, and/or fuel lean (oxidant rich) fluid flow such as F13, that generally flows axially along the Z axial direction.

[0240] Correspondingly, one or more fluid delivery ducts may be formed between the combustor side walls (or liners) to deliver one or more such fluids through the orifices in those side walls. This can help improve one or more of mixing, increase the residence time within the fluid, and increase the time for liquid diluent evaporation as needed.

Temperature Control by Diluent

[0241] With reference to Fig. 1D, and Fig. 1H relative to Fig. 1A, the downstream diluent delivery may be configured to provide a diluent flow distribution vapor and/or steam may also be delivered through the direct contactor.

Plan View Combusting chamber

[0242] Fig. 1I depicts a transverse X-Y cross-section through the combusting chamber (or region) 740 perpendicular to the axial flow in the Z axial direction. This cross-sectional view is in the A-A' plane noted in the elevation views Fig. 1C, Fig. 1D, and Fig. 1H. This depicts combusting chambers 740 between diluted fuel feeders 750 and diluted (rich) oXidant feeders 760.

[0243] The combusting chamber 740 is bounded along the shallow depth in the Y perpendicular direction by combusting chamber near side feeder wall 736 and combusting chamber far side feeder wall 737. Combusting chamber 740 is further bounded by combusting chamber transverse oXidant-Diluent end wall 734 along the elongated transverse width in the positive X transverse direction. Combusting chamber 740 is further bounded by combusting chamber transverse Fuel-Diluent end wall 735 in the negative X direction.

[0244] The combusting chamber near side feeder walls 736 and far side feeder walls 737 may be protected by a thermal barrier coating or insulation layer 738. The combusting chamber end walls 735 and 734 may similarly be protected by a combusting end wall thermal barrier coating or (TBC) insulation layer 738 in the positive and negative X axial sides.

[0245] The combusting chamber near (or inner) side feeder wall 736 is shown with a plurality of fuel orifices 81 as detailed in Fig. 1E. The combusting chamber far (or outer) side feeder wall 737 is shown with a plurality of oxidant orifices 82 as detailed in Fig. 1F. One or more of fuel orifices 81, and/or oXidant orifices 82 may be slant oriented at a transverse angle to the transverse X direction.

Diluted Fuel /Reactant Fluid Delivery

[0246] Reactant and/or Fuel fluid F1 may be delivered into fuel feeders 750, as depicted in the elevation view Fig. 1D, in perspective view Fig. 1A, and in the plan view Fig. 1I. As shown in perspective view Fig. 1E and plan view Fig. 1I, fuel fluid orifices 81 may be angled transversely to the axial fluid flow F12 through combusting chamber side feeder wall 736 and thermal barrier coating (TBC) 738.

Diluted Oxidant /Co-reactant Fluid Delivery

[0247] Co-reactant and/or Oxidant fluid F4 may be delivered into oXidant manifold 760, as depicted in elevation view Fig. 1H, in perspective view Fig. 1A, and in plan view Fig. 1I. As further shown in perspective view Fig. 1E and plan view Fig. 1I, oxidant fluid orifices 82 may be angled transversely to the axial fluid flow F12 through combustor chamber far side oxidant feeder wall 737 and thermal barrier coating (TBC) 738.

[0248] The fuel fluid orifices 81 and oxidant fluid orifices 82 may be circumferentially oriented about the axial flow axis in the same clockwise (CW) orientation as shown in Fig. 1I. Similarly, they may be equivalently oriented counterclockwise (CCW) about the fluid flow axis (about the normal to the plane of Fig. 1I). In further embodiments (not shown), the fuel fluid orifices 81 may be oriented clockwise (CW) and opposed to the opposite counterclockwise (CCW) orientation of oxidant fluid orifices 82 about the fluid flow axis (normal to the plane of Fig. 1I). Equivalently the fuel fluid orifices 81 may be oriented counterclockwise (CCW) to oppose the clockwise (CW) orientation of the oxidant fluid orifices 82 about the fluid flow axis.

Blend Trim Region

Downstream Oxidant and Diluent Delivery

[0249] With reference to Fig. 1D, Fig. 1F, and Fig. 1H, in context of Fig. 1A, in some embodiments, further diluent and oxidant containing fluid F5 may be delivered into the energetic fluid into Blend-Trim region 850 downstream of the combustor chamber 740. This oxidant fluid F5 may be delivered through diluted oxidant fluid duct 860 and/or diluted oxidant fluid duct 870 into the downstream Blend-Trim region 860. As depicted in Fig. 1F, diluted oxidant fluid ducts 860 and/or 870 may have perforated walls comprising multiple orifices 83, to deliver diluted oxidant fluid F5. These may be similar to upstream fuel feeders 750 and oxidant feeders 760 in the upstream combustion section 730 adjacent to the upstream combustor side (or liner) walls. E.g., with suitable thermal barrier coating 738 to protect the walls as needed.

[0250] With further reference to Fig. 1F, Fig. 1D, Fig. 1G, and Fig. 1H, downstream diluted oxidant duct 860 and/or diluted oxidant duct 870 may have a thermal barrier coating (TBC) 738 protecting the Blend-Trim duct wall 856 from high reaction or combustion temperatures. A fluid duct with feeder walls 856 may be used, similar to the perforated direct contactor combustor side feeder walls 736, and/or 737.

[0251] Similarly, per Fig. 1F and Fig. 1I, the diluted oxidant fluid delivery orifices 83 may be configured at a Clockwise (CW) and/or CounterClockWise (CCW) angle to the

reacting or combusting flow fluid flow axis, similar to the fuel fluid orifices 81 and/or oxidant fluid orifices 82, therein improving fluid mixing of injected diluted oxidant fluid F5 with incoming reacting fluid F12 and Blend-Trim fluid F13. The number and size of diluted oxidant orifices 83 and relative delivery pressure of diluted oxidant fluid F5 may be configured to achieve effective jet penetration into the energetic fluid F12.

[0252] Delivery of Blend-Trim diluted oxidant fluid F5 may be accomplished with a modest differential pressure compared to conventional combustors. Such downstream oxidant fluid may assist in reducing the oxygen concentration during most of the combustion and thus reducing the NO_x emissions. Yet the downstream oxidant delivery may provide sufficient excess oxidant to enable efficient conversion of fuel, unburned hydrocarbons and carbon monoxide to carbon dioxide.

[0253] Regarding Fig. 2A, Fig. 2D and Fig. 2E, the downstream Blend-Trim combustor region 850 may be differentiated into an upstream Blend-Trim region 852 and downstream Blend-Trim region 854. Fig. 2D depicts delivery of diluted oxidant F5 through diluted oxidant delivery perforated feeders 856 into upstream Blend-Trim region 852. Correspondingly, diluent fluid F7 may be delivered via downstream perforated Thermal Diluent Tube 106 through Diluent Orifices 78 into downstream Blend-Trim region 854.

[0254] Correspondingly, Fig. 2E depicts delivery of diluent fluid F44 through perforated Thermal Diluent Tubes 106 via diluent orifices 78 into the upstream Blend-Trim region 852. Perforated Thermal Diluent Tubes 106 may similarly deliver diluent fluid F44 through diluent orifices 78 into downstream Blend-Trim Region Duct 858. The upstream Blend-Trim Region Duct 858 may deliver Diluent Fluid F44 into downstream Blend-Trim Region Duct 858. Such Diluent Fluid F44 together with Blend-Trim Oxidant Fluid F42 may thence be delivered via orifices 83 into downstream Blend-Trim Region 854.

[0255] Fig. 2E, similarly depicts delivery of diluent fluid F46 through perforated Thermal Diluent Ducts or Tubes 107 via diluent orifices 78 into the upstream Blend-Trim region 852. Perforated Thermal Diluent Tubes 107 may similarly deliver Diluent Fluid F46 through orifices 78 into downstream Blend-Trim Region Duct 857. The upstream Blend-Trim Region Duct 857 may deliver Diluent Fluid F46 into downstream Blend-Trim Region Duct 857. Diluent Fluid F46 together with Blend-Trim Oxidant Fluid F45 may thence be delivered through downstream Blend-Trim Region Duct 859, and thence via diluted oxidant orifices 83 into downstream Blend-Trim region 854.

[0256] In further configurations, the methods of fluid delivery into the Blend-Trim region depicted in Fig. 2D and Fig. 2E may be combined and adapted. E.g., by transversely alternating delivery of Diluent Fluids and/or Diluted Oxidant fluids F5 and F7, and Diluent and/or Diluted Oxidant fluids F42 and F44, and F45 and F46 upstream and downstream by transversely alternating upstream versus downstream configurations of Blend-Trim delivery ducts 856 and 858, and between Blend-Trim delivery ducts 857 and 859. Such methods enable configuring the axial concentrations of trim oxidant delivery relative to the upstream fuel delivery (Λ). Similarly they may be used to configure the average axial concentrations of Balance-Trim residual diluent to the upstream fuel delivery (Ω).

[0257] This scalable combustor invention is designed to achieve ultra-clean combustion for gas turbines, combined heat and power systems, industrial heating, cooling, and other applications requiring clean controlled combustion and/or chemical reaction.

[0258] In some configurations, multiple fluid jets may be configured with shallower spacing between walls to improve relative jet penetration. The rate of diluted oxidant and fuel delivery to upstream combustor flow may be configured to increase operating range and operational robustness.

[0259] Rapidly Changing Gas Turbine Power Market

[0260] Power demand is increasing from rising population, economic growth, and growing electric vehicle fleets. Rapidly growing solar and wind power requires correspondingly greater rapid backup power. Rapidly growing Artificial Intelligence (AI) use is increasing data center power usage, which requires ultra-high reliability.

[0261] Consequently, the US Energy Information Agency's (herein EIA) Annual Energy Outlook (AEO 2022) long term power evaluation forecasts ~331 GW more US gas turbine power by 2050. EIA projects 175 GW Simple Cycle "Peaker" turbines and 156 GW Combined Cycle turbines. This is creating a \$195 billion (\$7.5 billion/year) US market for intermediate or backup power up through 2050. The International Energy Agency (herein IEA, 2020) finds the US with 500 GW gas fired power plants, has ~28% of global gas fired power plants, comprising ~1,785 GW.

[0262] Demand for reliable power is growing even faster in China, India, Southeast Asia, and Africa than in the US and EU. IEA (2023) reports gas turbines generate 21.8% of global power. The EIA (AEO 2022) projects global electrical power capacity to grow ~55%-108% by 2050. (i.e., much faster than power generation growth at 30% to 76%.)

[0263]The EIA expects natural gas turbines to supply 15% to 20% of total global power.

This indicates global power gas turbines will likely grow by 982 GW to 1,938 GW by 2050. This indicates a likely \$1,100 billion to \$2,150 billion global gas turbine growth market. This suggests potential global market share of \$550 billion to \$1,070 billion market for applicant's ultra clean gas turbine power innovations as described herein.

[0264]With finite supplies of natural gas, oil and coal, there is a strategic need to develop alternate sustainable power using renewable fuels. There are also concerns over climate change and greenhouse gases. These are driving efforts to develop and use sustainable fuels, such as hydrogen (herein H₂), ammonia (herein NH₃), methanol (herein CH₃OH), and ethanol (herein CH₃CH₂OH).

[0265]Ensuring Grid Reliability with Dispatchable Backup Power

[0266]Grid collapse from failure of a mid-sized power plant lost 78.64 GW of power in 2003, caused the US northeast blackout affecting 7.37 million people, and cost \$4 to \$10 billion in damages (Borenstein et al. 2023). California's CAISO power grid already has a ~24 GW "duck curve" demand power rise from no demand (excess mid-day solar and wind) to the evening peak demand after sunset under calm conditions.

[0267]Ensuring reliable power with increasing solar and wind power requires greater installed dispatchable backup power (or expensive storage) than the maximum demand, to ensure grid reliability at night with low wind. This is especially stringent considering power transmission limits during peak winter or summer loads. Existing grids cannot now support interstate or national Real Zero renewable energy goals without CO₂ emissions (herein "Real-Zero", or "Net-Zero" without CO₂ credits) power distribution demands. Such pressures form a strategic power system fragility.

[0268]For reliable power, grids must strategically maintain excess local dispatchable backup power sized at ~120% of peak power. This must allow for night use, cloudy periods, and low wind, while also accommodating plant maintenance and failures. Almost all current gas turbines rely on natural gas. Underground natural gas storage provides current energy buffers. Yet extreme winter conditions in Texas with equipment failures have challenged its reliability.

[0269]Achieving future Real Zero Renewable energy (without offsets) requires reliable cost-effective backup with Long Duration Energy Storage (LDES>4 hours). A 100% Real Zero renewable power grid must further cover long term climate variations. It must provide 300% of the worst 2 week's shortages, spread over a 4-month period, per Ruhnau and Qvist (2022), and Fekete et al. (2023).

[0270] Commonly touted batteries are too expensive. Biofuels have relatively little constrained production and backup capacity. Liquid NH₃ storage offers compact, long-term, cost-effective backup energy, leveraging existing transportation and storage infrastructure. However, the challenging NH₃ Paradox, of high NO_x emissions and potential ammonia slip, must be met reliably, economically, and quickly.

[0271] Ammonia Power Growth and Opportunities

[0272] At 202 million tons/yr (183 M t/yr) ammonia (NH₃) is the 2nd most manufactured chemical after sulfuric acid (H₂SO₄). Ammonia's energy density (22.5 MJ/kg) is similar to methanol's (22 MJ/kg). Widespread fertilizer production, agricultural infrastructure, and inexpensive liquid fuel transport favor sustainable NH₃ fuel over hydrogen. Transport dominates costs in energy importing countries.

[0273] Strategically, NH₃ will likely replace depleting hydrocarbon fuels, and become the primary sustainable fuel especially in energy importing regions and countries. NH₃ is 29 times cheaper to store than H₂. MacFarlane et al. (2020) provide "A Roadmap to the Ammonia Economy". Nazemi et al. (2021) review Georgia Tech's micro-NH₃ production system (MAPS). Hydrofuel acquired Kontak and licensed Georgia Tech's MAPS technology. These promise production of sustainable NH₃ cheaper than natural gas.

[0274] Industry is building green NH₃ production plants. Martin (2023) reports that Brazil's Unigel Chemicals plans to quadruple output to 240,000 tonne/year NH₃ by 2025. Saudi Arabia's NEOM complex will make 1.2 million tonne/year of green NH₃ by the end of 2026. China's Jilin province targets producing 2 million tonne/year NH₃ by 2030. Global ammonia production is forecast to grow 250% (from 200 Mt/y to 700 Mt/y) by 2050 (GPCA 2023).

[0275] The International Energy Agency (2023) updated its Ammonia Technology Roadmap and projects NH₃ to supply 44% of global shipping fuel by 2050 versus 19% each for biofuels and hydrogen. Laursen et al. (2023) extensively detail advantages and challenges of using NH₃ as a shipping fuel, for EMSA. Wood McKenzie (2022) projects ~50 Mt/year global NH₃ use in gas/coal fired power generation by 2050, rising to 100 Mt/yr in its high-end scenario. Adeli et al. (2023) review potentials for synthesizing and using green H₂ and NH₃ for fuel, and energy storage.

[0276] With few natural energy resources, Japan is strategically seeking sustainable fuel imports. Japan plans to import 3 Mt/y NH₃ by 2030, increasing to 30 Mt/year by 2050. At the G20 meeting in India in 2023, Japan committed to issue 20 trillion Yen (~USD

136 billion) in the Green Transformation (GX) Economy Transition Bonds, backed by future financial assets. This will encourage public/private investment of >150 trillion yen (~ USD 1 trillion) in the GX economy. G20(2023).

[0277]Large Gas Turbine Companies

5 [0278]IHI and General Electric's joint study found transport costs to Japan for imported hydrogen are reportedly 50% more expensive than ammonia (Patel 2024). IHI and GE are developing NH₃ combustion technology. Japan funded IHI co-firing to 70% NH₃ in a 2 MW gas turbine (Patel 2024). US Amogy (2023) and Mitsubishi Heavy Industries (MHI) are exploring the use of Amogy's NH₃ cracking technology. Mitsubishi is
10 developing a 100% NH₃ fired 40 MW H-25 gas turbine. Cesaro et al. (2024) model a Combined Cycle Gas Turbine (CCGT) on a Siemens SGT-800 (62.5 MW) gas turbine.

[0279]Japan's MHI, and JERA, its largest power company, are pursuing a 100% NH₃ fired combined cycle plant on Jurong Island, Singapore. MHI is jointly researching an NH₃ fired H-25 gas turbine with Indonesian Institute Teknologi Bandung (ITB). South Korea
15 plans to use hydrogen and NH₃ for 7.1% of its power by 2036.

[0280]Centrica and Mitsubishi Power Europe are exploring development, construction, and operation of the first NH₃ fired power generation facility in Europe, at the Whitegate in Cork Ireland.

[0281]Best in Class Clean Technology Requirements.

20 [0282]The US Clean Air Act directs the US Environmental Protection Agency (herein "EPA") to designate areas as requiring "Reasonable Attainment Clean Technology" (herein "RACT"), "Best Available Containment Technologies" (herein "BACT"), or the stringent "Lowest Available Emissions Requirement" (herein "LAER").

[0283]California legislation requires even more stringent "California Best Available
25 Containment Technology" (herein "CA-BACT") in its non-attainment counties. The US EPA's Green Book (1971) designates four California counties in the Los Angeles-South Coast Air Basin as Nitrogen Dioxide "non-attainment" areas for NO₂ emissions per EPA (2023).

[0284]Ultra-clean Scalable Combustion Design and Operation

30 [0285]Accordingly, several technical features in this disclosure lead to reactors that deliver and more cleanly burn reactant, oxidant, and in some examples, add diluent fluids. The techniques described herein include scalable combustors that combust fuel with an oxidant (e.g., air or oxygen), and that may add a diluent, such as water, carbon dioxide, nitrogen, and/or excess oxygen, in any phase and/or combination.

[0286]Such techniques enable features and methods that are more scalable than conventional gas turbine combustors, across broader ranges of commercial combustor pressures, temperatures, power levels, and/or power ramping rates, therein improving power system capabilities and economics.

5 [0287]The techniques described herein further address designing scalable combustor methods and systems for gas turbine systems, with fuel, oxidant, and diluent types, combinations, and mechanical, electrical, and/or thermal loads, therein enabling more reliable grid operation and backup, and offering major intermittent non-dispatchable renewable power penetration and growth rates.

10 [0288]The techniques described herein further offer breakthrough ultra-clean methane combustion without catalysts. Some configurations were modeled using Reactive Computational Fluid Dynamics (herein “RCFD”) by the U.S. Department of Energy’s Argonne National Laboratory (herein “ANL”) across gas turbine operating temperatures, pressures, and specific power ranges. Some configurations modeled achieved <1
15 ppmvd NO_x and CO emissions by volume diluted to 15% O₂ dry (herein “ppmvd”).

[0289]The results from modeling these techniques indicate a high probability that the present scalable combustor innovation will achieve best-in-class combustion in a VAST cycle gas turbine with ultra-clean emissions relative to other commercial power turbines.

20 [0290]The techniques in this invention offer ultra-clean best-in-class emissions on current fuels, sustainable fuels, and combinations of such fuels. These techniques may be used to design exemplary ultra-clean dual-fuel ammonia and/or natural gas combusting capability, and to provide major leading-edge advantages over existing gas turbines. Thus, these methods offer strategic sustainable power, and also Real Zero power (or
25 Net-Zero without CO₂ offsets), with more reliable, faster, dispatchable grid backup power.

[0291]The techniques herein enable “wet” cycle gas turbines, using the VAST power cycles, to displace a major portion of conventional cooling air (or oxidant) with diluent that recovers exhaust heat and recycles heated diluent back to the combustion system
30 (such as water, steam, CO₂, and N₂). Such methods enable more cleanly and competitively supplying a major portion of the projected >\$100 billion single gas turbine (“peaker”) portion of US gas turbine growth market, and >\$250 billion international single gas turbine growth market by 2050.

[0292]Mandated Ultra-clean Combustion Priority

[0293]Applying the techniques herein to achieve ultra-clean commercial combustors for power turbines on “natural gas” (including methane), will likely earn: 1) US Federal BACT rating required in US emission attainment areas; 2) EPA’s stricter LAER rating required in emission non-attainment areas; and 3) California’s CA-BACT required for non-attainment California counties. Applying these techniques to achieve RACT, BACT, LAER and CA-BACT ratings will likely mandate purchase priority for power systems using this combustor invention over other technologies in non-attainment regions.

[0294]NH₃ Power with Stringent NO_x and NH₃ “slip” Emission Rules

[0295]Such techniques may be applied to ultra-clean combustion of sustainable fuels such as hydrogen, ammonia, ethanol, and methanol. Such techniques may combust ammonia (NH₃) with far lower NO_x emissions than conventionally formed by burning NH₃, methane, or hydrogen etc. E.g., much cleaner than burning NH₃ in General Electric’s (GE’s) lean turbine combustors which form ultra-high NO_x.

[0296]E.g., with Reactive Computational Fluid Dynamics (RCFD) modeling, Gubbe et al. (2023) find that conventional single stage lean premixed combustion generates ~1,800 ppmvd NO_x in gas turbines at a Turbine Inlet Temperature (herein “TIT” or combustor outlet temperature) of TIT = 1,900 K (1,627°C) at a combustor outlet pressure P = 20 Bar.

[0297]These techniques may further adjust residence time to accommodate major differences in fuel flame speed, including NH₃ burning ~6 times slower than methane with much narrower combustion boundaries, increasing flameout challenges. These techniques may include reliably combusting hydrogen, which burns 33 times faster than ammonia, with much wider combustion boundaries, and with dangers of flash back and catastrophic explosion.

[0298]Such techniques may similarly be used to crack NH₃, and to combust cracked NH₃. Cracking NH₃ may include heat and/or catalysts, externally, or in situ within the combustor system. Combustion may include using combinations of NH₃, and cracked ammonia (3H₂ + N₂).

[0299]The techniques herein may be applied to achieve the US EPA’s (EPA Part 60 Subpart KKKK) requirement of 98% (60 times) lower gas turbine NO_x emissions than conventional lean NH₃ combustion.

[0300]That EPA regulation necessitates nationwide emission reductions especially for fuels such a NH₃ to serve in the primary dispatchable power market. E.g., reducing emissions

to <25 ppmvd (or 150 ng/J of useful output, or 1.2 lb/MWh) for the 14.7 MWt to 249 MWt (50 to 850 MMBtu/h) combustion range.

[0301] These techniques may be used to approach or meet emission regulations by California's Counties with severe smog that require 783-fold lower NO_x than caused by lean air (or oxidant) combustion, limiting NO_x emissions to 2.3 ppmvd. By contrast, conventional gas turbines require expensive cleanup (such as Selective Catalytic Reduction (SCR) with ongoing ammonia operating costs) to reach these limits. Some California counties further limit the unburned NH₃ ("slip") to <10 ppmvd, and then to <2.5 ppmvd.

[0302] The techniques to develop novel scalable combustors as described herein may be configured to design and operate combustors to achieve these far more difficult RACT, BACT, LAER and CA-BACT ultra-clean combustion emission ratings, especially for burning sustainable fuels such as ammonia, and "cracked" ammonia (herein a mixture of hydrogen and nitrogen with residual ammonia, from $2 \text{ NH}_3 = 3 \text{ H}_2 + \text{N}_2$).

[0303] Such techniques may further be used to develop dual fuel or multi-fuel use combustors, such as to use gaseous and/or liquid NH₃, cracked NH₃, hydrogen, and/or natural gas in various combinations.

[0304] Ultra-Clean Power Bidding Priority

[0305] The techniques may be used to achieve ultra-clean emissions sufficient to avoid emission cleanup costs. Industry personnel estimate that such NO_x emission cleanup can cost 7%-10% of total Capital Expenditure (herein "CapEx"). Applying such techniques to achieve ultra-clean emission ratings would likely eliminate such cleanup.

[0306] These techniques may further eliminate ongoing catalyst and NH₃ cleanup operating costs. Together, these techniques with scalable combustion cost breakthroughs would likely achieve power bidding priority to ensure grid reliability, strongly improve profitability, increase rapid commercialization, and offer major societal benefits.

[0307] Intermediate Dispatchable Power

[0308] The techniques herein may address the need to backup rapidly increasing renewable power and reduce fossil fuel usage. Rising renewable power is correspondingly reducing combined cycle turbines' annual capacity factors and profitability. Rising solar and/or wind power is reducing gas turbine backup power to an intermediate < 50% annual capacity factor range.

[0309] Accordingly, applying the techniques herein is expected to achieve more profitable intermediate VAST cycle power to commercially displace both new Peakers and new

Combined Cycle power turbines. The techniques promise to rapidly increase competitiveness of such clean power generation and increase the target market for such ultra-clean fast response dispatchable power.

[0310] The techniques may be used for quieter distributed scalable combustion and to avoid consequent high frequency fatigue. Such techniques may be used to reduce combustor turbine destroying noise by 30 dB or more. Using such independent temperature design and control techniques in scalable combustors may substantially reduce high temperature metal creep, cyclic thermal fatigue, maintenance, repair, downtime, and operating costs.

[0311] The techniques for scalable combustors combined with “wet” cycle VAST power cycle turbines may offer cleaner, cheaper, faster, more efficient, and more durable intermediate power than both conventional Brayton “peaker” turbines and combined cycle turbines. The techniques may be used to increase combustor and turbine life, profitability, and revenue.

[0312] The techniques include developing scalable dual-fuel ammonia and natural gas combustors. These will enable more rapid VAST cycle gas turbine power commercialization to ensure critical grid reliability with increasing solar and wind power penetration. Such techniques using sustainable ammonia fueled gas turbines promise far longer backup with better Economy, Energy, and Environment (E3) ranking than batteries.

[0313] The techniques may be further used to develop and operate scalable combustors burning gaseous and/or liquid ammonia (NH_3), cracked ammonia ($2 \text{ NH}_3 = 3 \text{ H}_2 + \text{N}_2$), hydrogen, ethanol, and/or methanol, together with or instead of gaseous and/or liquid natural gas (or methane). The techniques may enable flexible provision of more cost-effective practical intermediate gas turbine systems with conventional and/or sustainable fuels, including with higher efficiency and profitability than peaker turbines.

[0314] Increasing solar and/or wind power is reducing average annual capacity usage for Combined Cycle power turbines (hours used to total annual hours). Reducing annual capacity to <50% further gives VAST profitability advantages over Combined Cycle turbines.

[0315] Pressures to eliminate coal fired power portend a high demand for the techniques enabling rapid installation of ultra-clean ammonia fueled VAST power to prevent blackouts in Washington DC, and to ensure grid reliability across the US, Japan, and EU etc.

[0316]The techniques in designing scalable combustors address current and future fuels and operating trends in adapting to combusting future renewable and sustainable fuels to VAST power cycles providing greater flexibility than Brayton and/or combined cycle gas turbines to generate commercial mechanical or electrical power and/or combined heat and power (CHP). Such flexible multi-fuel scalable combustor design and operating techniques promise to meet this rapidly increasing demand for flexible power and CHP gas turbines.

[0317]Such techniques may be used to design and construct ultra-clean reliable combustion using current or future liquid and/or gaseous fuels, and/or with liquid and/or gaseous diluent, ranging in power from 10 MW to 100 MW, in D to G Class gas turbines. They may be used to scale such ultraclean combustion down to 100 kW gas microturbines or smaller, and up to 500 MW large gas turbines.

[0318]Such techniques may be used to design and construct ultra-clean combustion systems from 1,100°C to 1,500°C Combustor Outlet Temperatures, or Turbine Inlet Temperatures (TIT). Scalable combustor outlet temperatures may further extend to 700°C to 1,700°C, or from lower quenching temperatures, or up to combustion wall thermal limits.

[0319]Such techniques may be used to design and construct combustors with specific power over industrial ranges from ~50% turndown to maximum power, such as from 30-60 MW/bar/m³ specific power. Such techniques may similarly be used to extend such scalable combustion down to 10 MW/bar/m³ or lower, and up to 120 MW/bar/m³ or higher.

[0320]Such scalable techniques may be used to design and construct combustors with typical gas turbine combustion pressures ranging from 10 bar to 40 bar. These techniques may further be used to extend scalable combustion down to 1.1 bar or lower, and up to 100 bar or higher.

[0321]Such techniques may be used to cool walls of scalable combusting sections, including flowing liquid and/or oxidant, fuel, and/or diluent or combinations thereof, past or through scalable combustor walls. They may similarly provide cooling by flowing such fluids through multiple feeders about one or more walls of scalable combusting sections.

[0322]Such techniques may be used with scalable combustor walls for mean wall temperatures greater than or equal to about 1000°C, and up to or great than about 1500°C. Such techniques may similarly be used with scalable combustor wall

temperatures down to about 500°C or lower, and/or up to 2500 °C or higher, with suitable materials and/or cooling.

[0323]Such techniques may be used to preheat and/or crack a portion of ammonia by flowing it past scalable combustor walls. These may similarly be used to preheat and/or crack a portion of liquid and/or gaseous ammonia by flowing it through feeders distributed across such scalable combustor walls.

[0324]Scalable combustor techniques may be used for combustion with about 0.75-0.83 overall range of relative Fuel/Air Equivalence mass to stoichiometric mass ratio Φ (Φ) (or 1.33 to 1.20 Air/Fuel Equivalence mass to stoichiometric mass ratio Λ (Λ), and independently control temperatures by the diluent (or water)/fuel mass ratio Ω (Ω).

[0325]Such scalability techniques may similarly be extended to Fuel/Air equivalence mass ratio Φ (Φ) to 0.67 or lower, and 0.97 or higher (or equivalently for Air/Fuel equivalence ratio Λ (Λ) up to 1.50 or higher, and down to 1.03 or lower.) with corresponding independent control of temperature by diluent/fuel ratio Ω (Ω).

[0326]Such scalable combustor techniques may be used to displace 50% to 100% stoichiometric air (or oxidant) delivered as cooling fluid, by using recycled diluent such as steam and/or hot water. Such techniques may further help displace between 10% and 170% of stoichiometric air. Such methods may reduce the relative size of an air (or oxidant) compressor by 5% to 33% up to 67% or more depending on the gas turbine size.

[0327]Scalable combustor techniques may configure combusting and equilibration residence times from 100 ms to 700 ms. They may further extend combusting and equilibration residence time down to 30 ms and up to 3 seconds.

[0328]Scalable combustor techniques may correspondingly vary the combusting and/or equilibration system lengths relative to the specific fluid delivery rate of volumetric flow per combusting section outlet cross-sectional area. Adjusting such combustion system length may facilitate combustion of difficult fuels with slow flame speed such as ammonia. They may equally allow for typical combustion of common fuels like methane and natural gas. This also allows rapid combustion for fuels such as hydrogen.

[0329]Scalable combustor configuration techniques may configure the combusting system with lengths from 100 mm to 500 mm. They may extend down to 10 mm, or increase to 5 m in length. Blend-Trim regions may range from 20 mm to 100 mm. They may be

varied from 5 mm to 5 m. Equilibrating system lengths may similarly extend from 0.2 m to 2m. Equilibrating system lengths may extend down to 0.04 m, and up to 10 m.

[0330]Power System Schematic Layout

[0331]Fig. 3A schematically shows a VAST Cycle Power System with a VAST Combustion System (herein “CMB”) receiving compressed oxidant fluid from an upstream Compressor (herein “CPR”) axially at CZ3 to feed a downstream gas turbine expander (herein “EXP”) axially at CZ4. This adapts the gas turbine numbering methodology of the American Society of Mechanical Engineers (herein “ASME”), along the Combustor axial flow Z direction (herein “CZ”).

[0332]This VAST Cycle Power System depicts a Compressor (CPR) with a Compressor Inlet CZ2 and a Compressor Outlet CZ3. Compressed fluid flow (herein “WX3”) may flow into a Diffuser (herein “DIF”). A portion of compressed oxidant (herein “WX31”) may flow into an upstream ignition system or Pilot 100 (herein “P”) at a Pilot or combustor inlet plane CZ31. Another portion of compressed oxidant fluid (herein “WX34”) may be delivered upstream into the combustor such as at plane CZ32. Diluent fluid may be delivered upstream to CZ32, such as liquid water as a spray WDL32 into oxidant flow WX34.

[0333]A portion of diluent WDL32 may be delivered into an upstream typically fuel rich combusting region 730 from a combusting region inlet at CZ34 up to a Blend-Trim region inlet and combusting region outlet plane CZ35 (marked here as a combustor reference plane CBQ).

[0334]Fig. 3A further schematically shows a “Blend-Trim” Region 850 extending from an upstream Blend-Trim inlet plane CZ35 (or combusting region outlet plane) through to a downstream Equilibrating Region inlet plane CZ39 (or Blend-Trim Region outlet plane).

[0335]Equilibrating Region

[0336] With reference to Fig. 3A and 3B, an Equilibrating Region 900 may be provided downstream of the Blend-Trim region 850. This Equilibrating Region 900 may extend from the Blend-Trim region outlet at plane CZ39 to a Transition Zone Inlet plane CZ394 (or an Equilibrating Region outlet plane) to provide residence time to further complete the reaction or combustion.

[0337]Transition Region

[0338] Per Fig. 3A, a Transition Region or Zone 980 may follow the equilibrating region 900 to accelerate the hot flow to the combustor outlet. This may extend from the end of

the equilibration region at plane CZ394 to a combustor outlet at CZ4 and into an expander (herein “EXP”) or Turbine Inlet, with an expander outlet at an outlet plane CZ5. The equilibrating and transition regions may be aerodynamically configured to reduce flow pressure losses.

5 [0339]The Turbine Inlet mass flow (herein “W4”) flows into the Expander EXP at axial plane CZ4 from the Combustor outlet. Cooling diluent liquid mass flow (herein “WDL45”) may be delivered into the expander to cool hot components such as blades, stators and/or walls. Expanded fluid mass flow (herein “W5”) may flow from the expander EXP at axial plane CZ5 into a downstream heat exchanger, here depicted as
10 a Once Through Steam Generator (herein “OTSG”). The cooled mass flow (herein “W51”) exits out of the OTSG and into a downstream heat exchanger (herein “HX”) (at an axial mid heat exchanger flow stage CZ51 not shown).

[0340]A cooled heat exchanger outlet mass flow or exhaust flow (herein “W52”) (at an axial flow stage CZ52 downstream of the heat exchanger HX not shown) may be further
15 cooled downstream as desired to further condense diluent vapor and/or to further cool diluent liquid and non-condensable flue gas, such as by using water- or air-cooled heat exchangers (not shown). In some VAST Power Cycle configurations, vapor may be condensed, forming sub-atmospheric pressure with a recompressor compressing the cooled expanded excess oxidant and non-condensed combustion products back to
20 atmospheric pressure discharge as detailed in prior patents (not shown).

[0341]Fig. 3A further depicts upstream gas combusting temperatures being controlled by thermal diluent flows such as water and/or steam relative to fuel fluid delivery. Such diluent fluids may be delivered into multiple upstream combusting regions. E.g., shown here into seven Combusting regions (herein “C1” to “C7”) in Fig. 3A and Fig. 3G, six
25 Combusting regions (C1-C6 not labeled) in Fig. 3I, and eight combusting regions (C1-C8 implied, not labeled) in Fig 3N to Fig. 3Q. These may range from two to twenty combusting regions or more.

[0342]Fig. 3A shows further mass flow of oxidant fluid (herein “MX”) and mass flow of diluent fluid (herein “MD”) may be delivered into the Blend-Trim region. E.g., further
30 oxidant such as air, and diluent such as water and/or steam may be delivered into one or more Blend regions (herein shown as a first Blend Region One “B1” and a second Blend Region Two “B2”), and into one or more Trim regions (herein shown as a First Upstream Trim Region “T1” and a Second Downstream Trim Region “T2”).

[0343] The cooled exhaust mass flow (W52) at Heat Exchanger (HX) outlet (axial plane 52 not shown) may be further cooling as needed.

[0001] Fig. 3A shows further oxidant and diluent may be delivered into a Blend-Trim region. E.g., further oxidant such as air, and diluent such as water and/or steam may be delivered into the one or more Blend regions (e.g., **B1** and **B2**), and into the one or more Trim regions (e.g. Upstream **T1** and downstream **T2**).

[0002] Fig. 3A shows an inlet mass flow of oxidant (or air) (herein “**WX2**”) with an optional compressor inlet mass flow of liquid diluent (such as liquid water spray mass flow) (herein “**WDL2**”) into the inlet **CZ2** of the compressor **CPR**, with an optional compressor cooling liquid spray mass flow (herein “**WDL25**”) into the compressor **CPR** itself.

[0003] The compressor **CPR** may feed a mass flow of compressed oxidant fluid flow (or air) (with optional vaporized diluent) (herein “**WX3**”) into the upstream inlet of a VAST scalable combustor **CMB** at an upstream flow location **CZ3**. The downstream combustor outlet at flow location **CZ4** may flow into an expander **EXP**.

[0004] The scalable combustor **CMB** may include an upstream diffuser, **DIF**, that expands and slows the oxidant (or air) from the compressor outlet / diffuser inlet **CZ3** to feed an upstream combusting section from **CZ34** to **CZ5** a VAST combustor (**CMB**) extending from a combustor pilot inlet plane **CZ31** to the downstream outlet plane **CZ4**.

[0005] Fig. 3A further depicts an upstream ignition authority or Pilot **100 (P)**. Pilot **P** may be fed with a pilot fuel mass flow (herein “**WF31**”), a pilot oxidant mass flow (herein “**WX31**”), and optionally pilot diluent (herein “**WDL31**”) such as pilot liquid water. Further fuel fluid (herein “**WF32**”), and further diluent fluid (herein “**WDS32**”) such as steam, may be mixed and delivered as a diluted fuel fluid mass flow (herein “**MF**”) into a diluted fuel manifold, to feed transverse fuel feeders into combusting regions (such as **C1** to **C7**).

[0006] Further oxidant fluid (herein “**WX34**”) may be delivered together with various flows of upstream diluent fluid (herein “**WDL32**”) and/or mixtures may then be progressively fed into the combustor via multiple feeders (**C1** through **C7**), delivering one or more mass flows of fuel fluid (**MF**), oxidant fluid (**MX**), and diluent fluid (**MD**) oriented generally across or transverse to the axial flow.

[0007] Fig. 3A then depicts stoichiometric diluted oxidant and/or diluent mass flows being then fed into a Blend-Trim region **850** thru one or more transverse Blend region feeders (**B1** and **B2**), with the remaining oxidant and/or diluent fluids delivered through one or more Trim region feeders, (upstream **T1**, and optional downstream **T2** Trim regions etc., not shown) between combustor axial planes **CZ35** and **CZ39**.

[0008] Fig. 3A further shows mass flows of liquid diluent (herein “**WDL42**”) into a heat exchanger **HX**. Heated liquid from **HX** flows (herein “**WDL41**”) into the Once Through Steam Generator (herein “**OTSG**”), and upstream into the upstream combustor (herein “**WDL32**”), into the Blend-Trim region (herein “**WDL35**”), and into the downstream combustor walls in the equilibrating region and transition region, (herein “**WDL398**”).

[0009] Fig. 3A shows a portion of heated liquid diluent **WDL41** further recovering heat in the **OTSG** to form steam (herein “**WDS4**”). This vaporized diluent may be delivered back into the Blend Trim region as **WDS35**, and into the upstream region as **WDS32** such as into the upstream fuel mass flow **MF** at **CZ32**.

Premix Region

[0010] Referring to Fig. 3A, an upstream premix region may be provided between the compressor outlet / diffuser inlet **CZ3** and the combustor region outlet at **CZ35**. This may deliver liquid diluent **WDL32** into the oxidant mass flow **MX** feeding one or more combustor regions **C1** through **C7**. This premix region may similarly be located between an upstream combustor inlet plane **CZ31** near the inlet **100** pilot **P** and the combustor region inlet near **CZ34**.

[0011] The premix region may comprise perforated direct contact tubes **14** connected to a liquid diluent supply flow **WDL31** to deliver diluent spray into the upstream oxidant fluid **WX34**. One or more Valves may be configured to control delivery of one or more flows of fuel and/or diluent into one or more of the diffuser **DIF**, the pilot **P**, combustor region **730**, and Blend-Trim region **850**, etc.

[0012] Valve **VDL42** may control the return flow of diluent liquid through the heat exchanger **HX**. Valve **VDL35** may control flow of heated liquid diluent **WDL35** into the Blend-Trim region **850**. Valve **VDL32** may control liquid diluent **WDL32** to the combustor region manifold **730**. **VF32** may control fuel fluid flow **WF32** into the combustor system. Valve **VF31** may control fuel fluid flow **WF31** to the pilot **P**.

Scalable Radial Annular (“Fan”) Combusting Array Configurations

[0013] With reference to generic schematic three-dimensional perspective Fig. 3B, some

scalable combustor embodiments, may comprise a streamwise flow axis with transversely extended combusting sections **732** relative to shallowly separated opposed combustor walls **736**. Such transversely extended walls **736** of extended combusting sections **732** may be bounded with side walls **734**. The relative circumferential transverse wall elongation may be greater than 1.15 times the shallow spacing by radial depth of side walls **734**. adjacent combustor wall between opposed transverse – axial combusting chamber walls.

[0014] In Fig. 3B, a portion of the Scalable Combustor, **CMB** is depicted extending from a flame authority **100** or pilot **P** at axial flow location **CZ31** about the outlet of the upstream diffuser **DIF** through a combusting section **730** and a downstream Blend-Trim region **850** opening into the downstream equilibrating region **900**.

[0015] Fig. 3B shows an embodiment of a Cylindrical-Axial (circumferentially-radially stacked) combustor **702** shown in cylindrical coordinates with a Radial axis (“**R**”) perpendicular to an Axial flow axis (**Z**) with a circumferential direction Theta (**Θ**). In other configurations, scalable combustors may use a curvilinear flow axis with non-cylindrical walls.

[0016] Such embodiments may include multiple scalable (“fan”) combusting shells (or burners) configured generally about Radial - Circumferential Theta (**R - Θ**) cylindrical surfaces. These cylindrical combusting shells may be stacked radially, and generally perpendicularly, to the primary streamwise flow axis of oxidant fluid **F5** through the scalable combustor, oriented along the axial (**Z**) flow direction, from an upstream fluid inlet **134** to a fluid flow outlet **136** for heated pressurized hot combusted fluid **F20**.

[0017] Per Fig. 3B, for operation in elevated pressures, such scalable circumferential combustor embodiments **702** may be configured within an outer Pressure Vessel Wall **172**. A pilot fuel fluid flow **F3**, and a pilot oxidant fluid flow **F6**, may be delivered to an upstream Igniter, flame authority or Pilot **100**, configured to combust these fluids and to form a hot pilot fluid flow **F22**.

[0018] Pilot diluent fluid **F8** flow may be separately delivered to the Pilot **100**, and/or mixed in with pilot fuel fluid **F3**, and/or pilot oxidant fluid **F6** flowing into the Pilot **100** in an upstream pilot region **720**.

[0019] Per Fig. 3B, such upstream hot pilot fluid flow **F22** from Pilot **100** may be distributed in upstream pilot region **720** to an upstream end of a pilot fluid distribution system **722** comprising one or more scalable pilot fluid delivery ducts (or “fan” burner ducts) **728**. Such pilot fluid delivery ducts (or “fan” burners) **728** may be configured

circumferentially around the cylindrically stacked scalable combustor **702**.

[0020] Pilot fluid delivery ducts **728** may deliver hot pilot fluid into one or more combustoring systems (or mid-fan burners) **732** in an axially intermediate combustoring region **730**.

5 [0021] Further to Fig. 3B, each combustoring system **732** generally comprises two radially opposing circumferential combustoring radially outward side walls **736** (with corresponding radially inward side walls). These combustoring radially outward side walls **736** may be bounded and connected by corresponding combustoring (mid-fan) (circumferentially) end walls **734**. In other configurations, radial side walls **736** may be
10 curved around to radially meet and transversely or circumferentially bound the combustoring region.

[0022] Each combustoring system radial side wall **736** may comprise numerous fluid delivery orifices **80** such as schematically depicted in Fig. 3C. Pressurized oxidant fluid **F5** may be delivered into the Cylindrical-Axial combustoring system **702** and delivered
15 into combustoring system **732** through orifices **80** configured in combustoring system radial side walls **736**.

[0023] Similarly, per Fig. 3B, diluted fuel fluid **F2** may be delivered through a similar axial Fuel Manifold **770** between circumferentially adjacent combustoring regions on alternating sides of the combustoring regions from the oxidant fluid **F5** delivery.

20 [0024] In further configurations, premixed reactive fuel-oxidant mixture with optional diluent may be delivered into the cylindrical-axial combustor **702**, and delivered through perforated combustor radial side walls **736** in combustoring systems **732** within the combustoring region **730**.

[0025] Per Fig. 3B, energetic fluid from one or more combustoring systems **732** in
25 combustoring region **730** may be delivered to circumferential downstream Blend-Trim region **850** comprising Blend-Trim oxidant-diluent delivery and reacting region manifold walls **857** feeding related Blend-Trim reacting regions. Each Blend-Trim reacting region **850** may comprise opposing circumferential Blend-Trim perforated side walls **857** to bound combustion within that region.

30 [0026] The Blend-Trim region side walls **857** may generally be connected by one or more far-fan end walls **746**. The Blend-Trim side walls **857** may also be configured to join at their circumferentially transverse ends. Multiple sets of circumferential combustors **732** and Blend-Trim Regions **850** may be configured within combustor outer wall or pressure vessel **172**.

[0027] Fig. 3C depicts an expanded view of a combustor wall section radial side wall **736** showing orifices **80** through a combustor fluid duct wall **132** protected by a thermal insulating barrier **150**.

Symmetric Combustor

5 [0028] Fig. 3D depicts a sample radial circumferential (R Theta) cross section of a portion of a comBusting region extending circumferentially by a Combusting section angle **THC**. This example shows an oXidant Manifold on the **CCW** side feeding oxidant fluid **F5** with the **THBMX CW** portion shown as feeding two **CW** adjacent combusting regions. On the **CW** side, Fig. 3D depicts a fuel manifold encompassing a
10 **THBMF CW** portion correspondingly feeding the two radially adjacent combusting regions including a combusting feeder radial depth (Thickness) **CR15T**.

[0029] Fig. 3D further depicts an outer oxidant fluid feeder extending radially with a radial depth (Thickness) **CR12T** inside of an outer circumferential wall having an inner radius **CR12**. That outer oxidant fluid feeder extends circumferentially over an
15 included angle **THBFX4** and feeds oxidant fluid through multiple orifices into a combusting region extending radially with a radial depth (or Thickness) **CR15T** from outer wall inner radius **CR15** to inner wall outer radius **CR16**.

[0030] Oxidant fluid **F5** optionally with diluent (such as water vapor or mist) may flow along the oXidant fluid feeder and through oXidant orifices with a typical diameter
20 **DXO** into a radially adjacent outer combusting region extending radially with a depth (or Thickness) **CR15T** between combusting chamber outer radius **CR15** and combusting chamber inner radius **CR16**. These oxidant orifices may be offset from the **CCW** manifold by a circumferential angle **THBXO**, and spaced apart by a circumferential angle **THBXS**, with an Jth orifice in an Ith oxidant feeder positioned
25 at a circumferential angle **THBXIJ**.

[0031] Fig. 3D further depicts Fuel fluid flow **F2** optionally diluted with diluent fluid, flowing though a **CW** comBusting region manifold extending through circumferential
Theta angle **THBMF**. This **CW** fuel fluid manifold delivers fuel fluid through a fuel complementary feeder extending radially with a depth (Thickness) **CR18T**, and
30 feeding fuel fluid through fuel fluid orifices with typical fuel orifice diameter **DFO** into the outer combusting region between **CR15** and **CR16** extending radially with a depth (Thickness) **CR15T** and circumferentially about an angle **THBFF4**. This fuel feeder with a depth **CR18T** may similarly feed fluid into an inwards combusting

region extending radially between **CR25** and **CR26**, and circumferentially across **THBFF4**.

[0032] Further to Fig. 3D, oxidant fluid **F5** may similarly be delivered radially (and longitudinally) through the **CCW** manifold angle **THBQX** into a **CCW** combusting region. On the **CW** side, diluent fluid **F7** may be delivered through a **CW** diluent manifold extending circumferentially by **THMDS** for each of the central and **CW** combusting regions and axially along the combusting region.

[0033] Fig. 3E depicts an axial circumferential (Z Theta) “unrolled” plan view of two adjacent symmetric combusting and Blend-Trim regions with circumferentially **CCW** bounding end walls **734** and **CW** bounding end walls **735**. Such combusting regions may extend axially from an upstream Pilot **100** outlet or combusting inlet **CZ34** to downstream axial boundary **CZ35**. The downstream Blend Trim region may extend from **CZ35** to **CZ39**.

[0034] Per Fig. 3E, such adjacent symmetric combusting regions are shown here as having adjacent **CCW** oxidant fluid manifold regions ducting oxidant fluid **F5** per combusting region. They may have adjacent **CW** fuel manifold regions ducting diluted fuel fluid **F2**.

[0035] Such **CCW** oxidant manifolds and adjacent **CW** fuel manifolds may be commonly bounded and divided by a sigmoidally curved longitudinal (radial) manifold divider **250** between upstream **CZ34** and combusting downstream **CZ35** bounds, and thence to the Blend-Trim region axially between planes **CZ35** and the downstream **CZ39**.

[0036] Fig. 3E further depicts an upstream circumferentially increasing width region **731** with axial flow distance, downstream of the Pilot **100**, having an increasing width with an outward wall curvature along the axial direction. This may beneficially accommodate an axially increasing volumetric flow from increasing mass flow and from rising temperature with combustion, thereby reducing fluid acceleration and pressure drop losses.

[0037] Fig. 3A and 3E similarly depict a configuration with a downstream circumferentially decreasing combusting region **733** with a circumferentially axially declining width wall curvature. This may beneficially provide an aerodynamically smoother junction with an equilibrating region extending downstream from planes **CZ39** to **CZ394**. Fig. 3E further depicts an axially intermediate combusting transition region **732**. This combusting intermediate transition region **732** may change with axial

distance, from an axially increasing width wall curvature like in combusting upstream section **731**, to an axially decreasing width wall curvature like combusting downstream section **733**.

[0038] Fig. 3E depicts distributions of fuel fluid delivery orifices **81**, and distributions of oxidant fluid delivery orifices **82** opening into the combusting region from **CZ34** to **CZ35**. Further distributions of oxidant and/or diluent delivery orifices **83** may be configured to open downstream in the Blend-Trim region from planes **CZ35** to **CZ39**.

[0039] Per Fig. 3E, a downstream Blend-Trim manifold region may be provided to deliver oxidant fluid (**F4** not shown) or diluted oxidant fluid **F5** axially between axial planes **CZ35** and **CZ39**, and bounded by circumferential manifold **CCW** wall **250** and manifold **CW** wall **734**, with an axially upstream bounding wall **249** between the upstream delivery of diluted fuel flow **F2** (or fuel fluid flow **F1** not shown) and the downstream delivery of Blend-Trim diluted oxidant fluid **F5**. (See below for discussion of Fig. 3F showing exploratory NH₃ combustion.)

[0040] Fig. 3G depicts a corresponding outward (or inward) axial circumferential (Z Theta) “unrolled” plan view of a symmetric combustor fluid feeder region. This extends axially in the flow direction from an upstream Pilot **100**, with a **CCW** axial diluted oxidant fluid manifold region **244** ducting upstream diluted oxidant fluid **F4** to upstream oxidant feeders. The fluid feeder region of Fig. 3G may include a second **CCW** axial oxidant manifold **245** ducting diluted oxidant fluid **F5** further downstream.

[0041] The Fig. 3G configuration similarly depicts a **CW** inward upstream first fuel manifold region **242** ducting first fuel fluid **F1** comprising a fuel to upstream feeders. This may be divided by Upstream/Downstream Fuel Fluid Manifold Dividing wall **252** from a second intermediate **CW** outward fuel fluid manifold region **243**, such as ducting a Diluted Fuel Fluid flow **F2** (or another flow of Fuel Fluid) further downstream.

[0042] Further in Fig. 3G, similarly, an upstream to Downstream Fuel Feeder to Blend-Trim Dividing Wall **253** may divide and separate upstream diluted fuel fluid **F2**, flowing through the intermediate fuel fluid manifold region **243** between **CZ34** and **CZ35**, from Blend-Trim diluent flow **F7** flowing downstream to the Blend-Trim region **850** between planes **CZ35** and **CZ39**. Manifold bounding wall **253** may adjoin the downstream diluted oxidant or diluent fluid feeder extending down to plane **CZ39**.

[0043] In Fig. 3G, the **CCW** oxidant fluid manifolds and **CW** fuel fluid manifolds may be separated by a sigmoidally curved longitudinal radial manifold divider **250** that colds the downstream transverse Trim feeder ending axially at plane **CZ39**.

Downstream Combusting-oxidant fluid manifold divider **248** may be similarly curved and configured parallel to the manifold divider **250** and aerodynamically curved as it connects with the upstream of the transverse Blend-Trim feeder opening at **CZ35**.

[0044] An axial-radial manifold divider **253** bounding between diluted fuel fluid flow **F2** and diluent fluid flow **F7** may be curved or sigmoidal from upstream **CZ34** to downstream at **CZ35** where it adjoins oxidant feeder delivering oxidant fluid **X7** (or optionally diluted oxidant fluid).

[0045] In Fig. 3G, and axial radial mid Upstream Combusting oXidant Manifold Dividing wall **247** may divide Diluted Rich oXidant Upstream Fluid Manifold **244** from second Diluted Rich oXidant Downstream Fluid Manifold **245**. Similarly downstream axial radial oXidant-Blend-Trim manifold wall **248** may divide midstream second oxidant fluid manifold **245** from diluted oxidant Blend-Trim manifold **246**. With radially extending adjacent walls with multiple circumferentially adjoining oxidant fluid and fuel fluid manifolds and an upstream Pilot **100**.

[0046] In Fig. 3G, a first fuel fluid **F1** (optionally diluted) may be delivered into fuel fluid manifold **242** bounded by Fuel Feeder Upstream/Downstream Manifold Dividing Wall **252**, and be delivered as multiple fuel fluids, such as **U1**, **U2**, and **U3**, flowing through respective multiple transverse fluid fuel fluid feeders. These fuel fluid feeders may have an axially increasing number of fuel fluid orifices **81A** per transverse fuel fluid feeder over that range.

[0047] Similarly, a second diluted fuel fluid **F2** (or a second fuel fluid flow not shown) may be delivered into downstream fuel fluid manifold **243** and be delivered as multiple fuel fluid flows **U4**, **U5**, **U6** and **U7** flowing into multiple transverse fluid fuel fluid feeders and thence into the adjacent combusting region via fuel fluid orifices **81A**. These fuel fluid feeders may have an axially increasing number of fuel fluid orifices **81A** per transverse fuel fluid feeder over that axial range.

[0048] Per Fig. 3G, oxidant fluid **F4** may be delivered via Diluted Oxidant Fluid Upstream Manifold **244** as oxidant fluid flows **X1**, **X2**, and **X3** through multiple transverse oxidant fluid feeders and thence through oxidant fluid orifices **82A**. Such oxidant fluid **F4** delivery may interleave with delivery of first fuel fluid **F1**, such as through **U1** to **U3**, through respective upstream transverse fuel fluid feeders.

[0049] Similarly, oxidant fluid **F5** may be delivered via Diluted oXidant Fluid Downstream Manifold **245** as oxidant fluid flows such as **X4**, **X5**, **X6**, and **X7** (or optionally diluted oxidant fluid) through multiple respective transverse oxidant fluid feeders, and thence into the adjacent combusting region via multiple oxidant fluid orifices **82B**.

[0050] Such oxidant fluid delivery through oxidant feeders may interleave fuel fluid delivery flows, such as **U4** to **U7**, through respective transverse fuel fluid feeders in the upstream combusting region from **CZ34** to **CZ35**

[0051] Per Fig. 3G, diluted oxidant fluid **F6** may be delivered via **CCW** Diluted Oxidant Blend-Trim Manifold **246** to downstream Blend-Trim feeders. E.g., as one or more Blend fluids such as **B1** and **B2**, through transverse Blend feeders and through Upstream Blend-Trim orifices **83A**, and Midstream Blend-Trim Orifices **83B** into the radially adjacent Blend-Trim region downstream of the combusting region.

[0052] Similarly, a portion of diluted oxidant fluid **F6** may be delivered as one or more Trim fluid flows, such as **T1**, through a transverse trim feeder and thence through Downstream Blend-Trim orifices **83C** into the radially adjacent Blend-Trim region between planes **CZ35** and **CZ39**, axially downstream of the combusting region.

[0053] Per Fig. 3G, correspondingly, Blend-Trim diluent fluid **F7** may be delivered via **CW** Diluent-Trim manifold **238** downstream into Diluent-Trim region **850** between **CZ35** and **CZ39**. Blend-Trim diluent fluid **F7** may be delivered as one or more diluent fluids **D1**, **D2**, and **D3** through transverse diluent feeders and thence through diluent fluid orifices **86A**, **86B**, and **86C**, into the radially adjacent downstream Blend-Trim region of the combustor.

[0054] Per Fig. 3G, Per Fig. 3G, walls **253** and **250** of **CW** diluent trim manifold **238** to the Blend-Trim feeder region may be outwardly curved in an axially upstream section **731**. They may similarly be inwardly curved in axially downstream section **733**.

[0055] The intermediate combusting region **732** may be sigmoidally curved section to aerodynamically connect upstream section **731** and downstream section **733**. (In other configurations intermediate combusting region **732** may be linearly configured.) Downstream section **850** of bounding wall **250** may transition from inwardly curved section **733** to connect aerodynamically with the downstream equilibrating region axial slope.

Asymmetric Combusting Systems

[0056] Per Fig. 3H, and Fig. 3I, some combustor configurations may use an asymmetric combustor about a longitudinal oxidant manifold feeding transverse circumferential oxidant fluid feeders on the **CCW** and **CW** sides of the oxidant manifold. Such asymmetrical combusting configurations may similarly use a common longitudinal fuel manifold to feed corresponding multiple adjacent fuel feeders in adjacent combustors.

Asymmetric Combusting Regions

[0057] Fig. 3H depicts a circumferentially (Z Theta) “unrolled” plan view of two adjacent asymmetric combusting regions with an axial fluid flow axis Z, and circumferential axis Theta perpendicular to a radial axis R. This may have combustor walls radially adjacent to the combusting region, with fuel fluid orifices **81**, oxidant fluid orifices **82**, and/or Blend-Trim region diluent fluid delivery orifices such as **83**.

[0058] Per Fig. 3H, such asymmetric combusting region configurations may have circumferentially adjacent oxidant fluid manifold bounding Combustion Chamber Transverse **CCW** side End Wall **734** directing oxidant fluid **F5** between upstream combusting region inlet **CZ34** and combusting fluid downstream end **CZ35**. They may similarly have circumferentially adjacent bounding fuel fluid Combustion Chamber Transverse **CW** side End Wall **735** delivering fuel fluid **F2** between **CZ34** and combusting region Downstream Manifold End Dividing Wall **249**.

[0059] Further per Fig. 3H, diluted oxidant fluid **F7** may be delivered into the downstream Blend-Trim manifold region **850** bounded by side bounding manifold walls **735** and axially bounding Downstream Manifold End Dividing Wall **249**, extending axially from planes **CZ35** to **CZ39**. Some asymmetric combusting region configurations may include a common upstream Pilot **100** feeding adjacent combusting shells. This Pilot **100** may be fed by Pilot Fuel Fluid **F3**, Pilot Oxidant Fluid **F6**, and Pilot Diluent Fluid **F8**.

[0060] The asymmetric combustor configuration of Fig. 3H may have a sigmoidally curved oxidant fluid boundary such as described in Fig. 3H and adapted to such an asymmetric configuration. This may have a circumferentially (Theta) outwardly curving upstream manifold-combusting region bounding wall section **731** with axially increasing distance Z.

[0061] Per Fig. 3H, the asymmetric combustor may have a correspondingly circumferentially (Theta) inwardly curving downstream manifold with bounding Combustion Chamber Downstream Transverse End Wall section **733** with axially

increasing distance Z. The asymmetric combustor configuration of Fig. 3H may have a connecting intermediate Combusting Chamber Midstream Transverse End Wall **732** transitioning from the outward to the inward circumferential-axial curvature.

[0062] The oxidant fluid manifold of Fig. 3H may further have a downstream Blend-

Trim region **850** with a Blend-Trim diluent/oxidant fluid manifold wall **734** that may have an aerodynamically varying curvature between the axially upstream adjacent combustor region downstream transverse end wall **733** and the downstream equilibrating region wall beginning at **CZ39** and extending into equilibrating region **900** per Fig. 3A.

[0063] The corresponding fuel fluid side bounding manifold walls **735** may have similar curvature with correspondingly more shallow curvature. In other configurations, side bounding fuel fluid manifold walls **735** may be straight.

Asymmetric Manifolds and Transverse Fluid Delivery Regions

[0064] Fig. 3I depicts an example of a circumferentially “unrolled” circumferentially-

axially (Z Theta) asymmetric combustor fluid feeder configuration. This shows the combustor walls from the radially outward exterior, with fluid axial (longitudinal) manifold walls, upstream transverse fuel feeders and oxidant fluid feeders, fuel, oxidant, and diluent fluid delivery orifices, an axially upstream Pilot **100** delivering pilot fluid into an upstream combustor region at **CZ34**, and a downstream outlet into the combustor equilibrating region at **CZ39**.

[0065] Such circumferentially axially asymmetric configurations may utilize fewer fuel fluid manifolds and oxidant fluid manifolds than used with symmetric combustor system scalable shell combustors described in Fig. 3B to Fig. 3E and Fig. 3G.

[0066] The configuration shown in Fig. 3I, may include pilot fuel fluid **F3**, pilot oxidant fluid **F6**, and pilot diluent fluid **F8** feeding upstream Pilot **100**. On the clockwise side, a portion of first fuel fluid flow **F1** may be delivered into an upstream transverse fuel fluid feeder as fuel fluid **U1** and thence into the combustor region through one or more fuel fluid orifices **81A**.

[0067] Similarly, further portions of first fuel fluid **F1** may be delivered into progressively downstream transverse fuel fluid feeders as to feed fuel fluids **U2** and **U3**. These may be delivered from the transverse fuel fluid feeders through similar or increasing number of fuel fluid orifices **81A** into the radially adjacent combustor region.

[0068] Fig. 3I, similarly depicts an oxidant fluid manifold axially feeding oxidant fluid **F4** flows **X1**, **X2** and **X3** progressively axially into respective transverse oxidant fluid feeders and thence into oxidant fluid orifices **82A** into the radially adjacent combusting chamber.

5 [0069] The size, (or area) and number of the respective fuel fluid orifices **81** and oxidant fluid orifices **82** may be configured to provide a desired range of relative fuel to oxidant composition relative to stoichiometric composition (**PHI**) (Or equivalently, the relative oxidant to fuel ratio **LAMBDA**).

10 [0070] Per Fig. 3I, first fuel fluid **F1** and/or oxidant fluid **F4** may comprise gaseous and/or liquid diluent, such as steam, water vapor, and/or liquid water as delivered through transverse feeders and orifices into the combusting chamber.

15 [0071] Per Fig. 3I, diluted fuel fluid **F2** may be axially delivered through a fuel fluid manifold and thence into one or more transverse fuel fluid feeders as fuel fluid flows **U4**, **U5**, **U6** and/or **U7**. These may be delivered from the fuel fluid feeders through a plurality of fuel fluid orifices **81B** into the radially adjacent combusting chamber in the downstream portion of the combusting region from combusting mid-732 midstream wall region through combusting downstream wall 733 region.

20 [0072] Further per Fig. 3I, oxidant fluid flow **F5** may be delivered through the outer axial oxidant fluid manifold and then as one or more oxidant fluid feeder flows, such as **X4**, **X5**, **X6**, into respective transverse oxidant fluid feeders and thence through oxidant fluid orifices **82B** into the radially adjacent combusting region. E.g., in the downstream combusting region from mid-region 732 through combusting downstream region 733.

25 [0073] Per Fig. 3I, diluent fluid **F14**, such as liquid water, may be delivered to downstream Blend-Trim region through one or more transverse feeders such as diluent fluid flows **D1** and **D2**, and thence through orifices **86A** into radially adjacent Blend-Trim region **850** in the combustor axially between planes **CZ35** and **CZ39**.

30 [0074] Correspondingly per Fig. 3I, further oxidant fluid optionally with diluent fluid may be delivered through transverse Blend-Trim feeders as Blend-Trim fluids **B1** and/or **T1** and thence through Blend-Trim orifices **83A** and **83C** into the downstream Blend-Trim region **850** of the combusting chamber axially between planes **CZ35** and **CZ39**.

Cooling Upstream Combustion

[0075] The embodiments depicted herein enable further flexibility in configuring diluent delivery separately from oxidant and fluid delivery. This may be beneficially used to reduce combusting temperatures independently of relative fuel to oxidant composition (Phi) (or relative oxidant to fuel composition Lambda). This may reduce combusting temperature with higher oxidant compositions, and thus reduce harmful emissions such as NO_x emissions.

[0076] Thus, in some further configurations, some to all of the gaseous and/or liquid diluent fluid **D1** and **D2** may be delivered with one or more fuel fluid flows **U5** to **U7**. Similarly, some to all of such gaseous and/or liquid diluent fluid **D1** and **D2** may be delivered with oxidant fluids **X4**, **X5**, and/or **X6**.

[0077] Such increases in diluent fluid with the combusting fuel and oxidant fluid flows may be used to reduce the combusting temperatures and thence reduce emission formation such as NO_x. In some configurations, this may be delivered with rich to stoichiometric portion of oxidant delivery to form associated rich to stoichiometric combusting regions.

[0078] In some configurations, one or more of axially upstream to downstream manifold walls may be fairly aligned axially between the upstream combusting region at **CZ34**, and the downstream connection with related transverse fluid delivery feeders. Such alignment may beneficially reduce the rate of change in axial fluid flow cross sectional area (expansion) and delivery flow rate, and thereby reduce related fluid pressure drops.

[0079] Fig. 3J depicts a schematic circumferentially (Z Theta) “unrolled” combusting section of a radially inward (or outward) wall configuration, depicting larger and more numerous upstream oxidant fluid delivery orifices **82** and downstream smaller and fewer fuel fluid delivery orifices **81**. E.g., in a 2:1 ratio. Oxidant fluid orifices may be circumferentially offset from fuel fluid orifices to improve mixing and reduce quenching.

[0080] Fig. 3K depicts a schematic circumferentially (Z Theta) “unrolled” combusting section radially inward (or outward) wall configuration with fewer upstream fuel fluid delivery orifices **81**, and more numerous downstream oxidant fluid delivery orifices **82**. E.g., in a 1:2 ratio. Fuel fluid orifices may be circumferentially offset from oxidant fluid orifices to improve mixing and reduce quenching probabilities.

[0081] Fig. 3L depicts a schematic circumferentially (Z Theta) “unrolled” configuration a downstream Blend-Trim region section having oxidant fluid orifices **83A** and **83C**

in a radially outward (or inward) Blend-Trim region wall. Upstream Blend-Trim orifices **83A** may be offset ClockWise (**CW**) from downstream Blend-Trim region orifices **83C**.

[0082] Fig. 3M depicts a sample schematic configuration of a downstream Blend-Trim region section having oxidant fluid delivery orifices **83A** and **83C** in a radially inward (or outward) Blend-Trim region wall. Here upstream Blend-Trim orifices **83A** may be offset CounterClockWise (**CCW**) from ClockWise (**CW**) downstream Blend-Trim orifices **83C**.

[0083] Corresponding to Fig. 3L and Fig. 3M, Blend-Trim orifices **83A** and **83C** configured radially outward of a combustoring region may be offset ClockWise (**CW**) and CounterClockWise (**CCW**) from Blend-Trim orifices **83A** and **83C** configured radially inward of the combustoring shell. Similar methods may be used to improve mixing with fuel fluid orifices and/or oxidant fluid orifices in the combustoring upstream (**731**), midstream (**732**), and downstream (**733**) wall regions of the combustoring chamber.

[0084] Fig. 3N depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combustoring region upstream to downstream cut through a CounterClockWise (**CCW**) circumferentially outward combustoring region wall **734**.

[0085] This sample configuration Fig. 3N shows eight radially outward oxidant fluid delivery openings **X1** through **X8** for radially outward oxidant fluid feeders (or diluted oxidant fluid feeders). These may be complemented by and interspersed with eight radially inward oxidant fluid (or diluted oxidant fluid) passage openings **X1** through **X8**, in radially inward transverse oxidant fluid feeders.

[0086] Fig. 3O depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combustoring region upstream to downstream cut inward of the **CCW** circumferentially outward end wall (**734**) having eight radially outward oxidant fluid delivery openings (**X1** through **X8**) (or diluted oxidant fluid delivery openings) in outward transverse oxidant feeders.

[0087] Fig. 3O further shows these outwardly oxidant fluid openings (**X1-X8**) may be complemented with eight interspersed radially inward oxidant fluid delivery openings (**X1** through **X8**) (or diluted oxidant fluid delivery openings) in inward transverse oxidant feeders. These oxidant fluid passages (**X1-X8** and **X1-X8**) may be interspersed with narrower fuel fluid delivery passages (unmarked).

[0088] Fig. 3Q depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combusting region through a Clockwise (**CW**) circumferentially outward side bounding combusting region end wall **735** having eight radially outward fuel fluid delivery openings **U1** through **U8**. These may be complemented by and interspersed with eight radially inward fuel fluid passage openings **U1** through **U8**.

[0089] Fig. 3P depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combusting region inward of the **CW** circumferentially outward end wall (**735**) having eight oxidant fluid feeder delivery passage openings (**U1** through **U8**) interspersed with eight oxidant fluid feeder delivery passage openings (e.g., **X1-X8** not labeled).

[0090] Figures 3N through 3Q further depict combustor radial height (or length) parameters labeled from the first outward combusting shell towards the next inward combusting shell. E.g., **CR12** labels the radially outward oxidant fluid feeder wall outer radius. **CR15** labels the radially outward combusting region wall radially inner radius. **CR16** labels the radially inward combusting region wall outer radius. **CR24** labels the radially inward oxidant fluid feeder wall radially inner radius.

[0091] Figures 3N through 3Q further depict combustor radial inner height parameters labeled from the first outward combusting shell towards the next inward combusting shell along the radial R axis. E.g., **CR12T** labels the radially inner depth (height or Thickness) of the outer oxidant fluid transverse feeders shown in Fig. 3N and Fig. 3O. **CR12T** similarly labels the radially inner height of the outer fuel fluid transverse feeders shown in Fig. 3P and Fig. 3Q.

[0092] The radial parameter **CR15T** labels the combusting region radially inner height (Thickness) between **CR15** and **CR16** shown in Fig. 3O and Fig. 3P. **CR18T** similarly labels the radial thickness of the radially inner oxidant and fuel transverse feeders between **CR16** and **CR24** shown in Fig. 3N through Fig. 3Q.

[0093] Figures 3N through 3Q further depict the combustor axial boundaries from the upstream combusting region boundary at **CZ34** to the downstream combusting fluid delivery boundary at **CZ35** (at a reference plane **CBQ**) along the axial flow Z axis.

[0094] Fig. 3O further depicts typical Axially Inner Inlet Widths **810** of radially outer transverse oxidant fluid feeders **X1** to **X8** supplying the central combusting region near the outer open side (e.g., CounterClockWise **CCW** side near the oxidant fluid feeder opening from the adjacent oxidant manifold).

[0095] The axially inner axial widths of radially inner transverse oxidant fluid feeders X1 to X8 supplying oxidant fluid into the central combusting region in Fig. 3O may be similar and may be scaled according to the radial distance outward to the respective feeders from the combustor axis. Fig. 3O further depicts the corresponding Axially Inner Far End Widths **809** of radially outer transverse Fuel Fluid feeders **U1** to **U8** near the transversely closed end of the fuel fluid feeders near the adjacent oxidant fluid manifold (e.g., the **CCW** side).

[0096] Fig. 3P further depicts typical Axially Inner Inlet Widths **808** of radially outer transverse Fuel Fluid feeders **U1** to **U8** supplying the central combusting region near the outer open side (e.g., the Clockwise **CW** side near the fuel fluid feeder opening from the adjacent fluid manifold).

[0097] The inner axial widths of radially inner transverse fuel fluid feeders U1 to U8 supplying fuel fluid into the central combusting region in Fig. 3P may be similar and may be scaled according to the radial distance outward to the respective feeders from the combustor axis.

[0098] Fig. 3P further depicts the corresponding axially inner widths **811** of outer transverse oxidant fluid feeders (**X1-X8** not labeled) near the transversely closed end of the oxidant fluid feeders near the adjacent fuel fluid manifold (e.g., the **CW** side). Fig. 3P similarly shows the inner transverse oxidant fluid feeders (X1-X8 not labeled) between **CR16** and **CR24**, with corresponding inner widths (**811** not labeled) between fluid feeder walls.

[0099] Fig. 3R schematically depicts an axial circumferential (Z Theta) plan view perspective of a pair of transverse fluid feeders delivering oxidant fluid X into multiple oxidant fluid orifices **82** with typical oxidant fluid orifice diameters **DXO**, and delivering fluid F into multiple fuel fluid orifices **81** with typical fuel fluid orifice diameters **DFO**. The fuel fluid feeder is depicted with an axial width **DFD** compared to the wider Oxidant Fluid Feeder with an axial width **DFX**. In some configurations, diluent feeders may be utilized with a Diluent Fluid Feeder width **DFD** (not shown).

[0100] Per Fig. 3R, in some configurations, fuel fluid orifices **81** in the fuel fluid feeder may be circumferentially displaced by a circumferential angle **THF** from the vertical plane, ClockWise (**CW**) positive. In some configurations, oxidant fluid orifices **82** may be configured in pairs circumferentially positioned about fuel fluid orifices **81**, with a narrower circumferential separation angle **THXN** between oxidant fluid between nearest centers of oxidant fluid orifices **82** of separated orifice pairs. Oxidant

fluid orifices **82** may have a wider adjacent orifice circumferential separation angle **THXW** between oxidant orifice centers of wider separated orifice pairs.

[0101] In other configurations, oxidant orifices may be spaced further apart, or may be spaced uniformly apart. As schematically depicted in Fig. 3E, 3H, and Fig. 3I, circumferential spacing of orifices about the combustor may be further varied along axially differing fluid feeders. These may use one or both of circumferentially even spacing, and circumferentially asymmetric spacing.

[0102] In some configurations, circumferential spacing may be closer near one and/or both inner and outer combusting chamber boundaries than in circumferentially inner regions. Other configurations may provide more space between orifices near circumferential boundaries.

[0103] Fig. 3S shows another axial circumferential plan view of a fuel feeder feeding fuel fluid F through fuel fluid orifices **81** and an axially adjacent oxidant fluid feeder feeding oxidant fluid X through a multiplicity of oxidant fluid orifices **82**. This configuration depicts the oxidant fluid orifices **82** as axially (**Z**) separated and radially (**Theta**) aligned.

[0104] Oxidant fluid orifices **82** may similarly be circumferentially aligned with fuel fluid orifices **82** as depicted here. Such configurations may improve jet penetration into the combusting fluid flow. In other configurations, the oxidant orifices may be axially aligned, and collectively circumferentially offset from the fuel fluid orifices **82**.

[0105] Fig. 3T depicts a schematic radial circumferential (**R Theta**) cross section “elevation view” of an outer combusting region wall **736** with an insulating liner **738** bounding the combusting region with an outer radius **CR15**. Outer fuel fluid orifices **87** may be configured at a positive angle **PhiX** (or a negative angle **-PhiX**) from the radial axis **R** to deliver fuel fluid in the negative **CCW** direction.

[0106] Fig. 3T further shows an inner combusting region boundary wall at **CR16** radially displaced by a radial thickness **CR15T** from the outer combusting region wall. The radially inner combusting wall may have an outer insulating liner **738** protecting a radially inner structural wall **737**. Inner oxidant fluid orifices **88** may be configured at an opposing negative angle **-PhiX** (or an opposing positive angle **PhiX**) from the radial axis **R** to delivery oxidant fluid in the negative **CCW** direction.

[0107] The configuration of Fig. 3T may similarly be configured with fuel fluid orifices **87** oriented with a negative angle **-PhiX**, and oxidant fluid orifices **88** oriented in the

opposite direction with a positive angle **PhiX**. Further configurations may comprise both fuel fluid orifices **87** and oxidant fluid orifices **88** configured with the same positive angle **PhiX**. Similar configurations may comprise fuel fluid orifices **87** and oxidant fluid orifices **88** configured with a similar negative angle **-PhiX** (or positive angle **PhiX**).

[0108] In the Fig. 3T configuration, some fuel fluid delivery orifices **87** and oxidant fluid delivery orifices **88** in axially offset fluid feeders may be circumferentially oriented with similar positive angle **PhiX** (or negative angle **-PhiX**). In other configurations generically upstream fluid delivery orifices **87** (or **88**) and downstream fluid delivery orifices **88** (or **87**) may be configured with opposing positive angles **PhiX** and negative angles **-PhiX** oxidant (not shown).

[0109] Further generalizing configurations (such as in Fig. 3T) as shown in Fig. 3G, upstream fuel fluid orifices **81A** may be circumferentially offset from (or aligned with) downstream oxidant fluid orifices **82B**. Similarly, per Fig. 3G, upstream oxidant fluid orifices **82A** may be circumferentially offset to (or aligned with) downstream oxidant fluid orifices **82B**.

[0110] Fig. 3U depicts a radial circumferential (R Theta) “elevation” view of a sample configuration of outer transverse Fuel feeders marked **F**, and alternating outer oXidant transverse feeders marked **X**. These fuel and oxidant feeders may have a radially outer wall **802** bounded by an outer radius **CR11**. These feeders may have a radially inner wall **801** bounded by a feeder inner radius **CR15**, forming a radially outer surface of the inner first combusting region. The outer feeder inner wall **801** may comprise a radially outward (structural) side wall **736** covered on the inner combusting region side by a protective thermal insulating coating **738**.

[0111] Fig. 3U further depicts fuel feeders **F** comprising fuel fluid orifices **87** to deliver fuel fluid into the adjacent inner combusting region. Similarly, oxidant feeders **X** may comprise orifices **88** delivering oxidant fluid into the adjacent combusting region radially inwards of the feeder inner **801** wall at **CR15**. As shown, oxidant feeders **X** may be circumferentially wider in the transverse (Theta) direction than fuel feeders **F** to accommodate the larger volumetric oxidant fluid flows versus smaller fuel fluid flows.

[0112] Per Fig. 3U in some configurations, outer fuel fluid orifices **87** and oxidant fluid orifices **88** may both be angled circumferentially with a negative angle (**-PhiX**) from the radial axis R. Other configurations may use fuel fluid orifices **87** and oxidant fluid

orifices **88** with the opposite circumferential positive angle (**PhiX**) from the radial axis **R**.

[0113] Further configurations may alternate angles of fuel fluid orifices and oxidant fluid orifices positive (**PhiX**) and negative (**-PhiX**) angles between radially inward and outward orifices. (Such configurations may have orifices aligned with the combustor axial **Z** axis, similar to that shown in Fig. 3S.)

[0114] Further to Fig. 3U, shows a radially inward (“lower”) feeder array portion from the outer feeder wall radius **CR16** (or radially inner combusting region boundary) with outer insulating layer **738** protecting combusting chamber radially inner wall **737**, to radially inner feeder wall radius **CR20**. This depicts a cross section elevation view with Pairs of similar oxidant (**X**) fluid feeders of circumferential Passage Width **PWX** and Fuel (**F**) fluid feeders of circumferential Passage Width **PWF**. Joint fluid width widths of fluid feeder pairs shown in Fig. 3U may include a first oxidant-fuel fluid pair width (**FP1**) and a second oxidant-fuel fluid pair width (**FP2**).

[0115] In the radially inward (“lower”) portion of Fig. 3U, inner oxidant (**X**) fluid feeders may be configured opposite outer fuel (**F**) fluid feeders, and inner fuel (**F**) fluid feeders may be configured opposite to outer oxidant (**X**) fluid feeders. In this configuration common circumferentially transverse (outer) walls **133** may be used for opposite outer CounterClockWise (**CCW**) (“transverse”) and ClockWise (**CW**) boundaries.

[0116] In Fig. 3U, fuel (**F**) fluid orifices **87** may be configured circumferentially about the middle of fuel fluid feeder (**F**) with a circumferential offset of about **PWF/2** from the fuel -oxidant feeder dividing wall **133**. In the radially outer (“upper”) oxidant feeders **X**, the oxidant orifices **88** may be configured about midway (transversely) across the oxidant feeder displaced by a distance of about **PWX/2** from the fuel-oxidant feeder dividing wall **133** (such as circumferentially aligned oxidant fluid orifices **82** as shown in Fig. 3S).

[0117] Alternatively, Fig. 3U depicts a configuration where the radially inward (“lower”) oxidant feeders (**X**) may have two oxidant orifices **88** transversely configured within the oxidant feeder (**X**). For example, these two orifices **88** may be positioned transversely at about a distance **PWX/3** of about one third the passage Width of oXidant feeder from the oxidant feeder walls (similar to configurations of oxidant fluid orifices **82** of diameter **DXO** as shown in Fig. 3R.)

[0118] In some configurations, orifices may be aerodynamically configured to reduce

combustor pressure drop and to improve efficiency. Orifice inlet and outlet corners may be rounded to improve flows **F** and reduce pressure drops and efficiency losses, such as that shown in Fig. 3V.

[0119] Fig. 3V depicts a detailed view of a fluid orifice in the Radial Circumferential (R Theta) plane with fluid flow **F** through an outer combustor wall. E.g. fluid **F** may flow in through an oxidant fluid orifice of diameter **DXO** through a feeder structural wall of thickness **CR13T** protected by a feeder wall insulating coating of thickness **CR14T**. The fluid inlet and outlet may have rounded corners.

[0120] In some configurations, the upper orifice inlet may have a smaller radius **ROI** while the lower orifice outlet may have a larger orifice outlet **ROO**. Similarly, the outlet radius **ROO** may be about twice as large or larger than the inlet radius **ROI**. Such configurations may be formed using additive manufacturing (or “3D printing”).

[0121] Fig. 3W depicts a detailed view of an angled orifice in the Radial Circumferential (R Theta) plane through the outer combustor wall of thickness **CR13T** with an insulation layer of thickness **CR14T**. The angled oxidant fluid orifice may be configured with a flow axis at an angle **THM** relative to the Radial axis **R** with a diameter **DXO** perpendicular to the orifice flow axis.

[0122] Inlet corners of such angled orifices may be configured about an acute angle with a smaller radius **ROIA** and about an obtuse angle with a larger radius **ROIB**. Corresponding outlets of such angled orifices may have smaller radius **ROOA** for an acute angled outlet radius and a larger radius **ROOB** for an obtuse angled outlet radius.

[0123] Fig. 3X depicts a closed end of an oxidant feeder in the axial circumferential plane (Z Theta) for some configurations, with a manifold fuel fluid flow **FFM** flowing axially past the closed end, and a fuel feeder flow portion **FFF** flowing around the closed end. The oxidant fluid manifold may have an outer oxidant feeder axial width **PXWO**, and an inner oxidant feeder axial width **PXWI** with feeder wall thickness **FWT**.

[0124] The oxidant feeder axially upstream radius **R XU** may be configured smaller than the downstream oxidant radius **R XD**. E.g., the downstream radius **R XD** may be twice that of the upstream radius **R XU** or more.

[0125] Fig. 3Y depicts a closed end of a fuel fluid feeder in the axial circumferential plane (Z Theta) for some configurations, with a manifold oxidant fluid flow **FXM** flowing axially past the closed end, and an oxidant feeder flow portion **FXF** flowing around the closed end.

[0126] Per Fig. 3Y, such fuel fluid feeders may have an outer fuel feeder axial width **PFWO**,

and an inner fuel feeder axial width PFWI, with feeder wall thickness FWT. The oxidant feeder axially upstream radius RFU may be configured smaller than the downstream oxidant radius RFD. E.g., the downstream radius RFD may be twice that of the upstream radius RFU or more.

5 Numerous Orifices to Improve Mixing

[0127] In some configurations, fuel, oxidant, and/or diluent orifices may be used. Orifice size may be correspondingly reduced, such as to maintain overall cumulative orifice area within a desired range of the downstream combusting system cross sectional area.

10 [0128] More numerous orifices may be used to beneficially improve mixing, increase combustion, further diluent mixing, assist in temperature control, reduce hot spots, improve uniformity, and/or facilitate equilibration.

[0129] For example, in some configurations, each combusting shell may use 50 to 100 oxidant orifices. In other configurations this may be increased to 101 to 200 oxidant
15 orifices. Similarly, 201 to 400 oxidant orifices may be used. Further combustors may use 401 to 800 orifices or more, such as for difficult fuels like ammonia.

[0130] Such changes may beneficially be used to facilitate combustion of fuels with higher ignition energy, higher combusting temperature, slower flame speed, and/or slower combusting rates. E.g., in combusting one or more of ammonia, methane,
20 methanol, ethanol, cracked ammonia (combinations of H₂, N₂, and NH₃), and/or hydrogen.

Modeling Combustion and Emissions

[0131] The applicant won two US Department of Energy High Performance For Computing Manufacturing supercomputer grants. Simplified scalable combustors
25 (such as using an asymmetric combusting region and a cylindrical equilibrating region), were modeled using more than 110 independent parameters.

[0132] Of these, 23 parameters were selected to model combustion over typical gas turbine pressures, temperatures, and specific power rates. Argonne National Laboratory (herein ANL) conducted reactive computational fluid dynamic modeling
30 (herein “**RCFD**”) to evaluate low, medium, and high values (0%, 50%, 100%) for each of these selected parameter ranges.

[0133] Applicant ranked those parameters by parameter importance to Unburned Hydrocarbons (UHC) (or equivalent fuel), Nitrogen Oxides (Nox), and Carbon Monoxide (CO) emissions. Then ANL conducted 312 **RCFD** runs using combinations

of 5 values across low to high (0%, 25%, 50%, 75%, 100%), for the most significant 9 parameters.

[0134] Lawrence Livermore National Labs (herein “LLNL”) then used neural network methods to analyze the data and to create a software program to predict UHC, CO and NOx emissions, which can be run on a professional laptop computer.

[0135] Those methods and resulting software enabled the applicant to configure its scalable gas turbine combustor configurations so as to probably achieve less than 1 ppmvd each for UHC, Nox and CO emissions over commercial gas turbine operating conditions. This predicts emissions below the strictest California county emission requirements of 2.3 ppmvd Nox and CO without using catalysts.

[0136] Such very low emissions provide major advantages with typically 7% to 10% lower **CapEx** for commercial gas turbines operating on natural gas. It further promises substantially lower operating costs by eliminating ammonia delivery and associated “slip” emissions.

[0137] The techniques, configurations and methods as described herein further detail, extend, and/or adapt that initial modeling **RCFD** modeling on methane. They likely enable extending and/or improving the methods to further using the range of conventional to sustainable fuels. E.g., to include methane, natural gas, methanol, ethanol, ammonia, cracked ammonia (herein combinations of “H2 N2, and NH3”), and hydrogen.

Diluent to the Blend Region

[0138] NOx formation is likely to increase as the product of (Fuel * O₂) and exponentially with combustor temperature. Rich combustion cooled by steam and/or diluent in the upstream Blend region uniquely enables transitioning from rich hot upstream combustion to near stoichiometric combustion. This will likely be critically important to avoiding NOx formation.

Ammonia Combustion

[0139] Fig. 3F depicts an example of modeling combustor ammonia (NH₃) fuel with air, and diluent water and steam, along a flow axis from the upstream combustor inlet **CZ34** to the downstream combustor outlet at **CZ4**. This exploratory reactive **RCFD** modeling of diluted NH₃ air combustion was conducted in applicant’s prior simplified scalable combustor. The left axis shows the mean cross-sectional temperature, and the right axis the outlet NOx and NH₃ emissions in PPMVD (parts per million diluted to 15% O₂).

[0140] In this sample run, the mean upstream combustor hot gas temperature peaks near 1,830K (~1,557°C) about the end of the Blend-Trim region **T1**. For **RCFD** modeling, an assumed combustor wall cooling rate is prescribed, reducing the combustor outlet temperature at **CZ4** to a prescribed 1,527K (1,300°C) typical of a mid-range gas Turbine Inlet Temperature (TIT).

[0141] Per Fig. 3F, in this run, NH_3 peaked at ~13,000 ppmvd (~40,000 ppm) in the rich combustor region. It then declined to ~78 ppmvd (~227 ppm) at the combustor outlet. Combustion NO_x formation peaked at ~275 ppmvd (~800 ppm) downstream of the ammonia peak and upstream of the temperature peak. With excess NH_3 , and high H_2O , the NO_x declined to sub ~10 ppmvd (~29 ppm unadjusted) at the combustor outlet.

[0142] Such ~10 ppmvd NO_x emissions in Fig. 3F from initial exploratory NH_3 combustion already achieves NO_x emissions 60% or more below the US EPA's 25 ppmvd national emissions limit for mid-range gas turbines. These results appear remarkably lower than reported industrial and scientific combustion modeling reports found for this most difficult renewable or sustainable proposed fuel.

[0143] Applicant has identified means of further improving mixing and combustion by aerodynamic methods, improved orifice distributions and delivery staging, such as described herein. These promise to further improve combustion and lower both NH_3 and NO_x emissions.

[0144] With 24% higher efficiency for a single expander VAST cycle with exhaust heat recycling, this appears to offer a further 19% lower NO_x emissions per electricity generated (ppmvd/MWh) relative to a conventional simple cycle (Brayton) peaker gas turbine.

Cooling Combustion

[0145] In some configurations, remaining undelivered diluent may be moved from the downstream Trim region feeders **T1** to be delivered up into the Blend region feeders (e.g., **B1** and **B2**). A major portion of this remaining diluent may be delivered to the upstream Blend feeder **B1** to provide cooler rich (sub stoichiometric) combustion, with temperature being controlled independently of the relative local fuel to oxidant ratio Φ (or the relative local oxidant to fuel ratio Λ).

[0146] In further configurations, part of this diluent may further be delivered further upstream into the downstream end of the combustor region, such as to delivering with fuel **U7** and/or oxidant fluid **X7** (or optionally diluted oxidant fluid) in the

axially downstream (or last) combustng region axial 733. Such diluent may further be delivered into the last two to last seven combustng regions upstream of CZ35.

[0147] Excess oxidant (or air) T1 may similarly be delivered in through the downstream Trim region. Such a combination of upstream diluent and downstream excess oxidant may achieve the coolest Blend region rich combustion with the least oxidant up to stoichiometric combustion. This may well form the lowest NO_x emissions for such configurations, with no change in total oxidant or excess air delivered Φ (Φ).

In Situ Ammonia Cracking

[0148] In further configurations ammonia may be delivered upstream under hot fuel rich (excess fuel, sub-stoichiometric oxygen) conditions (with Φ (Φ) > 1 or Λ < 1). Upstream combustng temperatures may be increased by reducing upstream diluent. Such conditions may increase upstream ammonia cracking to hydrogen and nitrogen. Such *in situ* rich cracking of ammonia to hydrogen and nitrogen may facilitate downstream rich combustion, thereby reducing overall NO_x formation.

[0149] Some configurations may configure the temperature of transverse feeders adjacent to the combustng region, and/or in the upstream combustng region sufficient to thermally crack a portion of ammonia fuel to hydrogen and nitrogen. Catalysts may similarly be used within transverse fluid feeders to crack ammonia.

Thermally Igniting Flows

[0150] In some configurations, an energetic fluid may be formed by heating one or more delivered fluids to temperatures such that the temperature and flow rate of the delivered energetic reactant and co-reactant mixture gas is sufficient to ignite the reactive fluid in the primary reaction zone.

Manufacturing Methods

[0151] One or more of such scalable parametric combustor configurations depicted may be constructed using additive manufacturing (or “3D printing”) techniques. Such manufacturing techniques may facilitate forming the numerous oxidant fluid, fuel fluid, and diluent fluid transverse feeders with the corresponding orifices delivering fluid from the transverse feeders into the combustng chambers.

[0152] In some configurations, such scalable shell combustors may be formed in two halves with inner insulating coatings over outer structural walls. These may then be assembled and be suitably held, bonded or fastened together. In other configurations, such orifices may be formed by laser ablation, chemical etching, mechanical or fluid jet drilling, or similar material removal techniques.

Turbulence generators

[0153] In some embodiments, turbulence generators may be configured along one or both surfaces bounding a combustion region within the scalable combustor. These may comprise undulations of the scalable combustor walls. Similarly, they may comprise protuberances into the gas flow on one or both of the scalable combustor walls.

GENERALIZATION

[0154] From the foregoing description, it will be appreciated that a novel approach for distributed contacting, mixing and/or reacting of three or more fluids has been disclosed using one or more processes described herein. While the components, techniques and aspects of the invention have been described with a certain degree of particularity, it is manifest that many changes may be made in the specific designs, constructions and methodology herein above described without departing from the spirit and scope of this disclosure.

[0155] Where dimensions are given, they are generally for illustrative purposes, and are not prescriptive. Of course, as the skilled artisan will appreciate, other suitable sizes, orientations, configurations and distributions of fluid delivery orifices, fluid passages, and other components may be efficaciously utilized, as needed or desired, giving due consideration to the goals of achieving one or more of the benefits and advantages as taught or suggested herein.

[0156] Where duct, tube or array configurations are provided, similar two- or three-dimensional configurations or combinations of those configurations may be efficaciously utilized, including varying the nominal thicknesses, diameters, cross sectional shapes, spacings, orientations, and other dimensions and parameters for perforated ducts, perforated tubes, manifolds, sub-manifolds, feeders, combustors, blend, trim, equilibrating and transition regions, and tube arrays.

[0157] Where the terms fuel, reactant, diluent, water, steam, carbon dioxide, air, oxygen, and oxidant have been used, the processes are generally applicable to other combinations of those fluids or to other combinations of other reacting, co-reacting, and diluent or non-reacting fluids. Where fluid quantities are referred to, these processes are generally applicable to include quantities delivered at multiple times, and to continuous fluid flows. Where assembly processes are described, various alternative assembly processes may be efficaciously utilized to achieve configurations to achieve the benefits and advantages of one or more of the embodiments as taught or suggested herein.

[0158] Where transverse, axial, radial, circumferential, horizontal, perpendicular, normal, or other directions are referred to, it will be appreciated that any general coordinate system using curvilinear coordinates may be utilized including Cartesian, cylindrical, spherical or other specialized system, such as an annular system. Similarly, when one or more transverse or axial distributions or profiles are referred to, it will be appreciated that the configurations and processes similarly apply to spatial control in one or more curvilinear directions as desired or prescribed. Similarly, the contactor, array, device or duct orientations may be generally rearranged to achieve other beneficial combinations of the features and processes described.

[0159] Where fluid delivery controls refer to controlling the size and flow rate of fluids, ejecting drops, jets or micro-jets, it will be appreciated that the control measures may utilize one or more measures to control the differential ejection pressure distributions across the fluid orifices **80**, to vibrate the orifices, and/or to control the electro-magnetic field about the orifices **80** using one or more measures described herein, and/or by using similar means of modulating the orifices' location, the fluid pressure, and the surrounding electro-magnetic field.

[0160] Fig. 4A schematically shows a Scalable Gas Turbine Power System **1** with a Scalable ComBustion System (herein "**CMB**") as used in a VAST Power Cycle. This Scalable Gas Turbine Power System **1** is shown receiving compressed oxidant fluid from an upstream Compressor **407** (herein "**CPR**") axially to axially feed a downstream gas turbine expander **440** (herein "**EXP**"). This generally adapts the gas turbine location numbering methodology of the American Society of Mechanical Engineers (herein "**ASME**"), along the Combustor axial flow Z direction (herein "**CZ**") as follows.

[0161] This VAST Cycle Scalable Gas Turbine Power System **1** depicts a Compressor **407** (**CPR**) with a Compressor Inlet at **CZ2** and a Compressor Outlet at **CZ3**. Compressed oxidant fluid flow (herein "**WX3**") may flow into a Diffuser (herein "**DIF**"). A portion of compressed oxidant (herein "**WX31**") may flow into an upstream ignition system or Pilot **100** (herein "**P**") at a Pilot or combustor inlet plane **CZ31**. Another portion of compressed oxidant fluid (herein "**WX34**") may be delivered upstream into a hot ignitor fluid delivery at **CZ31** into the combusting section such as at plane **CZ32**. Diluent fluid may be delivered upstream to **CZ32**, such as liquid water as a spray **WDL32** into upstream inlet oxidant flow **WX34**.

[0162] A portion of diluent **WDL32** may be delivered into an upstream typically fuel rich combusting region **730** from a combusting region inlet at **CZ34** up to a Blend-Trim region inlet and combusting region outlet plane **CZ35** (marked here as a combustor reference plane **CBQ**).

5 [0163] Fig. 4A further schematically shows a “Blend-Trim” Region **850** extending from an upstream Blend-Trim inlet plane **CZ35** (or combusting region outlet plane) through to a downstream Equilibrating Region inlet plane **CZ39** (or Blend-Trim Region outlet plane).

Equilibrating Region

10 [0164] With reference to Fig. 4A and 4B, an Equilibrating Region **900** may be provided downstream of the Blend-Trim region **850**. This Equilibrating Region **900** may extend from the Blend-Trim region outlet at plane **CZ39** to a Transition Zone Inlet plane **CZ394** (or an Equilibrating Region outlet plane) to provide residence time to further complete the reaction or combustion.

15 Transition Region

[0165] Per Fig. 4A, a Transition Region or Zone **980** may follow the equilibrating region **900** to accelerate the hot flow to the combustor outlet. This may extend from the end of the equilibration region at plane **CZ394** to a combustor outlet at **CZ4** and into an expander (herein “**EXP**”) or Turbine Inlet, with an expander outlet at an outlet plane

20 **CZ5**. The equilibrating and transition regions may be aerodynamically configured to reduce flow pressure losses.

[0166] The Turbine Inlet mass flow (or Combustor Outlet mass flow), (herein “**W4**”) flows into the Expander **EXP** from the Combustor outlet at axial plane **CZ4**. Cooling diluent liquid mass flow (herein “**WDL45**”) may be delivered into the expander to

25 cool hot components such as blades, stators and/or walls. Expanded fluid mass flow (herein “**W5**”) may flow from the expander **EXP** at axial plane **CZ5** into a downstream heat exchanger, here depicted as a Once Through Steam Generator (herein “**OTSG**”). The cooled mass flow (herein “**W51**”) exits out of the **OTSG** and into a downstream heat exchanger (herein “**HX**”) (at an axial mid heat exchanger

30 flow stage **CZ51** not shown).

[0167] A cooled heat exchanger outlet mass flow or exhaust flow (herein “**W52**”) (at an axial flow stage **CZ52** downstream of the heat exchanger **HX** not shown) may be further cooled downstream as desired to further condense diluent vapor and/or to further cool diluent liquid and non-condensable flue gas, such as by using water- or

air-cooled heat exchangers (not shown). In some VAST Power Cycle configurations, diluent vapor may be condensed, forming sub-atmospheric pressure, together with a recompressor compressing the cooled expanded excess oxidant and non-condensed combustion products back to atmospheric pressure discharge as detailed in prior patents (not shown).

[0168] Fig. 4A further depicts upstream gas combusting temperatures being controlled by thermal diluent flows such as water and/or steam (or similarly CO₂) relative to fuel fluid delivery. Such diluent fluids may be delivered into multiple upstream combusting regions (from **CZ34** to **CZ35**). E.g., shown here into seven Combusting regions (herein “**C1**” to “**C7**”) in Fig. 4A and Fig. 4G, six Combusting regions (**C1-C6** not labeled) in Fig. 4I, and eight combusting regions (**C1-C8** implied, not labeled) in Fig 4N to Fig. 4Q. These may range from two combusting regions to twenty combusting regions, or more.

[0169] Fig. 4A shows further mass flow of oxidant fluid (herein “**MX**”) and mass flow of diluent fluid (herein “**MD**”) may be delivered into the Blend-Trim region (from **CZ35** to **CZ39**). E.g., further oxidant such as air, and diluent such as water and/or steam may be delivered into one or more Blend regions (herein shown as a first Blend Region One “**B1**” and a second Blend Region Two “**B2**”), and into one or more Trim regions (herein shown as a First Upstream Trim Region “**T1**” and optionally a Second Downstream Trim Region “**T2**”).

[0170] The cooled exhaust mass flow (**W52**) at Heat Exchanger (**HX**) outlet (axial plane **52** not shown) may be further cooling as needed.

[0171] Fig. 4A shows further oxidant and/or diluent may be delivered into a Blend-Trim region. E.g., further oxidant such as air, and/or diluent such as water and/or steam may be delivered into the one or more Blend regions (e.g., **B1** and **B2**), and similarly into the one or more Trim regions (e.g. Upstream **T1** and downstream **T2**).

[0172] Fig. 4A shows an inlet mass flow of oxidant (or air) (herein “**WX2**”) with an optional compressor inlet mass flow of liquid diluent (such as liquid water spray mass flow) (herein “**WDL2**”) into the inlet **CZ2** of the compressor **407 (CPR)**. An optional compressor cooling liquid spray mass flow (herein “**WDL25**”) may be delivered into the compressor **CPR** itself between the inlet **CZ2** and outlet **CZ3** of the compressor **407 (CPR)**.

[0173] The compressor **407 (CPR)** may feed a mass flow of compressed oxidant fluid flow (or air) (with optional vaporized diluent) (herein “**WX3**”) into the upstream inlet

of a VAST scalable combustor **CMB** at an upstream flow location **CZ3**. The downstream combustor outlet may feed equilibrated and accelerated hot gas flow **W4** at flow location **CZ4** into an expander **EXP**.

[0174] The scalable combustor **CMB** may include an upstream diffuser, **DIF**, that expands and slows the oxidant (or air) from the compressor outlet / diffuser inlet **CZ3** to feed an upstream combustor section from **CZ34** to **CZ5** a VAST combustor (**CMB**) that extends from the upstream diffuser (**DIF**) inlet at **CZ3** (to a combustor pilot inlet plane **CZ31**) (to the transition zone at **CZ394**), and to the downstream outlet plane **CZ4**.

[0175] Fig. 4A further depicts an upstream ignition authority or Pilot **100 (P)**. Pilot **P** may be fed with a pilot fuel mass flow (herein "**WF31**"), a pilot oxidant mass flow (herein "**WX31**"), and optionally pilot diluent (herein "**WDL31**") such as pilot liquid water. Further fuel fluid (herein "**WF32**"), and further diluent fluid (herein "**WDS32**") such as steam, may be mixed and delivered as a diluted fuel fluid mass flow (herein "**MF**") into a diluted fuel manifold, to feed transverse fuel feeders into combustor regions (such as **C1** to **C7**).

[0176] Further oxidant fluid (herein "**WX34**") may be delivered together with various flows of upstream diluent fluid (herein "**WDL32**") and/or mixtures may then be progressively fed into the combustor via multiple feeders (**C1** through **C7**), delivering one or more mass flows of fuel fluid (**MF**), oxidant fluid (**MX**), and diluent fluid (**MD**) oriented generally across or transverse to the axial flow.

[0177] Fig. 4A then depicts stoichiometric diluted oxidant and/or diluent mass flows being then fed into a Blend-Trim region **850** thru one or more transverse Blend region feeders (**B1** and **B2**), with the remaining oxidant and/or diluent fluids delivered through one or more Trim region feeders, (upstream **T1**, and optional downstream **T2** Trim regions etc., not shown) between combustor axial planes **CZ35** and **CZ39**.

[0178] Fig. 4A further shows mass flows of liquid diluent (herein "**WDL42**") into a heat exchanger **HX**. Heated liquid from **HX** flows (herein "**WDL41**") into the Once Through Steam Generator (herein "**OTSG**"), and upstream into the upstream combustor (herein "**WDL32**"), into the Blend-Trim region (herein "**WDL35**"), and into the downstream combustor walls in the equilibrating region and transition region, (herein "**WDL398**").

[0179] Fig. 4A shows a portion of heated liquid diluent **WDL41** further recovering heat in the **OTSG** to form steam (herein "**WDS4**"). This vaporized diluent may be

delivered back into the Blend Trim region as **WDS35**, and into the upstream region as **WDS32** such as into the upstream fuel mass flow **MF** at **CZ32**.

Premix Region

[0180] Referring to Fig. 4A, an upstream premix region may be provided between the compressor outlet / diffuser inlet **CZ3** and the combustor region outlet at **CZ35**. This may deliver liquid diluent **WDL32** into the oxidant mass flow **MX** feeding one or more combustor regions **C1** through **C7**. This premix region may similarly be located between an upstream combustor inlet plane **CZ31** near the inlet **100** pilot **P** and the combustor region inlet near **CZ34**.

[0181] The premix region may comprise perforated direct contact tubes **14** connected to a liquid diluent supply flow **WDL31** to deliver diluent spray into the upstream oxidant fluid **WX34**. One or more Valves may be configured to control delivery of one or more flows of fuel and/or diluent into one or more of the diffuser **DIF**, the pilot **P**, combustor region **730**, and Blend-Trim region **850**, etc.

[0182] Valve **VDL42** may control the return flow of diluent liquid through the heat exchanger **HX**. Valve **VDL35** may control flow of heated liquid diluent **WDL35** into the Blend-Trim region **850**. Valve **VDL32** may control liquid diluent **WDL32** to the combustor region manifold **730**. **VF32** may control fuel fluid flow **WF32** into the combustor system. Valve **VF31** may control fuel fluid flow **WF31** to the pilot **P**.

Scalable Radial Annular (“Fan”) Combustor Array Configurations

[0183] With reference to a generic schematic three-dimensional perspective view Fig. 4B, some scalable combustor embodiments may comprise a cylindrical combustor **704**, with an outer cylindrical outer pressure vessel **172**, and an inner cylindrical axial pressure wall **147**, with a common axis from an upstream inlet **134** to a downstream outlet **136**, parallel to the combustion flow direction.

[0184] Fig. 4B further depicts an upstream ignition (pilot) section **720**, a fuel rich Combustor section **730**, a Blend-Trim region **850** with residual diluent and oxidant delivery, and a downstream Equilibration region **900**.

[0185] upstream to downstream axis streamwise flow axis with transversely extended combustor sections **732** relative to shallowly separated opposed combustor walls **736**. Such transversely extended walls **736** of extended combustor sections **732** may be bounded with side walls **734**. The relative circumferential transverse wall elongation may be greater than 1.15 times the shallow spacing by radial depth of side walls **734**. adjacent combustor wall between opposed transverse – axial combustor chamber

walls.

[0186] In Fig. 4B, a portion of the Scalable Combustor, **CMB** is depicted extending from a flame authority **100** or pilot **P** at axial flow location **CZ31** from the outlet of the upstream diffuser through a combusting section **730** and a downstream Blend-Trim region **850** opening into the downstream equilibrating region **900**.

[0187] Fig. 4B shows an embodiment of a Cylindrical-Axial (circumferentially-radially stacked) combustor **702** shown in cylindrical coordinates with a Radial axis ("**R**") perpendicular to an Axial flow axis (**Z**) with a circumferential direction Theta (**Θ**). In other configurations, scalable combustors may use a curvilinear flow axis with non-cylindrical walls.

[0188] Such embodiments may include multiple scalable ("fan") combusting shells (or burners) configured generally about Radial - Circumferential Theta (**R - Θ**) cylindrical surfaces. These cylindrical combusting shells may be stacked radially, and generally perpendicularly, to the primary streamwise flow axis of oxidant fluid **F5** through the scalable combustor, oriented along the axial (**Z**) flow direction, from an upstream fluid inlet **134** to a fluid flow outlet **136** for heated pressurized hot combusted fluid **F20**.

[0189] Per Fig. 4B, for operation in elevated pressures, such scalable circumferential combustor embodiments **702** may be configured within an outer Pressure Vessel Wall **172**. A pilot fuel fluid flow **F3**, and a pilot oxidant fluid flow **F6**, may be delivered to an upstream Ignition Authority (Flame Igniter or Pilot) **100**, configured to combust these fluids and to form a hot pilot fluid flow **F22**.

[0190] Pilot diluent fluid **F8** flow may be separately delivered to the Pilot **100**, and/or mixed in with pilot fuel fluid **F3**, and/or pilot oxidant fluid **F6** flowing into the Pilot **100** in an upstream pilot region **720**.

[0191] Per Fig. 4B, such upstream hot pilot fluid flow **F22** from Pilot **100** may be distributed in upstream pilot region **720** to an upstream end of a pilot fluid distribution system **722** comprising one or more scalable pilot fluid delivery ducts (or "fan" burner ducts) **728**. Such pilot fluid delivery ducts (or "fan" burners) **728** may be configured circumferentially around the cylindrically stacked scalable combustor **702**.

[0192] Pilot fluid delivery ducts **728** may deliver hot pilot fluid into one or more combusting systems (or mid-fan burners) **732** in an axially intermediate combusting region **730**.

[0193] Further to Fig. 4B, each combusting system **732** generally comprises two radially opposing circumferential combusting radially outward side walls **736** (with

corresponding radially inward side walls). These combusting radially outward side walls **736** may be bounded and connected by corresponding combusting (mid-fan) (circumferentially) end walls **734**. In other configurations, radial side walls **736** may be curved around to radially meet and transversely or circumferentially bound the combusting region.

[0194] Each combusting system radial side wall **736** may comprise numerous fluid delivery orifices **80** such as schematically depicted in Fig. 4C. Pressurized oxidant fluid **F5** may be delivered into the Cylindrical-Axial combusting system **702** and delivered into combusting system **732** through orifices **80** configured in combusting system radial side walls **736**. Ref. to Fig. 4C, in some configurations, the diameter or size of orifices **80** may vary transversely to adjust the fluid delivery rate per orifice.

[0195] Similarly, per Fig. 4B, diluted fuel fluid **F2** may be delivered through a similar axial Fuel Manifold **770** between circumferentially adjacent combusting regions on alternating sides of the combusting regions from the oxidant fluid **F5** delivery.

[0196] In further configurations, premixed reactive fuel-oxidant mixture with optional diluent may be delivered into the cylindrical-axial combustor **702**, and delivered through perforated combustor radial side walls **736** in combusting systems **732** within the combusting region **730**.

[0197] Per Fig. 4B, energetic fluid from one or more combusting systems **732** in combusting region **730** may be delivered to circumferential downstream Blend-Trim region **850** comprising Blend-Trim oxidant-diluent delivery and reacting region manifold walls **857** feeding related Blend-Trim reacting regions. Each Blend-Trim reacting region **850** may comprise opposing circumferential Blend-Trim perforated side walls **857** to bound combustion within that region.

[0198] The Blend-Trim region side walls **857** may generally be connected by one or more far-fan end walls **746**. The Blend-Trim side walls **857** may also be configured to join at their circumferentially transverse ends. Multiple sets of circumferential combustors **732** and Blend-Trim Regions **850** may be configured within combustor outer wall or pressure vessel **172**.

[0199] Fig. 4C depicts an expanded view of a combustor wall section radial side wall **736** showing orifices **80** through a combustor fluid duct wall **132** protected by a thermal insulating barrier **150**.

Symmetric Combustor

[0200] Fig. 4D depicts a sample radial circumferential (R Theta) cross-section of a portion of a comBusting region extending circumferentially by a Combusting section angle **THC**. This example shows an oXidant Manifold on the **CCW** side feeding oxidant fluid **F5** with the **THBMX CW** portion shown as feeding two **CW** adjacent combusting regions. On the **CW** side, Fig. 4D depicts a fuel manifold encompassing a **THBMF CW** portion correspondingly feeding the two radially adjacent combusting regions including a combusting feeder radial depth (Thickness) **CR15T**.

[0201] Fig. 4D further depicts an outer oxidant fluid feeder extending radially with a radial depth (Thickness) **CR12T** inside of an outer circumferential wall having an inner radius **CR12**. That outer oxidant fluid feeder extends circumferentially over an included angle **THBFX4** and feeds oxidant fluid through multiple orifices into a combusting region extending radially with a radial depth (or Thickness) **CR15T** from outer wall inner radius **CR15** to inner wall outer radius **CR16**.

[0202] Oxidant fluid **F5** optionally with diluent (such as water vapor or mist) may flow along the oXidant fluid feeder and through oXidant orifices with a typical diameter **DXO** into a radially adjacent outer combusting region extending radially with a depth (or Thickness) **CR15T** between combusting chamber outer radius **CR15** and combusting chamber inner radius **CR16**. These oxidant orifices may be offset from the **CCW** manifold by a circumferential angle **THBXO**, and spaced apart by a circumferential angle **THBXS**, with an *J*th orifice in an *I*th oxidant feeder positioned at a circumferential angle **THBXIJ**.

[0203] Fig. 4D further depicts Fuel fluid flow **F2** optionally diluted with diluent fluid, flowing through a **CW** comBusting region manifold extending through circumferential Theta angle **THBMF**. This **CW** fuel fluid manifold delivers fuel fluid through a fuel complementary feeder extending radially with a depth (Thickness) **CR18T**, and feeding fuel fluid through fuel fluid orifices with typical fuel orifice diameter **DFO** into the outer combusting region between **CR15** and **CR16** extending radially with a depth (Thickness) **CR15T** and circumferentially about an angle **THBFF4**. This fuel feeder with a depth **CR18T** may similarly feed fluid into an inwards combusting region extending radially between **CR25** and **CR26**, and circumferentially across **THBFF4**.

[0204] Further to Fig. 4D, diluted (“humid”) oxidant fluid **F5** may similarly be delivered radially inward (and longitudinally) through the radial manifold feeder length **RBFX4** and width **Theta12T** between circumferential angles **Theta12** and **Theta15** into a

radial combusting region of circumferential width **Theta15T**. On the radially inward side, diluent fluid **F12** may be delivered into axially extending region **RBMF** of width **Theta18T** and thence through orifices of diameter **DFO** a radial **CCW** diluent manifold extending circumferentially by **Theta18T** for each of the central combusting regions extending by **Theta 15T** and radially by **RBFF4**, axially along the combusting region.

[0205] Fig. 4E depicts a Radial Axial circumferential (**R-Z**) plan view of two radially adjacent symmetric combusting regions (**CZ34** to **CZ35**) and Blend-Trim regions (**CZ35** to **CZ39**). The radially lower (visually right or clockwise **CW**) region depicts radially outward (**CCW**) bounding end walls **734** and radially inward (**CW**) bounding end walls **735**. Such combusting regions may extend axially from the upstream Pilot **100** outlet or combusting region inlet **CZ34** to combusting region downstream axial boundary **CZ35**. The downstream Blend Trim region may extend axially (**Z**) from **CZ35** to **CZ39**.

[0206] Per Fig. 4E, such adjacent symmetric combusting regions may have radially outward adjacent (**+R** or **CCW**) oxidant fluid manifold regions, between manifold wall **250** and combusting wall **734** ducting oxidant fluid (or diluted oxidant fluid) **F5** from upstream of inlet **CZ34** into such adjacent combusting regions. Correspondingly, such symmetric combusting regions may have adjacent radially inward (**-R** or **CW**) fuel manifold regions, between manifold wall **250** and combusting wall **735**, ducting fuel fluid (or diluted fuel fluid) **F2**.

[0207] Such outwardly adjacent (**R+ CCW**) oxidant manifolds and inwardly adjacent (**-R CW**) fuel manifolds may be commonly bounded and divided by a sigmoidally curved longitudinal (radial-axial **R-Z**) manifold divider wall **250** between combusting upstream inlet **CZ34** and combusting midstream outlet **CZ35** bounds, and thence to the Blend-Trim region axially between midstream Blend-Trim inlet planes **CZ35** and the downstream Blend-Trim outlet planes **CZ39**.

[0208] The left (**+R, CCW**) portion of Fig. 4E further depicts an upstream region circumferentially increasing transverse (radial) width region **731** with axial flow distance, downstream of the Pilot **100**, having an increasing radial (**R**) width with an outward wall curvature along the axial (**Z**) direction. This axially increasing combustion region volume may beneficially accommodate an axially increasing volumetric flow from increasing delivered oxidant, fuel and diluent mass flows, and

from rising temperature with combustion, thereby reducing fluid acceleration and pressure drop losses.

[0209] Fig. 4A and 4E similarly depict a configuration with a downstream combusting region **733** with transversely increasing width (radially **+R** to **-R**) (or **CCW-CW**) but with decreasing radial-axial wall curvature. This may beneficially provide an aerodynamically smoother transition between the Blend-Trim region and an equilibrating region extending downstream from planes **CZ39** to **CZ394** (as shown in Fig. 4A). Fig. 4E further depicts an axially intermediate combusting transition region **732**. This intermediate combusting transition region **732** transverse width (**+R** to **-R**) may increase downstream with axial (**Z**) distance, from an axially increasing width wall curvature from combusting upstream section **731**, to an axially decreasing width wall curvature such as in combusting downstream section **733**.

[0210] Fig. 4E depicts distributions of fuel fluid delivery orifices **81**, and distributions of oxidant fluid delivery orifices **82** opening into the combusting region from **CZ34** to **CZ35**. Further distributions of oxidant and/or diluent delivery orifices **83** may be configured downstream to open into the Blend-Trim region axially between planes **CZ35** to **CZ39**. This Blend-Trim combusting region with delivery orifices **83** may be transversely bounded by radially outward combusting wall **734** and radially inward combusting wall **735**.

[0211] Per Fig. 4E, a downstream Blend-Trim manifold region may be provided to deliver diluted oxidant fluid **F5** (or oxidant fluid **F4** not shown) axially between axial planes **CZ35** and **CZ39**, and bounded by radially outward (**+R**) transverse manifold (**CCW**) wall **250** and radially inward (**-R**) manifold (**CW**) wall **734**. This radially outward (**+R**) oxidant fluid delivery manifold between transverse manifold wall **250** and inward manifold wall **734** may be bounded downstream at **CZ39** by manifold wall **250** joining manifold wall **734**. Inward manifold wall **734** may be bounded with transverse manifold wall **250** joining with an axially upstream bounding wall **249** between the upstream delivery of diluted fuel flow **F2** (or fuel fluid flow **F1** not shown) and the downstream delivery bound (between manifold wall **250** and combusting wall **734**) for Blend-Trim diluted oxidant fluid **F5**. (See below for discussion of Fig. 4F showing exploratory NH_3 combustion.)

[0212] Fig. 4E further depicts varying transverse positioning versus axial location of oxidant orifices **82**, fuel orifices **81**, and Blend-Trim diluted oxidant orifices **83**

[0213] Fig. 4G depicts a corresponding outward (or inward) axial circumferential (Z Theta) “unrolled” plan view of a symmetric combustor fluid feeder region. This extends axially in the flow direction from an upstream Pilot **100**, with a **CCW** axial diluted oxidant fluid manifold region **244** ducting upstream diluted oxidant fluid **F4** to upstream oxidant feeders. The fluid feeder region of Fig. 4G may include a second **CCW** axial oxidant manifold **245** ducting diluted oxidant fluid **F5** further downstream.

[0214] The Fig. 4G configuration similarly depicts a **CW** inward upstream first fuel manifold region **242** ducting first fuel fluid **F1** comprising a fuel to upstream feeders. This may be divided by Upstream/Downstream Fuel Fluid Manifold Dividing wall **252** from a second intermediate **CW** outward fuel fluid manifold region **243**, such as ducting a Diluted Fuel Fluid flow **F2** (or another flow of Fuel Fluid) further downstream.

[0215] Further in Fig. 4G, similarly, an upstream to Downstream Fuel Feeder to Blend-Trim Dividing Wall **253** may divide and separate upstream diluted fuel fluid **F2**, flowing through the intermediate fuel fluid manifold region **243** between **CZ34** and **CZ35**, from Blend-Trim diluent flow **F7** flowing downstream to the Blend-Trim region **850** between planes **CZ35** and **CZ39**. Manifold bounding wall **253** may adjoin the downstream diluted oxidant or diluent fluid feeder extending down to plane **CZ39**.

[0216] In Fig. 4G, the **CCW** oxidant fluid manifolds and **CW** fuel fluid manifolds may be separated by a sigmoidally curved longitudinal radial manifold divider **250** that colds the downstream transverse Trim feeder ending axially at plane **CZ39**. Downstream Combusting-oxidant fluid manifold divider **248** may be similarly curved and configured parallel to the manifold divider **250** and aerodynamically curved as it connects with the upstream of the transverse Blend-Trim feeder opening at **CZ35**.

[0217] An axial-radial manifold divider **253** bounding between diluted fuel fluid flow **F2** and diluent fluid flow **F7** may be curved or sigmoidal from upstream **CZ34** to downstream at **CZ35** where it adjoins oxidant feeder delivering oxidant fluid **X7** (or optionally diluted oxidant fluid).

[0218] In Fig. 4G, and axial radial mid Upstream Combusting oXidant Manifold Dividing wall **247** may divide Diluted Rich oXidant Upstream Fluid Manifold **244** from second Diluted Rich oXidant Downstream Fluid Manifold **245**. Similarly downstream axial radial oXidant-Blend-Trim manifold wall **248** may divide

midstream second oxidant fluid manifold **245** from diluted oxidant Blend-Trim manifold **246**. With radially extending adjacent walls with multiple circumferentially adjoining oxidant fluid and fuel fluid manifolds and an upstream Pilot **100**.

[0219] In Fig. 4G, a first fuel fluid **F1** (optionally diluted) may be delivered into fuel fluid manifold **242** bounded by Fuel Feeder Upstream/Downstream Manifold Dividing Wall **252**, and be delivered as multiple fuel fluids, such as **U1**, **U2**, and **U3**, flowing through respective multiple transverse fluid fuel fluid feeders. These fuel fluid feeders may have an axially increasing number of fuel fluid orifices **81A** per transverse fuel fluid feeder over that range.

[0220] Similarly, a second diluted fuel fluid **F2** (or a second fuel fluid flow not shown) may be delivered into downstream fuel fluid manifold **243** and be delivered as multiple fuel fluid flows **U4**, **U5**, **U6** and **U7** flowing into multiple transverse fluid fuel fluid feeders and thence into the adjacent combusting region via fuel fluid orifices **81A**. These fuel fluid feeders may have an axially increasing number of fuel fluid orifices **81A** per transverse fuel fluid feeder over that axial range.

[0221] Per Fig. 4G, oxidant fluid **F4** may be delivered via Diluted Oxidant Fluid Upstream Manifold **244** as oxidant fluid flows **X1**, **X2**, and **X3** through multiple transverse oxidant fluid feeders and thence through oxidant fluid orifices **82A**. Such oxidant fluid **F4** delivery may interleave with delivery of first fuel fluid **F1**, such as through **U1** to **U3**, through respective upstream transverse fuel fluid feeders.

[0222] Similarly, oxidant fluid **F5** may be delivered via Diluted Oxidant Fluid Downstream Manifold **245** as oxidant fluid flows such as **X4**, **X5**, **X6**, and **X7** (or optionally diluted oxidant fluid) through multiple respective transverse oxidant fluid feeders, and thence into the adjacent combusting region via multiple oxidant fluid orifices **82B**.

[0223] Such oxidant fluid delivery through oxidant feeders may interleave fuel fluid delivery flows, such as **U4** to **U7**, through respective transverse fuel fluid feeders in the upstream combusting region from **CZ34** to **CZ35**

[0224] Per Fig. 4G, diluted oxidant fluid **F6** may be delivered via **CCW** Diluted Oxidant Blend-Trim Manifold **246** to downstream Blend-Trim feeders. E.g., as one or more Blend fluids such as **B1** and **B2**, through transverse Blend feeders and through Upstream Blend-Trim orifices **83A**, and Midstream Blend-Trim Orifices **83B** into the radially adjacent Blend-Trim region downstream of the combusting region.

[0225] Similarly, a portion of diluted oxidant fluid **F6** may be delivered as one or more Trim fluid flows, such as **T1**, through a transverse trim feeder and thence through Downstream Blend-Trim orifices **83C** into the radially adjacent Blend-Trim region between planes **CZ35** and **CZ39**, axially downstream of the combustor region.

5 [0226] Per Fig. 4G, correspondingly, Blend-Trim diluent fluid **F7** may be delivered via **CW** Diluent-Trim manifold **238** downstream into Diluent-Trim region **850** between **CZ35** and **CZ39**. Blend-Trim diluent fluid **F7** may be delivered as one or more diluent fluids **D1**, **D2**, and **D3** through transverse diluent feeders and thence through diluent fluid orifices **86A**, **86B**, and **86C**, into the radially adjacent downstream Blend-Trim region of the combustor.

[0227] Per Fig. 4G, walls **253** and **250** of **CW** diluent trim manifold **238** to the Blend-Trim feeder region may be outwardly curved in an axially upstream section **731**. They may similarly be inwardly curved in axially downstream section **733**.

15 [0228] The intermediate combustor region **732** may be sigmoidally curved section to aerodynamically connect upstream section **731** and downstream section **733**. (In other configurations intermediate combustor region **732** may be linearly configured.) Downstream section **850** of bounding wall **250** may transition from inwardly curved section **733** to connect aerodynamically with the downstream equilibrating region axial slope.

20 Asymmetric Combusting Systems

[0229] Per Fig. 4H, and Fig. 4I, some combustor configurations may use an asymmetric combustor about a longitudinal oxidant manifold feeding transverse circumferential oxidant fluid feeders on the **CCW** and **CW** sides of the oxidant manifold. Such asymmetrical combustor configurations may similarly use a common longitudinal fuel manifold to feed corresponding multiple adjacent fuel feeders in adjacent combustors.

Asymmetric Combusting Regions

30 [0230] Fig. 4H depicts a circumferentially (Z Theta) “unrolled” plan view of two adjacent asymmetric combustor regions with an axial fluid flow axis **Z**, and circumferential axis Theta perpendicular to a radial axis **R**. This may have combustor walls radially adjacent to the combustor region, with fuel fluid orifices **81**, oxidant fluid orifices **82**, and/or Blend-Trim region diluent fluid delivery orifices such as **83**.

[0231] Per Fig. 4H, such asymmetric combustor region configurations may have circumferentially adjacent oxidant fluid manifold bounding Combustion Chamber

Transverse **CCW** side End Wall **734** directing oxidant fluid **F5** between upstream combusting region inlet **CZ34** and combusting fluid downstream end **CZ35**. They may similarly have circumferentially adjacent bounding fuel fluid Combustion Chamber Transverse **CW** side End Wall **735** delivering fuel fluid **F2** between **CZ34** and combusting region Downstream Manifold End Dividing Wall **249**.

[0232] Further per Fig. 4H, diluted oxidant fluid **F7** may be delivered into the downstream Blend-Trim manifold region **850** bounded by side bounding manifold walls **735** and axially bounding Downstream Manifold End Dividing Wall **249**, extending axially from planes **CZ35** to **CZ39**. Some asymmetric combusting region configurations may include a common upstream Pilot **100** feeding adjacent combusting shells. This Pilot **100** may be fed by Pilot Fuel Fluid **F3**, Pilot Oxidant Fluid **F6**, and Pilot Diluent Fluid **F8**.

[0233] The asymmetric combustor configuration of Fig. 4H may have a sigmoidally curved oxidant fluid boundary such as described in Fig. 4H and adapted to such an asymmetric configuration. This may have a circumferentially (Theta) outwardly curving upstream manifold-combusting region bounding wall section **731** with axially increasing distance **Z**.

[0234] Per Fig. 4H, the asymmetric combustor may have a correspondingly circumferentially (Theta) inwardly curving downstream manifold with bounding Combustion Chamber Downstream Transverse End Wall section **733** with axially increasing distance **Z**. The asymmetric combustor configuration of Fig. 4H may have a connecting intermediate Combusting Chamber Midstream Transverse End Wall **732** transitioning from the outward to the inward circumferential-axial curvature.

[0235] The oxidant fluid manifold of Fig. 4H may further have a downstream Blend-Trim region **850** with a Blend-Trim diluent/oxidant fluid manifold wall **734** that may have an aerodynamically varying curvature between the axially upstream adjacent combusting region downstream transverse end wall **733** and the downstream equilibrating region wall beginning at **CZ39** and extending into equilibrating region **900** per Fig. 4A.

[0236] The corresponding fuel fluid side bounding manifold walls **735** may have similar curvature with correspondingly more shallow curvature. In other configurations, side bounding fuel fluid manifold walls **735** may be straight.

Asymmetric Manifolds and Transverse Fluid Delivery Regions

[0237] Fig. 4I depicts an example of a circumferentially “unrolled” circumferentially-axially (Z Theta) asymmetric combustor fluid feeder configuration. This shows the combusting walls from the radially outward exterior, with fluid axial (longitudinal) manifold walls, upstream transverse fuel feeders and oxidant fluid feeders, fuel, oxidant, and diluent fluid delivery orifices, an axially upstream Pilot **100** delivering pilot fluid into an upstream combusting region at **CZ34**, and a downstream outlet into the combustor equilibrating region at **CZ39**.

[0238] Such circumferentially axially asymmetric configurations may utilize fewer fuel fluid manifolds and oxidant fluid manifolds than used with symmetric combusting system scalable shell combustors described in Fig. 4B to Fig. 4E and Fig. 4G.

[0239] The configuration shown in Fig. 4I, may include pilot fuel fluid **F3**, pilot oxidant fluid **F6**, and pilot diluent fluid **F8** feeding upstream Pilot **100**. On the clockwise side, a portion of first fuel fluid flow **F1** may be delivered into an upstream transverse fuel fluid feeder as fuel fluid **U1** and thence into the combusting region through one or more fuel fluid orifices **81A**.

[0240] Similarly, further portions of first fuel fluid **F1** may be delivered into progressively downstream transverse fuel fluid feeders as to feed fuel fluids **U2** and **U3**. These may be delivered from the transverse fuel fluid feeders through similar or increasing number of fuel fluid orifices **81A** into the radially adjacent combusting region.

[0241] Fig. 4I, similarly depicts an oxidant fluid manifold axially feeding oxidant fluid **F4** flows **X1**, **X2** and **X3** progressively axially into respective upstream transverse oxidant fluid feeders and thence into oxidant fluid orifices **82A** into the radially adjacent combusting chamber.

[0242] Combinations of the size, (or area), number of the respective fuel fluid orifices **81**, oxidant fluid orifices **82**, and relative fuel fluid and oxidant fluid delivery pressures may be configured to provide a desired range of relative fuel to oxidant composition relative to stoichiometric composition (**PHI**). (Or equivalently, the relative oxidant to fuel ratio **LAMBDA**).

[0243] Per Fig. 4I, first fuel fluid **F1** and/or oxidant fluid **F4** may comprise gaseous and/or liquid diluent, such as steam, water vapor, and/or liquid water as delivered through transverse feeders and orifices into the combusting chamber.

[0244] Per Fig. 4I, diluted fuel fluid **F2** may be axially delivered through a fuel fluid manifold and thence into one or more transverse fuel fluid feeders as fuel fluid flows

U4, U5, U6 and/or U7. These may be delivered from the fuel fluid feeders through a plurality of fuel fluid orifices **81B** into the radially adjacent combusting chamber in the downstream portion of the combusting region from combusting mid-**732** midstream wall region through combusting downstream wall **733** region.

5 [0245] Further per Fig. 4I, oxidant fluid flow **F5** may be delivered through the outer axial oxidant fluid manifold and then as one or more oxidant fluid feeder flows, such as **X4**, **X5**, **X6**, into respective transverse oxidant fluid feeders and thence through oxidant fluid orifices **82B** into the radially adjacent combusting region. E.g., in the downstream combusting region from mid-region **732** through combusting
10 downstream region **733**.

[0246] Per Fig. 4I, diluent fluid **F14**, such as liquid water, may be delivered to downstream Blend-Trim region through one or more transverse feeders such as diluent fluid flows **D1** and **D2**, and thence through orifices **86A** into radially adjacent Blend-Trim region **850** in the combustor axially between planes **CZ35** and **CZ39**.

15 [0247] Correspondingly per Fig. 4I, further oxidant fluid optionally with diluent fluid may be delivered through transverse Blend-Trim feeders as Blend-Trim fluids **B1** and/or **T1** and thence through Blend-Trim orifices **83A** and **83C** into the downstream Blend-Trim region **850** of the combusting chamber axially between planes **CZ35** and **CZ39**.

20 Cooling Upstream Combustion

[0248] The embodiments depicted herein enable further flexibility in configuring diluent delivery separately from oxidant and fluid delivery. This may be beneficially used to reduce and control combusting temperatures independently of relative fuel to oxidant composition (Φ) (or relative oxidant to fuel composition Λ). This may
25 beneficially reduce combusting temperatures while enabling higher oxidant compositions, particularly in upstream rich combustion conditions in the combusting region from **CZ34** to **CZ35**. Such methods may beneficially reduce undesired emissions, particularly of NO_x emissions.

[0249] Thus, in some further configurations, some to all of the gaseous and/or liquid
30 diluent fluid **D1** and **D2** may be delivered with one or more fuel fluid flows **U5** to **U7**. Similarly, some to all of such gaseous and/or liquid diluent fluid **D1** and **D2** may be delivered with oxidant fluids **X4**, **X5**, and/or **X6**.

[0250] Such increases in diluent fluid with the combusting fuel and oxidant fluid flows may be used to reduce the combusting temperatures and thence reduce emission

formation such as NO_x. In some configurations, this may be delivered with rich to stoichiometric portion of oxidant delivery to form associated rich to stoichiometric combusting regions.

[0251] In some configurations, one or more of axially upstream to downstream manifold walls may be fairly aligned axially between the upstream combusting region at **CZ34**, and the downstream connection with related transverse fluid delivery feeders. Such alignment may beneficially reduce the rate of change in axial fluid flow cross-sectional area (expansion) and delivery flow rate, and thereby reduce related fluid pressure drops.

[0252] Fig. 4J depicts a schematic circumferentially (Z Theta) “unrolled” combusting section of a radially inward (or outward) wall configuration, depicting larger and more numerous upstream oxidant fluid delivery orifices **82** and downstream smaller and fewer fuel fluid delivery orifices **81**. E.g., in a 2:1 ratio. Oxidant fluid orifices may be circumferentially offset from fuel fluid orifices to improve mixing and reduce quenching.

[0253] Fig. 4K depicts a schematic circumferentially (Z Theta) “unrolled” combusting section radially inward (or outward) wall configuration with fewer upstream fuel fluid delivery orifices **81**, and more numerous downstream oxidant fluid delivery orifices **82**. E.g., in a 1:2 ratio. Fuel fluid orifices may be circumferentially offset from oxidant fluid orifices to improve mixing and reduce quenching probabilities.

[0254] Fig. 4L depicts a schematic circumferentially (Z Theta) “unrolled” configuration a downstream Blend-Trim region section having oxidant fluid orifices **83A** and **83C** in a radially outward (or inward) Blend-Trim region wall. Upstream Blend-Trim orifices **83A** may be offset ClockWise (**CW**) from downstream Blend-Trim region orifices **83C**.

[0255] Fig. 4M depicts a sample schematic configuration of a downstream Blend-Trim region section having oxidant fluid delivery orifices **83A** and **83C** in a radially inward (or outward) Blend-Trim region wall. Here upstream Blend-Trim orifices **83A** may be offset CounterClockWise (**CCW**) from ClockWise (**CW**) downstream Blend-Trim orifices **83C**.

[0256] Corresponding to Fig. 4L and Fig. 4M, Blend-Trim orifices **83A** and **83C** configured radially outward of a combusting region may be offset ClockWise (**CW**) and CounterClockWise (**CCW**) from Blend-Trim orifices **83A** and **83C** configured radially inward of the combusting shell. Similar methods may be used to improve

mixing with fuel fluid orifices and/or oxidant fluid orifices in the combusting upstream (731), midstream (732), and downstream (733) wall regions of the combusting chamber.

[0257] Fig. 4N depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combusting region upstream to downstream cut through a CounterClockWise (CCW) circumferentially outward combusting region wall 734.

[0258] This sample configuration Fig. 4N shows eight radially outward oxidant fluid delivery openings X1 through X8 for radially outward oxidant fluid feeders (or diluted oxidant fluid feeders). These may be complemented by and interspersed with eight radially inward oxidant fluid (or diluted oxidant fluid) passage openings X1 through X8, in radially inward transverse oxidant fluid feeders.

[0259] Fig. 4O depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combusting region upstream to downstream cut inward of the CCW circumferentially outward end wall (734) having eight radially outward oxidant fluid delivery openings (X1 through X8) (or diluted oxidant fluid delivery openings) in outward transverse oxidant feeders.

[0260] Fig. 4O further shows these outwardly oxidant fluid openings (X1-X8) may be complemented with eight interspersed radially inward oxidant fluid delivery openings (X1 through X8) (or diluted oxidant fluid delivery openings) in inward transverse oxidant feeders. These oxidant fluid passages (X1-X8 and X1-X8) may be interspersed with narrower fuel fluid delivery passages (unmarked).

[0261] Fig. 4Q depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combusting region through a Clockwise (CW) circumferentially outward side bounding combusting region end wall 735 having eight radially outward fuel fluid delivery openings U1 through U8. These may be complemented by and interspersed with eight radially inward fuel fluid passage openings U1 through U8.

[0262] Fig. 4P depicts a sample (nominally radial-axial R-Z) schematic configuration of an upstream combusting region inward of the CW circumferentially outward end wall (735) having eight oxidant fluid feeder delivery passage openings (U1 through U8) interspersed with eight oxidant fluid feeder delivery passage openings (e.g., X1-X8 not labeled).

[0263] Figures 4N through 4Q further depict combustor radial height (or length) parameters labeled from the first outward combusting shell towards the next inward combusting shell. E.g., CR12 labels the radially outward oxidant fluid feeder wall

outer radius. **CR15** labels the radially outward combusting region wall radially inner radius. **CR16** labels the radially inward combusting region wall outer radius. **CR24** labels the radially inward oxidant fluid feeder wall radially inner radius.

[0264] Figures 4N through 4Q further depict combustor radial inner height parameters labeled from the first outward combusting shell towards the next inward combusting shell along the radial R axis. E.g., **CR12T** labels the radially inner depth (height or Thickness) of the outer oxidant fluid transverse feeders shown in Fig. 4N and Fig. 4O. **CR12T** similarly labels the radially inner height of the outer fuel fluid transverse feeders shown in Fig. 4P and Fig. 4Q.

[0265] The radial parameter **CR15T** labels the combusting region radially inner height (Thickness) between **CR15** and **CR16** shown in Fig. 4O and Fig. 4P. **CR18T** similarly labels the radial thickness of the radially inner oxidant and fuel transverse feeders between **CR16** and **CR24** shown in Fig. 4N through Fig. 4Q.

[0266] Figures 4N through 4Q further depict the combustor axial boundaries from the upstream combusting region boundary at **CZ34** to the downstream combusting fluid delivery boundary at **CZ35** (at a reference plane CBQ) along the axial flow Z axis.

[0267] Fig. 4O further depicts typical Axially Inner Inlet Widths **810** of radially outer transverse oxidant fluid feeders **X1** to **X8** supplying the central combusting region near the outer open side (e.g., CounterClockWise **CCW** side near the oxidant fluid feeder opening from the adjacent oxidant manifold).

[0268] The axially inner axial widths of radially inner transverse oxidant fluid feeders **X1** to **X8** supplying oxidant fluid into the central combusting region in Fig. 4O may be similar and may be scaled according to the radial distance outward to the respective feeders from the combustor axis. Fig. 4O further depicts the corresponding Axially Inner Far End Widths **809** of radially outer transverse Fuel Fluid feeders **U1** to **U8** near the transversely closed end of the fuel fluid feeders near the adjacent oxidant fluid manifold (e.g., the **CCW** side).

[0269] Fig. 4P further depicts typical Axially Inner Inlet Widths **808** of radially outer transverse Fuel Fluid feeders **U1** to **U8** supplying the central combusting region near the outer open side (e.g., the Clockwise **CW** side near the fuel fluid feeder opening from the adjacent fluid manifold).

[0270] The inner axial widths of radially inner transverse fuel fluid feeders **U1** to **U8** supplying fuel fluid into the central combusting region in Fig. 4P may be similar and

may be scaled according to the radial distance outward to the respective feeders from the combustor axis.

[0271] Fig. 4P further depicts the corresponding axially inner widths **811** of outer transverse oxidant fluid feeders (**X1-X8** not labeled) near the transversely closed end of the oxidant fluid feeders near the adjacent fuel fluid manifold (e.g., the **CW** side). Fig. 4P similarly shows the inner transverse oxidant fluid feeders (**X1-X8** not labeled) between **CR16** and **CR24**, with corresponding inner widths (**811** not labeled) between fluid feeder walls.

[0272] Fig. 4R schematically depicts an axial circumferential (Z Theta) plan view perspective of a pair of transverse fluid feeders delivering oxidant fluid X into multiple oxidant fluid orifices **82** with typical oxidant fluid orifice diameters **DXO**, and delivering fluid F into multiple fuel fluid orifices **81** with typical fuel fluid orifice diameters **DFO**. The fuel fluid feeder is depicted with an axial width **DFX** compared to the wider Oxidant Fluid Feeder with an axial width **DFX**. In some configurations, diluent feeders may be utilized with a Diluent Fluid Feeder width **DFD** (not shown).

[0273] Per Fig. 4R, in some configurations, fuel fluid orifices **81** in the fuel fluid feeder may be circumferentially displaced by a circumferential angle **THF** from the vertical plane, ClockWise (**CW**) positive. In some configurations, oxidant fluid orifices **82** may be configured in pairs circumferentially positioned about fuel fluid orifices **81**, with a narrower circumferential separation angle **THXN** between oxidant fluid between nearest centers of oxidant fluid orifices **82** of separated orifice pairs. Oxidant fluid orifices **82** may have a wider adjacent orifice circumferential separation angle **THXW** between oxidant orifice centers of wider separated orifice pairs.

[0274] In other configurations, oxidant orifices may be spaced further apart, or may be spaced uniformly apart. As schematically depicted in Fig. 4E, 4H, and Fig. 4I, circumferential spacing of orifices about the combustor may be further varied along axially differing fluid feeders. These may use one or both of circumferentially even spacing, and circumferentially asymmetric spacing.

[0275] In some configurations, circumferential spacing may be closer near one and/or both inner and outer combusting chamber boundaries than in circumferentially inner regions. Other configurations may provide more space between orifices near circumferential boundaries.

[0276] Fig. 4S shows another axial circumferential plan view of a fuel feeder feeding fuel fluid F through fuel fluid orifices **81** and an axially adjacent oxidant fluid feeder

feeding oxidant fluid X through a multiplicity of oxidant fluid orifices **82**. This configuration depicts the oxidant fluid orifices **82** as axially (**Z**) separated and radially (**Theta**) aligned.

[0277] Oxidant fluid orifices **82** may similarly be circumferentially aligned with fuel fluid orifices **82** as depicted here. Such configurations may improve jet penetration into the combusting fluid flow. In other configurations, the oxidant orifices may be axially aligned, and collectively circumferentially offset from the fuel fluid orifices **82**.

[0278] Fig. 4T depicts a schematic radial circumferential (**R Theta**) cross-section “elevation view” of an outer combusting region wall **736** with an insulating liner **738** bounding the combusting region with an outer radius **CR15**. Outer fuel fluid orifices **87** may be configured at a positive angle **PhiX** (or a negative angle **-PhiX**) from the radial axis **R** to deliver fuel fluid in the negative **CCW** direction.

[0279] Fig. 4T further shows an inner combusting region boundary wall at **CR16** radially displaced by a radial thickness **CR15T** from the outer combusting region wall. The radially inner combusting wall may have an outer insulating liner **738** protecting a radially inner structural wall **737**. Inner oxidant fluid orifices **88** may be configured at an opposing negative angle **-PhiX** (or an opposing positive angle **PhiX**) from the radial axis **R** to delivery oxidant fluid in the negative **CCW** direction.

[0280] The configuration of Fig. 4T may similarly be configured with fuel fluid orifices **87** oriented with a negative angle **-PhiX**, and oxidant fluid orifices **88** oriented in the opposite direction with a positive angle **PhiX**. Further configurations may comprise both fuel fluid orifices **87** and oxidant fluid orifices **88** configured with the same positive angle **PhiX**. Similar configurations may comprise fuel fluid orifices **87** and oxidant fluid orifices **88** configured with a similar negative angle **-PhiX** (or positive angle **PhiX**).

[0281] In the Fig. 4T configuration, some fuel fluid delivery orifices **87** and oxidant fluid delivery orifices **88** in axially offset fluid feeders may be circumferentially oriented with similar positive angle **PhiX** (or negative angle **-PhiX**). In other configurations generically upstream fluid delivery orifices **87** (or **88**) and downstream fluid delivery orifices **88** (or **87**) may be configured with opposing positive angles **PhiX** and negative angles **-PhiX** oxidant (not shown).

[0282] Further generalizing configurations (such as in Fig. 4T) as shown in Fig. 4G, upstream fuel fluid orifices **81A** may be circumferentially offset from (or aligned

with) downstream oxidant fluid orifices **82B**. Similarly, per Fig. 4G, upstream oxidant fluid orifices **82A** may be circumferentially offset to (or aligned with) downstream oxidant fluid orifices **82B**.

[0283] Fig. 4U depicts a radial circumferential (R Theta) “elevation” view of a sample configuration of outer transverse Fuel feeders marked **F**, and alternating outer oXidant transverse feeders marked **X**. These fuel and oxidant feeders may have a radially outer wall **802** bounded by an outer radius **CR11**. These feeders may have a radially inner wall **801** bounded by a feeder inner radius **CR15**, forming a radially outer surface of the inner first combusting region. The outer feeder inner wall **801** may comprise a radially outward (structural) side wall **736** covered on the inner combusting region side by a protective thermal insulating coating **738**.

[0284] Fig. 4U further depicts fuel feeders **F** comprising fuel fluid orifices **87** to deliver fuel fluid into the adjacent inner combusting region. Similarly, oxidant feeders **X** may comprise orifices **88** delivering oxidant fluid into the adjacent combusting region radially inwards of the feeder inner **801** wall at **CR15**. As shown, oxidant feeders **X** may be circumferentially wider in the transverse (Theta) direction than fuel feeders **F** to accommodate the larger volumetric oxidant fluid flows versus smaller fuel fluid flows.

[0285] Per Fig. 4U in some configurations, outer fuel fluid orifices **87** and oxidant fluid orifices **88** may both be angled circumferentially with a negative angle (**-PhiX**) from the radial axis **R**. Other configurations may use fuel fluid orifices **87** and oxidant fluid orifices **88** with the opposite circumferential positive angle (**PhiX**) from the radial axis **R**.

[0286] Further configurations may alternate angles of fuel fluid orifices and oxidant fluid orifices positive (**PhiX**) and negative (**-PhiX**) angles between radially inward and outward orifices. (Such configurations may have orifices aligned with the combustor axial **Z** axis, similar to that shown in Fig. 4S.)

[0287] Further to Fig. 4U, shows a radially inward (“lower”) feeder array portion from the outer feeder wall radius **CR16** (or radially inner combusting region boundary) with outer insulating layer **738** protecting combusting chamber radially inner wall **737**, to radially inner feeder wall radius **CR20**. This depicts a cross-section elevation view with Pairs of similar oxidant (**X**) fluid feeders of circumferential Passage Width **PWX** and Fuel (**F**) fluid feeders of circumferential Passage Width **PWF**. Joint fluid

width widths of fluid feeder pairs shown in Fig. 4U may include a first oxidant-fuel fluid pair width (**FP1**) and a second oxidant-fuel fluid pair width (**FP2**).

[0288] In the radially inward (“lower”) portion of Fig. 4U, inner oxidant (**X**) fluid feeders may be configured opposite outer fuel (**F**) fluid feeders, and inner fuel (**F**) fluid feeders may be configured opposite to outer oxidant (**X**) fluid feeders. In this configuration common circumferentially transverse (outer) walls **133** may be used for opposite outer CounterClockWise (**CCW**) (“transverse”) and ClockWise (**CW**) boundaries.

[0289] In Fig. 4U, fuel (**F**) fluid orifices **87** may be configured circumferentially about the middle of fuel fluid feeder (**F**) with a circumferential offset of about **PWF/2** from the fuel -oxidant feeder dividing wall **133**. In the radially outer (“upper”) oxidant feeders **X**, the oxidant orifices **88** may be configured about midway (transversely) across the oxidant feeder displaced by a distance of about **PWX/2** from the fuel-oxidant feeder dividing wall **133** (such as circumferentially aligned oxidant fluid orifices **82** as shown in Fig. 4S).

[0290] Alternatively, Fig. 4U depicts a configuration where the radially inward (“lower”) oxidant feeders (**X**) may have two oxidant orifices **88** transversely configured within the oxidant feeder (**X**). For example, these two orifices **88** may be positioned transversely at about a distance **PWX/3** of about one third the passage Width of oXidant feeder from the oxidant feeder walls (similar to configurations of oxidant fluid orifices **82** of diameter **DXO** as shown in Fig. 4R.)

[0291] In some configurations, orifices may be aerodynamically configured to reduce combustor pressure drop and to improve efficiency. Orifice inlet and outlet corners may be rounded to improve flows **F** and reduce pressure drops and efficiency losses, such as that shown in Fig. 4V.

[0292] Fig. 4V depicts a detailed view of a fluid orifice in the Radial Circumferential (**R Theta**) plane with fluid flow **F** through an outer combustor wall. E.g. fluid **F** may flow in through an oxidant fluid orifice of diameter **DXO** through a feeder structural wall of thickness **CR13T** protected by a feeder wall insulating coating of thickness **CR14T**. The fluid inlet and outlet may have rounded corners.

[0293] In some configurations, the upper orifice inlet may have a smaller radius **ROI** while the lower orifice outlet may have a larger orifice outlet **ROO**. Similarly, the outlet radius **ROO** may be about twice as large or larger than the inlet radius **ROI**. Such configurations may be formed curing additive manufacturing (or “3D printing”).

[0294] Fig. 4W depicts a detailed view of an angled orifice in the Radial Circumferential (R Theta) plane through the outer combustor wall of thickness **CR13T** with an insulation layer of thickness **CR14T**. The angled oxidant fluid orifice may be configured with a flow axis at an angle **THM** relative to the Radial axis **R** with a diameter **DXO** perpendicular to the orifice flow axis.

[0295] Inlet corners of such angled orifices may be configured about an acute angle with a smaller radius **ROIA** and about an obtuse angle with a larger radius **ROIB**. Corresponding outlets of such angled orifices may have smaller radius **ROOA** for an acute angled outlet radius and a larger radius **ROOB** for an obtuse angled outlet radius.

[0296] Fig. 4X depicts a closed end of an oxidant feeder in the axial circumferential plane (**Z Theta**) for some configurations, with a manifold fuel fluid flow **FFM** flowing axially past the closed end, and a fuel feeder flow portion **FFF** flowing around the closed end. The oxidant fluid manifold may have an outer oxidant feeder axial width **PXWO**, and an inner oxidant feeder axial width **PXWI** with feeder wall thickness **FWT**.

[0297] The oxidant feeder axially upstream radius **R XU** may be configured smaller than the downstream oxidant radius **R XD**. E.g., the downstream radius **R XD** may be twice that of the upstream radius **R XU** or more.

[0298] Fig. 4Y depicts a closed end of a fuel fluid feeder in the axial circumferential plane (**Z Theta**) for some configurations, with a manifold oxidant fluid flow **FXM** flowing axially past the closed end, and an oxidant feeder flow portion **FXF** flowing around the closed end.

[0299] Per Fig. 4Y, such fuel fluid feeders may have an outer fuel feeder axial width **PFWO**, and an inner fuel feeder axial width **PFWI**, with feeder wall thickness **FWT**. The oxidant feeder axially upstream radius **R FU** may be configured smaller than the downstream oxidant radius **R FD**. E.g., the downstream radius **R FD** may be twice that of the upstream radius **R FU** or more.

Numerous Orifices to Improve Mixing

[0300] In some configurations, fuel, oxidant, and/or diluent orifices may be used. Orifice size may be correspondingly reduced, such as to maintain overall cumulative orifice area within a desired range of the downstream combusting system cross-sectional area.

5 [0301] More numerous orifices may be used to beneficially improve mixing, increase combustion, further diluent mixing, assist in temperature control, reduce hot spots, improve uniformity, and/or facilitate equilibration.

[0302] For example, in some configurations, each combusting shell may use 50 to 100 oxidant orifices. In other configurations this may be increased to 101 to 200 oxidant
10 orifices. Similarly, 201 to 400 oxidant orifices may be used. Further combustors may use 401 to 800 orifices or more, for more uniform combustion of difficult fuels like ammonia.

[0303] Such changes may beneficially be used to facilitate combustion of fuels with higher ignition energy, higher combusting temperature, slower flame speed, and/or
15 slower combusting rates. E.g., in combusting one or more of ammonia, methane, methanol, ethanol, cracked ammonia (combinations of H₂, N₂, and NH₃), and/or hydrogen.

Modeling Combustion and Emissions

[0304] The applicant won a US Department of Energy High Performance For
20 Computing Manufacturing (HPC4Mfg) supercomputer grant, and an HPC4EnergyInnovation supercomputer grant. Simplified VAST scalable combustors (such as using a scalable combusting region and a cylindrical equilibrating region), were modeled using more than 110 independent parameters.

[0305] Of these, 23 parameters were selected to model combustion over typical gas
25 turbine pressures, temperatures, and specific power rates. Argonne National Laboratory (herein ANL) conducted reactive computational fluid dynamic modeling (herein “**RCFD**”) to evaluate low, medium, and high values (0%, 50%, 100%) for each of these selected parameter ranges.

[0306] Applicant ranked those parameters by parameter importance to Unburned
30 Hydrocarbons (**UHC**) (or equivalent unburnt fuel), Nitrogen Oxides (**NO_x**), and Carbon Monoxide (**CO**) emissions. Then ANL conducted 312 **RCFD** runs using combinations of 5 values across low to high (0%, 25%, 50%, 75%, 100%), for the most significant 9 parameters.

[0307] Lawrence Livermore National Labs (herein “LLNL”) then used neural network methods to analyze the data and to create a software program to predict UHC, CO and NO_x emissions, which can be run on a professional laptop computer.

[0308] Those methods and resulting software enabled the applicant to configure its scalable gas turbine combustor configurations so as to probably achieve less than 1 ppmvd each for **UHC**, **NO_x** and **CO** emissions over commercial gas turbine operating conditions. This predicts emissions below the strictest California county emission requirements of 2.3 ppmvd **NO_x** and **CO** without using catalysts.

[0309] Such very low emissions provide major advantages with typically 7% to 10% lower **CapEx** for commercial gas turbines operating on natural gas with emissions control using Selective Catalytic Conversion (SCR). It further promises substantially lower operating costs by eliminating ammonia delivery and associated “slip” emissions.

[0310] The techniques, configurations and methods as described herein further detail, extend, and/or adapt that initial modeling **RCFD** modeling on methane. They likely enable extending and/or improving the methods to further using the range of conventional to sustainable fuels. E.g., to include methane, natural gas, methanol, ethanol, ammonia, cracked ammonia (herein combinations of “H₂ N₂, and NH₃”), and hydrogen.

Diluent to the Blend Region

[0311] **NO_x** formation is likely to increase as the product of (Fuel * **O₂**) and exponentially with combustor temperature. Rich combustion cooled by steam and/or diluent in the upstream combustor region with residual combustion Blend region uniquely enables transitioning from rich hot upstream combustion to near stoichiometric combustion. This will likely be highly beneficial in avoiding **NO_x** formation. Fig. 4F schematically shows a typical combustor axial Temperature profile with 1,570K (1397°C) outlet temperature. Such runs reduced outlet NO_x (and CO) emissions on Methane to sub 1 ppmvd (parts per million by volume diluted to 15% O₂).

Ammonia Combustion

[0312] Following VAST’s sub 1 ppmvd **CO** and **NO_x** emissions achieved with CH₄ combustion, preliminary modeling was conducted on Ammonia combustion. Conventional **NH₃** combustion can cause >1,000 ppmvd **NO_x**. Published experiments have achieved 25 ppmvd NO_x. Fig. 4F depicts an example of preliminary modeling of

ammonia (NH_3) combustion with air, and diluent water and steam. Temperature and emissions are depicted along a flow axis from the upstream combustor inlet **CZ34** to the downstream combustor outlet at **CZ4**. This exploratory reactive **RCFD** modeling of diluted NH_3 air combustion was conducted in applicant's prior simplified scalable combustor.

[0313] The left axis shows the mean cross-sectional temperature, and the right axis the outlet NO_x and NH_3 emissions in ppmvd (parts per million diluted to 15% O_2). In this sample run, the mean upstream combustor hot gas temperature peaks near 1,830K ($\sim 1,557^\circ\text{C}$) about the end of the Blend-Trim region **T1**. For **RCFD** modeling, an assumed combustor wall cooling rate is prescribed, reducing the combustor outlet temperature at **CZ4** to a prescribed 1,527K ($1,300^\circ\text{C}$) typical of a mid-range gas Turbine Inlet Temperature (TIT).

[0314] Per Fig. 4F, in this run, NH_3 peaked at $\sim 13,000$ ppmvd ($\sim 40,000$ ppm) in the rich combustor region. Residual NH_3 then declined to ~ 78 ppmvd (~ 227 ppm) at the combustor outlet. Combustion NO_x formation peaked at ~ 275 ppmvd (~ 800 ppm) downstream of the ammonia peak and upstream of the temperature peak. With excess NH_3 , and high H_2O , the NO_x declined to sub ~ 10 ppmvd (~ 29 ppm unadjusted) at the combustor outlet.

[0315] Such ~ 10 ppmvd NO_x emissions in Fig. 4F from initial exploratory NH_3 combustion already achieves NO_x emissions 60% or more below the US EPA's 25 ppmvd national emissions limit for mid-range Brayton Cycle gas turbines. These results appear remarkably lower than reported industrial and scientific combustion modeling reports found for this most difficult renewable or sustainable proposed fuel.

[0316] Applicant has identified means of further improving mixing and combustion by aerodynamic methods, improved orifice distributions and delivery staging, such as described herein. These promise to further improve combustion and lower both NH_3 and NO_x emissions observed. With 24% higher efficiency for a single expander VAST cycle with exhaust heat recycling, this preliminary NH_3 combustion modeling appears to offer a further 19% lower NO_x emissions per electricity generated (ppmvd/MWh) relative to a conventional simple cycle (Brayton) peaker gas turbine.

Cooling Combustion

[0317] In some configurations, remaining undelivered diluent may be moved from the downstream Trim region feeders **T1** to be delivered up into the Blend region feeders (e.g., **B1** and **B2**). A major portion of this remaining diluent may be delivered to the

upstream Blend feeder **B1** to provide cooler rich (sub stoichiometric) combustion, with temperature being controlled independently of the relative local fuel to oxidant ratio Φ (or the relative local oxidant to fuel ratio Λ).

[0318] In further configurations, part of this diluent may further be delivered further upstream into the downstream end of the combustor region, such as to delivering with fuel **U7** and/or oxidant fluid **X7** (or optionally diluted oxidant fluid) in the axially downstream (or last) combustor region axial **733**. Such diluent may further be delivered into the last two to last seven combustor regions upstream of **CZ35**.

[0319] Excess oxidant (or air) **T1** may similarly be delivered in through the downstream Trim region. Such a combination of upstream diluent and downstream excess oxidant may achieve the coolest Blend region rich combustion with the least oxidant up to stoichiometric combustion. This may well form the lowest NO_x emissions for such configurations, with no change in total oxidant or excess air delivered Φ (Φ).

In Situ Ammonia Cracking

[0320] In further configurations ammonia may be delivered upstream under hot fuel rich (excess fuel, sub-stoichiometric oxygen) conditions (with Φ (Φ) > 1 or $\Lambda < 1$). Upstream combustor temperatures may be increased by reducing upstream diluent. Such conditions may increase upstream ammonia cracking to hydrogen and nitrogen. Such *in situ* rich cracking of ammonia to hydrogen and nitrogen may facilitate downstream rich combustion, thereby reducing overall NO_x formation.

[0321] Refer to Fig. 4Z and heating/cracking section **853** within the Blend-Trim region 850. Ammonia fuel may be delivered as Fuel **F1** into this region, (and/or as diluted Fuel **F2**, not shown). A portion Ammonia Fuel **F1** may be cracked to hydrogen and nitrogen, with residual ammonia recovered from this region as cracked Fuel fluid **F16**.
5 This region **853** may provide multiple serpentine passages without orifices to increase (or fewer to decrease) the residence time, or to modify it. Some combustor configurations may configure the temperature of transverse feeders without orifices, adjacent to the combusting region, and/or in the upstream combusting region.

[0322] One or more of the axial location, temperature, fuel **F1** fluid flow rate, number of
10 transverse passages, and contact duration may be adjusted sufficient to thermally crack a portion of ammonia fuel to hydrogen and nitrogen. E.g. from 2% to 98% ammonia cracking, or 5% to 60% cracking, or from 10% to 40% cracking, and/or for 15% to 25% cracking etc. Catalysts may similarly be used within transverse fluid feeders to facilitate cracking of ammonia. Such cracking may further be configured
15 together with diluent to then form diluted fuel fluid **F2** for delivery into the combustor.

Thermally Igniting Flows

[0323] In some configurations, an energetic fluid may be formed by heating one or more
20 delivered fluids to temperatures such that the temperature and flow rate of the delivered energetic reactant and co-reactant mixture gas is sufficient to ignite the reactive fluid in the primary reaction zone.

Manufacturing Methods

[0324] One or more of such scalable parametric combustor configurations depicted may
25 be constructed using additive manufacturing (or “4D printing”) techniques. Such manufacturing techniques may facilitate forming the numerous oxidant fluid, fuel fluid, and diluent fluid transverse feeders with the corresponding orifices delivering fluid from the transverse feeders into the combusting chambers.

[0325] In some configurations, such scalable shell combustors may be formed in two
30 halves with inner insulating coatings over outer structural walls. These may then be assembled and be suitably held, bonded or fastened together. In other configurations, such orifices may be formed by laser ablation, chemical etching, mechanical or fluid jet drilling, or similar material removal techniques.

Radial Annular Multiple Scalable Combustors

[0326] Such Radial Annular Multiple Scalable Combustors (or “Multi-Fan burners”)

may be designed to achieve ultra-clean combustion for gas turbines, combined heat and power systems, industrial heating and/or cooling, and other applications requiring ultra-clean well controlled combustion and/or similar chemical reaction.

[0327] In some configurations, walls with multiple fluid jets delivered through orifices may be configured with relatively shallow spacing between those walls to improve relative jet penetration. For example, the mass flow rates of fuel, oxidant, and diluent delivery, or any combination thereof, into an upstream combusting flow may be configured to increase reliable combustion operating range, combustion operational robustness, and/or the degree and/or uniformity of fluid mixing.

[0328] Similar to the Annular – Radial configuration of Fig. 4B, Fig. 5A shows an end on Downstream to Upstream view of the downstream end of multiple Scalable Combustors Radially Oriented in the upstream portion of an Annular Gas Turbine Combustor **750** extending from a combusting region inlet **134** to a combusting region outlet **136** such as for use in a gas turbine combustion system.

[0329] Per Fig. 5A, one or more flame authorities **100** (ignition authorities, or pilot lights) may be configured to supply hot igniting gas **F22** into an upstream flame authority duct (ignition authority duct or pilot feeder duct) configured about the upstream inlet region **720** of a combusting system **750**. The upstream flame authority duct may feed the hot igniting gas **F22** into the upstream region, such as from **CZ31** to **CZ34** of one or more combusting shells (such as are shown in perspective Fig. 4B, and from the downstream view in Fig. 5B and the upstream view in Fig. 5C.)

[0330] The one or more upstream flame authorities **100**, such as depicted in Fig. 4B and Fig. 5B, may be fed with Pilot Fuel fluid **F3** comprising a fuel fluid (or first reactant fluid), a Pilot Oxidant Fluid **F6** comprising an oxidant fluid (or second reactant fluid), and a Pilot Diluent Fluid **F8** comprising a diluent fluid or thermal diluent.

[0331] With reference to Fig. 5B, some embodiments may configure a scalable combustor **730** with multiple scalable combustion sections (or combusting chambers or “fan burners”) as depicted in a downstream to upstream radial - circumferential (**R-Theta**) view. These may have a radial configuration of combusting chambers **730** between an inner annular duct wall **147**, and an outer Pressure Vessel Wall **172**, to form the radial multi-fan annular combustor **730**.

[0332] Similarly, Fig. 5C shows a radial-circumferential (**R-Theta**) view of multiple outwardly oriented combustion sections (or multi-fan burners). These combustion sections are configured along a vector **S** at an angle **Phi** rotated clockwise from the

radial vector **R**, to form a radial multi-fan annular combustor **741**.

[0333] Fig. 5C further shows a more detailed perspective view of a combustion section **730** as portion of the radial multi-fan annular combustor **741** (as configured in Fig. 5C). An upstream combusting section **741** is configured between an upstream combusting fluid duct inlet transverse plane **134**, and a downstream combusting fluid duct outlet transverse plane **136**. (The configuration of Fig. 5B has similar detailed configuration of the radial multi-fan annular combustor **730** with outwardly oriented multi-fan burners configured along radial orientations, not shown.).

[0334] All or some of Fig. 5 curves can be cycloidal shaped curves. In summary, cycloidal curves can indeed improve flow efficiency by minimizing abrupt directional changes, reducing separation, and optimizing flow attachment. Their effectiveness is often most notable in systems where fluid needs to turn within constrained spaces or where maintaining laminar flow is advantageous. These cycloidal properties can also be beneficial for fluid dynamics in applications where maintaining flow velocity and smooth directional change is beneficial.

[0335] Fig. 5C shows an exploded outward to inward perspective view of Fig. 5B, (and correspondingly for Fig. 5A). An upstream igniter or flame authority **100** receives, mixes, and reacts a pilot fuel fluid **F3** mixed with pilot oxidant fluid **F6**, with one or both fluids optionally mixed with pilot diluent fluid **F8**, to form a hot pilot fluid **F22**.

[0336] Per Fig. 5C, the hot pilot fluid **F22** from upstream flame authority **100** may then be distributed to the upstream end **134** of one or more mid-fan combusting sections or burners **74** such as at plane **134**, *** via an optional hot pilot duct **138**. One or more of the scalable combustors **732***** and **742***** may be configured and extended between a surrounding duct wall **132** *** and/or a surrounding pressure vessel **172** as described herein with respect to the circumferential annular multi-combusting chamber scalable combustor **750** as depicted in Fig. ***.

Radial Annular Multi-Fan ***

[0337] With reference to Fig. ***, the orifice dimensions, side wall depth spacing **Ld** {***} and pressure drop across the circumferential annular scalable combustor **730***** may be configured to deliver premix fluid **F14** ***into fan burners at a rate sufficient to feed and react with the incoming hot pilot fluid **F22** to form more hot or energetic fluid **F20** without quenching the reaction within the scalable combustor. The delivery rate of premix fluid **F14** may similarly be configured to maintain the temperature of the reacting fluid within each fan burner above a prescribed reaction temperature quench

limit.

Transverse and Axial Composition and Temperature Distributions

[0338] One or more transverse distributions of one or more of fuel fluid delivery orifices, oxidant fluid delivery orifices, and/or diluent fluid delivery orifices, may be configured to achieve one or more of a prescribed transverse composition distribution, a prescribed transverse temperature distribution, and/or a prescribed transverse velocity distribution, about one or more prescribed axial planes normal to the combusting fluid flow, between the hot pilot fluid **F22** inlet at **CZ34**, and the combustor outlet at **CZ4**.

[0339] Similarly, a plurality of transverse distributions of orifice size, spacing, and/or orientation may preferably be configured to achieve a desired change in transverse composition and/or temperature distributions in a plurality of curvilinear surfaces distributed across the streamwise flow direction within the combustor. Such transverse distributions of orifices in perpendicular planes and/or transverse curvilinear surfaces, may be configured at multiple locations along the streamwise flow.

[0340] Such as depicted in Figures 5D through 5G and 5H to 5J, some configurations may physically configure orifice distributions and size, and/or dynamically control fluid delivery to control the temperature **T** of the hot combusting gas at a radial location **R** in an axial plane at axial location **CZ** between the combustor inlet at **CZ34** (as shown in Fig. 5D), into an upstream combusting fuel rich region between axial locations **CZ34** and **CZ35**.

[0341] Similarly, some configurations may configure and/or control one or more oxidant and/or diluent fluid flows in a downstream Blend-Trim region between axial locations **CZ35** and **CZ39** (***). Such configurations may further configure fuel, oxidant and/or diluent orifices to control fluid flows compositions, and/or temperatures in an equilibrating region from **CZ39** to the combusting region outlet at **CZ4**.

[0342] Fig. 5D shows a schematic graph of combusting fluid Temperature at an axial transition location **CZ35** between an upstream combusting fuel rich region and a downstream Blend-Trim region. The methods described herein may be used to control a temperature **T35i** at the inner radius **Ri** relative to (such as higher than) a desired corresponding radially outer temperature **T35o** at the outer radius **Ro**. E.g., to accommodate inner wall cooling from transition combustor transverse plane **CZ35** to the outlet axial location **CZ4** in the combustor outlet plane.

[0343] Such temperature control may be achieved by adjusting the diluent to fuel ratio Omega. E.g., the water to fuel mass ratio omega may be increased to reduce outlet

temperatures and reduced to increase outlet temperatures. Such configurations may similarly control an outer temperature **T35o** at the outer radius **Ro** to be higher than a desired corresponding downstream outlet temperature. E.g., this may accommodate outer wall cooling at outer radius **Ro** from the transition axial location **CZ35** to the combustor outlet axial location **CZ4** in the combustor outlet plane.

[0344] Such combusting configurations per Fig. 5D may further control a first intermediate temperature **T35j** at a combustor intermediate radius **Rj** between the inner radius **Ri** and outer radius **Ro**. This first intermediate temperature **T35j** may be controlled relative to (such as below) one or both of the inner radial temperature **T35i** at the combustor inner radius **Ri**, and the outer radial temperature **T35o** at the outer radius **Ro**.

[0345] Such configurations may further control a second intermediate temperature **T35k** at a second intermediate radius **Rk**. E.g., the second intermediate temperature **T35k** may be controlled relative to (such as below) one or both of the inner temperature **T35i** at inner radius **Ri**, and the outer radial temperature **T35o** at the outer radius **Ro** (such as shown in Fig. 5D).

[0346] Such configurations as shown in Fig. 5E, may assist in controlling one or more corresponding downstream outlet temperatures in the outlet plane at **CZ4** as shown in Fig. 5F. E.g., to control an outlet temperature **T4j** at that combustor intermediate radius **Rj**. Such configurations may further control temperature **T35J** to assist in controlling a corresponding second intermediate outlet temperature **T4k** at the second intermediate radius **Rk** (as shown in Fig. 5E).

[0347] Per Fig. 5D, the first intermediate temperature **T35j** at a first intermediate radius **Rj**, and second intermediate temperature **T35k** at the second intermediate radius **Rk** may further be configured to obtain a desired intermediate temperature gradient **DT35jk** between that first intermediate radius **Rj** and that second intermediate radius **Rk** in the combustor axial transition plane **CZ35**.

[0348] Fig. 5E shows a corresponding schematic graph of the hot gas outlet temperature **T4** versus combustor radius **R** at an axial location **CZ4** in the combustor outlet plane (or the turbine inlet plan) downstream of the equilibrating region. Some configurations may control upstream fluid delivery of one or more of fuel fluid, oxidant fluid, and/or diluent fluid to control the outlet temperature **T4** with a radially inner outlet temperature **T4i** at the inner radius **Ri** in the outlet plane at axial location **CZ4**.

[0349] Further to Fig. 5E, such configurations may similarly control the outlet

temperature **T4** to have a radially outer outlet temperature **T4o** at the outer radius **Ro** in the outlet plane at axial location **CZ4**. This outer temperature **T4o** may be configured relative to (such as higher than) the radially inner outlet temperature **T4i** at the inner radius **Ri** in the outlet plane.

[0350] Per Fig. 5E, upstream delivery of one or more of fuel fluid, oxidant fluid, and/or diluent fluid, may be further varied to control a first intermediate temperature **T4j** at a first intermediate radius **Rj**, in the combustor outlet. Similarly, upstream fluid delivery may be configured to control a second intermediate temperature **T4k** at a second intermediate radius **Rk** in the outlet plane at **CZ4**.

[0351] Further to Fig. 5D, and Fig. 5E, one or more upstream intermediate temperatures **T35j** and/or **T35k** (with the intermediate temperature gradient **DT35jk** of Fig. 5D) and/or corresponding diluent and oxidant fluid delivery orifices in the Blend-Trim region. These upstream orifices may be configured towards achieving desired downstream outlet temperatures shown in Fig. 5E. e.g. to achieve outlet temperature **T4j** at a first intermediate radius **Rj**, and/or the second intermediate temperature **T4k** at the second intermediate radius **Rk** with the corresponding temperature gradient **DT4jk** between those two intermediate outlet temperatures in the combustor outlet plane at the axial location **CZ4**.

[0352] Referring to Fig. 5D, some configurations may control one or both of an inner temperature **T35i** at the inner radius **Ri**, and /or an outer temperature **T35o** at the outer radius **Ro** relative to (such as higher than) a desired corresponding downstream outlet temperature **T4o** such as shown in Fig. 5E. Such configurations may be adjusted to accommodate outer wall cooling at outer radius **Ro** from the transition axial location **CZ35** to the combustor outlet axial location **CZ4** in the combustor outlet plane.

[0353] Fig. 5F shows a schematic graph of a hot Wall Temperature **Tw** versus combustor axial length **Z**, from an outer transition wall temperature **TW35o** at the transition boundary **CZ35** at the downstream end of the fuel delivery region, to the outlet outer wall temperature **TW4o** the combustor outlet at axial outlet location **CZ4**.

[0354] Further to Fig. 5F, such temperatures may further be adjusted to control an inner wall temperature **TW4i**, and an outer wall temperature **TWro**. These may begin at an upstream inner wall temperature **TW35i**, and/or outer wall temperature of **TW35o** at the rich/blend-trim axial boundary **CZ35**. Such temperatures may include an intermediate inner wall temperature **TW39i**, and/or an outer wall temperature **TW39o** at the blend-Trim region outlet axially at **CZ39**. One or more temperature distributions

may be varied to a downstream outer wall temperature of **TW4i** at the inner wall, and/or **TW4o** at the outer wall, at the combustor axial outlet at **CZ4**.

[0355] Fig. 5G shows a schematic graph of an axial Velocity **V** of combustion hot gas versus the combustor radius **R**, from radially inner to radially outer walls, at the combustor outlet, at the downstream axial location. This hot gas configuration may be adjusted by adjusting the radial distribution of the sum of **CZ4** axial orifices in the upstream combustion region. E.g., these may be adjusted to have an axial velocity **V** of **V4i** near the combustor inner radius **R4i** near the inner wall (axially at **CZ4**). This mean velocity **V** may be increased up to a mean velocity **V4j** at the first intermediate radius **R4j**. The velocity **V** may further be increased (or decreased) to a value **V4k** at the second intermediate radius **R4k**. The velocity **V** may then be reduced to a radially outer value of **V4o** near the combustor outer radius **R4o**.

[0356] Fig. 5H is a graph showing an “unrolled” section of circumferential distribution of hot gas temperature **T** versus combustor circumferential angle **Theta** for a region encompassing a first radially oriented combustor located CounterClockWise (**CCW**) (left side) marked **Theta1**. It further extends Clockwise to and similarly depicts a second radially oriented combustor located ClockWise (**CW**) (right side) marked **Theta2**.

[0357] Fig. 5I further shows radially inner temperatures in an upper (hotter) line between a lower fluid temperature **Tsi** and upper fluid inlet temperature **Ti**, at a combustor inner radius **Ri**, marked “At **Ri**”. Fig. 5I similarly shows corresponding radially outer fluid temperatures between **Tso** and **To** versus circumferential angle **Theta** near or at a combustor outer radius **Ro**, marked “At **Ro**”. On the CounterClockWise (**CCW**) combusting region, these range from counterclockwise circumferential angle **Theta1wo** to clockwise angle **Theta1co** about the mid outer circumferential combusting angle **Theta1o**.

[0358] Fig. 5I similarly shows a cooled counterclockwise (**CCW**) first combustion inner section at **R1** centered at **Theta1I**. This covers a circumferential width of **Delta Theta 1** (1) from **Theta1WI** to **Theta1WO**. It shows a second combustion inner section displaced clockwise from the first inner section, and centered at **Theta2I** from a counterclockwise angle **Theta2WI** to a clockwise angle **Theta2CI**.

[0359] Fig. 5I Graph of hot gas temperature **T** versus combustor circumferential angle **Theta**, with temperatures between **Ts** and **Ti**, at inner radius **Ri**, and at outer radius **Ro**, with a heated counterclockwise first combustion section **Theta1** and a second clockwise combustion section **Theta2**.

[0360] Fig. 5J Graph of hot gas velocity versus combustor circumferential angle **Theta**, between velocities **Vs** and **V1**, for values at inner radius **Ri**, and at outer radius **Ro**, with a cooled counterclockwise first combustion section at **Theta1** and a clockwise second combustion section at **Theta2**.

5 [0361] ***

[0362] Combustors Radially Oriented in the inlet of an Annular Gas Turbine Combustor.

[0363] ***

Scalable Omega Combustor

[0364] One or more curves ranging from cycloidal to hyperbolic to parabolic may be used for portions of the diffuser, combustor, and/or transition zone walls. These may include curves from the family of brachistochrone or cycloidal curves. The Scalable Combustor may further be axially configured into an Omega shaped combustor as depicted in Fig. 5K in the Radial-Axial (**R-Z**) Cross-Section Elevation View. This Scalable Combustor extends radially outward from the Turbine Axis, herein a Scalable Omega Combustor **707** (or Omega Combustor). Oxidant fluid flow **WX34** may be delivered through an upstream diffuser into a generally axially oriented combusting region inlet **CZ31** to the Scalable Omega Combustor (per the terminology of Fig. 4A and Fig. 4B). The walls and shape of the Omega Combustor **707** may be configured using one of the cycloidal family of curves.

[0365] Oxidant Fluid (or Second Fluid) **F4** may be delivered from an upstream compressor **407 (CPR)** and redirected radially outwardly (**+R**) and then outwardly upstream (**+R -Z**) through an outwardly reversing duct into scalable combusting and trim-blend region **704** between upstream combustor plane **CZ34** and downstream combustor plane **CZ39** (similarly to that depicted in Fig. 4A and Fig. 4B). Oxidant, fuel and diluent fluids may be delivered into the Combusting Region **704** (similarly to that shown schematically in Fig. 4A, Fig. 4B, and to other Figures and disclosure herein referencing Combusting Region **704**).

[0366] Hot combusting fluid may then be delivered from Combusting Region **704** into Equilibrating Region **900** within an outer and inner pressure vessel wall **172**. This pressure vessel wall **172** may be protected by a thermal barrier coating **34**. Forming such an Omega combustor may increase the combusting fluid residence time for combustion between the shortened axial distance from **CZ31** to **CZ4** along the Turbine Axis. This may beneficially increase the ratio of Equilibrating volume per axial length. This may provide or increase residence time to reduce emissions while shortening the gas turbine shaft length.

Fluid Premixing Chambers

[0367] Combustion may be improved and/or emissions reduced by premixing one or more of fuel, oxidant, and diluent fluids prior to delivery into the upstream combusting and/or downstream Blend-Trim regions such as in Fig. 5L shown in a Radial-Axial Plan View.

5 [0368] Fig. 5L depicts Premixing Chambers configured in the Scalable Combustor to Premix one or more of Fuel fluid **F2**, Oxidant fluid **F5**, and Diluent fluids **F7**. Fig. 5L shows a detailed circumferentially inward-looking Plan View in the Radial-Axial (**R-Z**) plane. A portion of the axially upstream combusting region, (e.g., between **CZ34** and **CZ35**) is shown depicting multiple perforated transversely extended radial circumferential (**R Theta**) fuel feeder walls **842** and multiple perforated transversely extended radial circumferential (**R Theta**) oxidant feeder walls **844**. These perforated transversely extended fuel feeder walls **842** and oxidant feeder walls **844** are in contrast with continuous radial circumferential fuel feeder walls and oxidant feeder walls such as shown in Fig. 4G and Fig. 4I.

10 [0369] A plurality of radial – circumferentially extending (**R-Theta**) walls **842** (such as at and upstream of **CZ35**) may be used to form one or more transverse fuel fluid feeder passages **751**. Such fuel fluid feeders **751** may deliver fuel fluid **F2** radially outward from fuel feeder manifold **770** such as bounded by radially inner manifold wall **253**.

15 [0370] Similarly, a plurality of radial – circumferentially extending (**R-Theta**) walls **844** (such as between upstream bound **CZ34** and downstream bound **CZ35**) may be used to form one or more transverse oxidant fluid feeder passages **761**. Such oxidant fluid feeder passages **761** may deliver oxidant fluid **F5** radially inward from an outer oxidant fluid feeder manifold **780** such as bounded by manifold wall **250**.

20 [0371] Such radial-circumferential extending feeder walls **842** and **844** may be used to form one or more premixing regions radially bounded by radially inner end walls **828** and radially outer end walls **826**. Such premixing regions may be formed into multiple smaller blended feeder premixing chambers **847** by separating them radially with axial-circumferential blended feeder divider walls **846** extending axially between radial-circumferential extending feeder walls **842** and **844**.

25 [0372] One or more fuel fluid delivery orifices **81** may be configured between fuel fluid feeder **751** and premixing chambers **847**. Such fuel fluid orifices **81** may deliver fuel fluid **F2** into multiple fluid premixing chambers **847**.

30 [0373] One or more premixed reactive fluid orifices **87** may be configured in the circumferential – radial (**Theta – R**) combusting region walls to deliver premixed fuel rich reactive fluid mixture **F12** from such premixing chamber(s) into the circumferentially

adjacent combusting region. The diameter of such premixed reactive fluid orifices **87** may be constrained to avoid flashback from the combusting region back into such premixing chambers **847** under operating conditions with applicable fuels. For example, with one or more of ammonia, methane, ethanol, methanol, hydrogen, JP6, diesel, and/or gasoline fuels.

5 [0374] The number of premixed reactive fluid orifices **87** may be configured within a prescribed range to provide a prescribed range of cumulative premixed fluid delivery area to deliver into the adjacent combusting chamber the amount of premixed rich fluid **F12** formed per such premixing regions formed between the fuel feeder **751** and oxidant feeder **761**.

10 [0375] The number of such premixed reactive fluid orifices **87** and/or the related premixed fluid orifice delivery area may be configured relative to the premixed fluid formed to constrain one of a pressure drop across said premixing orifices to be below a prescribed premixing pressure drop, and a ratio of premixed fluid delivery distance per axial flow distance relative to the local combusting fluid axial velocity within the combusting region.

15 Premixing Blend-Trim Feeder

[0376] As described above for reactive premixing chambers, non-reactive dilutive premixing chambers **851** may be configured in the Blend-Trim region downstream of **CZ35**. Oxidative Fluid **F5** may be delivered oxidative orifices **83** into premixing dilutive chambers **851**. Dilutive fluid **F7** may similarly be fed through dilutive orifices **84** into such dilutive premixing chambers **851**. Oxidative Fluid **F5** and Dilutive Fluid **F7** may be premixed with in such premixing chambers **851** and delivered through premixed dilutive orifices **852** into the Blend Trim region downstream of the Combusting to Blend Trim boundary **CZ35**.

20 Controllable Flexible Scalable Ignition Authority

[0377] Referring to Fig. 5M depicts the outer fluid delivery region of a Controllable Flexible Scalable Ignition Authority **100**, (or Pilot Authority). Igniter or Pilot Fuel fluid **F3** may be delivered into a fuel fluid delivery feeder. Such a fluid delivery feeders may be semi-circular having an Inner Fuel Feeder Radius **RFI** and an Outer Fuel Feeder Radius **RFO**. One or more fuel Fluid Orifices **81** may be distributed about the upper fluid delivery feeder in an Ignition Authority **100**.

30 [0378] Fig. 5M further depicts the Ignition Authority **100** as having an oXidant (or air) fluid delivery inlet port feeding an oxidant fluid delivery feeder axially upstream at **CZ31**. Such oxidant fluid may be delivered through an outer delivery feeders such as depicted. This outer oXidant pilot feeder may be semi-circular having an Inner Oxidant Outer Feeder Inner Radius **RXOI** (similar to the outer Fuel Feeder Radius (**RFO**), and

an Outer Oxidant Feeder Outer Radius **RXOO**.

[0379] Such oxidant fluid may similarly be delivered through an inner Oxidant delivery feeder. Such an inner oXidant pilot fluid feeder may be semi-circular having an Inner Oxidant Feeder Outer Radius **RXIO**.

5 [0380] Per Fig. 5M, one or more Oxidant Fluid Orifices **82** may be distributed about the upper oxidant fluid Outer delivery feeder in an Ignition Authority **100**. Similarly, one or more Oxidant Fluid Orifices **82** may be distributed about the upper oxidant fluid Inner delivery feeder in an Ignition Authority **100**. Alternatively, such an inner Oxidant pilot feeder may have an inner wall forming semi-circular inner oxidant Feeder.

10 [0381] Fig. 5N depicts a schematic Perspective View of an Ignition Authority Outer Fuel and Oxidant Feeders with Fuel and Oxidant Orifices above an intermediate or middle Combusting Region. Fig. 5O through Fig. 5S show plan views of five cross-sections of such Ignition Authorities 100.

[0382] Fig. 5O shows a Schematic Plan View of an Ignition Authority Outer Fuel and
15 Oxidant Feeders with Fuel and Oxidant Orifices into the middle or central Combusting Region, similar to Fig. 5M.

[0383] Fig. 5P depicts Fuel Orifices 81 and Oxidant Orifices 82 in a Plan View of Ignition Authority Upper Inner Wall to the Ignition Authority's central combusting chamber.

[0384] Fig. 5Q Depicts a cross-section Plan View through Igniter Authority Mid-Section
20 along the normal to the Ignition Authority outer and inner surfaces.

[0385] Fig. 5R depicts Fuel Orifices 81 and Oxidant Orifices 82 in a Plan View of Ignition Authority Lower Inner Wall to the Ignition Authority's central combusting chamber.

[0386] Fig. 5S shows a Schematic Plan View of an Ignition Authority Inner Fuel and Oxidant Feeders with Fuel and Oxidant Orifices into the central Combusting Region, similar
25 to Fig. 5M and Fig. 5O.

[0387] Fig. 5T depicts a Close-up schematic view of an Igniter in the Wall of the central Pilot Combusting Region. Such igniters may have two electrodes **124** connected to an ignition source **126**. Other igniters may similarly be used, such as glow plugs, spark plugs, and/or plasma sources.

30 [0388] Fig. 5U depicts methods for combustor wall cooling which may utilize a diluent, or provide for ammonia cracking, or combinations thereof. E.g., this Fig. 5U depicts a Radial-Axial (**R-Z**) Cross-Section of an outer Combustor Wall such as between the Combusting region or Blend-Trim region and/or the Equilibrating region or downstream diffuser region. E.g., such as axially between CZ34 and CZ97.

[0389] Fig. 5U depicts an inner combustor wa***

[0390] Fluid Cooling Capable of Ammonia Cracking. ***

[0391] Fig. 5V Radial Inner to Outer Temperature Profile (T vs R) of Equilibrating Zone Flow Temperature Upstream at CZ39 and Downstream at CZ4.}

5 [0392]

Design and Emergency Power

[0393] Fig. 6A “Power Versus Temperature Graph of Brayton Cycle and VAST Cycles” schematically displays the drastic reduction in typical Brayton Design Power 650 with increasing ambient Compressor Inlet Temperature of a gas turbine operating in a Brayton Cycle (or “Simple Cycle”). E.g., dropping from ~120% of design power at -17.8°C (0°F) (such as in winter), down to ~75% of design power at 60°C (140°F) (such as in Kuwait in summer). Similarly, a Brayton Emergency Power 652 in a Brayton or Simple Cycle Gas Turbine may typically rise to about 110% of design Brayton or Simple Cycle Power at a given ambient temperature, and likely less than 120% of design Brayton Cycle Power.

10 [0394] Such drastic 25% drop in Brayton cycle design peaking power generating capacity when warming from 15°C to 60°C (59°F to 140°F) typically raises dangers of substantially higher blackout probabilities during the strong increase in air condition power loads hot season heat waves. This is particularly dangerous in equatorial regions and in southern US States.

20 [0395] Conversely Fig. 6A depicts how the gas turbine operating in a simple VAST Cycle (or VASTIG Cycle) may have a level VAST Design Power 640 with increasing ambient temperature. Such as gas turbine power system may further operate in a rising VAST Cycle Emergency Power curve 646 with ambient temperature. VAST Design Power 640 and VAST Emergency Power 464 may generate 55% to 65% more power for the same gas turbine expander by controlling combustor temperature using recycled steam and/or hot water, over such a temperature range as from -18 °C to 60°C (0°F to 140°F).

25 [0396] E.g., Fig. 6A depicts how the VAST Cycle (or VASTIG Cycle) may increase the design Simple (Brayton) Cycle gas turbine design power 650 from 100 MW up to a VAST Cycle Design Power 640 to generate ~155 MW of power for the same expander together with a smaller compressor 407 (CPR), and heat recovery systems at standard ISO conditions (15°C, 1 Atm, 60% RH).

30 [0397] Correspondingly, the VAST Cycle may increase such a Simple (Brayton) Cycle Emergency Power 652 from ~110 MW at ISO conditions to a VAST Cycle Emergency Power 646 of ~170 MW assuming a higher operating temperature for the same allowable

air flow within a compressor surge margin of the compressor **407 (CPR)**, with a generator **620** sized for that higher power, for the same ISO reference expander inlet air conditions.

[0398] Similarly, Fig. 6A depicts an option of the VAST Cycle Upper Design Power **642** to leverage the declining oxidant or air flow with increasing ambient temperature by cooling the oxidant or air flow with increasing thermal diluent and higher exhaust heat recovery up to the maximum ambient design temperature (e.g., 60°C or 140°F).

[0399] Such increased cooling by higher diluent (e.g., steam and/or water) would enable raising the VAST Upper Emergency Power **648** to ~185 MW using the same expander in a VASTIG Cycle operating at maximum ambient design temperature such as 60°C (or 140°F).

This configuration sizes the generator for ~185 MWe to deliver that VAST Upper Emergency Power **648** output assuming a maximum 60°C ambient temperature. This increases maximum emergency electrical power by ~125% above the 82 MW in the Brayton Emergency Power (Simple Cycle) **652** at the same maximum ambient air temperature of 60°C, 140°F.

[0400] Such configurations are estimated to increase the VAST Maximum Emergency Power by 6.5% (from 155 MW at -17.8°C (0°F) up to about 165 MW at 60°C (140°F)) for the same size expander and with the generator sized for the maximum emergency power at the maximum ambient temperature. This would enable the VAST Scalable Gas Turbine Power System **1** to generate more power to supply higher summer peaking power demand, not less.

[0401] Alternatively, Fig. 6A further depicts how the VAST Design Power may be held constant independent of temperature over that -18°C to 60°C (0°F to 140°F) with the generator sized for the highest (or coldest) temperature power.

[0402] Fig. 6A further depicts increasing the VAST Upper Design Power by 6.5% (from 155 MW at -17.8°C (0°F) up to about 165 MW at 60°C (140°F) for the same size expander and with the generator sized for this Upper Design Power (or Upper Emergency Power) at the maximum ambient temperature. This would enable the VAST power system to generate more power to supply higher summer peaking power demand.

[0403] Fig. 6A schematically depicts a potential declining lower bound for a VAST Power System nominally distinguishing its expected power performance versus temperature from other power cycles, including degradation due to operating and environmental factors.

Controller Subsystems

[0404] Fig. 6B depicts a high-level schematic of a Control System **588** having one or more Controllers which may comprise one or more Processors **589** in communication with

one or more Memory systems **591**. The one or more Processors **589** and one or more Memory systems **591** in the Control System **588** may further be configured or described as comprising one or more Controller Sub-Systems. Each of the Controller Sub-Systems may further comprise one or more processors **589** in communications with one or more memory systems **591**. One of the Control System **588**, and/or each of the Controller Sub-Systems may comprise an Energy Storage System **630**, and optionally an Energy Storage Controller **618**.

[0405] Per Fig. 6B, the Control System **588** may comprise a Pilot Controller **619A** and a Combustor Controller **619B** with one or both comprising Processors **589** and one or more memory systems **591**. These may respectively control the operations of the Ignition Authority (Pilot), and the Combusting System. Per Fig. 6B, the overall Control System **588** and/or each of the Controller Sub-Systems may be configured to interact hierarchically, cooperatively, and/or relatively independently and to communicate accordingly. Further processor systems **589**, memory systems **591**, energy storage systems **630**, and/or energy storage controllers **618** may be configured to provide one or more degrees system redundancy to achieve greater system reliability.

[0406] Further per Fig. 6B, such Controller Sub-Systems may include functions of a Mass Controller **614**, and a Thermal Controller **615**. The Control System may further comprise one or both of a Power Controller **616**, an Emissions Controller **617**, and/or an Energy Storage Controller **618**. One or more of the controller Sub-Systems may further have separate processors, memory systems, communications systems, and/or energy storage to facilitate operations, maintenance, and/or reliability.

Mass Controller

[0407] The Mass Controller **614** portion of Fig. 6B may be configured to control one or more flows of fuel comprising one or more of Gaseous Hydrocarbons such as Methane (CH_4), Ethane (C_2H_6), Propane (C_3H_8), Liquid Hydrocarbons such as Diesel Fuel, Jet Fuel JP5, Heavy Crude, Bitumen, or fractions thereof, Alcohols such as Methanol, Ethanol, and Butanol, and Renewable or Sustainable Fuels such as Hydrogen (H_2), and Ammonia (NH_3).

[0408] The Mass Controller **614** may control one or more input Oxidant flows comprising one or more of Oxygen, Air, Liquid Air, or mixtures of Oxygen and diluents comprising one or more of Nitrogen, Argon, Carbon Dioxide and/or other non-reactive or low reactive gases. The Mass Controller **614** may control the formation and flow of one or more output fluids such as the Hot Gas flowing out of a VAST Combustor or Flare, and/or in and/or out of a Gas Turbine Expander.

[0409] The Mass Controller **614** of Fig. 6B may further control one or more diluent flows such as Water, Steam, Ice slurry, excess Oxidant, excess Air, Nitrogen, liquid Nitrogen, Carbon Dioxide, Liquid Carbon Dioxide, Supercritical CO₂, Argon, Helium, and/or other inert gases. The Mass Controller **614** of Fig. 6B may further control one or more Reactant
5 flows such as Ammonia, or Nitrogen Oxides (NO_x) (such as to react with excess Nitrogen Oxides and/or Ammonia.) to an Emissions Controller **617**.

[0410] The Mass Controller **614** of Fig. 6B, may control such flows to one or more upstream Flame Authorities (fluid ignitors, or pilot lights), to one or more Combusting regions, to one or more Blend regions, to one or more Trim regions, and to one or more
10 downstream Equilibrating Regions (such as are shown in other figures). By so doing, the Mass Controller **614** of Fig. 6B may control formation and flows of one or more flows of Hot Gas, such as from one or more flame authorities into one or more combusting sections, blend regions, or trim sections, thus forming a hot gas.

[0411] By controlling such mass flows, the Mass Controller **614** of Fig. 6B may control
15 flows of a portion of Hot gas to a Thermal Controller Sub-System which in turn controls formation and direction of Steam, Hot Water, (and/or Hot Gas, CO₂ etc.), to an End Use such as Industrial applications. The Mass Controller **614** and/or Thermal Controller **615** may in turn control the Gas Composition, and/or Gas Temperature of such a hot fluid formed.
Thermal Controller

[0412] The Thermal Controller **615** may control flows of Hot Gas such as controlling
20 fuel Ignition, combustion, and delivery the gases to form steam and/or hot water and their delivery to End Use applications. The Thermal Controller **615** may further control one or more of Gas Composition and/or Gas temperature. Thermal Controller **615** may receive feedback from one or both of the Power Grid and/or Power Use. The Mass Controller **614**
25 may receive feedback from one or both of the Power Grid and Power Use.

Power Controller

[0413] The Control System **588** of Fig. 6B and Fig. 6C may comprise a Power Controller
616 that may control one or both of electrical power generated and delivered to a Power Grid, and/or to a Power Use such as in a local or industrial power application such as is
30 depicted in Fig. 6C. The Power Controller **616** may comprise a Processor **589** and Memory **591** in communication with the Control System **588**.

[0414] Power Controller **616** of Fig. 6B and Fig. 6C may control one or more of power flows, including one or more of turbine shaft mechanical power and/or electrical power from a Generator **620**. This may include one or more of generator Voltage (V), Current Amps (A),

shaft rotational speed Omega S (ωS), Generator rotational speed or frequency Omega G (ωG), Generator output Power frequency Omega P (ωP), and the Generator Phase angle Omega Phi ($\omega \Phi$). Power Controller **616** may further receive feedback from one or both of the Power Grid and/or Power Use.

5 Emissions Controller

[0415] Per Fig. 6B and Fig. 6C, the Control System **588** may comprise an Emissions Controller **617** which may have a Processor in communication **589** with Memory **591**. Emissions Controller **617** may control one or more of formation or discharge of Nitrogen Oxides (**NO_x**), Ammonia (**NH₃**), Carbon Monoxide (**CO**), Unburned Fuel (**UF**) (including
10 any Unburned Hydrocarbon). Per Fig. 6C, an Emissions Treater **471** may be positioned in the gas turbine expander outlet flow **F24**, such as between the Steam Generator **472**, and the Economizer **474**.

[0416] Per Fig. 6C, Such an Emissions Treater **471** may include mixing or spraying fluid (such as water or carbon dioxide) comprising one of ammonia (**NH₃**) and/or nitrogen oxides
15 (**NO_x**). Such treatment by ammonia (**NH₃**) in Emissions Treater **471** may be used to reduce residual NO_x emissions to below required emission standards. Conversely, Emissions Treater **471** may be used to spray fluid comprising nitrogen oxides (**NO_x**) to react with and reduce residual excess ammonia (**NH₃**) fuel to below prescribed ammonia emissions levels.

[0417] Referring to Fig. 6B and Fig. 6C, each of the Mass Controller **614**, Thermal
20 Controller **615**, Power Controller **616**, and Emissions Controller **617** may comprise separate independently controllable sections of an Ignition Controller, and a Combustor Controller.

Energy Storage Controller

[0418] Control System **588** may comprise an Energy Storage Controller **618** which may
25 comprise a Processor **589** in communication with Memory **591**. The Energy Storage Controller **618** may provide reliable and/or backup power to one or more of the Control System **588**, the Mass Controller **614**, the Thermal Controller **615**, the Power Controller **616**, and/or the Emissions Controller **617**, as well as to the Energy Storage Controller **618** itself.
30

[0419] As schematically shown in Fig. 6C, the Energy Storage Controller **618** may further control Energy Storage **630** for the Gas Turbine Energy System (such as shown in Fig. 4A). Such Energy Storage **630** may provide energy for black start capabilities, and to buffer power system fluctuations. The Energy Storage **630** may comprise sufficient energy

storage to sustain the VAST Power System with Thermal Power and/or Power Generation to operate at full power for two months to four months. This would enable the VAST Power System to accommodate natural variations in Climate over two to four months at half power or full power with associated annual capacity factors.

5 Combustion/Power System Controllers

[0420] Fig. 6C depicts major components of the Control System **588** including one or more of Fuel Controller **592**, Oxidant (O₂/Air) Controller **594**, Water Controller **597**, Steam Controller **598**, Trim Controller, **599** and/or Generator Controller **622**. The Control System **588** may comprise a processor **589** and/or memory **591**. A processor **589** and/or memory **591** may be included in one or more of each of these Controllers **592**, **594**, **597**, **598**, **599** and/or **622**.

[0421] The Fuel Controller **592** may control one or more of inlet Fuel Flow Control **233A**, Fuel Pump **P1**, and/or Pilot/Combustor Fuel Flow Control **233B** to deliver pilot fuel fluid **F3**. Pilot/Combustor Fuel Flow control **223B** may similarly control primary fuel fluid **F2** to the Combustor **704**. Oxidant (O₂/Air) Fluid Control **594** may control one or more inlet oxidant valves **232** to vary delivery of oxidant fluid **F4** into the Compressor **407 (CPR)** such as by compressor inlet control vanes.

[0422] Diluent or Water control **597** may control water diluent valve **236** to regulate the flow of water condensed from combustion hot gas **F20** via Condenser **480** and to deliver it back into the combustion / power system, or to discharge a portion of excess net recovered water for potable water or for other use.

[0423] Water Control **597** may regulate diluent or water pump **P2** to pressurize recovered diluent/water and deliver it to the Economizer **474** to condense water vapor from the combustion gas exiting the expander exhaust gas steam heat exchanger or Once Thru Steam Generator **472**.

[0424] Water Control **597** may control water diluent valve **239** to control one or more of water diluent delivery into the inlet of Compressor **407 (CPR)**, and/or within Compressor **407** itself at one or more locations such as through orifices in stationary vanes and/or orifices in rotating blades.

[0425] The Power or Generator Controller **622** may control one or more of gas turbine shaft speed Omega (ω_S), generator speed (ω_G), and/or generated power frequency Omega (ω_P). Power Controller may further control one or more of shaft power, generator Voltage (**V**), generator current (**A**), and power phase angle Phi (Φ). (The Power Controller may further control individual power generation phase angles Phi1 (Φ_1), Phi2 (Φ_2), and Phi3

(**Φ3**), not shown).

[0426] The Power or Generator Controller **622** may further control one or more of power from a Generator **620** delivered to a Power Grid, to a non-grid Power Use, and/or to an Energy Storage system **630**, such as a black start power system, battery storage, thermal storage, hydro-power storage, and/or compressed gas storage.

[0427] Control System Sensors

[0428] Fig. 6D depicts a Schematic Graph of Control System Sensors and Actuators. These may sense and regulate fluid properties to one or more of the Compressor **407 (CPR)**, the Combustor **704**, the Expander **440**, the Steam Generator, such as a Once Through Steam Generator (OTSG) **472**, an Economizer **474**, and a Condenser **480**. The Compressor **407** and Expander **440** may be connected by a shaft to the Generator **620** to generate three phase (or single phase) power.

Fuel Sensors

[0429] Per Fig. 6D, and Fig. 6C, the fuel delivery system may comprise delivering fuel **F2** to a fuel pump (or first pump) **P1** monitored with a pilot fuel speed sensor **SFω**. The properties of fuel fluid **F2** pressurized by Pump **P1** may be measured by fuel pressure sensor **SFP**, fuel temperature Sensor **SFT** and Fuel Flow Sensor **SFF**. The pressurized Fuel **F2** may be controlled by a two-way fuel valve or splitter **SXF** to deliver a portion as Pilot Fuel **F3** into the upstream Pilot **100**, and as Fuel Fluid **F2** into the Combustor region **704**.

[0430] Delivery of Pilot Fuel **F3** into upstream region CZ33 may be monitored by a Pilot Fuel mass flow sensor **SFF33**, a Pilot Fuel Pressure Sensor **SFP33**, and/or a Pilot Fuel Temperature Sensor **SFT33**. A

[0431] Pilot Fuel Pump speed may monitor fuel delivery to the fuel **ST32 ***???** pump **P1**. A speed sensor **SωP1** may monitor the speed of Fuel Pump **P1** delivering Fuel Fluid to a control valve ******* to deliver pilot fuel **F**** to the Pilot, and optionally combustor fuel **F***** to the Pilot and/or the Combustor.

[0432] (Similar sensors and actuators may be used for multiple fuels, not shown.)

Combustor Fuel Sensors

[0433] Control of the Combustor **704** may similarly utilize one or more of the First fuel Pump **P1**, with Fuel Pump 2 Speed Sensor **SωF34**, Fuel ***** 233B** for Fuel Mass Flow sensor **SWF34**, Fuel Pressure Sensor **SFP34**, and/or Fuel Temperature sensor **SFT34-5**,

Combustor Diluent Water Flow Sensors

[0434] Control of the Combustor **704** may further utilize one or more of a liquid diluent or water pump **P2**, a liquid diluent or Water Mass Flow Sensor **SWω34**, a liquid diluent or

Water Pressure Sensor **SWP34**, and liquid diluent or Water Temperature Sensor **SWT34-5**.

Power Generation Sensors

[0435] The power generation system may comprise a common Compressor - Expander – Generator drive shaft monitored by a Rotational speed Sensor **S ω R**, The Power generated by the Generator **620** may be monitored by a Power Frequency Sensor **S ω P**, a Power Phase Sensor **S Φ P**, a System Voltage sensor **SV**, and Power Current Sensor **SA**. These may further be differentiated with Voltage, Current, and Phase of each of three power generation phases (not shown). Where the Compressor **407**, Expander **440**, and/or Generator **620** are rotated at different rates, the individual shaft speeds may be monitored (not shown).

Preheating Turbine Pilots, Combustors, and Expanders. ***

Condenser Sensors

[0436] Per Fig. 6D, the power generation system may comprise a Condenser **480** to recover net cooling diluent liquid water from the Expander discharge after heat recovery in the Once Through Steam Generator and Economizer. The gaseous fluid flow out of the Flue Exhaust discharged from the Condenser may be monitored by one or more of an Exhaust Temperature Sensor **STX**, an Exhaust Pressure Sensor **SPX**, and an Exhaust Humidity Sensor **SHX**.

[0437] Further per Fig. 6C and 6D, the condensed liquid flow recovered from the Condenser **480** may be controlled by valve **236**. Mass flow of diluent required within the power cycle is returned via flow **F7** to pump **P2** to feed the Economizer **474** and thence into the Steam Generator **472** and the Combustor **704**. Cooling mass flow may further be directed to pump **P3** to feed and cool the Compressor **407** via flow **F*****. Mass flow of excess condensed liquid diluent, such as liquid water discharge monitored, by discharged Exhaust Water Temperature Sensor **SWT8**, discharged Exhaust Water Pressure Sensor **SWP8**. Vaporized diluent **F188** delivered to outside thermal use such as steam for industrial heat, may be condensed, recovered, cleaned as needed, and recycled via diluent fluid flow **F***** back into the power system via mixing valve **236**. Recycled condensed diluent mass flow may be monitored by liquid Water mass flow sensor to the Economizer **474** **SWF**.

Economizer Sensors

[0438] Per Fig. 6D, the inlet diluent flow **F2** into the Economizer via diluent or water Pump **P2** may be monitored by one or more of a pump speed (Omega) sensor **S ω** , a diluent or water mass flow (W) Pressure Sensor **SWP**, a diluent or Water Temperature flow

Sensor **SWT**,

[0439] Economizer discharge flow out of the Economizer may be monitored by Temperature Sensor **ST7**. Water mass flow resolution and accuracy may be increased by use of a high resolution optical encoder.

5 Preheating from Standby to Operating and Emergency Power

[0440] In the context of Fig. 4A and Fig. 4B, Fig. 6E discloses system operational flexibility of the novel embodiments and control methods disclosed. These embodiments and methods include multiple low temperature and high temperature control methods. Exemplary embodiments exhibit novel selected ranges of preheating and operating options in VAST Cycle gas turbine systems.

10 [0441] Such embodiments depicted Fig. 6E include various sequential actions to transition from a cold start at time Tau Zero (**$\tau 0$**) to starting power generation about Tau Eleven (**$\tau 11$**). Such depictions further exemplify various operating power embodiments from Tau Eleven (**$\tau 11$**) to Tau Twenty-One (**$\tau 21$**). These may include operating at multiple Turbine Inlet Temperatures (TIT) such as from **T4C** to **T4G**. Such embodiments may control power generation over multiple power levels. E.g., as from Power level One to Power level Five (**P1-P5**).

15 [0442] Such power operation may be followed by various shutdown operations from Tau Twenty-One (**$\tau 21$**) to Tau Twenty-Five (**$\tau 25$**). These show Pilot Outlet Temperatures (**T34**) at the inlet to the combustor region inlet at upstream axial location **CZ34**. They further show combustor outlet / expander inlet temperature **T4** at combustor outlet / expander inlet axially at **CZ4**.

20 [0443] The techniques described herein may be used to preheat, operate, and shutdown gas turbines. They may be used to achieve lower startup and standby heat losses. They may be used to benefit reliability temperature and emissions during ramp up to power generation at Power One (**P1**) at Tau 11 (**$\tau 11$**). Such techniques may then improve power generation control, efficiency, and emissions, from initial power **P1** on to Design power **P3** at Tau 15 (**$\tau 15$**). These may be designed for best power magnitude, temperature control with the highest efficiency and lowest operating cost. Alternatively, such power generation may be configured and controlled as shown in **P4A** and **P4B** for according to grid need to achieve higher peaking power, or maximum emergency peak power as needed as discussed as follows.

25 **Slow Rotation Preheating**

30 [0444] Per Fig. 6E and Fig. 6F (as subsets of Fig. 6G), a gas turbine compressor may be

rotated about its axis by one or more of exciting the generator to operate as a motor, using a separate starter motor, and/or a fuel driven engine, with mechanical, magnetic, electromechanical, hydraulic and/or gaseous power transmission, to rotate the expander and generator. (This may similarly use discharging compressed air through the compressor or through a hydraulic or pneumatic motor). Such operations may be conducted from time Tau One ($\tau 1$) to Tau Two ($\tau 2$), and from stationary up to a speed Omega R (ωR). These steps may provide a flow of oxidant fluid (such as air) to first flush or purge the gas turbine combustor and expander system of potentially explosive oxidant and fuel fluid mixtures. These startup steps may follow industry purging or fluid flushing standards to prevent explosions, such as used for gas turbines or boilers. Per Fig. 6E, Fig. 6F, (and Fig. 6G), such system preheating may be used with a stationary rotor, or with a prescribed rate of mechanical or electrical system rotation during preheating. Such system preheating rotation may be controlled over a prescribed rotational rate range. E.g., the rotational rate may be between 0.001 Hz and 45 Hz (0.06 RPM and 2,700 RPM), between 0.002 Hz and 20 Hz, (0.12 RPM and 1,200 RPM), between 0.02 Hz and 10 Hz (1.2 RPM and 600 RPM), between 0.06 Hz and 5 Hz (3.6 RPM and 300 RPM), between 0.1 Hz and 3 Hz (6 RPM and 180 RPM), between 0.2 Hz and 1.5 Hz (12 RPM and 90 RPM), and/or between 0.3 Hz and 0.8 Hz (24 RPM and 48 RPM). Other ranges in system rotation rates may similarly be used for such gas turbine preheating.

[0445] =====

[0446] Per Fig. 6E (and Fig. 6G), in a starting period between time Tau Two ($\tau 2$) and Tau Three ($\tau 3$), pilot fuel fluid, pilot oxidant fluid, and pilot diluent fluid may be provided to one or more upstream multifluid flame authorities (or pilot lights) **100**. A pilot blower and/or pressurized oxidant storage may alternatively be used to supply oxidant to the pilot during startup (not shown).

[0447] Per Fig. 6E (and Fig. 6G) this flame authority startup operation may ignite the mixture of Ignition Authority (pilot) fuel fluid, and Ignition Authority (pilot) oxidant fluid and pilot diluent fluid in the flame authorities **100** to generate stable low emission flames at Tau Three ($\tau 3$). These pilot outlet / combusting region(s) may generate pilot fluid and deliver it to the combustor inlet at temperature **T34A**. One or more flows of thermal diluent fluid may be delivered to flame authorities **100** to cool and control the pilot combusting fluids.

[0448] In conventional gas turbine operations, NO_x and CO emissions from pilot lights

alone have been known to cause ~60% of allowed NO_x emissions. The techniques here may ameliorate this. For example, combinations of oxidant fluid, fuel fluid and diluent fluid may control the flame authority (pilot) combusting fluids to desired pilot fluid temperatures **T34A** at the flame authority outlet **CZ34**, such as between 600°C and 1300°C. Such diluted flame authority operation may control pilot NO_x and CO emissions to below 1 ppmvd.

[0449] The flame authority **100** delivered to **CZ34** may be used to ignite mixtures of fuel, oxidant and optionally diluent in the combustor and to preheat the combustor. One or more of fuel fluid, oxidant fluid and/or diluent fluid may be delivered to the combustor in multiple axial and transverse locations.

Flame Authority Delivery Temperatures

[0450] Thermal diluent fluid may be delivered to cool and control initial warming fluid temperatures within a prescribed range, and to achieve a prescribed rate of fluid warming. This warming fluid may be delivered to and through a plurality of combusting and equilibrating regions and into the turbine expander at **CZ4**. For example, initial warming fluid may be formed by combusting and cooling combusting gases for delivery at a temperature **T34A** to **T34B** within a range such as between 0°C to 1000°C. e.g., in Fig. 6E from time Tau Three A (**τ3A**) to time Tau Five (**τ5**), and/or from time Tau Three A (**τ3A**) to time Tau Six (**τ6**).

[0451] Such preliminary flame authority fluid deliver temperature **T4A** may be selected as within 20°C to 700°C, or 30°C to 400°C, or within 40°C to 200°C, or 50°C to 100°C, etc. In other configurations, the flame authority fluid delivery temperature **T4A** may be configured to be within 500°C to 1800°C, or 600°C to 1600°C, or within 800°C to 1400°C, or within 1000°C to 1200°C, etc. In other configurations, the flame authority fluid delivery temperature **T4A** may similarly be configured to be within 700°C to 1,500°C, or between 800°C and 1,300°C, or within 900°C to 1,200°C, or within 1000°C to 1,100°C, or between 1,200°C to 1,400°C etc.

Controlling Thermal Warmup Ramp Rates

[0452] Referring to Fig. 6E and Fig. 6F, in such initial warming from Start to Standby times, warming fluid (or multifluid pilot fluid) may be delivered while slowly rotating the gas turbine expander. Such slow warmup system rotation may be achieved by mechanical, hydraulic, pneumatic, and/or electrical power etc. The warming rate may be ramped up at one or more prescribed temperature rise rates to achieve downstream combustor wall, expander stator, blade, and/or expander wall preheating rate(s).

Preheating Rate to Standby Operating Temperatures

[0453] Fig. 6F (as duplicated in Fig. 6G) depicts preheating the VAST gas turbine to hot Standby Operating conditions typical of gas turbine operating temperatures. E.g., such Standby Operating temperatures may require stator and/or blade cooling, and/or combustor or turbine wall cooling. Fig. 6F depicts combustor outlet temperature / Turbine Inlet Temperature **T4** being warmed from ambient temperature at Tau 4 (**$\tau 4$**) up to Turbine Inlet operating temperatures of **T4D** at Tau Seven B (**$\tau 7B$**).

[0454] Fig. 6E (and Fig. 6G) depict preheating the VAST gas turbine to a nominal heated combustor and expander temperature without cooling, such as from 30°C to 1,100°C, between from time Tau Five (**$\tau 5$**) to time Tau Six (**$\tau 6$**). Such warming fluid may raise the combustor outlet temperature **T4A**, (in Fig. 6E without **cooling**) at various selected temperature rise rates, such as depicted from a start at time Tau Four (**$\tau 4$**) up to time Tau Seven A (**$\tau 7A$**) in Fig. 6, Similarly warming fluid to combustor outlet temperature **T4B** in Fig. 6F may be ramped up from starting time Tau Four (**$\tau 4$**) up to a higher standby temperature **T4D** (requiring blade cooling) by time Tau Seven B (**$\tau 7B$**).Preheating Ramp Rates.

[0455] [0417] Per Fig. 5M through Fig. 5S, the Flame Authorities 100 may have multiple fuel and oxidant orifices. E.g., three fuel orifice and six oxidant orifices are shown in Fig. 5M. A similar configuration may further be placed on the opposite side of the ignition authority. Fuel, oxidant and diluent fluid may be delivered to one or both sides of each ignition authority. The number of flame authorities **100** (fluid igniters or pilot lights) and/or the temperature of hot flame authority delivery fluid generated may be controlled to achieve the prescribed rate of preheating. E.g., by using between one of 1 and 40 fluid igniters, between 2 to 20 fluid igniters, between 3 to 10 fluid igniters, or between 4 to 6 fluid igniters. In other configurations, other ranges of fluid igniters may similarly be prescribed, such as between 1 and 16 fluid igniters, or between 2 and 8 fluid igniters, or between 3 and 6 fluid igniters.

[0417] Combustor thermal ramp rates may be configured within a range of 10°C/minute to 10,000°C/min, or within 20°C/min to 2,000°C/min, or within 30°C/min to 500°C/min, or within 40°C/min to 250°C/min or within 50°C/min to 100°C/min etc. Similar variations in warming fluid temperature ramp ranges may be configured as desired, considering grid power premiums for faster startup versus reductions in equipment life, and increased maintenance from mechanical creep, thermal creep, thermal fatigue, and/or mechanical fatigue.Standby Operating Temperatures

[0456] Per Fig. 6F (and Fig. 6G), such Standby operation may be configured to preheat the combustion outlet temperature or Turbine Inlet Temperature (TIT) to selected temperatures. E.g., combustor outlet temperature or Turbine Inlet Temperature (TIT) may be warmed from ambient temperature at time Tau 4 ($\tau 4$) up to an operating Turbine Inlet Temperature of **T4D** at time Tau Seven B ($\tau 7B$). Such heating may then be reduced maintain such TIT at **T4D** under Standby operation. Such Standby temperatures **T4D** may be controlled to temperatures requiring blade cooling, such as between 1100°C and 1800°C, or between 1200°C and 1600°C, or between 1300°C and 1500°C, or between 1350°C and 1450°C. Other preheated standby temperature ranges may similarly be selected, such as to combustion outlet or Turbine Inlet Temperatures (TIT) between 1200°C and 1500°C, or to between 1300°C and 1400°C.

[0457] Per Fig. 6E (and Fig. 6G) a low flame authority combustor temperature may be selected for the upstream flame authority **100** from time period from Tau Three A ($\tau 3A$) to time Tau Five ($\tau 5$), such as 650 deg C. The Combustor Outlet Temperature/Turbine Inlet temperature may be increased over this period from ambient temperature at time Tau Three A ($\tau 3A$) to near 600°C at time Tau Six ($\tau 6$).

[0458]

[0459] Further to this embodiment of Fig. 6E, (and Fig. 6G) the flame authority **100** may be warmed from temperature **T34A** at Tau Five ($\tau 5$) to temperature **T34B** at Tau Six ($\tau 6$) e.g., from about e.g., Fig. 6E depicts the flame authority **100** outlet hot gas being heated from ~650°C to about 1150°C over this period. The Combustor outlet temperature may correspondingly be increased to **T34B** at Tau Seven A ($\tau 7A$). e.g., nominally preheating the VAST gas turbine from 600°C to 1100°C. Such preheating and standby temperatures are then shown as being held up to time Tau Nine ($\tau 9$).

Configuring Start to Emergency Power Operations

[0460] The various operating paths from Fig. 6E and Fig. 6F (and as shown in Fig. 6G) may be combined in various configurations to achieve multiple alternative configurations. These may utilize differing start/standby configurations with low and high ignition authority temperatures. E.g., these may utilize lower warming to a lower temperature such as **T34A** without blade cooling. Alternatively, they may use higher warming to a higher temperature such as **T34D** with blade cooling. Startup temperature ramp rates may differ such as between **T4A** and **T4B**.

[0461] Operating temperatures may vary between and about one or more of temperatures such as **T4D**, Peak **T4E**, **T4F**, Emergency **T4G**, Peak **T4H**, and **T4J**. Generated power

frequency may vary about ωP (not shown). Gas turbine and Generator Rotor speeds may increase from a power frequency ωP to a generator rotational frequency (speed) ωR . Per Fig. 6G, similarly note the varying Power generated between Power one (**P1**), Power Two (**P2**), Power 3 (**P3**), Peaking Power Four A (**P4A**), Emergency Power Four B (**P4B**), and regular Power Five (**P5**).

[0462] Per Fig. 6E (and Fig 6G), the preheated gas turbine at temperature **T4C** may be rapidly ramped up the expander-generator speed from Omega R (ωR) to Omega P (ωP). When the generator reaches near grid frequency, it begins Power One (**P1**) over the time Tau Eight ($\tau 8$) to time Tau Ten ($\tau 10$). During this time, the Ignition Authority 100 may ignite the gas turbine and may be ramped up the turbine temperature from temperature **4C (T4C)** on up to part way towards Temperature Four D (**T4D**) by Time Tau Eleven ($\tau 11$).

[0463] Power may then be ramped up to Power P2 with the temperature reaching peaking temperature Four D (**T4D**) at time Tau Thirteen ($\tau 10$). This may be held till time Tau Fourteen ($\tau 14$). Temperature may then be ramped up to Emergency Temperature Four (**T4E**) at with power ramping up to Power Three (**P3**) at time Tau Fifteen ($\tau 15$). Meanwhile the ignition authority temperature T34B maybe ramped up to a medium operating Temperature Thirty Four C (**T34C**).

[0464] At time Tau Seventeen ($\tau 17$) the Power may then be ramped UP to Power Four A (**P4A**) while the Temperature TIT is being ramped Down from peaking temperature to operating Temperature Four F (**T4F**) while the Power may then be ramped up to Emergency Power Four A (**P4A**) at Time Tau Eighteen ($\tau 18$).

[0465] This power and temperature may be held until time Tau Nineteen ($\tau 19$). Temperature may then be ramped up to Emergency Temperature Four (**T4E**) at with power ramping up to Power Three (**P3**) at time Tau Fifteen ($\tau 15$). Temperature may then be ramped Up from Temperature Four E (**T4E**) to Temperature Four F (**T4F**) while power is ramped back Down from time Tau Ninteen ($\tau 19$) to time Tau Twenty ($\tau 20$).

[0466] Power may then be shut down from Power Five (**P5**) over Time Tau Twenty-One ($\tau 20$) to Time Tau Twenty Two ($\tau 20$). Meanwhile, the temperature may be independently ramped down from Temperature Five G (**T5G**) back down to ambient temperature.

Configuring Start to Emergency Power Operations

[0467] The various operating paths from Fig. 6E and Fig. 6F (and as shown in Fig. 6G) may be combined in various configurations to achieve multiple alternative

configurations. These may utilize differing start/standby configurations with low and high ignition authority temperatures. E.g., these may utilize lower warming to a lower temperature such as **T34A** without blade cooling. Alternatively, they may use higher warming to a higher temperature such as **T34D** with blade cooling. Startup temperature ramp rates may differ such as between **T4A** and **T4B**.

[0468] Operating temperatures may vary between and about one or more of temperatures such as **T4D**, Peak **T4E**, **T4F**, Emergency **T4G**, Peak **T4H**, and **T4J**. Generated power frequency may vary about ωP (not shown). Gas turbine and Generator Rotor speeds may increase from a power frequency ωP to a generator rotational speed (frequency) ωR . Per Fig. 6G, similarly note the varying Power generated between Power one (**P1**), Power Two (**P2**), Power 3 (**P3**), Peaking Power Four A (**P4A**), Emergency Power Four B (**P4B**), and regular Power Five (**P5**).

[0469] Per Fig. 6F (and Fig 6G), the Ignition Authority is preheated to temperature T Thirty_Four D (**T34D**) by Time Tau 3B ($\tau 3B$). The Combustor and gas Turbine Expander have been preheated to operating Temperature 4D (**T4D**). This enables rapidly ramping up the expander-generator speed to Power speed or frequency Omega P (ωP) that may be over time Tau Eight ($\tau 8$) to Tau Ten ($\tau 10$). While the generator may ramp up to near grid

[0470] Power may then be ramped up to Power (**P2**) while temperature may be held at operating temperature (**T4D**) at time Tau Thirteen ($\tau 10$). This may be held till time Tau Fourteen ($\tau 14$). Temperature may then be ramped up to Emergency Temperature Four (**T4E**) at with power ramping up to Power Three (**P3**) at time Tau Fifteen ($\tau 15$). Meanwhile the ignition authority temperature T34B maybe ramped up to a medium operating Temperature Thirty-Four C (**T34C**).

[0471] At time Tau Seventeen ($\tau 17$) the Power may then be ramped UP to Power Four A (**P4A**) while the Temperature TIT is being ramped Down from peaking temperature to operating Temperature Four F (**T4F**) while the Power may then be ramped up to Emergency Power Four A (**P4A**) at Time Tau Eighteen ($\tau 18$).

[0472] This generator power Four B (**P4B**) and turbine operating temperature Four F (**T4F**) may be held until time Tau Nineteen ($\tau 19$). Temperature may then be ramped back down to normal Operating Temperature, Frequency WP temperature to Four G (**T4G**), and Power and Power Five (**P5**).

[0473] Power may then be shut down from Power Five (**P5**) over Time Tau Twenty-One ($\tau 21$) to Time Tau Twenty-Two ($\tau 22$). Meanwhile, the Combustor/Expander

temperature may be independently ramped down from Temperature Four G (**T4G**) back down to ambient temperature over Time Twenty-One (**τ21**) to Time Twenty-Three (**τ23**). The Ignition Authority Temperature may similarly be ramped back down from Temperature Thirty-Four D (**T34D**) to ambient over time from Tau Twenty-Two (**τ22**) to Tau Twenty-Fou (**τ24**). Alternatively the ignition authority and the Combustor/Gas Turbine may be ramped back to Standby conditions as before.

[0474]

[0475] Such preheating may control one or more of the relative ratio Lambda of oxidant fluid to fuel fluid, relative to the corresponding relative stoichiometric ratio (Omega: oxidant to fuel mass ratio relative to the stoichiometric oxidant to fuel mass ratio), the diluent to oxidant mass ratio (Lambda), the gaseous diluent (e.g., steam) to fuel ratio, the liquid diluent (e.g., water) to fuel ratio, or some combination of such ratios sufficient to control combustion within combustion quench limits.

[0476] Such ratios may further control one or more of these fluid ratios sufficient to control prescribed emission rates during warmup to below prescribed concentrations. E.g., to control unburned fuel concentrations during startup, such as hydrogen, ammonia, hydrocarbons, or alcohol fuels. e.g., unburned hydrocarbons (abbreviated **UHC**). Such ratios may further control concentrations of nitrogen oxide emissions (**NO_x**), and/or carbon monoxide (**CO**) emissions during system warmup.

Preheating and Standby Temperature Ranges

[0477] Such preheating may generate hot fluid to within a prescribed combusting range. E.g., such as within 600°C to 1,800°C, or 800°C to 1,600°C, or 900°C to 1400°C, or 1000°C to 1300°C, or 1100°C to 1200°C etc. In some configurations, the upper range of preheating fluid may be selected to be lower than a prescribed maximum temperature for gas turbine blades without cooling. Alternatively, in other configurations, the upper range of the preheating fluid may be selected to be higher than the minimum temperature requiring cooling and lower than the maximum temperature for gas turbine expander blades with fluid cooling. The composition and equilibrating times may be correspondingly configured to achieve prescribed emission limits during such combustion.

[0478] Such hot combusting fluid may be diluted with one or both of gaseous diluent and liquid diluent (such as steam and/or liquid water, gaseous CO₂, liquid CO₂, and/or supercritical CO₂), and/or excess oxidant (such as air) to reduce the temperature of the

combusting fluid to within such prescribed warming fluid temperature delivery ranges, and to increase temperature with prescribed temperature warming rates such as described above. Low Power Standby

[0479] Such turbine preheating may be configured to reduce the preheating fuel use and corresponding stand by fuel use to below that used for a prescribed minimum turbine operating power. E.g., such as below 40%, below 30%, below 20%, below 10%, below 5%, below 2%, and/or below 1% of design operating power **P3**.

[0427] Such combustion, hot fluid formation, fluid cooling, and fluid temperature ramp rates may further be configured to constrain material strains, and/or strain rates in the combustor and/or expander to with prescribe strain ranges, and/or strain rate ranges. Such methods may similarly be conducted to reduce thermal stresses and/or stress rates to within prescribed ranges. Such methods may reduce equipment fatigue and creep. They may maintenance frequency and system and power generating costs.

Fast Ramping Scalable Combustors.

[0480] VAST Cycle starting, ramping, operating, peak power and emergency power methods such as depicted in Fig. 6E, and Fig. 6F, (as compared in Fig. 6G) may be utilized to provide rapid gas turbine dispatches. Such techniques may achieve lower loss standby and/or faster dispatch rates with shorter ramp-up times than conventional industrial turbine ramp speeds. e.g., by reducing startup or ramp times from historic slow ramps (e.g., 8 hours) down to one or more of 30 minutes, 15 minutes, 5 minutes, 2 minutes, and 1 minute, or less.

[0481] Such VAST Cycle operating techniques may be used to more effectively and reliably meet increasing requirements for hot standby power, such as California's fifteen (15) minute dispatch schedule, its five (5) minute dispatch schedule, and/or its one (1) minute emergency dispatch time period (**EDT**).

[0482] Such hybrid gas turbine power operating techniques may similarly supply California's 10-minute spinning-reserve and/or non-spinning reserve. Such techniques may further be used to reduce thermal creep, reduce cyclic thermal fatigue, reduce cyclic mechanical fatigue, improving longevity, and reduce hot standby fuel use. One or more of these may reduce operating, maintenance, repair, and/or replacement costs. They may correspondingly reduce down time. Such novel capabilities may further earn higher revenues, and better ensure essential grid reliability with lower costs, lower risks, and/or improved profitability.

[0483] Methods used herein may precisely control combustor outlet temperature /

Turbine Inlet Temperature **T4** by the ratio Omega of liquid diluent flow to fuel flow rates. For example, liquid water flow may be monitored with a turbine flow meter using a high resolution optical encoder.

Such operating techniques may be used to control ignition authority temperature, combustor temperature, and gas/or turbine temperature faster, more reliably, and/or more accurately using scalable combustors, more independently of power scheduling and/or power demand. These techniques may be used to enable faster power ramps, and reduce combustor and/or turbine temperature gradients. They may improve one or more of compressor, pilot, combustor, expander, generator, and/or overall efficiency. Flexible Combined Heat and Power

[0484] Such combustor and system configuration and/or control methods may further be used to independently control a thermal ramp up (and/or shut down) rate of the Once Thru Steam Generator (OTSG) to hot standby and/or to full hot operating temperatures, separately from the ignition authority, combustor, expander, and/or generator temperature and/or power. Such methods may reduce the thermal stresses and cyclic fatigue of the Once Through Steam Generator (OTSG) heat recovery system, or for a similar Heat Recovery Steam Generator (HRSG).

[0485] The combustion configuration and control methods described may be used for hybrid Combined Heat and Power (CHP) applications. Such CHP applications may deliver heat to one or more thermal applications, such as through hot water and/or steam, and/or hot gas, such as nitrogen, oxygen and/or carbon dioxide. They may independently generate power, and separately control combustion temperature by delivery of one or more of residual steam, hot water, and/or cold water or other thermal diluent such as Carbon Dioxide (CO₂).

[0486] SOME OTHER EMBODIMENTS

Some embodiments per figure are listed below:

[0487] For Fig. 4B

A combustor system comprising:

- a. an inner annular combustor wall and an outer annular combustor wall defining an annular combustion chamber therebetween;
- b. a plurality of combustor shells radially oriented between the inner and outer annular combustor walls and configured circumferentially about a combustor axis;

- c. each combusting shell comprising:
 - i. a plurality of oxidant fluid feeders;
 - ii. a plurality of fuel fluid feeders; and
 - iii. a plurality of diluent fluid feeders;
- 5 d. an upstream flame authority configured to:
 - i. receive and mix pilot fuel fluid, pilot oxidant fluid, and pilot diluent fluid;
 - ii. combust the mixed pilot fluids to form a hot pilot fluid; and
- e. a pilot fluid distribution system configured to:
 - i. receive the hot pilot fluid from the upstream flame authority;
 - 10 ii. distribute the hot pilot fluid to inlet portions of the plurality of combusting shells via pilot fluid delivery ducts;
- f. wherein the pilot fluid delivery ducts are configured circumferentially around the combustion chamber to deliver the hot pilot fluid into the combusting shells.

15 [0488] For Fig. 4C

- A combustor system comprising:
- a. a combustor wall comprising a fluid duct wall and a thermal insulating barrier;
 - b. a plurality of orifices extending through the combustor wall;
 - c. wherein the plurality of orifices are configured with:
 - 20 i. varying diameters across a transverse direction of the combustor wall; or
 - ii. varying spatial density distribution across the transverse direction of the combustor wall;
 - d. wherein the plurality of orifices are configured to:
 - i. receive fluid from one or more fluid feeders; and
 - ii. deliver the fluid into a combustion chamber;
 - 25 e. wherein the fluid comprises at least one of:
 - i. an oxidant fluid;
 - ii. a fuel fluid; or
 - iii. a diluent fluid;
 - f. wherein the varying diameters or varying spatial density of the orifices controls:
 - 30 i. fluid delivery rates into the combustion chamber; and
 - ii. fluid mixing within the combustion chamber.

[0489] For Fig. 4D

A combustor system comprising:

- a. a combustor having an axial flow direction;
- b. opposing radially and circumferentially extended fluid manifolds comprising:
 - i. an oxidant fluid manifold configured to deliver diluted oxidant fluid; and
 - ii. a fuel fluid manifold configured to deliver diluted fuel fluid;
- 5 c. a plurality of adjacent combusting regions positioned between the opposing fluid manifolds;
- d. wherein the oxidant fluid manifold comprises:
 - i. a plurality of oxidant orifices configured to deliver the diluted oxidant fluid into the adjacent combusting regions;
 - 10 ii. an outer oxidant fluid feeder extending radially with a first radial depth; and
 - iii. oxidant orifices circumferentially offset from fuel orifices to improve mixing and reduce quenching;
- e. wherein the fuel fluid manifold comprises:
 - i. a plurality of fuel orifices configured to deliver the diluted fuel fluid into the adjacent
 - 15 combusting regions;
 - ii. a fuel fluid feeder extending radially with a second radial depth; and
 - iii. fuel orifices positioned circumferentially about the fuel fluid feeder;
- f. wherein the oxidant fluid manifold and fuel fluid manifold are separated by a sigmoidally curved longitudinal manifold divider

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[0490] For FIG. 4I

A combustor system comprising:

- a. a combustor having an axial flow direction and a radial direction;
- b. a plurality of axially spaced fluid feeders comprising:
 - 25 i. fuel fluid feeders configured to deliver diluted fuel fluid; and
 - ii. oxidant fluid feeders configured to deliver diluted oxidant fluid;
- c. wherein each fuel fluid feeder comprises:
 - i. a plurality of fuel orifices distributed in a radially transverse pattern; and
 - ii. fuel orifices configured to deliver progressively varying fuel fluid flows U1 through U7;
- 30 d. wherein each oxidant fluid feeder comprises:
 - i. a plurality of oxidant orifices distributed in a radially transverse pattern; and
 - ii. oxidant orifices configured to deliver progressively varying oxidant fluid flows X1 through X6;
- e. a control system configured to control the radially transverse distribution of the fuel

orifices and oxidant orifices to achieve:

- i. prescribed oxidant to fuel ratios across the radial direction;
 - ii. prescribed temperature distributions at the combustor outlet; and
 - iii. prescribed axial velocity distributions at the combustor outlet;
- 5 f. wherein the control system is further configured to:
- i. vary the ratio of oxidant delivery to fuel delivery between upstream and downstream portions of a combustor chamber; and
 - ii. control fluid delivery rates to maintain combustion temperature above a combustion quench limit.

10 A combustor system comprising:

- a. a combustor having an axial flow direction and a radial direction;
- b. an asymmetric manifold configuration comprising:
 - i. a radially wider oxidant manifold configured to deliver oxidant fluid; and
 - 15 ii. a radially narrower fuel manifold configured to deliver fuel fluid;
- c. wherein the oxidant manifold comprises:
 - i. a plurality of oxidant feeders delivering oxidant fluid flows X1 through X7;
 - ii. oxidant fluid orifices configured in the oxidant feeders; and
 - iii. a circumferentially wider oxidant feeder passage width to accommodate larger
 - 20 volumetric oxidant fluid flows;
- d. wherein the fuel manifold comprises:
 - i. a plurality of fuel feeders delivering fuel fluid flows U1 through U7;
 - ii. fuel fluid orifices configured in the fuel feeders; and
 - iii. a circumferentially narrower fuel feeder passage width corresponding to smaller fuel
 - 25 fluid flows;
- e. wherein the asymmetric manifold configuration provides:
 - i. transverse-axial fluid delivery;
 - ii. controlled mixing of oxidant and fuel fluids; and
 - iii. progressive delivery of oxidant and fuel fluids along the axial direction;
- 30 f. a downstream blend-trim region configured to receive:
 - i. diluted oxidant fluid flows through blend-trim orifices; and
 - ii. diluent fluid flows through diluent orifices.

[0491] For FIGS. 4J to 4M

A combustor system comprising:

- a. a combustor having an axial flow direction and a radial direction;
- b. a plurality of fluid orifices configured in combustor walls, wherein the fluid orifices comprise:

- 5 i. oxidant fluid orifices configured to deliver oxidant fluid;
- ii. fuel fluid orifices configured to deliver fuel fluid; and
- iii. diluent fluid orifices configured to deliver diluent fluid;
- c. wherein the fluid orifices are arranged in a radially transverse spatial distribution comprising:

- 10 i. upstream orifices having a first spatial distribution pattern; and
- ii. downstream orifices having a second spatial distribution pattern;
- d. wherein the upstream orifices comprise:
 - i. larger and more numerous upstream oxidant fluid delivery orifices; and
 - ii. smaller and fewer downstream fuel fluid delivery orifices in a 2:1 ratio;

- 15 e. wherein the downstream orifices comprise:
 - i. fewer upstream fuel fluid delivery orifices; and
 - ii. more numerous downstream oxidant fluid delivery orifices in a 1:2 ratio;
- f. wherein:

- i. oxidant fluid orifices are circumferentially offset from fuel fluid orifices to improve
- 20 mixing and reduce quenching;
- ii. upstream blend-trim orifices are offset from downstream blend-trim orifices; and
- iii. the spatial distribution patterns control fluid mixing and reaction rates within the combustor.

25 A combustor system comprising:

- a. a combustor having an axial flow direction and a radial direction;
- b. a plurality of fluid orifices configured in combustor walls comprising:

- i. upstream orifices configured to deliver fluids in a first radially transverse spatial configuration; and
- 30 ii. downstream orifices configured to deliver fluids in a second radially transverse spatial configuration;

- c. wherein the upstream orifices comprise:
 - i. fuel fluid orifices configured to deliver fuel fluid;
 - ii. oxidant fluid orifices configured to deliver oxidant fluid; and

- iii. diluent fluid orifices configured to deliver diluent fluid;
- d. wherein the downstream orifices comprise:
 - i. fuel fluid orifices configured in a different spatial pattern than the upstream fuel fluid orifices;
 - 5 ii. oxidant fluid orifices configured in a different spatial pattern than the upstream oxidant fluid orifices; and
 - iii. diluent fluid orifices configured in a different spatial pattern than the upstream diluent fluid orifices;
- e. wherein:
 - 10 i. the upstream oxidant fluid orifices are circumferentially offset from the upstream fuel fluid orifices;
 - ii. the downstream oxidant fluid orifices are circumferentially offset from the downstream fuel fluid orifices; and
 - iii. the upstream and downstream spatial configurations control fluid mixing and reaction
 - 15 rates within the combustor;
- f. a control system configured to:
 - i. vary the ratio of oxidant delivery to fuel delivery between the upstream and downstream orifices; and
 - ii. control fluid delivery rates to maintain combustion temperature above a combustion
 - 20 quench limit

[0492] For FIG. 4Z

A combustor system comprising:

- a. a combustor having a combustor shell with an outer portion;
- 25 b. a heated combustor region within the combustor shell configured to:
 - i. receive fuel fluid comprising ammonia;
 - ii. thermally crack the ammonia fuel to generate hydrogen and nitrogen;
- c. wherein the heated combustor region comprises:
 - i. sufficient volume to provide residence time for thermal cracking;
 - 30 ii. temperatures between about 400°C to about 650°C to facilitate ammonia cracking;
- d. a fuel delivery system configured to:
 - i. deliver the ammonia fuel fluid to the outer portion of the combustor shell;
 - ii. control fuel delivery rates to maintain combustion temperature above a combustion
 - quench limit;

- e. wherein the heated combusting region is configured to:
 - i. crack a major portion of the ammonia fuel to hydrogen and nitrogen;
 - ii. achieve ammonia conversion efficiency greater than about 99%;
- f. a control system configured to:
 - 5 i. monitor and control the residence time of the ammonia fuel;
 - ii. control the temperature rise in the heated combusting region;
 - iii. maintain temperatures sufficient for thermal cracking of ammonia.

[0493] For FIG. 5A

- 10 A combustor system comprising:
 - a. an annular combustor comprising:
 - i. an inner annular combusting region wall;
 - ii. an outer annular combusting region wall; and
 - iii. a combusting region extending radially between the inner and outer walls;
 - 15 b. wherein the combusting region comprises:
 - i. a radially extended width oriented from the inner wall to the outer wall;
 - ii. a plurality of combusting shells configured circumferentially about a combustor axis;
 - c. wherein each combusting shell comprises:
 - i. a first combusting chamber wall deposited axially and circumferentially;
 - 20 ii. a radially opposed second combusting chamber wall;
 - iii. a plurality of fluid feeders configured about the combusting chamber walls;
 - d. wherein the fluid feeders comprise:
 - i. fuel fluid feeders configured to deliver fuel fluid;
 - ii. oxidant fluid feeders configured to deliver oxidant fluid; and
 - 25 iii. diluent fluid feeders configured to deliver diluent fluid;
 - e. wherein the combusting region is configured to:
 - i. receive and mix the fuel, oxidant and diluent fluids;
 - ii. combust the mixed fluids to generate hot combustion products;
 - f. wherein the radially extended width of the combusting region provides:
 - 30 i. sufficient volume for fluid mixing; and
 - ii. controlled residence time for combustion reactions.

[0494] For FIG. 5B

A combustor system comprising:

- a. an annular combustor comprising:
 - i. a radially inner wall;
 - ii. a radially outer wall; and
 - iii. expander inlet stators positioned between the inner and outer walls;
- 5 b. a combusting region comprising:
 - i. an outwardly extended width oriented along a radial direction;
 - ii. an opening extending radially between the expander inlet stators;
 - iii. a plurality of combusting shells configured circumferentially about a combustor axis;
- c. wherein each combusting shell comprises:
 - 10 i. a first combusting chamber wall deposited axially and circumferentially;
 - ii. a radially opposed second combusting chamber wall;
 - iii. a plurality of fluid feeders configured about the combusting chamber walls;
- d. wherein the fluid feeders comprise:
 - i. fuel fluid feeders configured to deliver fuel fluid;
 - 15 ii. oxidant fluid feeders configured to deliver oxidant fluid; and
 - iii. diluent fluid feeders configured to deliver diluent fluid;
- e. wherein the combusting region is configured to:
 - i. receive and mix the fuel, oxidant and diluent fluids;
 - ii. combust the mixed fluids to generate hot combustion products;
- 20 f. wherein the outwardly extended width of the combusting region provides:
 - i. controlled fluid mixing between the expander inlet stators; and
 - ii. prescribed temperature distributions at the expander inlet.

[0495] For FIG. 5C

- 25 A combustor system comprising:
 - a. a combustor having an upstream combusting region comprising:
 - i. a first combusting chamber wall deposited axially and circumferentially;
 - ii. a radially opposed second combusting chamber wall;
 - iii. an inner combustor wall and an outer combustor wall;
 - 30 b. a plurality of fluid orifices configured in the combusting chamber walls comprising:
 - i. fuel fluid orifices configured to deliver fuel fluid;
 - ii. oxidant fluid orifices configured to deliver oxidant fluid;
 - iii. diluent fluid orifices configured to deliver diluent fluid;
 - c. wherein the fluid orifices are distributed in a radial pattern configured to:

- i. control radial temperature distribution across the combusting region;
- ii. accommodate cooling of the inner combustor wall;
- iii. accommodate cooling of the outer combustor wall;
- d. a control system configured to:
 - 5 i. control delivery of fuel fluid through the fuel fluid orifices;
 - ii. control delivery of oxidant fluid through the oxidant fluid orifices;
 - iii. control delivery of diluent fluid through the diluent fluid orifices;
- e. wherein the control system is further configured to maintain:
 - i. a first temperature at an inner radius relative to a second temperature at an outer radius;
 - 10 ii. prescribed intermediate temperatures between the inner and outer radii;
 - iii. temperature gradients between intermediate radial positions;
- f. wherein the control system controls fluid delivery to:
 - i. maintain combustion temperature above a combustion quench limit;
 - ii. achieve prescribed temperature distributions at the combustor outlet;
 - 15 iii. control wall cooling requirements along the radial direction.

[0496] For FIG. 5E

A combustor system comprising:

- a. a combustor having:
 - 20 i. a radially inner wall;
 - ii. a radially outer wall; and
 - iii. an upstream combusting region and a blend-trim region between the inner and outer walls;
- b. a plurality of fluid orifices configured in the combusting region comprising:
 - 25 i. fuel fluid orifices configured to deliver fuel fluid;
 - ii. oxidant fluid orifices configured to deliver oxidant fluid;
 - iii. diluent fluid orifices configured to deliver diluent fluid;
- c. a plurality of blend-trim orifices configured in the blend-trim region to deliver:
 - i. additional oxidant fluid;
 - 30 ii. additional diluent fluid;
 - iii. fluid mixtures to control combustion completion;
- d. wherein the fluid orifices and blend-trim orifices are distributed to achieve:
 - i. a radially inner outlet temperature T_{4i} at an inner radius R_i ;
 - ii. a radially outer outlet temperature T_{4o} at an outer radius R_o ;

- iii. wherein T_{4o} is higher than T_{4i} at the combustor outlet;
- e. a control system configured to control:
 - i. fuel fluid delivery through the fuel fluid orifices;
 - ii. oxidant fluid delivery through the oxidant fluid orifices;
 - 5 iii. diluent fluid delivery through the diluent fluid orifices;
- f. wherein the control system maintains:
 - i. prescribed intermediate temperatures T_{4j} and T_{4k} between T_{4i} and T_{4o} ;
 - ii. prescribed temperature gradients between intermediate radial positions;
 - iii. combustion temperature above a combustion quench limit

10 [0497] For FIG. 5F

A combustor system comprising:

- a. a combustor having:
 - i. a radially inner wall;
 - 15 ii. a radially outer wall; and
 - iii. an upstream combusting region and a blend-trim region between the inner and outer walls;
- b. a plurality of fluid orifices configured in the combusting region comprising:
 - i. fuel fluid orifices configured to deliver fuel fluid;
 - 20 ii. oxidant fluid orifices configured to deliver oxidant fluid;
 - iii. diluent fluid orifices configured to deliver diluent fluid;
- c. a plurality of blend-trim orifices configured in the blend-trim region to deliver:
 - i. additional oxidant fluid;
 - ii. additional diluent fluid;
 - 25 iii. fluid mixtures to control combustion completion;
- d. wherein the fluid orifices and blend-trim orifices are distributed to achieve:
 - i. an inner wall temperature T_{w4i} at the inner wall;
 - ii. an outer wall temperature T_{w4o} at the outer wall;
 - iii. prescribed wall temperature ranges between T_{w4i} and T_{w4o} ;
- 30 e. wherein the wall temperatures are controlled through:
 - i. an upstream inner wall temperature T_{w35i} at a transition boundary;
 - ii. an upstream outer wall temperature T_{w35o} at the transition boundary;
 - iii. intermediate inner and outer wall temperatures T_{w39i} and T_{w39o} at a blend-trim region outlet;

- f. a control system configured to maintain:
 - i. the inner and outer wall temperatures within desired temperature ranges;
 - ii. prescribed temperature gradients between intermediate wall positions;
 - iii. combustion temperature above a combustion quench limit.

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[0498] For FIG. 5G

A combustor system comprising:

a. a combustor having:

- i. a radially inner wall at a radius R_{4i} ;
- 10 ii. a radially outer wall at a radius R_{4o} ; and
- iii. an upstream combusting region between the inner and outer walls;
- b. a plurality of fluid orifices configured in the upstream combusting region comprising:
 - i. fuel fluid orifices configured to deliver fuel fluid;
 - ii. oxidant fluid orifices configured to deliver oxidant fluid;
 - 15 iii. diluent fluid orifices configured to deliver diluent fluid;
- c. wherein the fluid orifices are distributed to achieve at a combustor outlet:
 - i. a radially inner axial velocity V_{4i} near the inner wall;
 - ii. a first intermediate axial velocity V_{4j} at a first intermediate radius R_{4j} ;
 - iii. a second intermediate axial velocity V_{4k} at a second intermediate radius R_{4k} ;
 - 20 iv. a radially outer axial velocity V_{4o} near the outer wall;
- d. wherein at least one of:
 - i. the radially inner axial velocity V_{4i} is lower than both intermediate velocities V_{4j} and V_{4k} ; and
 - ii. the radially outer axial velocity V_{4o} is lower than both intermediate velocities V_{4j} and
 - 25 V_{4k} ;
- e. a control system configured to control:
 - i. fuel fluid delivery through the fuel fluid orifices;
 - ii. oxidant fluid delivery through the oxidant fluid orifices;
 - iii. diluent fluid delivery through the diluent fluid orifices;
- 30 f. wherein the control system maintains:
 - i. prescribed velocity distributions between the inner and outer walls;
 - ii. prescribed velocity gradients between intermediate radial positions;
 - iii. combustion temperature above a combustion quench limit.

A combustor system comprising:

a. a combustor having:

i. a radially inner wall at a radius R_{4i} ;

ii. a radially outer wall at a radius R_{4o} ; and

5 iii. an upstream combusting region between the inner and outer walls;

b. a plurality of fluid orifices configured in the upstream combusting region comprising:

i. fuel fluid orifices configured to deliver fuel fluid;

ii. oxidant fluid orifices configured to deliver oxidant fluid;

iii. diluent fluid orifices configured to deliver diluent fluid;

10 c. wherein the fluid orifices are distributed to achieve at a combustor outlet:

i. a radially inner axial velocity V_{4i} near the inner wall;

ii. a first intermediate axial velocity V_{4j} at a first intermediate radius R_{4j} ;

iii. a second intermediate axial velocity V_{4k} at a second intermediate radius R_{4k} ;

iv. a radially outer axial velocity V_{4o} near the outer wall;

15 d. wherein:

i. the first intermediate velocity V_{4j} is greater than the inner axial velocity V_{4i} ;

ii. the second intermediate velocity V_{4k} is greater than the outer axial velocity V_{4o} ;

iii. the intermediate velocities V_{4j} and V_{4k} are greater than both V_{4i} and V_{4o} ;

e. a control system configured to control:

20 i. fuel fluid delivery through the fuel fluid orifices;

ii. oxidant fluid delivery through the oxidant fluid orifices;

iii. diluent fluid delivery through the diluent fluid orifices;

f. wherein the control system maintains:

i. the velocity distribution by controlling the sum of axial orifices in the upstream

25 combustion region;

ii. prescribed velocity gradients between intermediate radial positions;

iii. combustion temperature above a combustion quench limit.

[0499] For FIG. 5H

30 A combustor system comprising:

a. a combustor having:

i. a circumferentially inner region;

ii. a circumferentially outer region; and

iii. an upstream combusting region between the inner and outer regions;

- b. a plurality of fluid orifices configured in the upstream combusting region comprising:
 - i. fuel fluid orifices configured to deliver fuel fluid;
 - ii. oxidant fluid orifices configured to deliver oxidant fluid;
 - iii. diluent fluid orifices configured to deliver diluent fluid;
- 5 c. wherein the fluid orifices are distributed to achieve at a combustor outlet:
 - i. a circumferentially inner temperature T_i ;
 - ii. a circumferentially intermediate temperature T between T_i and T_o ;
 - iii. a circumferentially outer temperature T_o ;
 - iv. wherein at least one of T_i and T_o is lower than T ;
- 10 d. wherein the temperature distribution is controlled through:
 - i. a first circumferential section centered at angle Θ_1 ;
 - ii. a second circumferential section centered at angle Θ_2 ;
 - iii. prescribed temperature gradients between the circumferential sections;
- e. a control system configured to control:
 - 15 i. fuel fluid delivery through the fuel fluid orifices;
 - ii. oxidant fluid delivery through the oxidant fluid orifices;
 - iii. diluent fluid delivery through the diluent fluid orifices;
- f. wherein the control system maintains:
 - i. prescribed temperature distributions between inner and outer circumferential regions;
 - 20 ii. prescribed temperature gradients between intermediate circumferential positions;
 - iii. combustion temperature above a combustion quench limit.

[0500] For FIG. 5I

A combustor system comprising:

- 25 a. a combustor having:
 - i. a circumferentially inner region;
 - ii. a circumferentially outer region; and
 - iii. an upstream combusting region between the inner and outer regions;
- b. a plurality of fluid orifices configured in the upstream combusting region comprising:
 - 30 i. fuel fluid orifices configured to deliver fuel fluid;
 - ii. oxidant fluid orifices configured to deliver oxidant fluid;
 - iii. diluent fluid orifices configured to deliver diluent fluid;
- c. wherein the fluid orifices are distributed to achieve at a combustor outlet:
 - i. a circumferentially inner temperature T_i ;

- ii. a circumferentially intermediate temperature T between T_i and T_o ;
- iii. a circumferentially outer temperature T_o ;
- iv. wherein at least one of T_i and T_o is higher than T ;
- d. wherein the temperature distribution is controlled through:
 - 5 i. a first combustion section centered at angle Θ_{1i} ;
 - ii. a second combustion section centered at angle Θ_{2i} ;
 - iii. prescribed temperature gradients between the combustion sections;
 - e. wherein the combustion sections comprise:
 - i. a first section extending circumferentially from angle Θ_{1wi} to Θ_{1ci} ;
 - 10 ii. a second section displaced clockwise from the first section;
 - iii. temperature ranges between T_s and T_i at inner radius R_i ;
 - iv. temperature ranges between T_{so} and T_o at outer radius R_o ;
 - f. a control system configured to maintain:
 - i. prescribed temperature distributions between inner and outer circumferential regions;
 - 15 ii. prescribed temperature gradients between intermediate circumferential positions;
 - iii. combustion temperature above a combustion quench limit.

[0501] For FIG. 5J

A combustor system comprising:

- 20 a. a combustor having:
 - i. a radially inner region at an inner radius R_i ;
 - ii. a radially outer region at an outer radius R_o ; and
 - iii. an upstream combusting region between the inner and outer regions;
- b. a plurality of fluid orifices configured in the upstream combusting region comprising:
 - 25 i. fuel fluid orifices configured to deliver fuel fluid;
 - ii. oxidant fluid orifices configured to deliver oxidant fluid;
 - iii. diluent fluid orifices configured to deliver diluent fluid;
- c. wherein the fluid orifices are distributed to achieve at a combustor outlet:
 - i. inner velocities V_i at the inner radius R_i ;
 - 30 ii. outer velocities V_o at the outer radius R_o ;
 - iii. prescribed velocity distributions between V_i and V_o ;
- d. wherein the velocity distribution is controlled through:
 - i. a first combustion section centered at angle Θ_{1i} ;
 - ii. a second combustion section centered at angle Θ_{2i} ;

- iii. prescribed velocity gradients between the combustion sections;
- e. wherein the combustion sections comprise:
 - i. a cooled counterclockwise first section from angle Θ_{1wi} to Θ_{1ci} ;
 - ii. a clockwise second section from angle Θ_{2wi} to Θ_{2ci} ;
- 5 iii. velocity ranges between V_{si} and V_i at inner radius R_i ;
- iv. velocity ranges between V_{so} and V_o at outer radius R_o ;
- f. a control system configured to maintain:
 - i. prescribed velocity distributions between inner and outer circumferential regions;
 - ii. prescribed velocity gradients between intermediate circumferential positions;
 - 10 iii. combustion temperature above a combustion quench limit.

[0502] For FIG. 5K

A combustor system comprising:

- a. a combustor having:
 - 15 i. an upstream combusting region;
 - ii. a plurality of mixing chambers; and
 - iii. fluid delivery passages connected to the mixing chambers;
- b. a plurality of fluid feeders configured to deliver into the mixing chambers:
 - i. fuel fluid comprising a fuel;
 - 20 ii. oxidant fluid comprising an oxidant;
 - iii. diluent fluid comprising a diluent;
- c. wherein the mixing chambers are configured to:
 - i. receive and mix combinations of at least two of:
 - fuel fluid and oxidant fluid;
 - 25 - fuel fluid and diluent fluid;
 - oxidant fluid and diluent fluid;
 - ii. form premixed fluid mixtures;
 - iii. deliver the premixed fluid mixtures into the upstream combusting flow;
- d. wherein the mixing chambers comprise:
 - 30 i. radial-circumferential extending feeder walls;
 - ii. radially inner and outer end walls;
 - iii. axial-circumferential blended feeder divider walls;
- e. wherein the mixing chambers include:
 - i. fuel fluid delivery orifices configured between fuel fluid feeders and mixing chambers;

- ii. premixed reactive fluid orifices configured to deliver premixed fluid into adjacent combusting regions;
- iii. orifice diameters constrained to avoid flashback from combusting regions;
- f. a control system configured to:

- 5 i. control delivery of fluids to the mixing chambers;
- ii. maintain combustion temperature above a combustion quench limit;
- iii. achieve prescribed temperature distributions at the combustor outlet.

A combustor system comprising:

- 10 a. a combustor having:
 - i. a downstream combusting region;
 - ii. a plurality of mixing chambers; and
 - iii. fluid delivery passages connected to the mixing chambers;
- b. a plurality of fluid feeders configured to deliver into the mixing chambers:
 - 15 i. oxidant fluid comprising an oxidant;
 - ii. diluent fluid comprising a diluent;
 - iii. fluid mixtures to control combustion completion;
- c. wherein the mixing chambers are configured to:
 - i. receive and mix combinations of:
 - 20 - oxidant fluid and diluent fluid;
 - ii. form premixed diluted oxidant fluid mixtures;
 - iii. deliver the premixed diluted oxidant fluid mixtures into the downstream combusting flow;
 - d. wherein the mixing chambers comprise:
 - 25 i. non-reactive dilutive premixing chambers in a blend-trim region;
 - ii. oxidative fluid orifices delivering oxidative fluid into the premixing chambers;
 - iii. dilutive fluid orifices delivering dilutive fluid into the premixing chambers;
- e. wherein the mixing chambers include:
 - i. premixed dilutive orifices configured to deliver premixed diluted oxidant fluid into the
 - 30 blend-trim region;
 - ii. orifice configurations to achieve prescribed mixing;
 - iii. orifice distributions to control combustion completion;
 - f. a control system configured to:
 - i. control delivery of oxidant and diluent fluids to the mixing chambers;

- ii. maintain combustion temperature above a combustion quench limit;
- iii. achieve prescribed temperature distributions at the combustor outlet.

[0503] SECTION ON AMMONIA MANIPULATION FOR IMPROVED RESIDUAL
5 DISCHARGES.

The techniques described herein provide for the use of ammonia injection for added technical benefits, such as improving residual discharges, for example, of NO_x and NH₃.

[0504] METHOD – 1

[0505] In one example, a Method for Ammonia manipulation in a Two-Stage Combustor
10 System is provided.

[0506] The method is applied via a combustor, including all combustor embodiments and examples described herein. A combustor with a long barrel exhaust is particularly well suited.

[0507] Stage 1: Combustor SCR for NO_x

15 1. Creating an NH₃-rich zone in the Equilibration Zone (e.g., Equilibrating Regions shown in FIGS. 4) of the Combustor by:

- Maintaining a certain O₂ level to allow uncracked NH₃ to remain at a combustor exit plane.
- Balancing O₂ levels to enable CO to CO₂ conversion
- Performing a selective catalytic reduction (SCR) function within the
20 Equilibration Zone instead of later stage SCR unit. Indeed, in some examples, there would be no dedicated SCR unit.

2. Addressing Operational Considerations: by

- Monitoring and managing corrosion risks from diluted NH₃ in moist hot
25 working fluid, for example, by implement NH₃-resistant ceramic coatings on expansion blades to mitigate the aforementioned corrosion risks.

[0508] Stage 2: NO_x – SCR for NH₃ - After an expansion turbine section, create a thermogenerator to serve as a NO_x generator using CH₄, diesel, or other hydrocarbonaceous fuel.

30 1. Configure Post-Expansion Components by:

- Creating thermogenerator after expansion turbine section

- Operating the thermogenerator as NO_x generator using hydrocarbonaceous fuels
- Running thermogenerator dry (w=0) to maximize NO_x formation

2. Implement Storage and Control Systems by:

- 5 ○ Installing pressurized surge tank for NO_x storage
- Maintaining pressure of surge tank above exhaust gas stream level of a simple cycle gas turbine or above low pressure of HRSG in a combined cycle gas turbine.
- 10 ○ Using sensors to measure NH₃ concentrations downstream of the expansion power turbine section but before entrance to the HRGS or release up an exhaust stack.

3. Process Control by:

- Calculating real-time NO_x injection rates
- Providing sufficient residence time for mixing and reaction
- 15 ○ Utilizing the method in a Long Barrel exhaust system similar to combustor's Equilibration Zone (Equilibrium region)
- Enabling reaction between NH₃ and NO₂ to generate H₂O and N₂

[0509] System Advantages

Operational Benefits:

- 20 Reduced pollution in exhaust
- Easier fuel sourcing and storage
- More economical fuel options
- Enhanced system integration
- Improved heat recovery efficiency

25 [0510]METHOD – 2

[0511] A method for treating Nitrogen Oxides (NO_x) and Ammonia (NH₃) emissions in combustion systems, particularly focused on achieving ultra-clean emissions below prescribed regulatory limits.

[0512] Method Steps

30 1. Forming a liquid mixture comprising one of:

- Ammonia (NH₃)
- Nitrogen Oxides (NO_x)

2. Providing an array of orifices within a transverse feeder positioned across the downstream Trim region (e.g., trim regions in FIGS. 4, including Blend-Trim regions) of a scalable combustor shell.
3. Configuring sufficient equilibrating region volume to provide adequate residence time for NH₃ and NO_x mixing and reaction below prescribed limits.
4. Monitoring NO_x and Ammonia concentrations in the gas turbine exhaust.
5. Injecting a dilute mixture through the Trim region transverse feeder into the combustor, using either:
 - Ammonia solution
 - NO_x solution
6. Controlling the delivery of the selected solution to maintain concentrations below prescribed limits:
 - For ammonia fuel combustion: Delivering sufficient NO_x solution to react with residual unburnt NH₃
 - For hydrogen, natural gas, hydrocarbon, or alcohol fuels: Delivering NH₃ solution to react with formed NO_x

[0513] Emission Control Targets

1. Achieve EPA requirements:
 - Reduce emissions to <25 ppmvd
 - Meet 150 ng/J useful output requirement
 - Maintain 1.2 lb/MWh emission rate
2. Meet California Counties' strict emission regulations:
 - Achieve NO_x emissions <2.3 ppmvd
 - Limit unburned NH₃ "slip" to <10 ppmvd
 - Further reduce NH₃ slip to <2.5 ppmvd

[0514] Implementation Benefits

1. Eliminate expensive cleanup systems:
 - Remove need for Selective Catalytic Reduction (SCR)
 - Reduce ongoing ammonia operating costs
2. Achieve cost savings:
 - Reduce Capital Expenditure by 7-10%

- Lower operating costs through elimination of cleanup systems

GENERALIZATION

[0344] From the foregoing description, it will be appreciated that a novel approach for distributed contacting, mixing and/or reacting of three or more fluids has been disclosed using one or more processes described herein. While the components, techniques and aspects of the invention have been described with a certain degree of particularity, it is manifest that many changes may be made in the specific designs, constructions and methodology herein above described without departing from the spirit and scope of this disclosure.

[0345] Where dimensions are given, they are generally for illustrative purposes, and are not prescriptive. Of course, as the skilled artisan will appreciate, other suitable sizes, orientations, configurations and distributions of fluid delivery orifices, fluid passages, and other components may be efficaciously utilized, as needed or desired, giving due consideration to the goals of achieving one or more of the benefits and advantages as taught or suggested herein.

[0346] Where duct, tube or array configurations are provided, similar two- or three-dimensional configurations or combinations of those configurations may be efficaciously utilized, including varying the nominal thicknesses, diameters, cross sectional shapes, spacings, orientations, and other dimensions and parameters for perforated ducts, perforated tubes, manifolds, sub-manifolds and tube arrays.

[0347] Where the terms fuel, diluent, water, steam, air, oxygen, and oxidant have been used, the processes are generally applicable to other combinations of those fluids or to other combinations of other reacting, co-reacting, and diluent or non-reacting fluids. Where fluid quantities are referred to, these processes are generally applicable to include quantities delivered at multiple times, and to continuous fluid flows. Where assembly processes are described, various alternative assembly processes may be efficaciously utilized to achieve configurations to achieve the benefits and advantages of one or more of the embodiments as taught or suggested herein.

[0348] Where transverse, axial, radial, circumferential, or other directions are referred to, it will be appreciated that any general coordinate system using curvilinear coordinates may be utilized including Cartesian, cylindrical, spherical or other specialized system, such as an annular system. Similarly, when one or more transverse

or axial distributions or profiles are referred to, it will be appreciated that the configurations and processes similarly apply to spatial control in one or more curvilinear directions as desired or prescribed. Similarly, the contactor, array, device or duct orientations may be generally rearranged to achieve other beneficial combinations of the features and processes described.

[0349] Where fluid delivery controls refer to controlling the size and flow rate of fluids, ejecting drops, jets or micro-jets, it will be appreciated that the control measures may utilize one or more measures to control the differential ejection pressure distributions across the fluid orifices 80, to vibrate the orifices, and/or to control the electro-magnetic field about the orifices 80 using one or more measures described herein, and/or by using similar means of modulating the orifices' location, the fluid pressure, and the surrounding electro-magnetic field.

[0350] While the components, techniques and aspects of the invention have been described with a certain degree of particularity, it is manifest that many changes may be made in the specific designs, constructions and methodology herein above described without departing from the spirit and scope of this disclosure.

[0351] Various modifications and applications of the invention may occur to those who are skilled in the art, without departing from the true spirit or scope of the invention. It should be understood that the invention is not limited to the embodiments set forth herein for purposes of exemplification but includes the full range of equivalency to which each element is entitled.

I Claim:

1. A scalable combustor system, comprising:

a fluid delivery system configured to deliver into a combustor:

- a fuel fluid comprising a fuel;
- an oxidant fluid comprising an oxidant; and
- a diluent fluid comprising a diluent;

the combustor, comprising:

a combustor fluid flow axis, comprising:

a combustor chamber having a first combustor chamber wall disposed axially and circumferentially;

a second combustor chamber wall disposed radially;

a plurality of fuel feeders comprising fuel orifices; and

a plurality of oxidant feeders comprising oxidant orifices disposed about at least one of the first combustor chamber wall and the second combustor chamber wall;

an upstream flame authority; and

a downstream combustor outlet, wherein the first and second combustor chamber walls are transversely elongated relative to a shallow spacing between the first and second combustor chamber walls, along directions transverse and perpendicular to a streamwise flow direction through the combustor, wherein a ratio of transverse elongation to shallow spacing is greater than 1.15, wherein the combustor is configured to deliver into the combustor chamber the fuel fluid through the plurality of fuel feeders and fuel orifices; the oxidant fluid through the plurality of oxidant feeders and oxidant orifices, and to deliver the diluent fluid with at least one of the fuel fluid and the oxidant fluid through one or more of the plurality of fuel orifices, and through one or more of the oxidant orifices to combust the fuel with the oxidant in the combustor chamber; and wherein the combustor is configured to the combustor outlet, a combustion fluid comprising products of combustion, diluent, and residual oxidant; and

a control system configured to control delivery of the fuel fluid, the oxidant fluid, and the diluent fluid, and to ignite the fuel with the oxidant by controlling one or more fluid delivery rates to maintain a combustion temperature in the combustor chamber above a combustion quench limit.

2. The scalable combustor system of claim 1, wherein a cross-sectional area of the combusting chamber disposed perpendicular to the streamwise flow, increases along the streamwise flow direction within a prescribed fuel fluid delivery region.
3. The scalable combustor system of claim 1, wherein the combusting chamber further comprises a first end wall, and a second end wall, wherein the first and second end walls join transversely outer ends of first and second shallowly spaced combustor walls, and wherein the second combustor wall comprises a second plurality of orifices.
4. The scalable combustor system of claim 2, wherein a rate of increase in a combusting chamber cross sectional area is constrained below a maximum increase rate.
5. The scalable combustor system of claim 4, wherein the rate of increase in the combusting chamber cross sectional area declines downstream of an axial location of a maximum axial increase rate.
6. The scalable combustor system of claim 1, wherein one of, a portion of diluent fluid and a portion of oxidant fluid, is delivered downstream of a total fuel delivery.
7. The scalable combustor system of claim 1, wherein oxidant fluid is delivered through a plurality of oxidant orifices downstream of a major portion of a fuel-oxidant combustion sufficient to provide residual oxidant at the combustor outlet.
8. The scalable combustor system of claim 1, wherein diluent fluid is delivered, through one of a plurality of oxidant orifices and a plurality of diluent orifices, downstream of a major portion of a fuel-oxidant combustion.
9. The scalable combustor system of claim 1, wherein gaseous diluent fluid is delivered through orifices together with fuel fluid.
10. The scalable combustor system of claim 1, wherein controlling diluent delivery to constrain an outlet energetic fluid temperature below a prescribed outlet temperature at the combustor outlet.
11. The scalable combustor of system claim 1, wherein varying one of the ratio of oxidant delivery to fuel delivery and the ratio of diluent to fuel delivery between upstream and downstream portions of the combusting chamber.
12. The scalable combustor system of claim 1, wherein varying one of the ratio of excess oxidant delivery to total fuel delivery and the ratio of diluent to fuel delivery the upstream and downstream portions of a downstream Blend-Trim region.

13. The scalable combustor system of claim 1 further comprising a plurality of diluent orifices in one of said combustor walls, and comprising one or more diluent feeders feeding diluent fluid through the one or more of said diluent orifices.
14. A combustor system, comprising:
- a fluid delivery system configured to deliver a fuel fluid comprising a fuel, an oxidant fluid comprising an oxidant and a diluent fluid comprising a diluent into a combustor in fluid communication with the fluid delivery system; and
 - the combustor comprising:
 - a combusting chamber having an upstream flame authority;
 - a first combustor wall;
 - an opposed second combustor wall;
 - a plurality of orifices in at least one of the first and second combustor walls;
 - a plurality of fluid feeders feeding one or more of said fuel fluid, oxidant fluid, and/or diluent fluid, to said plurality of orifices; and
 - a combustor outlet; wherein the first and second combustor walls are transversely elongated relative to a shallow spacing between the first and second combustor walls, along directions transverse and perpendicular to a streamwise flow direction through the combustor.
15. The combustor system of claim 14, wherein a ratio of transverse elongation to shallow spacing is greater than 1.15.
16. The combustor system of claim 1, wherein the control system is configured to control one of a wall temperature, a residence time, and a catalyst in transverse fuel feeders, so as to crack a portion of ammonia fuel into hydrogen and nitrogen.
17. A combustor system, comprising:
- a combusting chamber, comprising:
 - a first combustor wall;
 - a second combustor wall;
 - a plurality of fluid feeders; and
 - a plurality of orifices in at least one of the first and second combustor walls; and
 - a combustor outlet, wherein the first and second combustor walls are transversely elongated relative to a shallow spacing between the first and second combustor walls, along directions transverse and perpendicular to a streamwise flow direction through the combustor system.

18. A scalable combustor system comprising:

a combustor comprising:

a combusting fluid flow axis;

a combusting chamber comprising:

a first combusting chamber wall deposited axially and circumferentially;

a radially opposed second combusting chamber wall;

a plurality of fuel feeders comprising fuel orifices; and

a plurality of oxidant feeders comprising oxidant orifices, configured about at least one of the first and second combusting chamber walls;

an upstream flame authority; and

a downstream combustor outlet, wherein the first and second combusting chamber walls are transversely elongated relative to a shallow spacing between the first and second combusting chamber walls, along directions transverse and perpendicular to a streamwise flow direction through the combustor, and wherein a ratio of transverse elongation to shallow spacing is greater than 1.15.

19. The scalable combustor system of claim 18, comprising a control system configured to control a fuel flow and an ammonia flow, wherein the ammonia flow is directed towards a thermogenerator.

20. The scalable combustor system of claim 19, wherein the thermogenerator is configured to crack the ammonia into at least a water to reduce NO_x emissions.

Fig. 1A

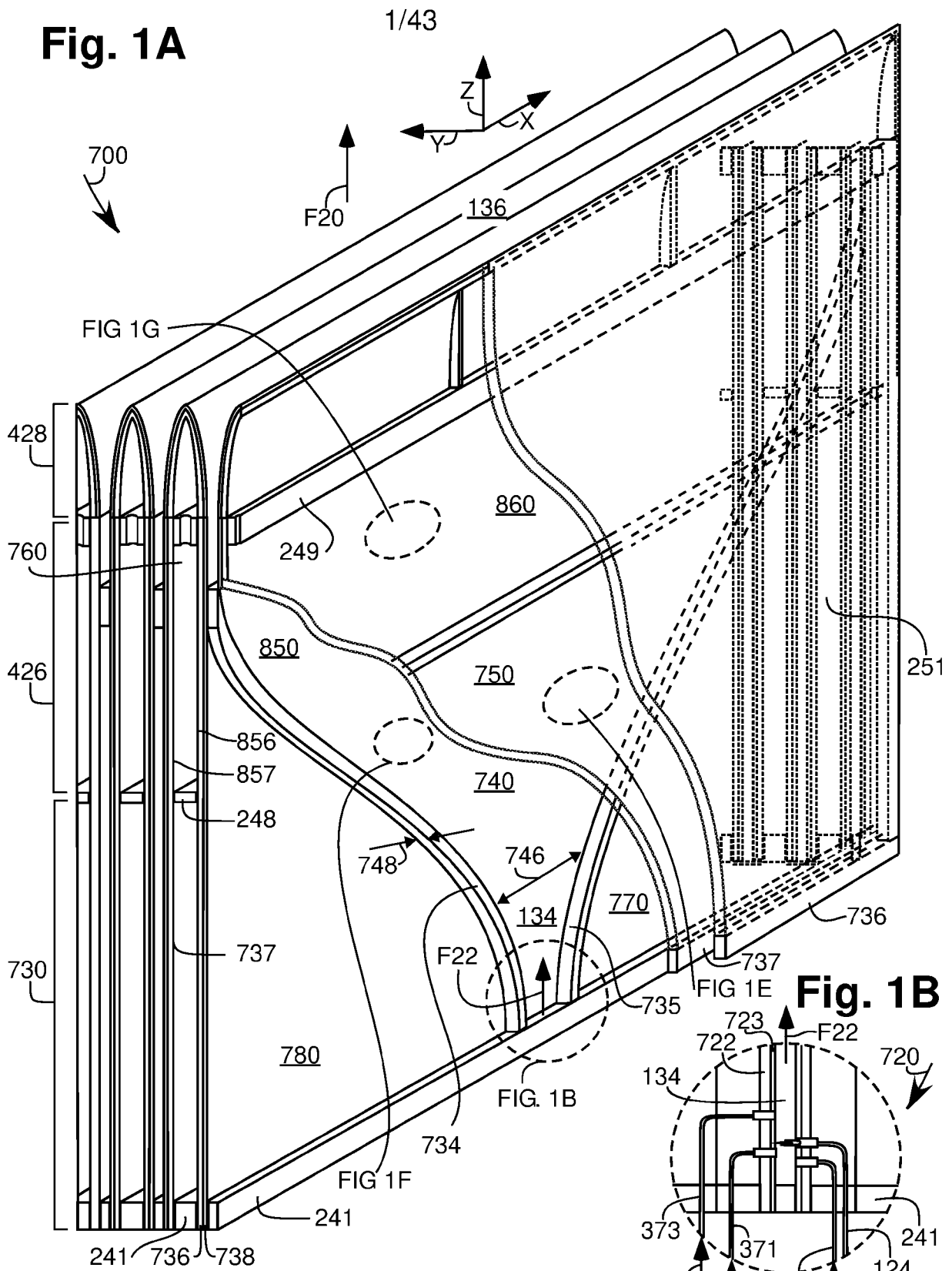


Fig. 1C

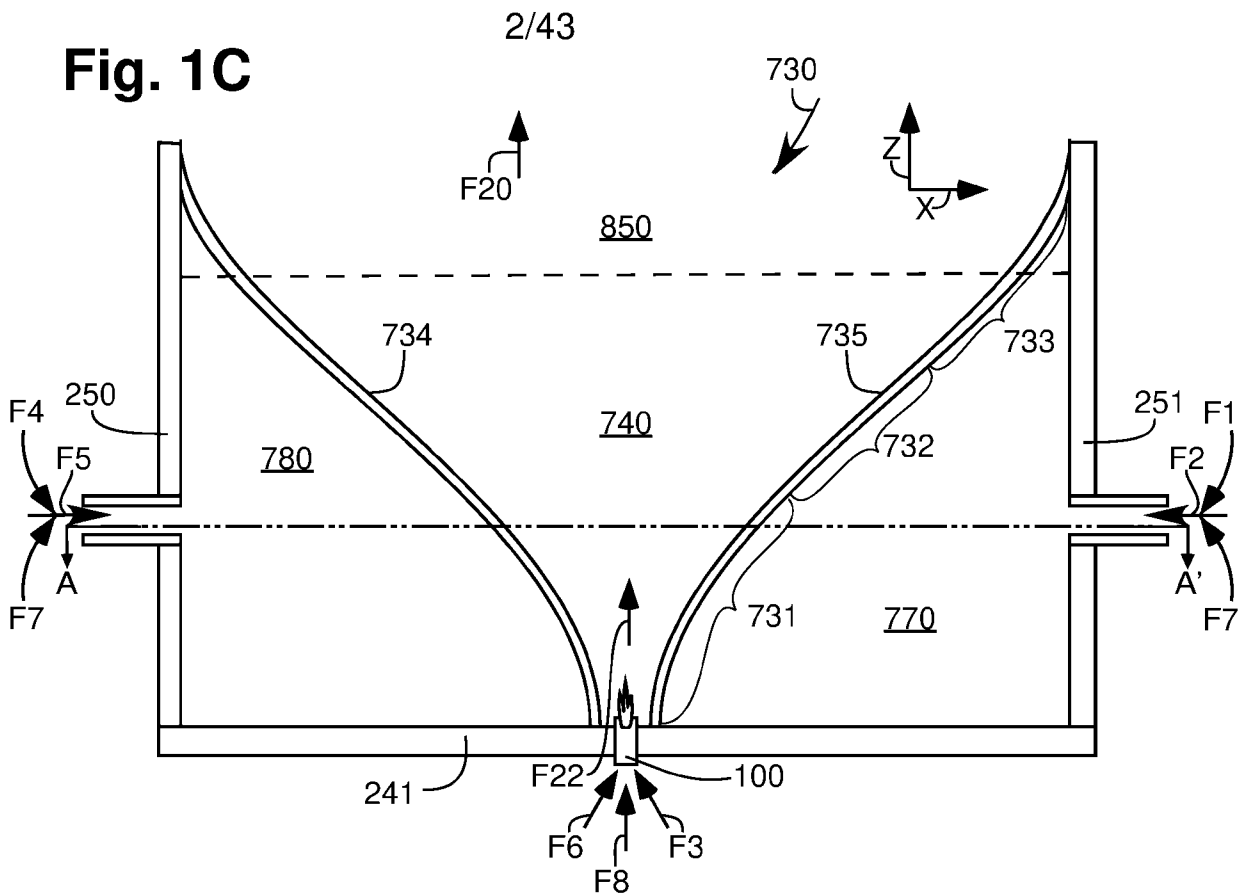
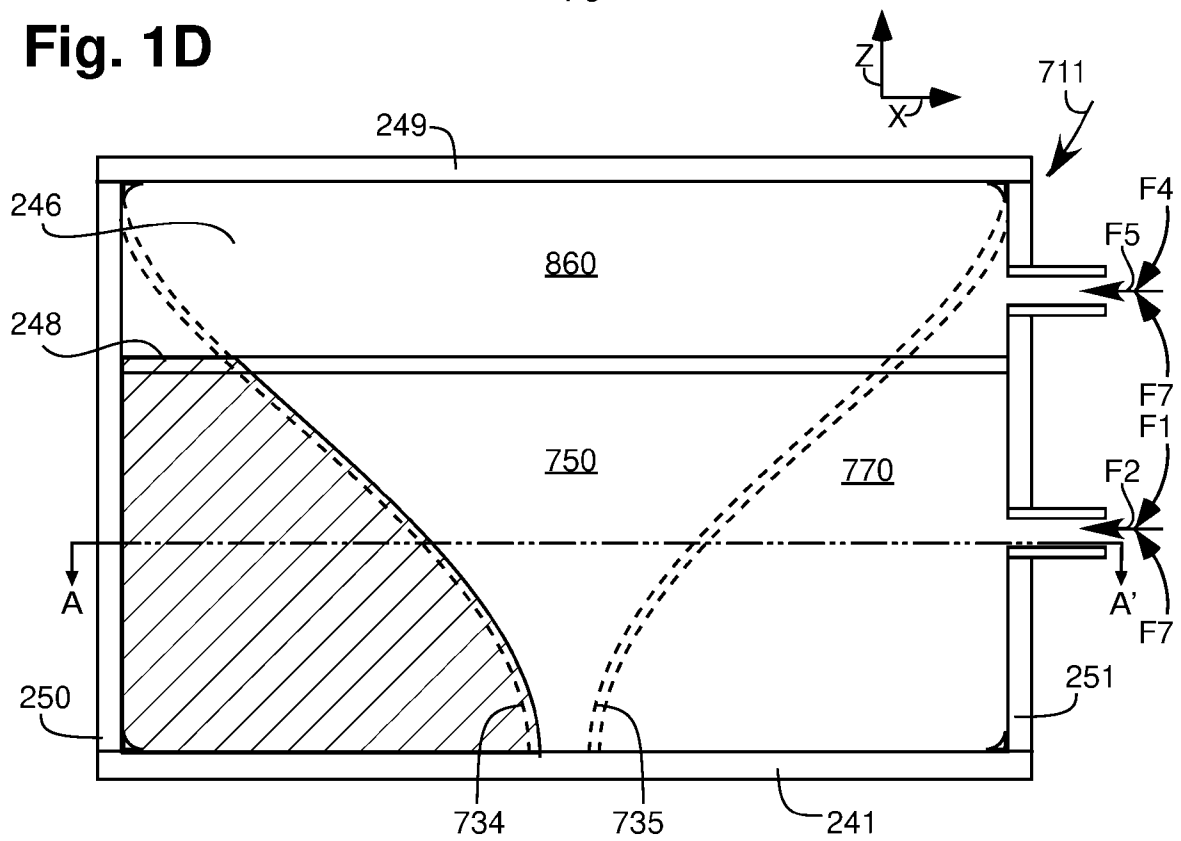


Fig. 1D



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Fig. 1E

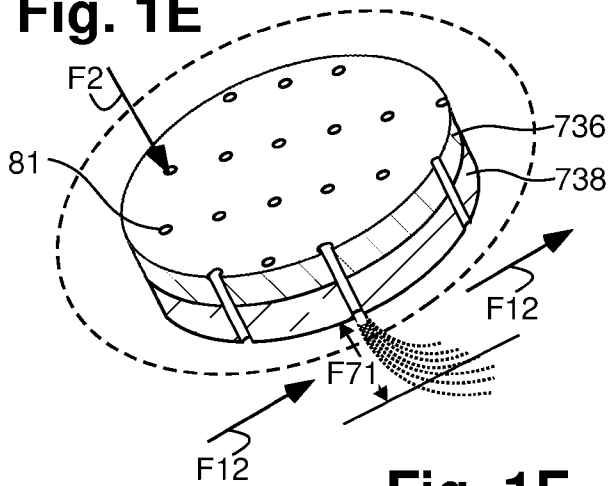


Fig. 1G

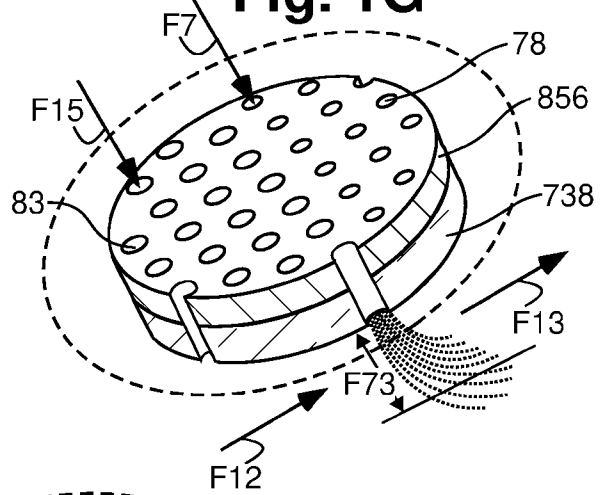


Fig. 1F

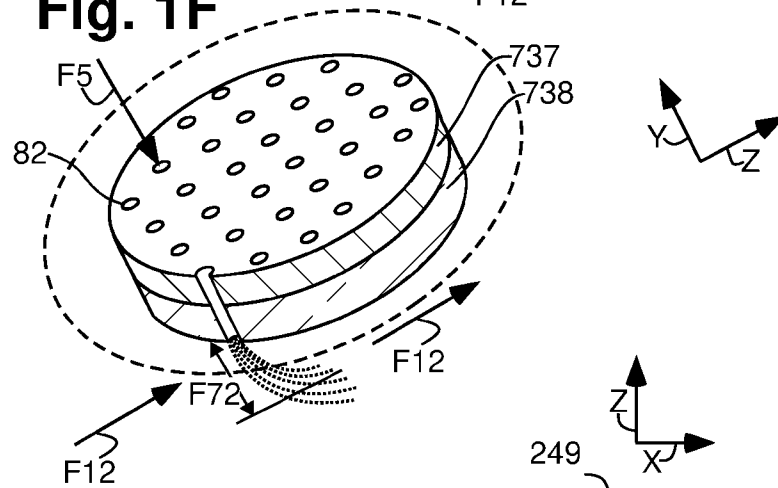


Fig. 1H

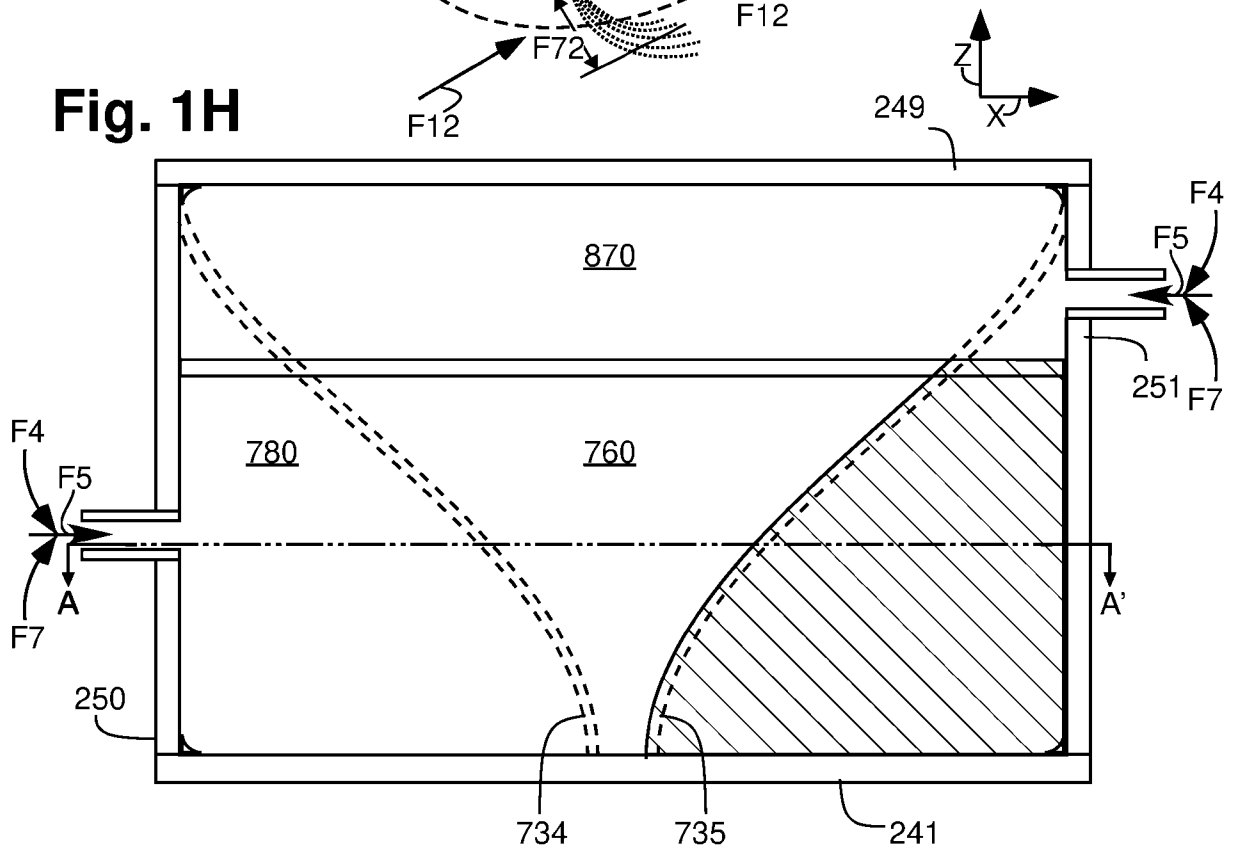
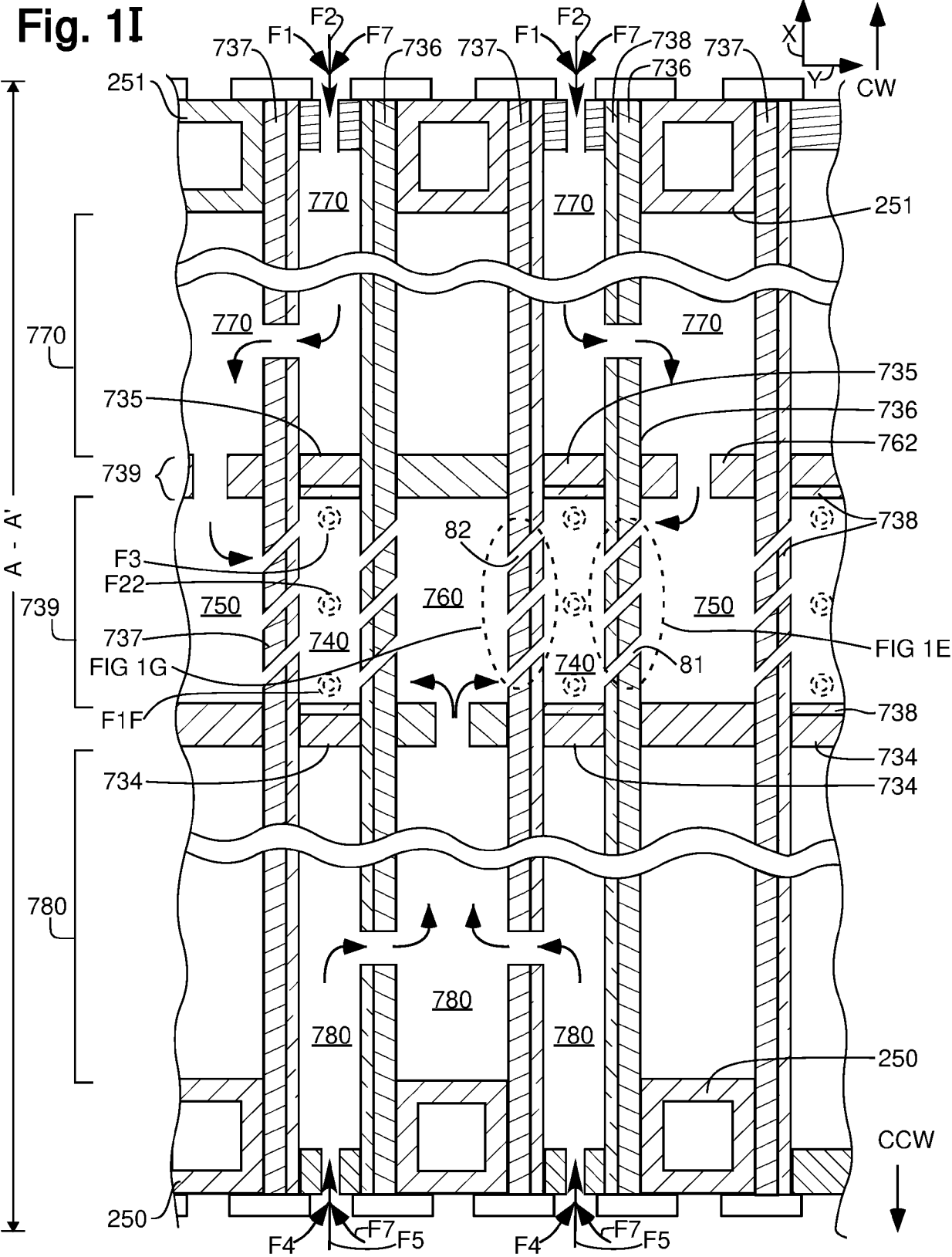
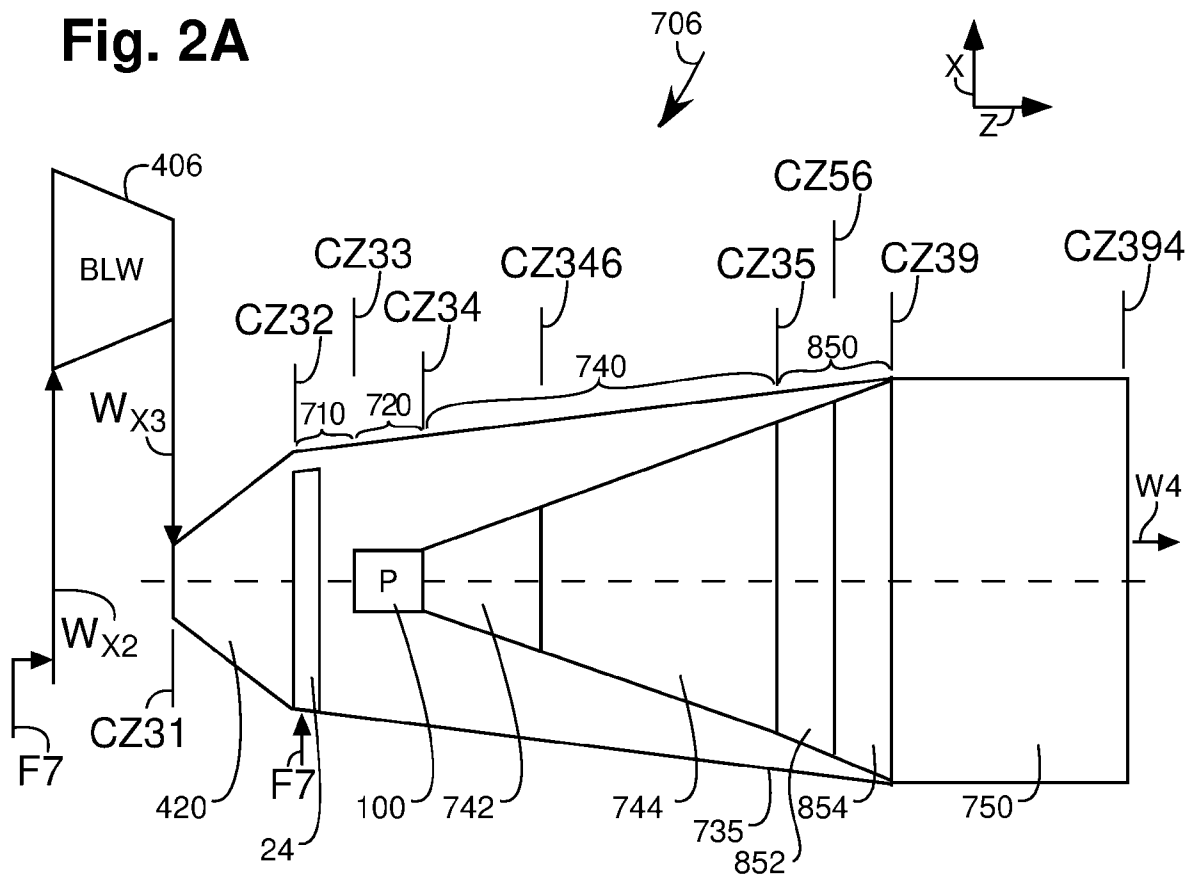


Fig. 1I



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Fig. 2A



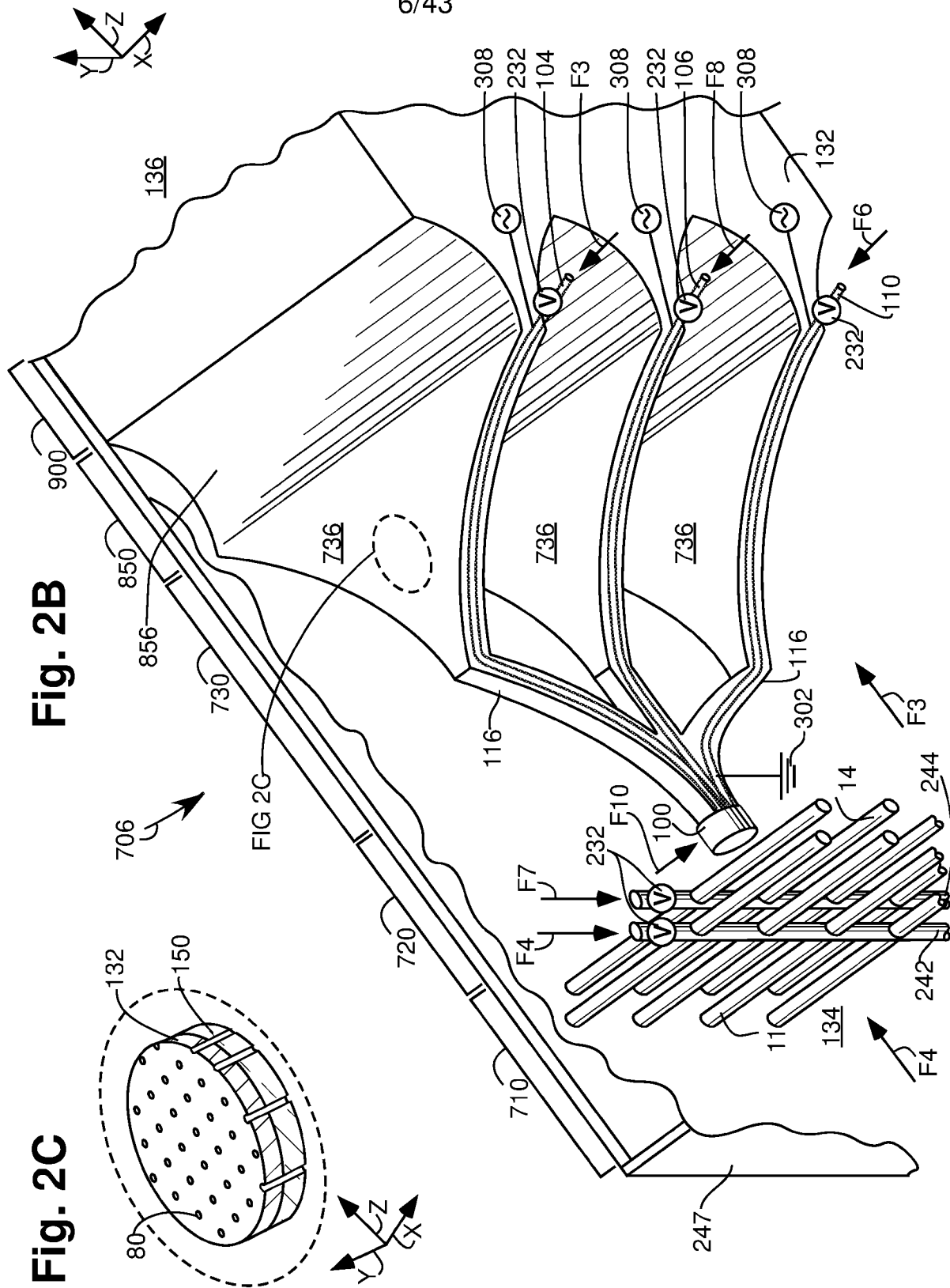


Fig. 2D

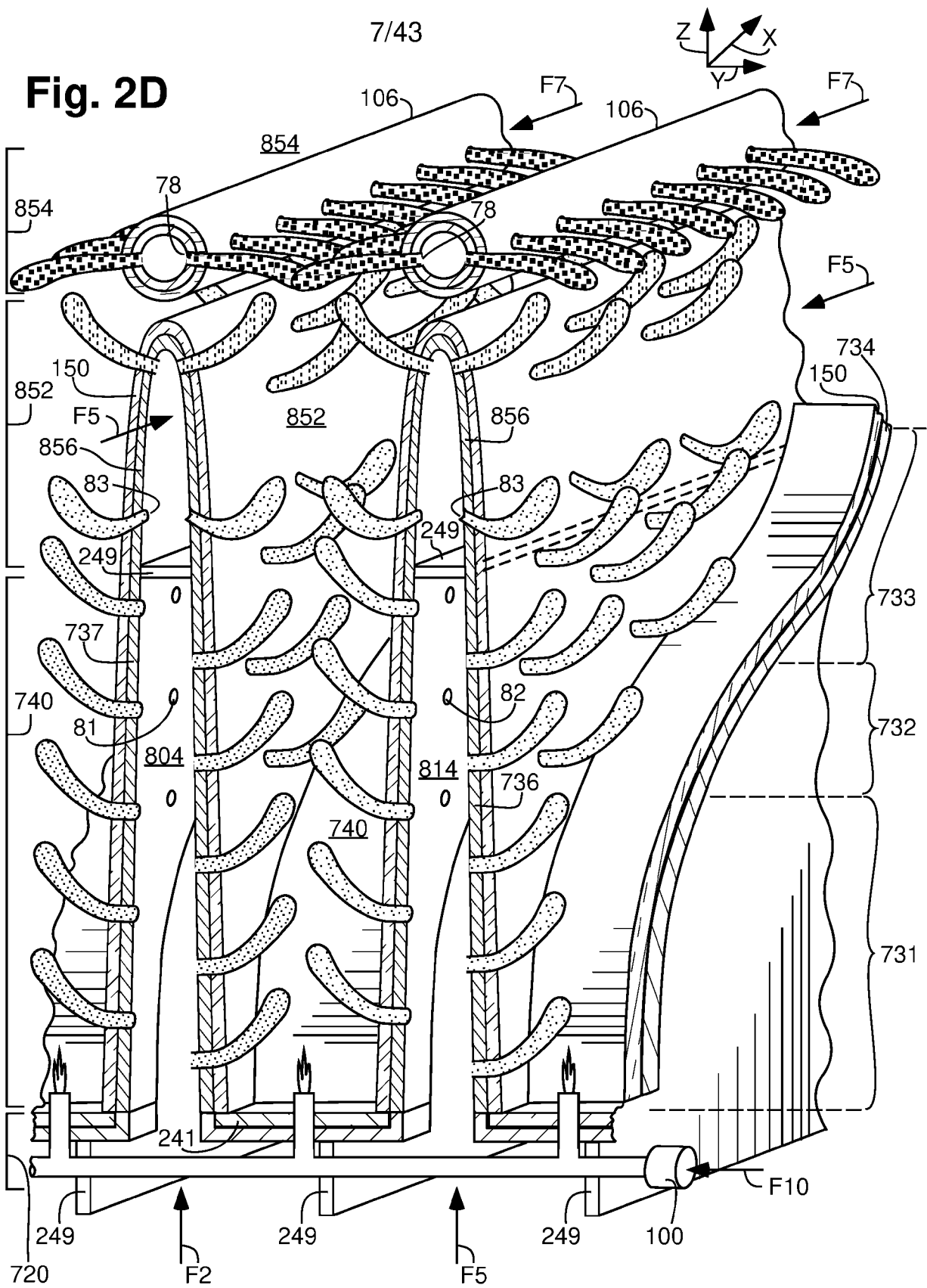


Fig. 2E

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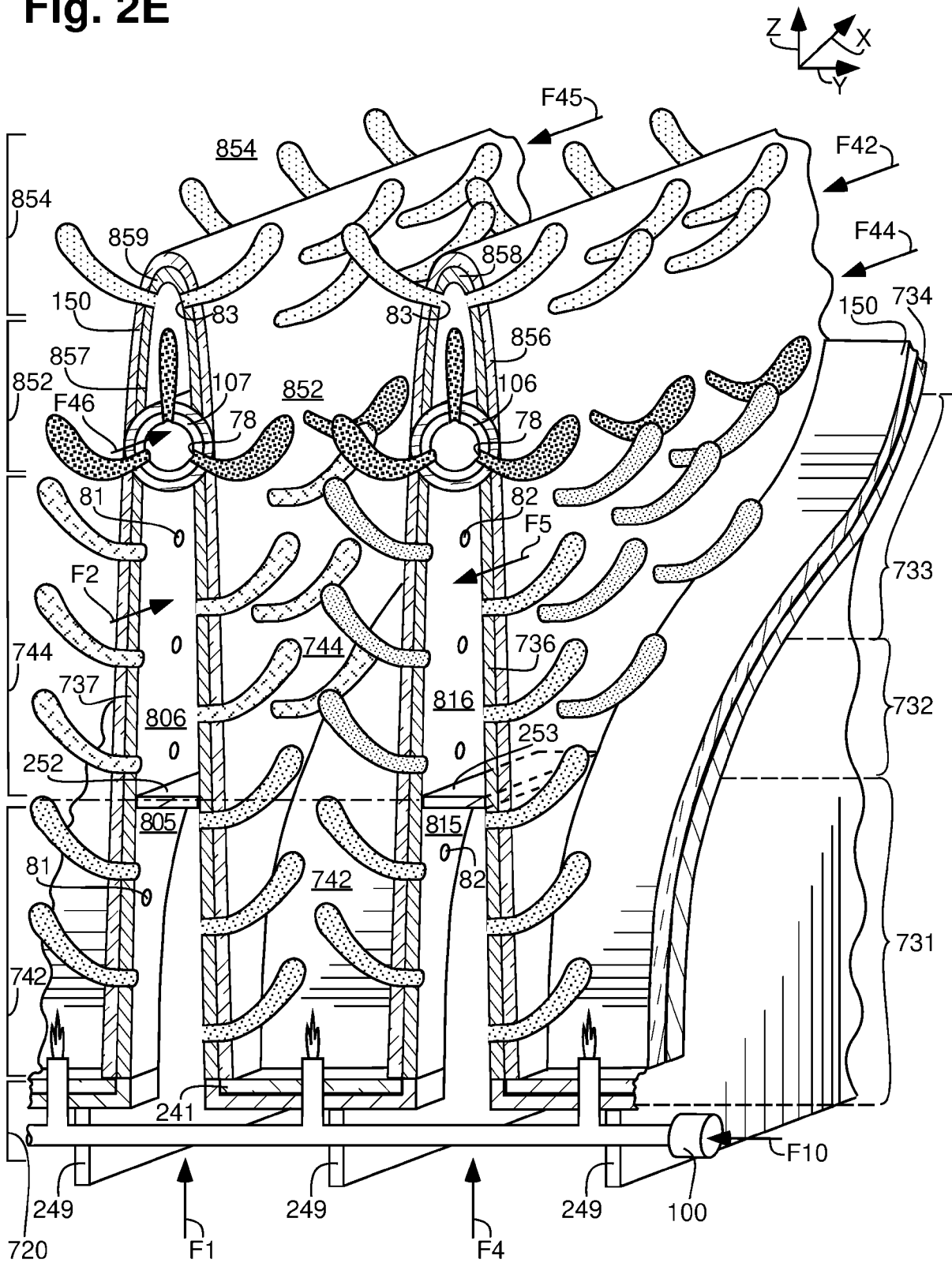
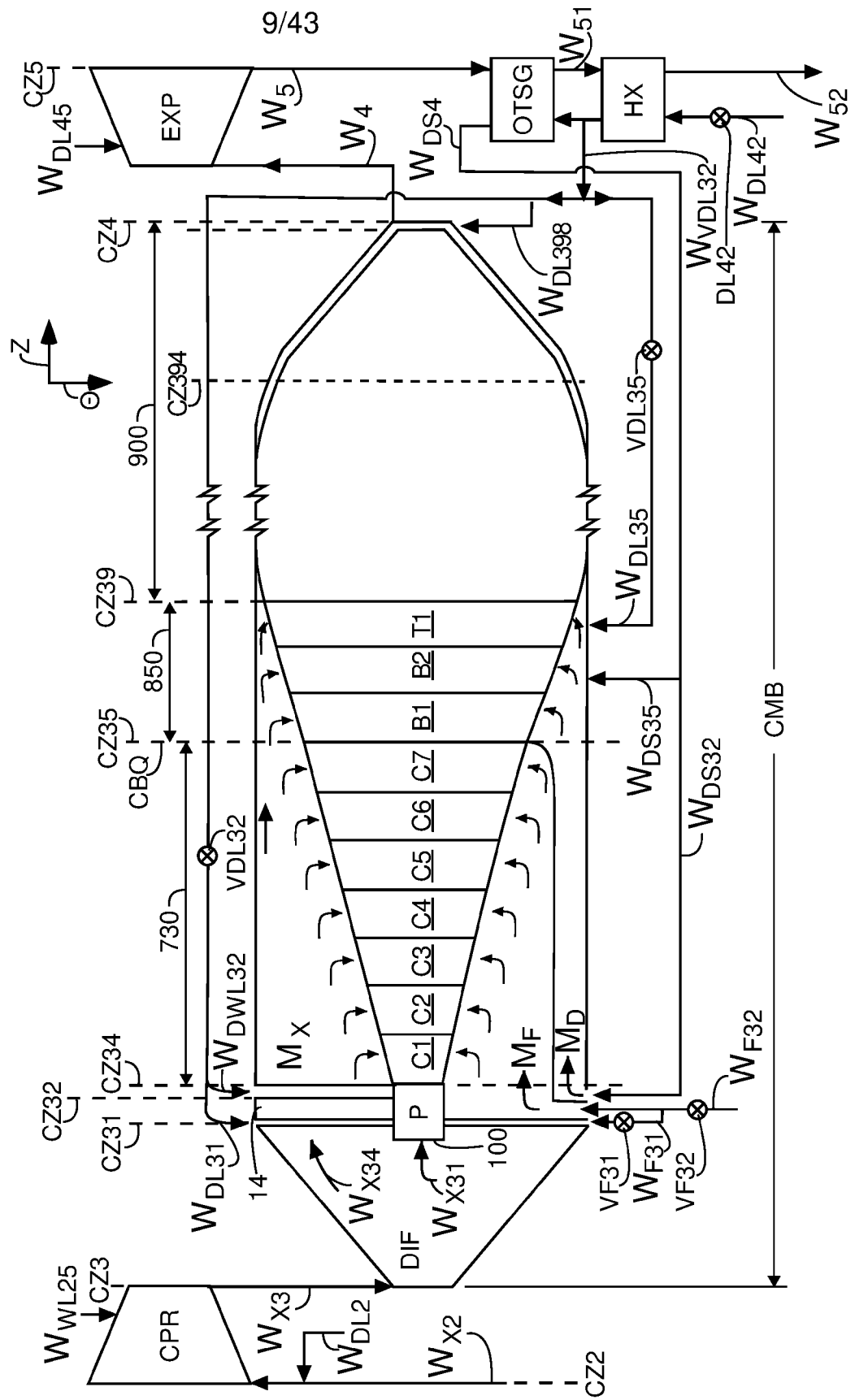


Fig. 3A



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Fig. 3B

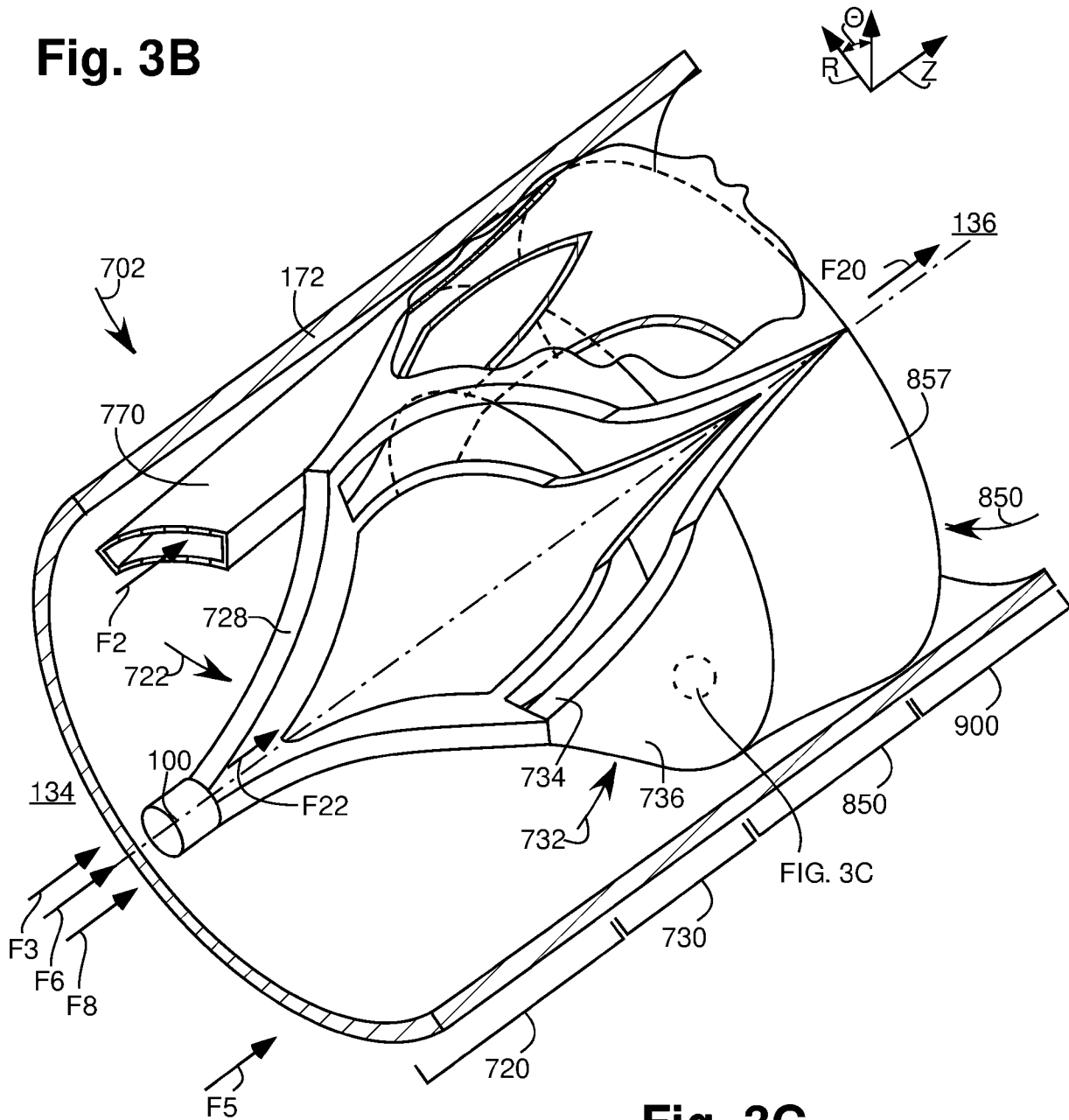


Fig. 3C

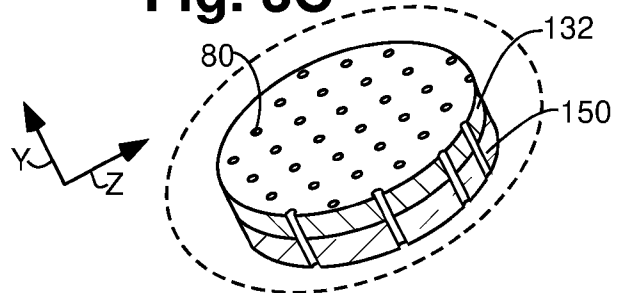


Fig. 3D

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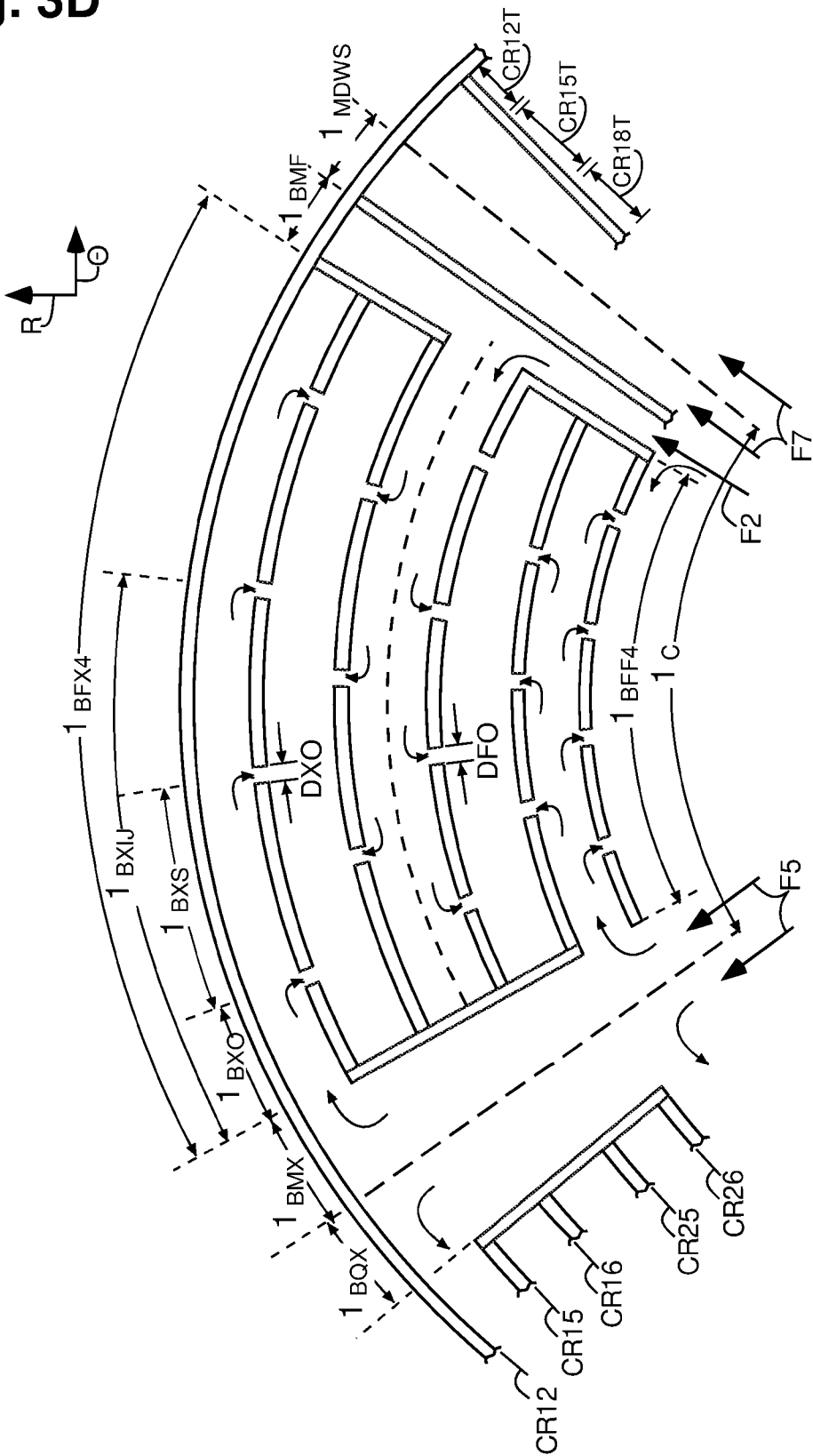


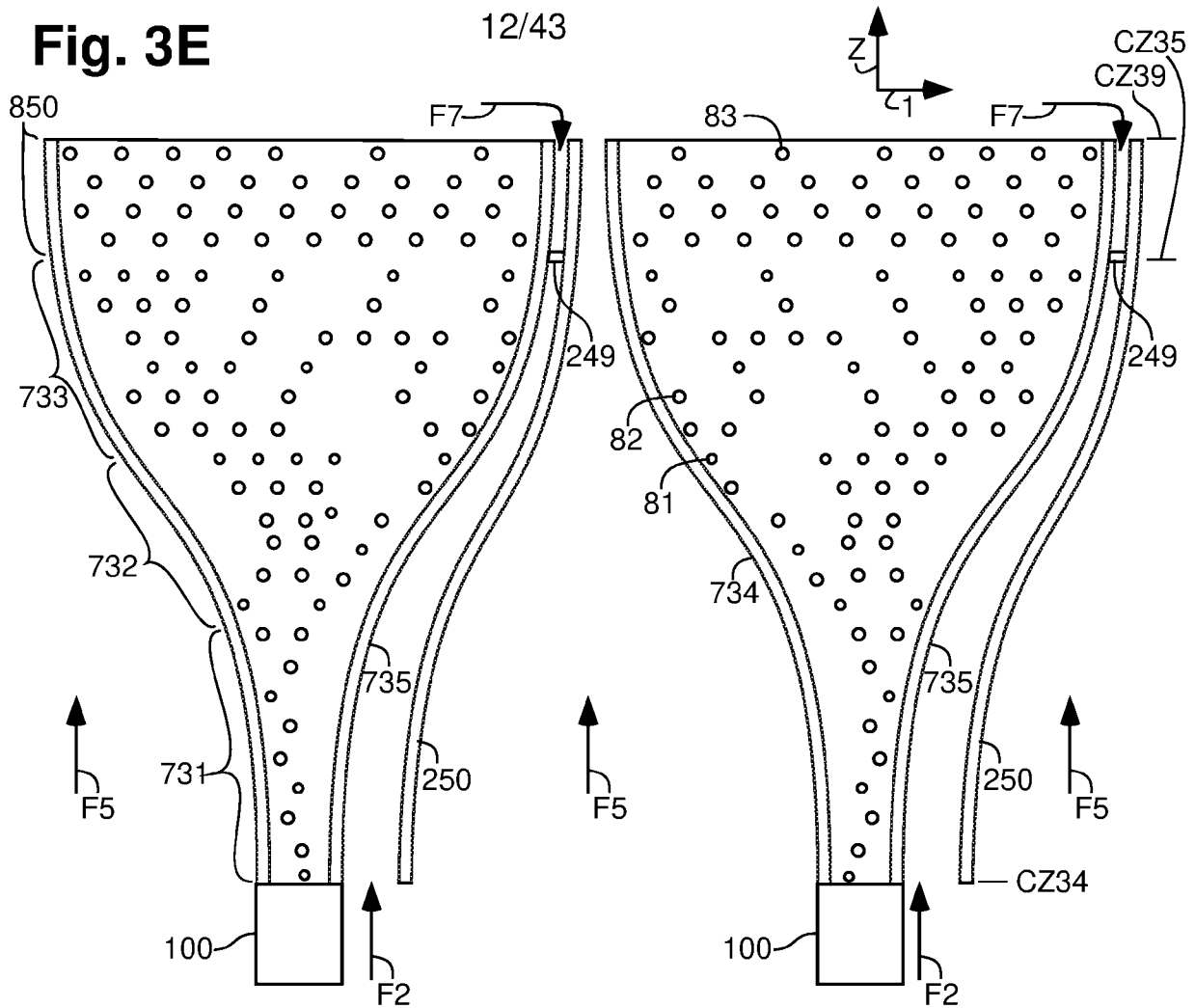
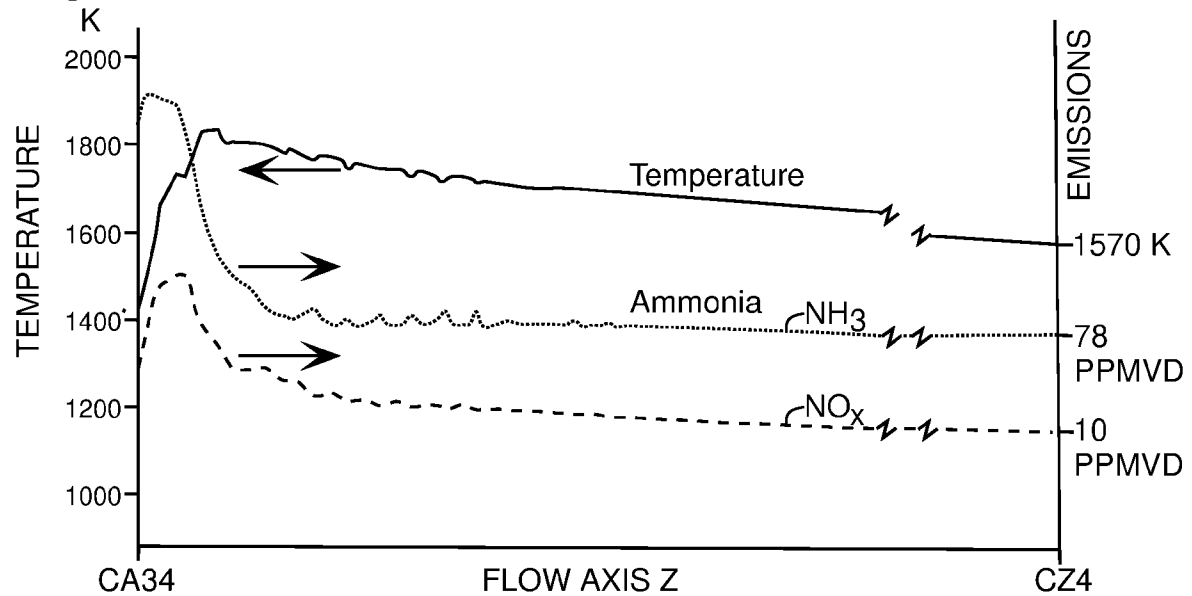
Fig. 3E**Fig. 3F**

Fig. 3G

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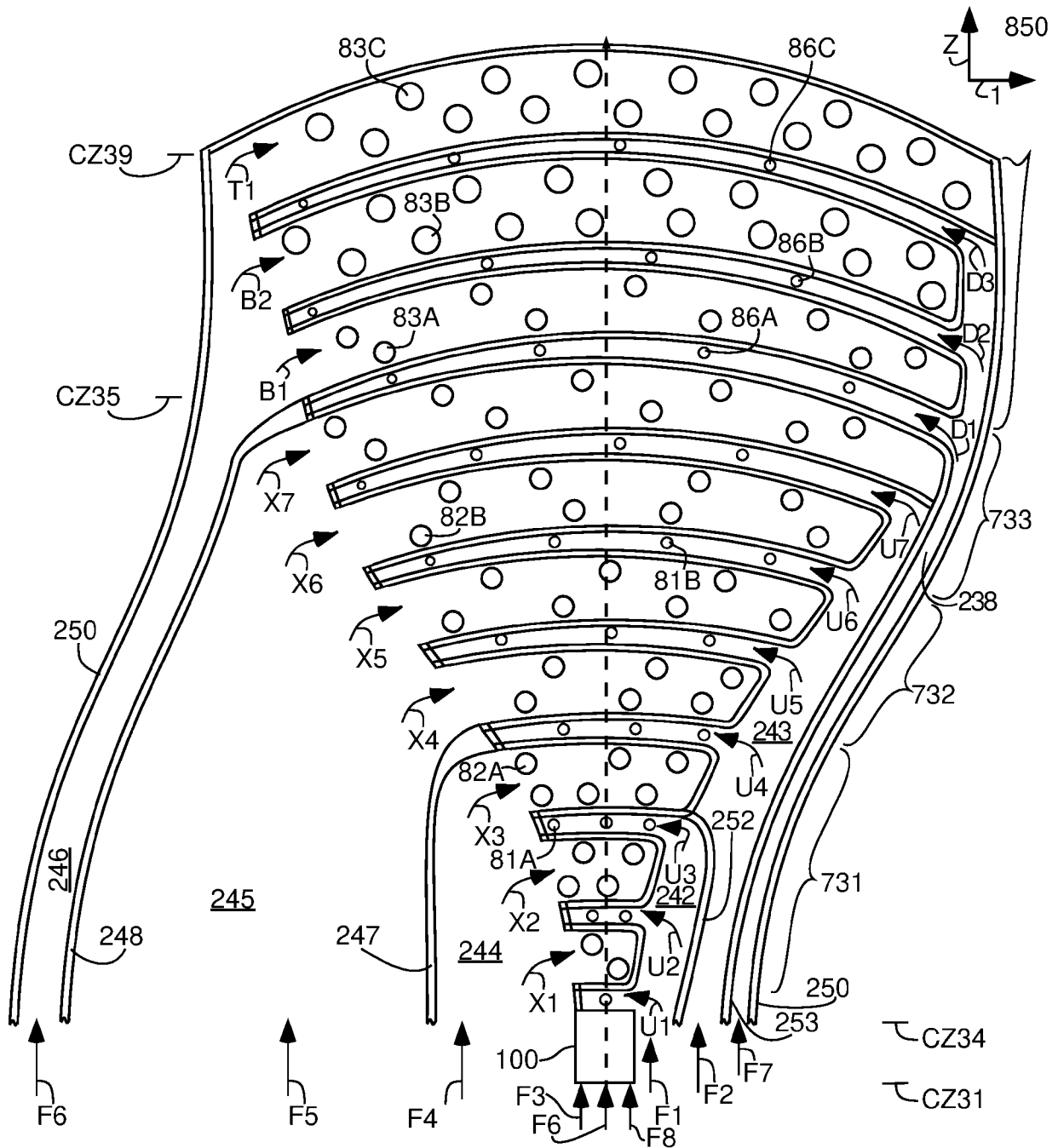


Fig. 3H

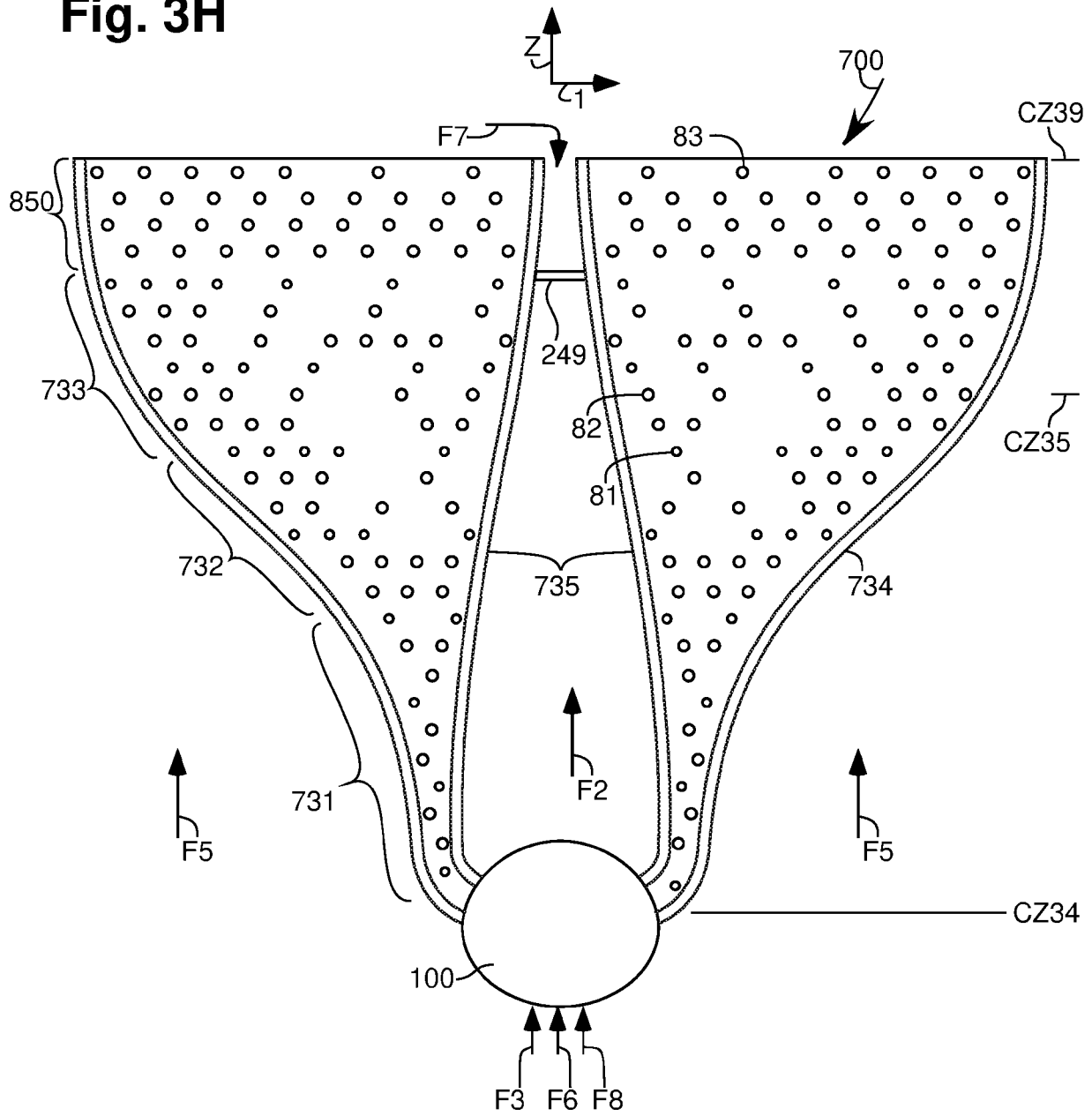


Fig. 3I

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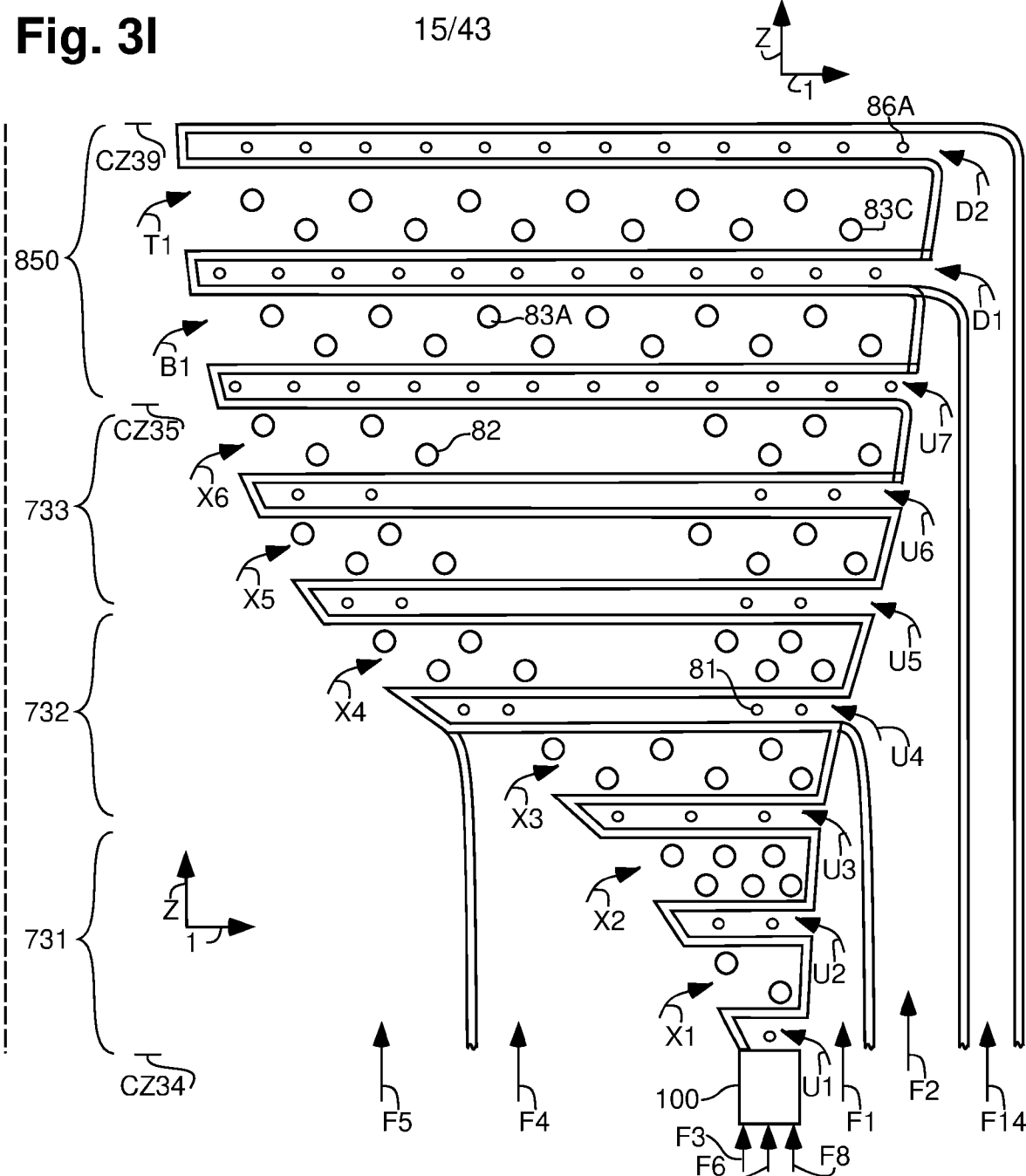


Fig. 3J

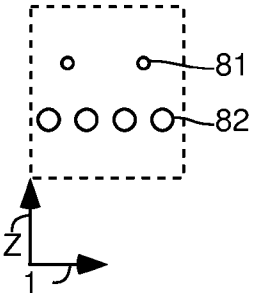


Fig. 3K

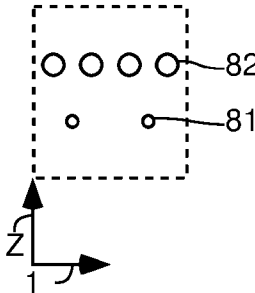


Fig. 3L

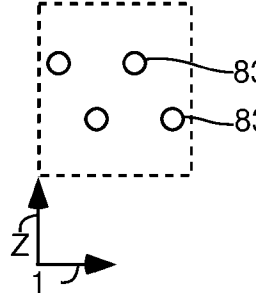


Fig. 3M

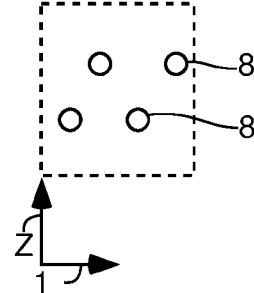


Fig. 3N

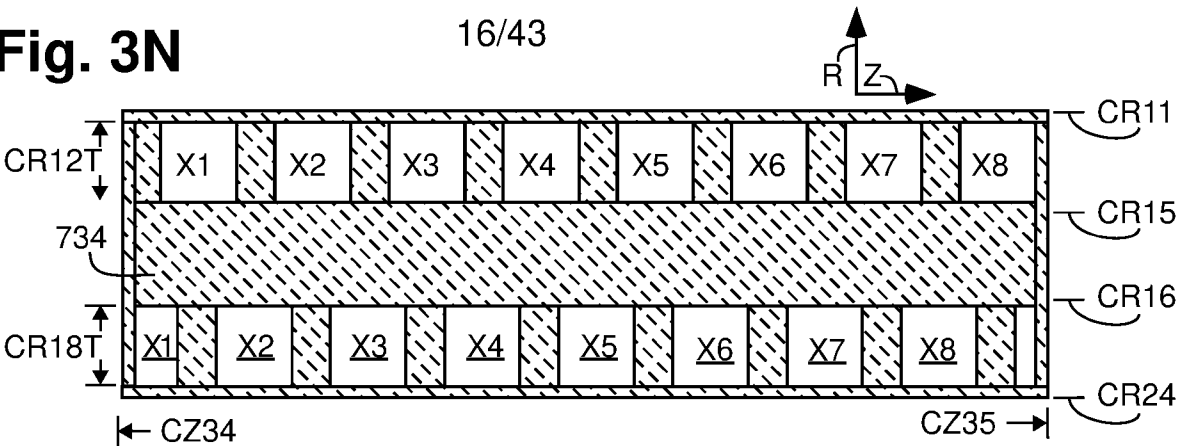


Fig. 3O

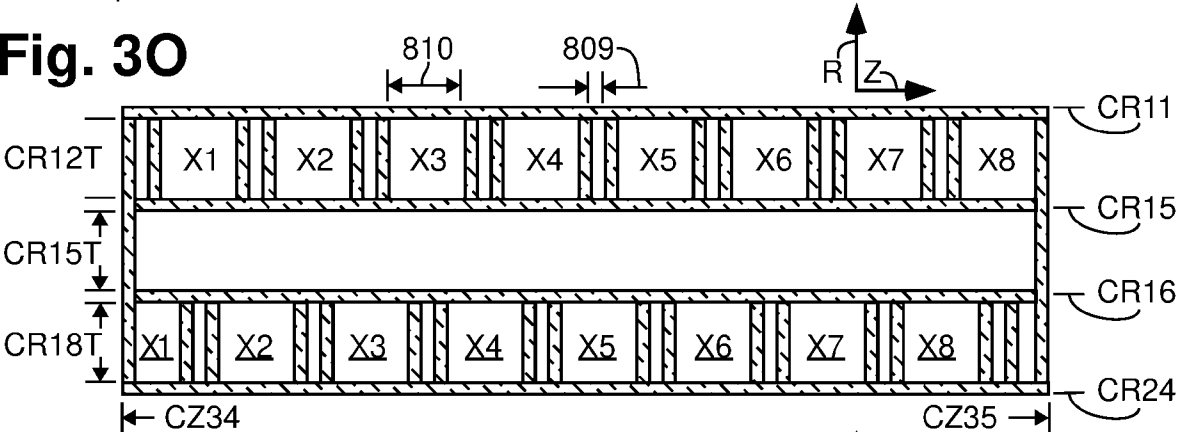


Fig. 3P

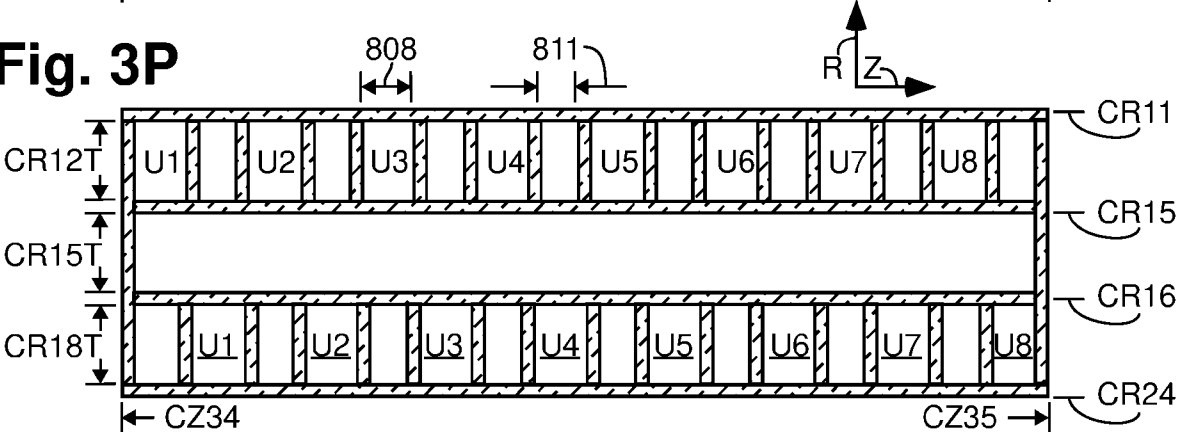


Fig. 3Q

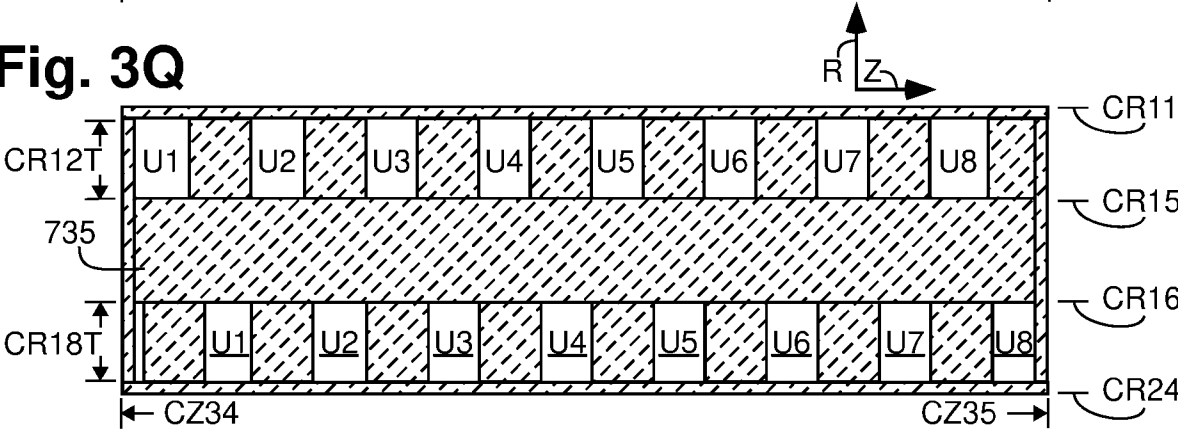


Fig. 3R

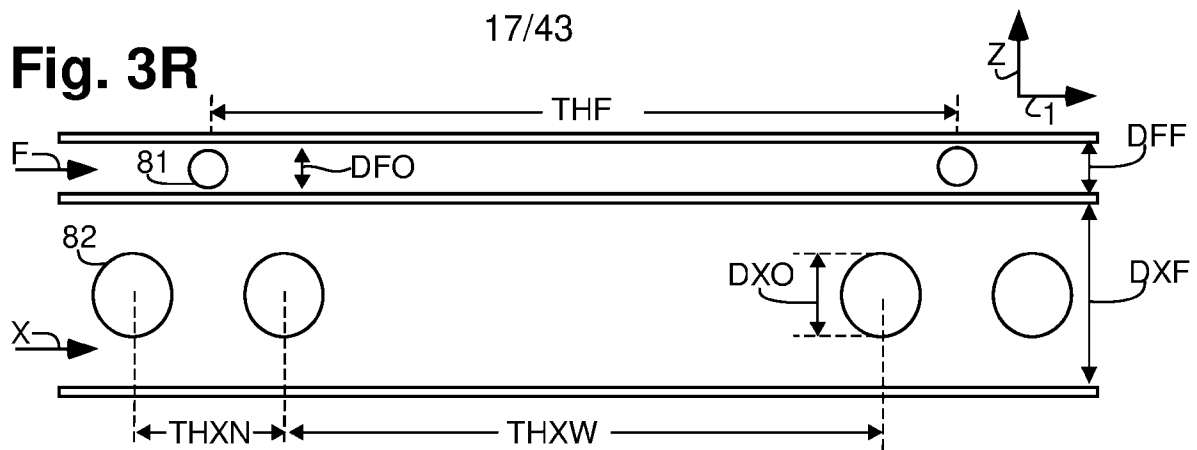


Fig. 3S

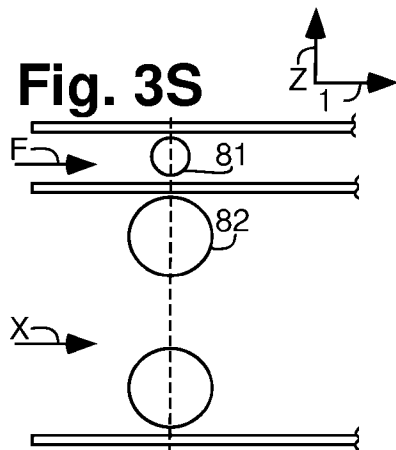


Fig. 3T

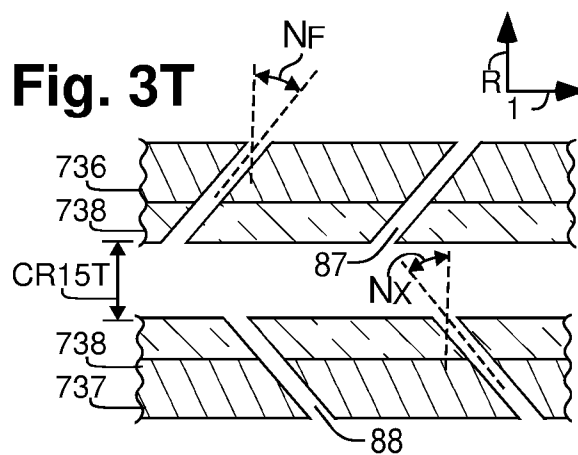
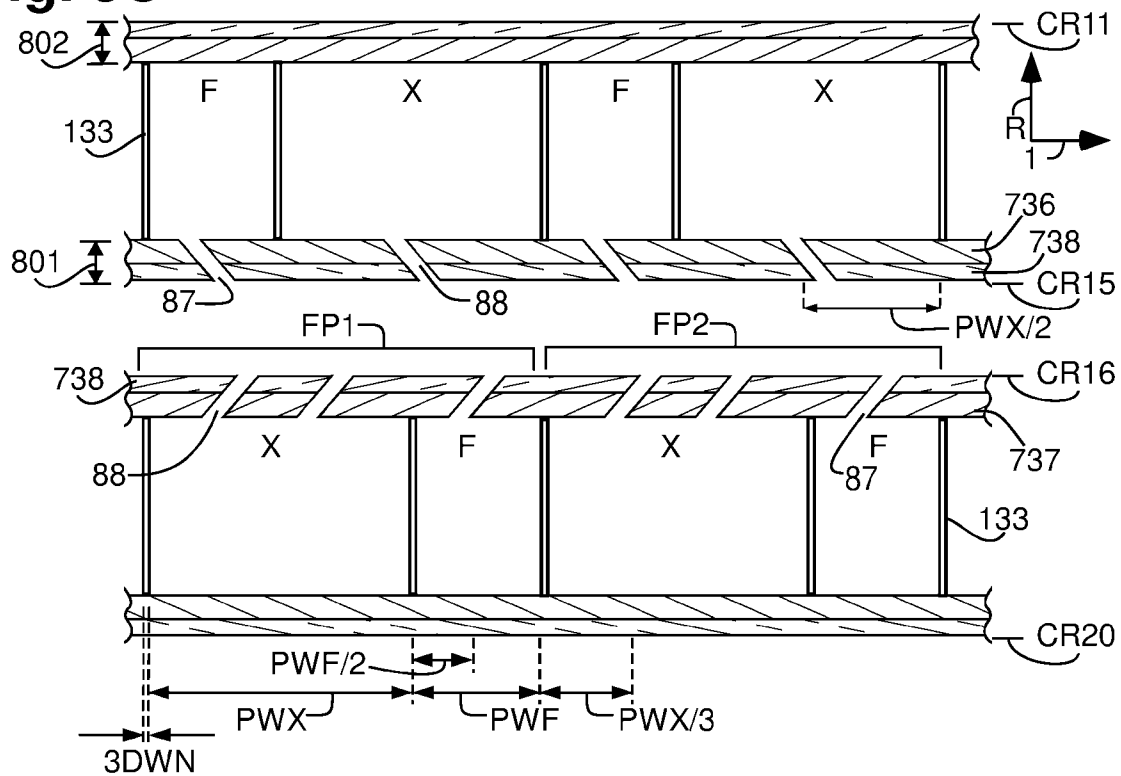


Fig. 3U



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Fig. 3V

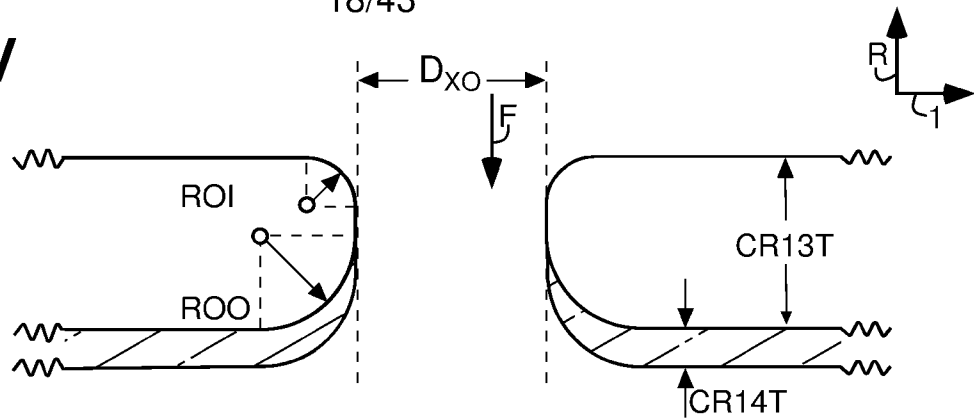


Fig. 3W

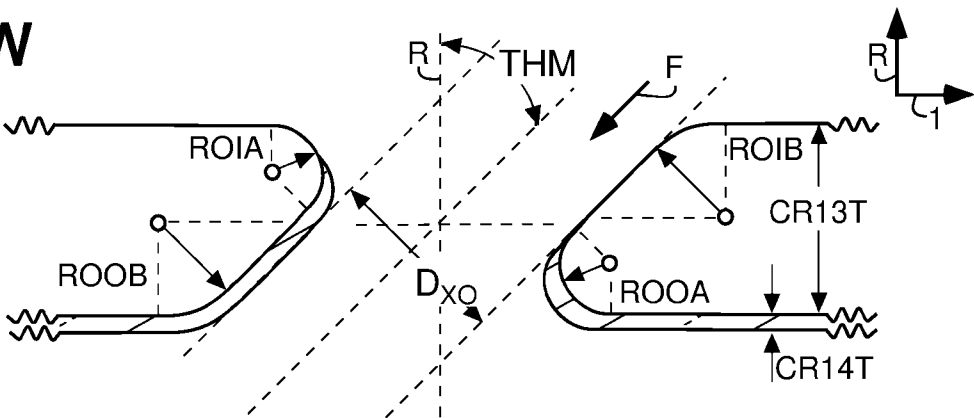


Fig. 3X

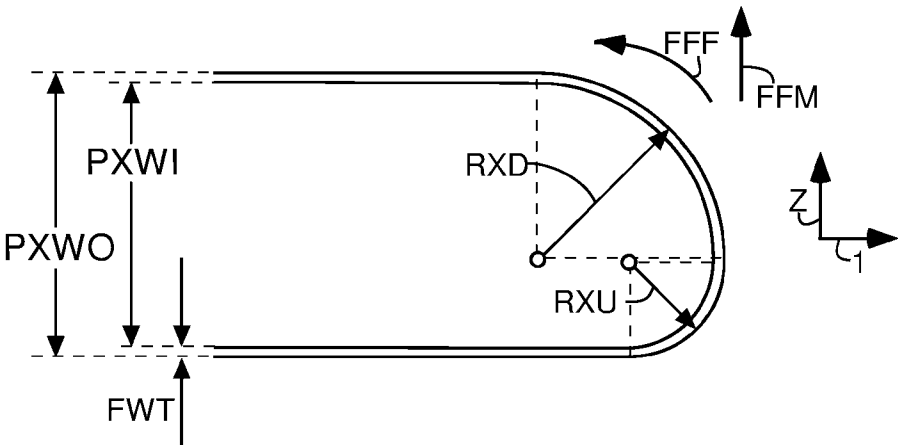


Fig. 3Y

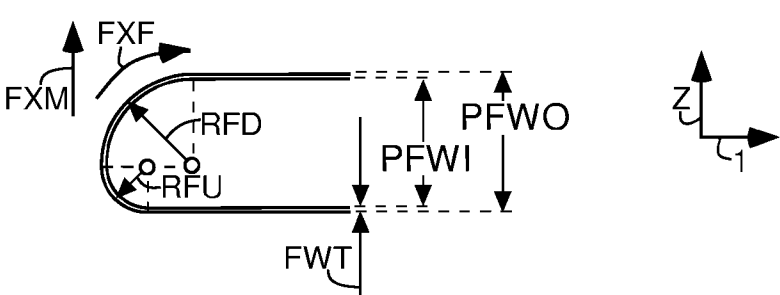


Fig. 4D

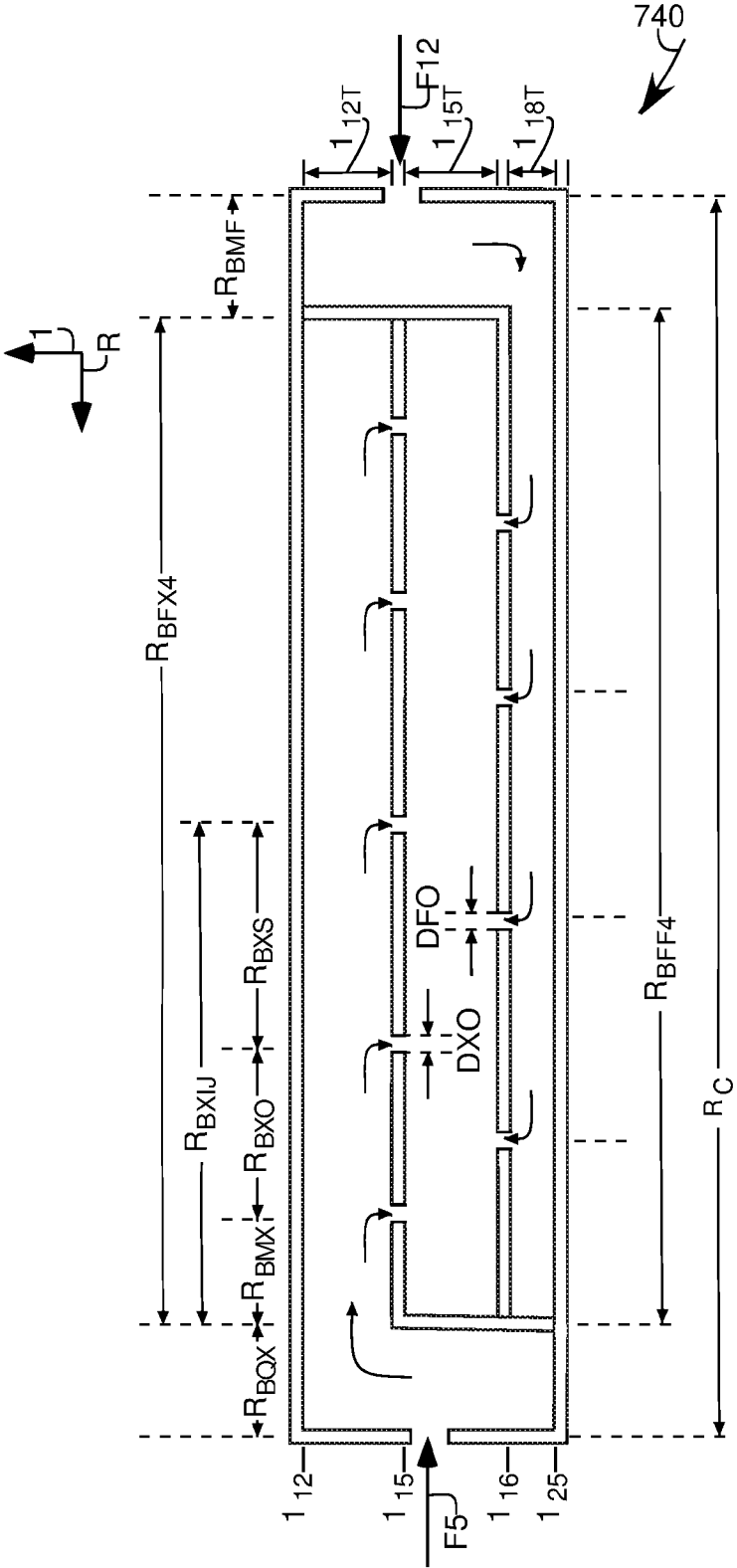
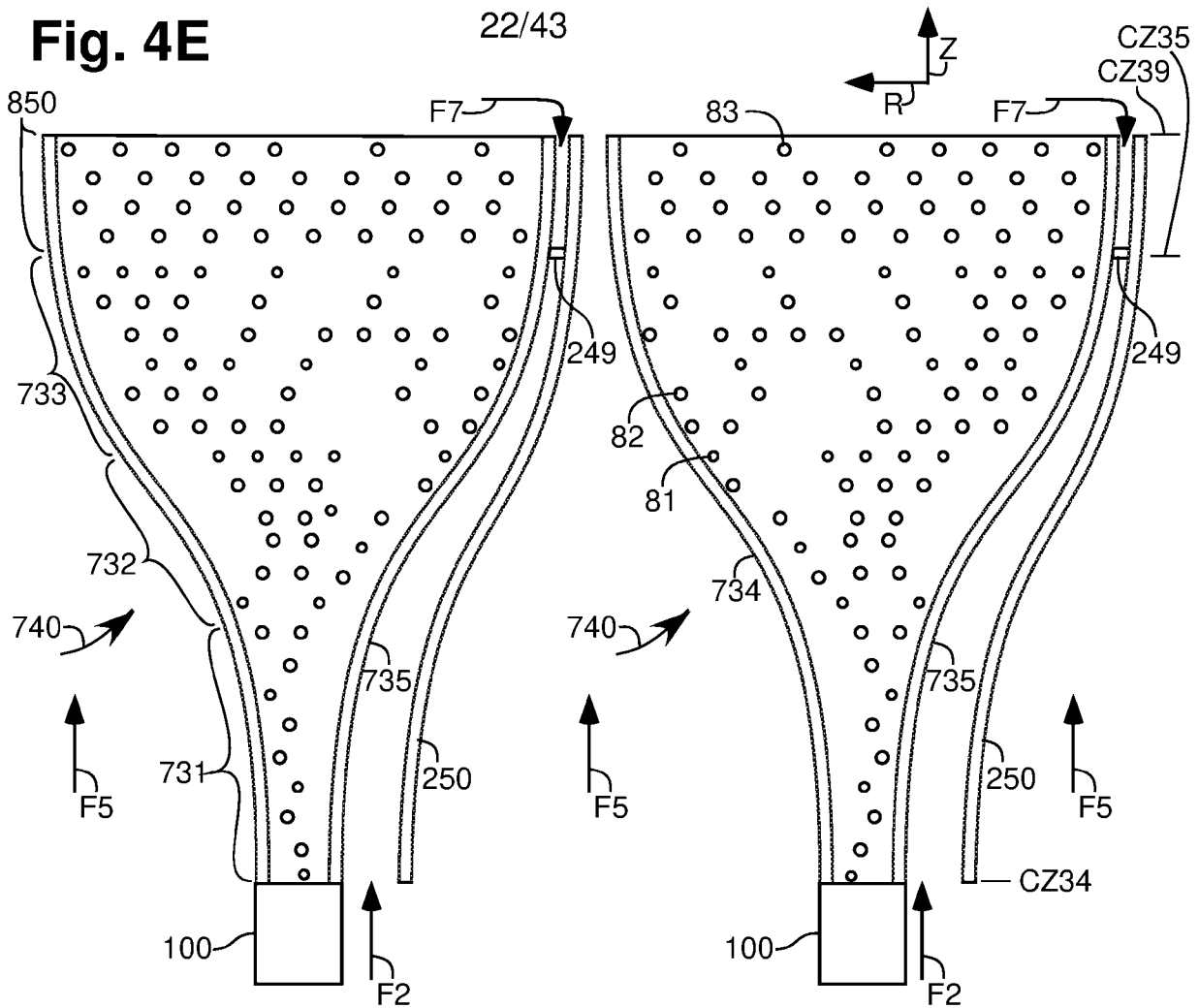
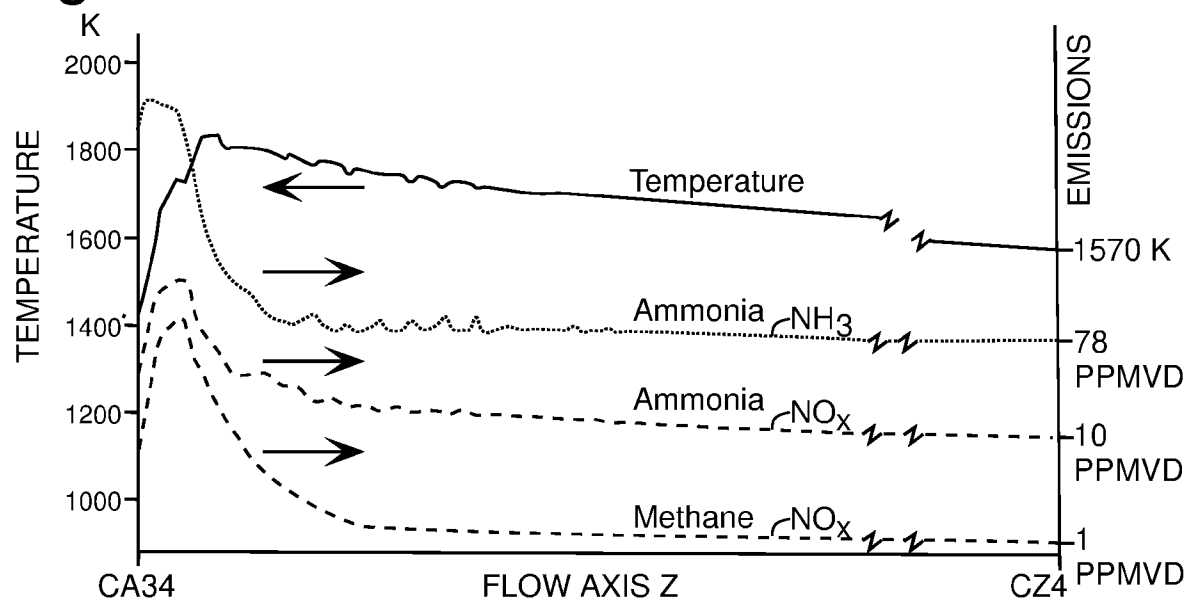
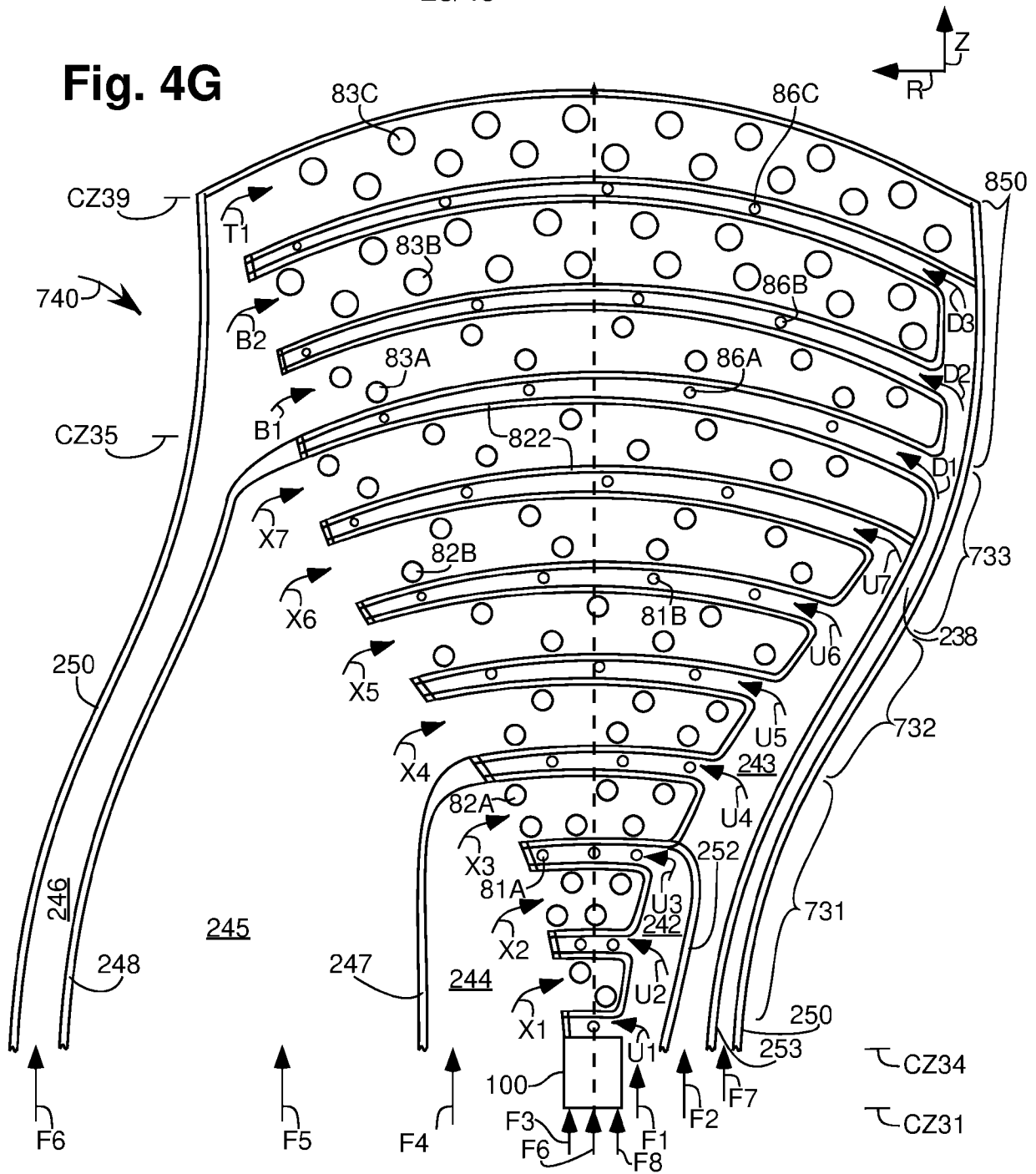


Fig. 4E**Fig. 4F**

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Fig. 4G



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Fig. 4H

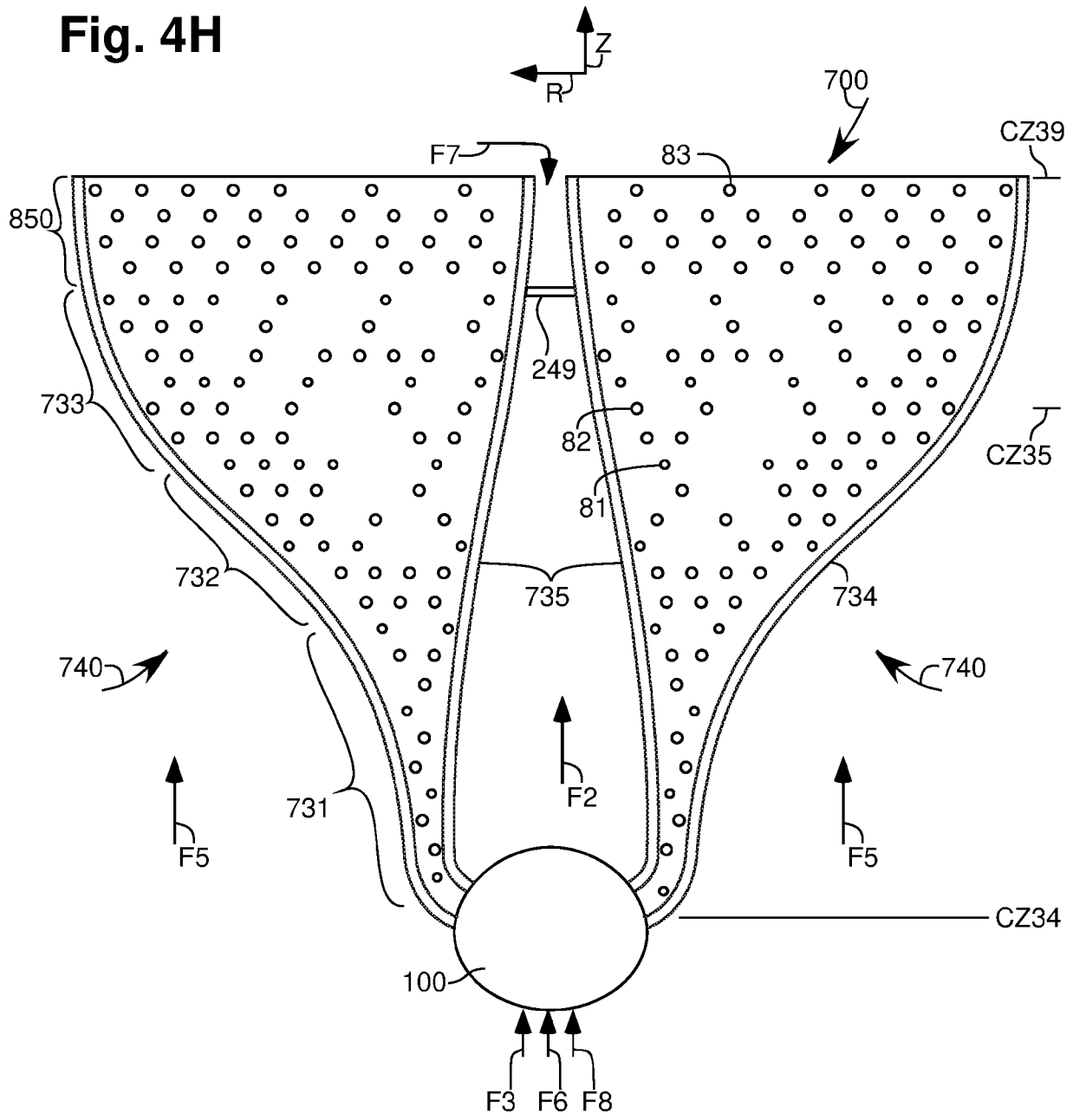


Fig. 4N

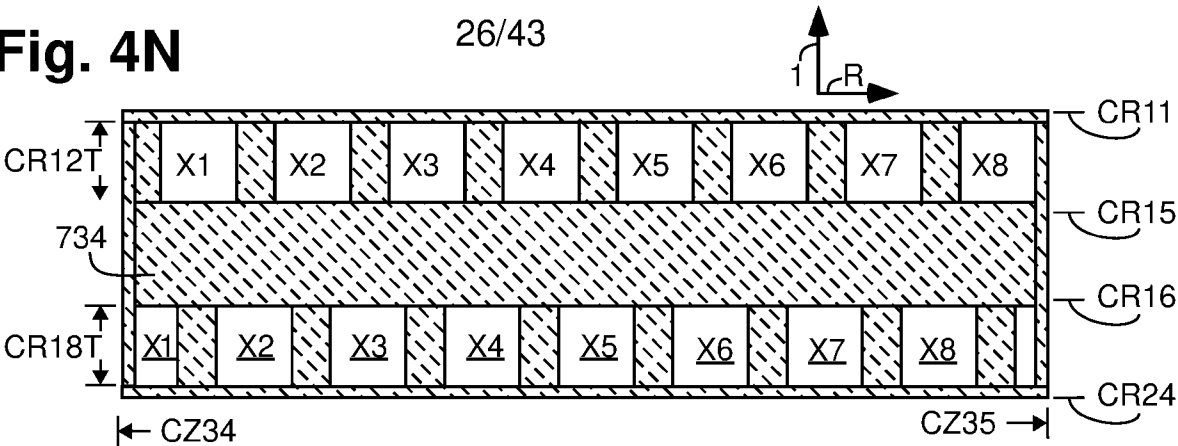


Fig. 4O

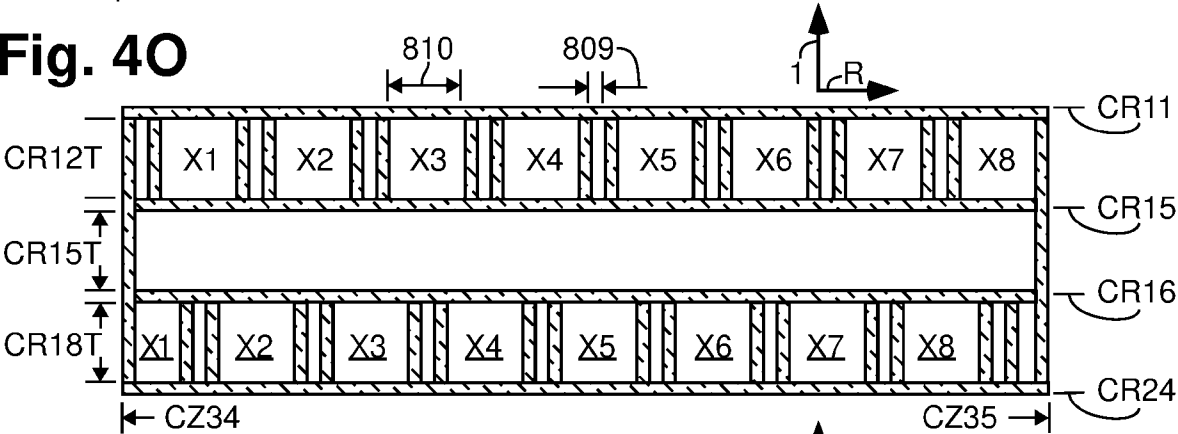


Fig. 4P

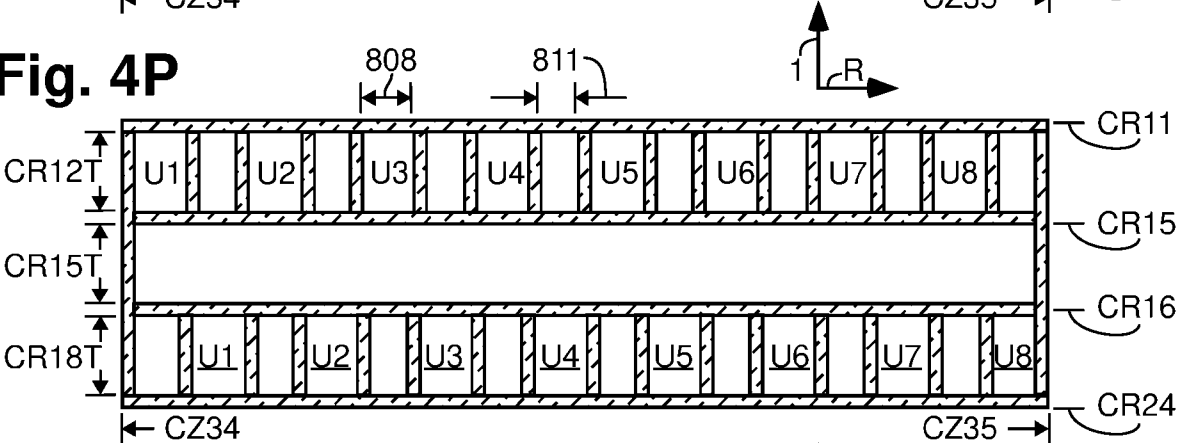


Fig. 4Q

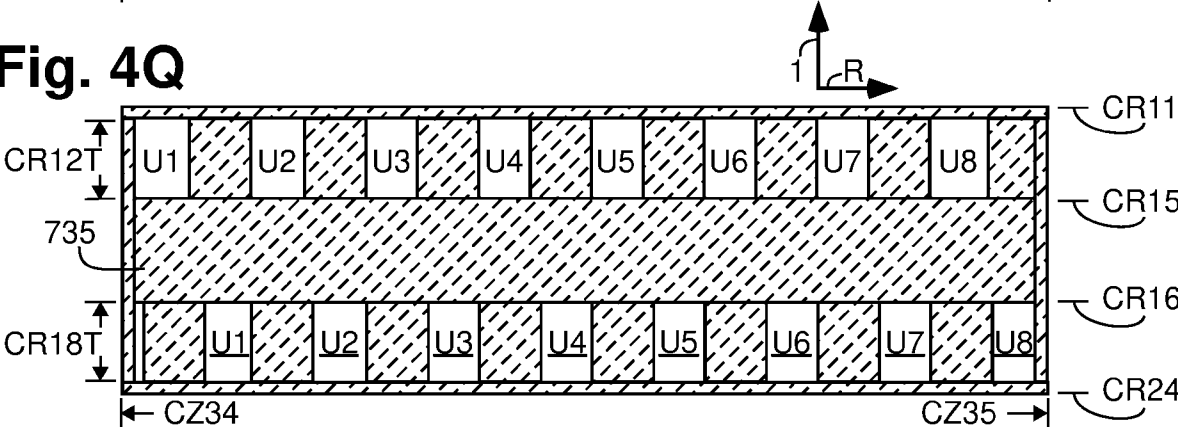


Fig. 4R

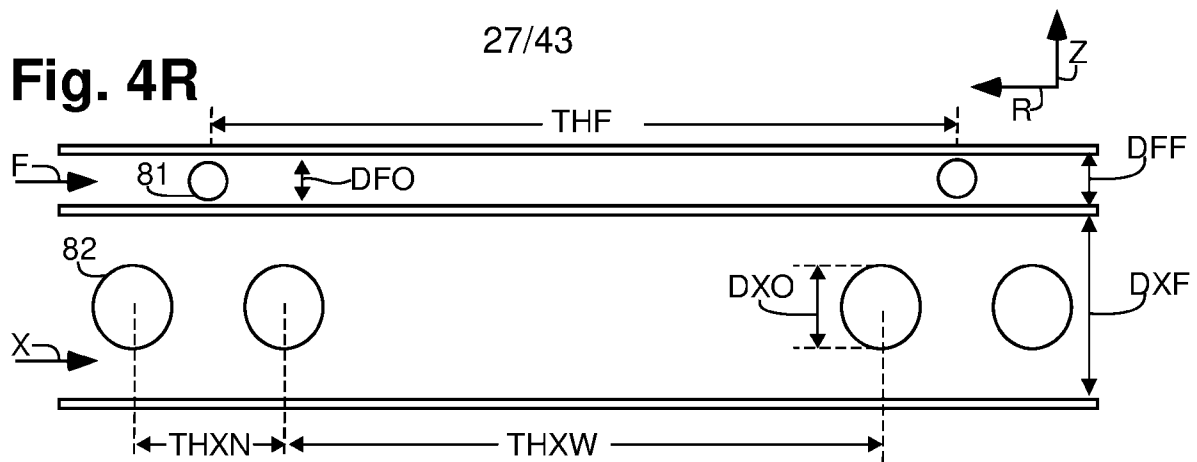


Fig. 4S

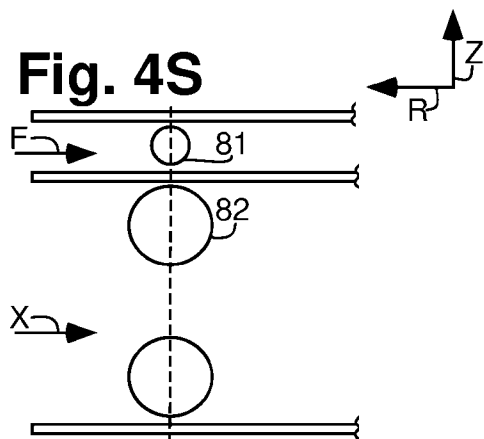


Fig. 4U

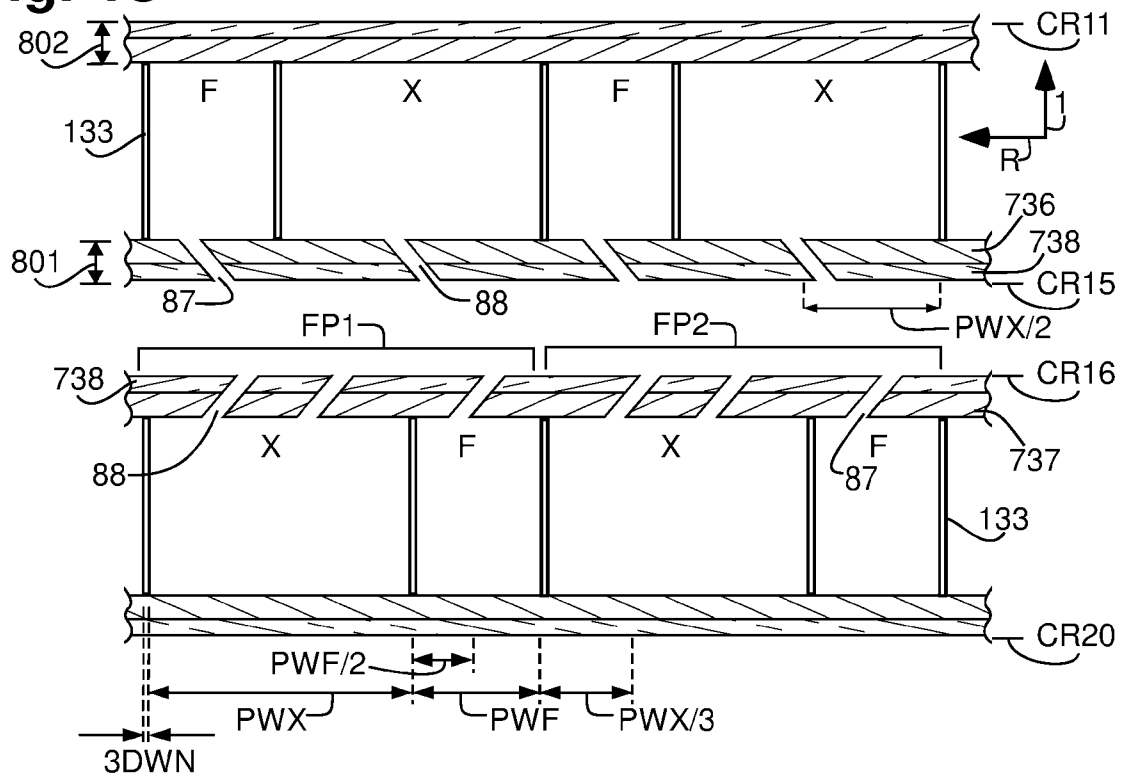


Fig. 4V

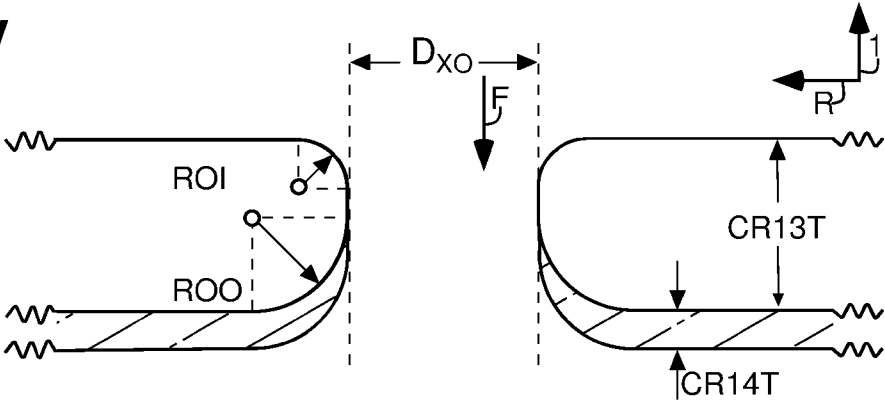


Fig. 4W

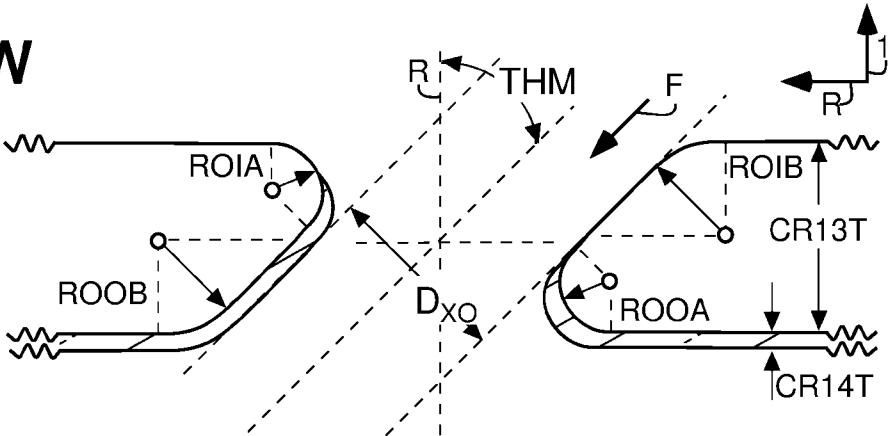


Fig. 4X

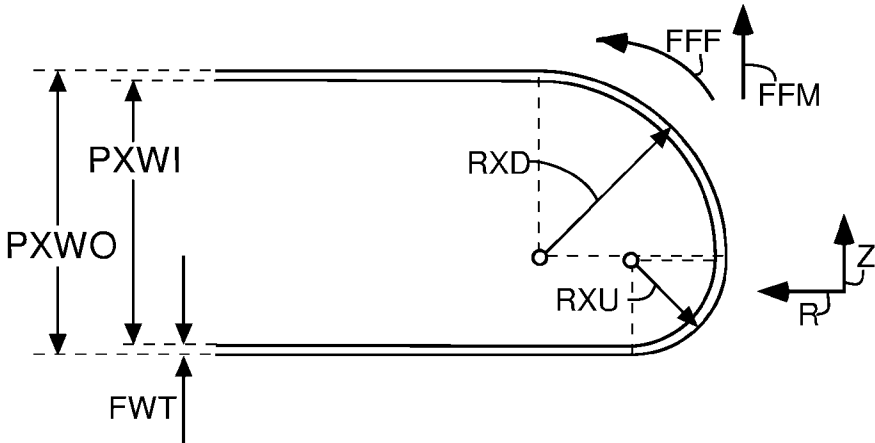


Fig. 4Y

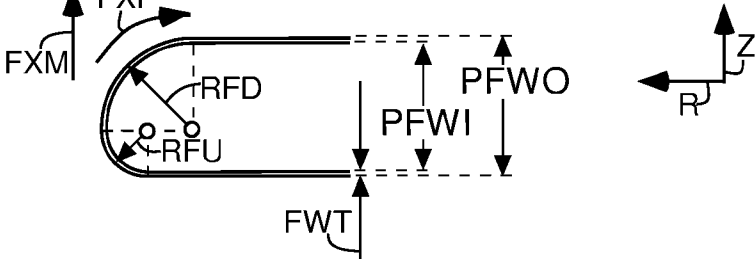
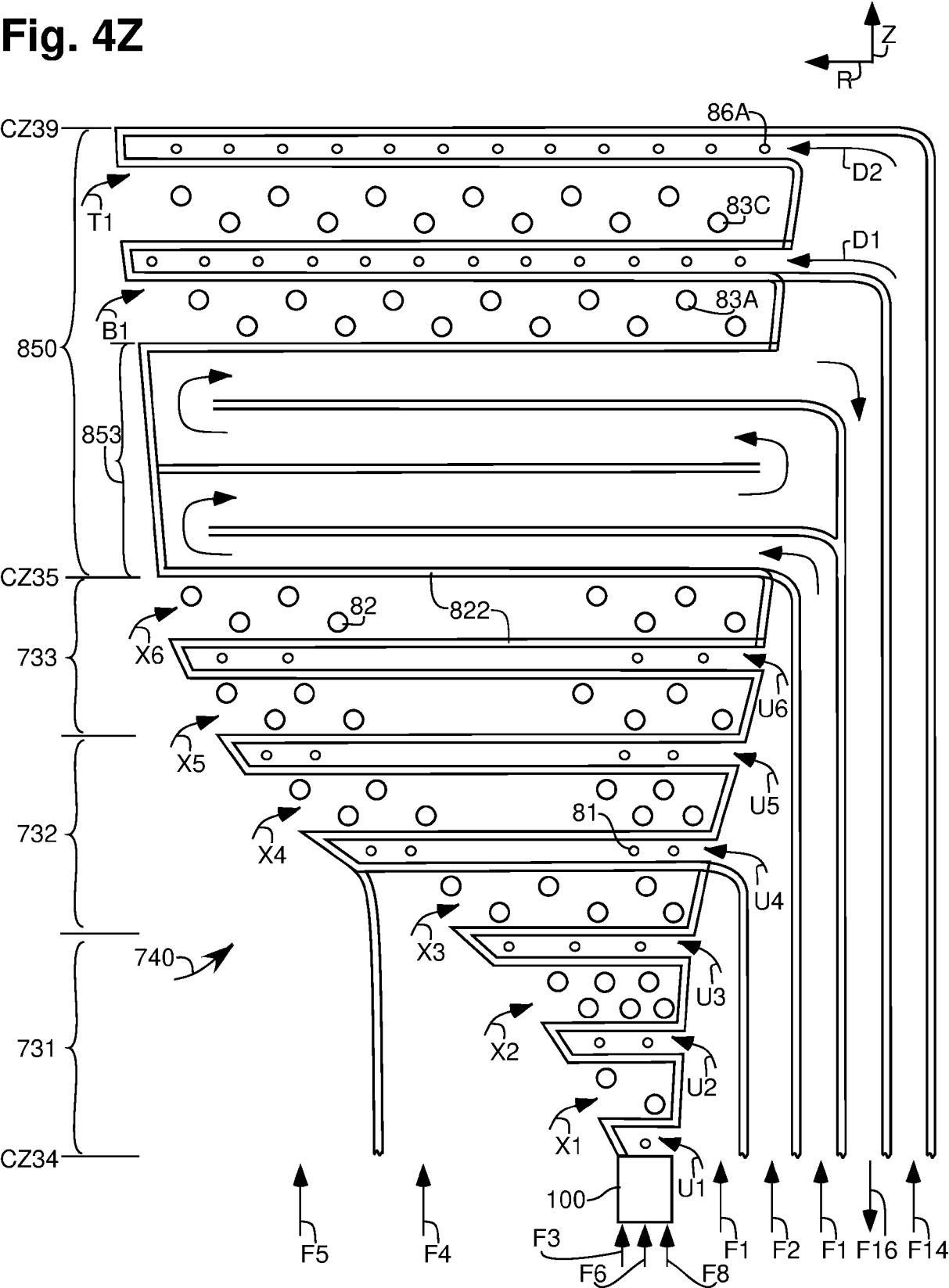


Fig. 4Z



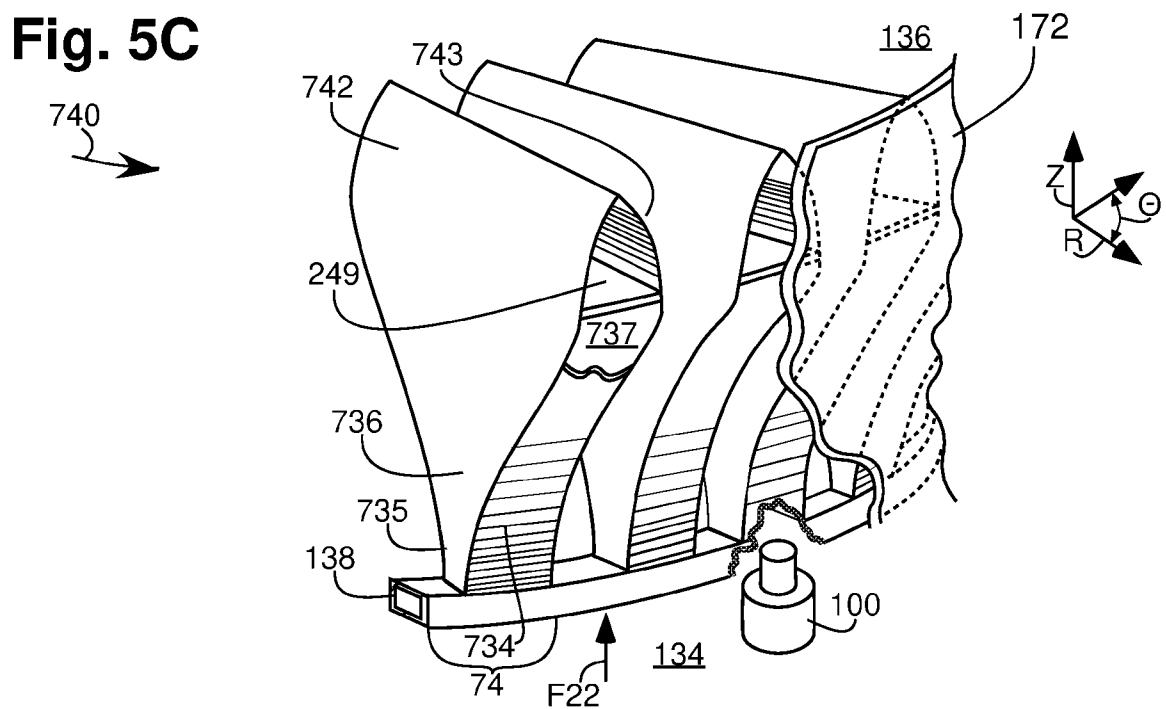
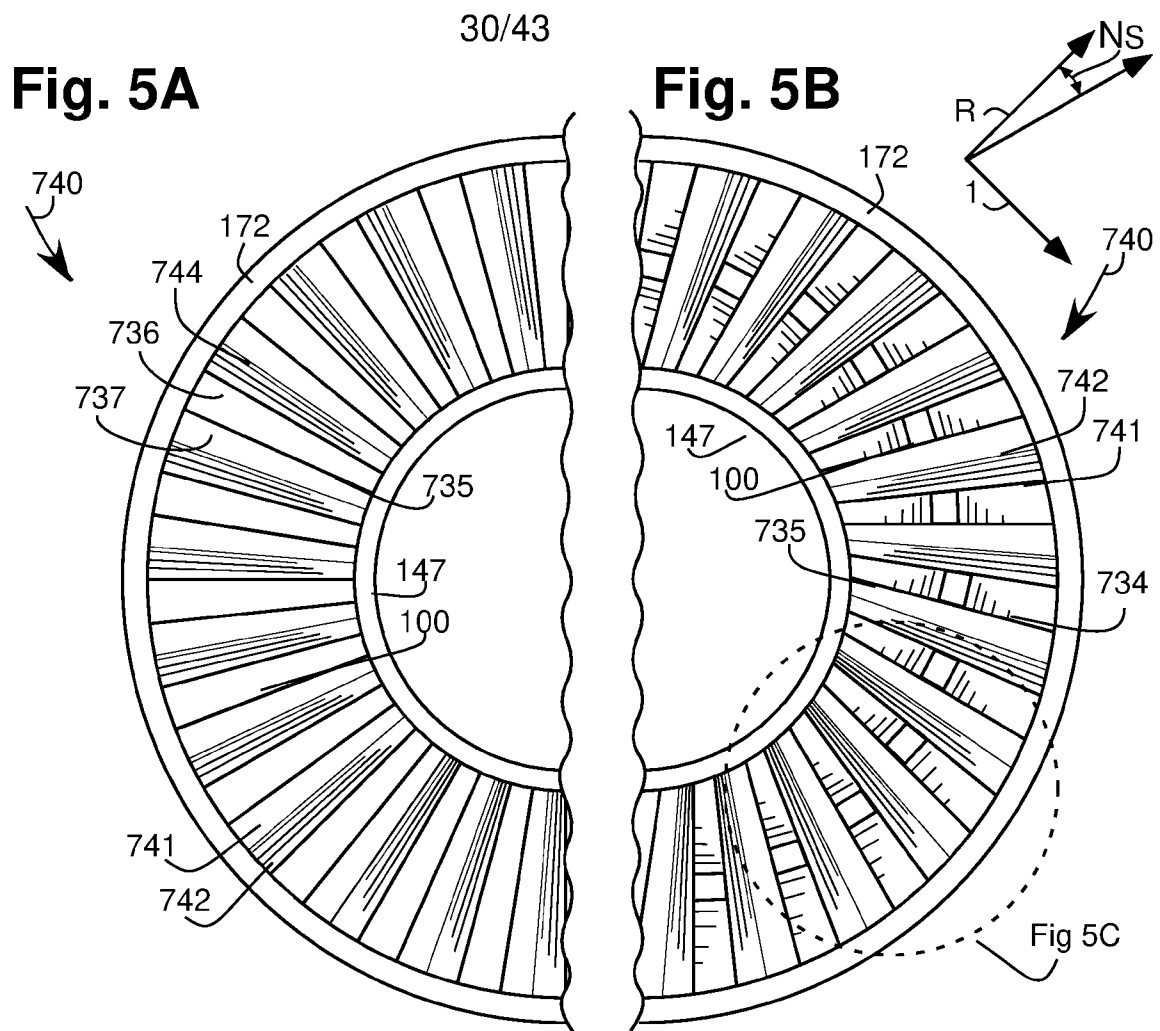


Fig. 5D

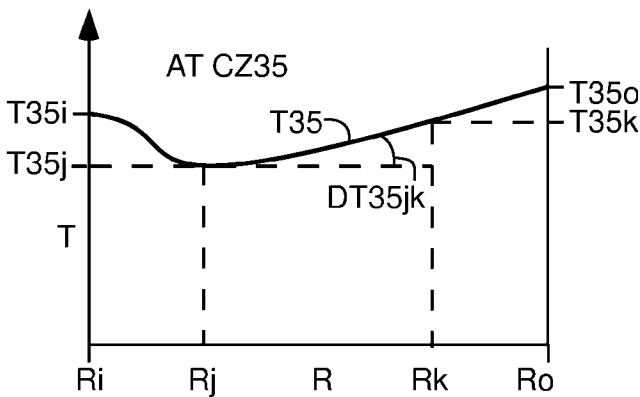


Fig. 5E

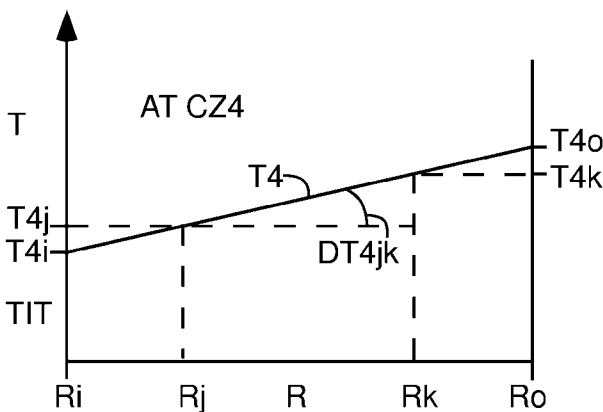


Fig. 5F

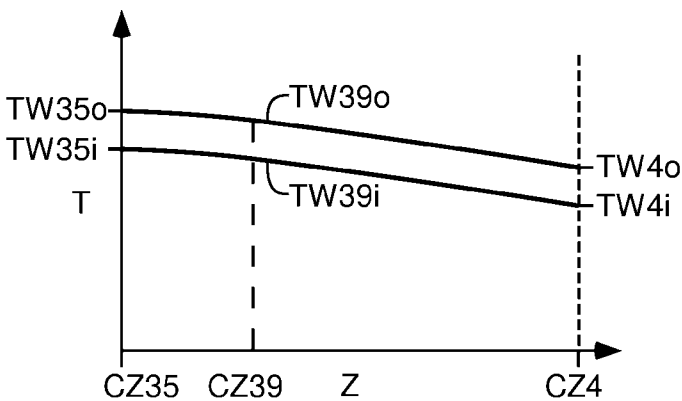


Fig. 5G

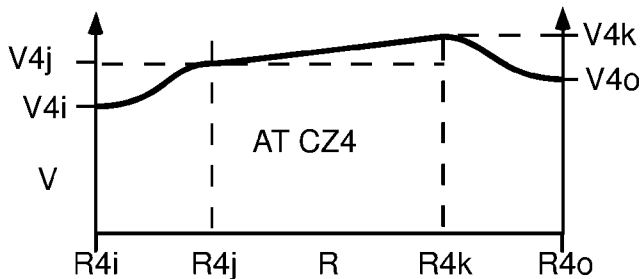


Fig. 5H

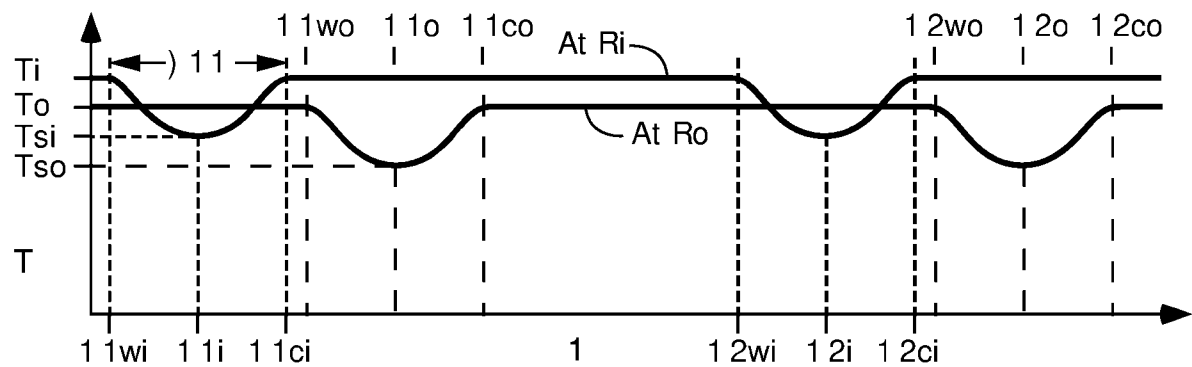


Fig. 5I

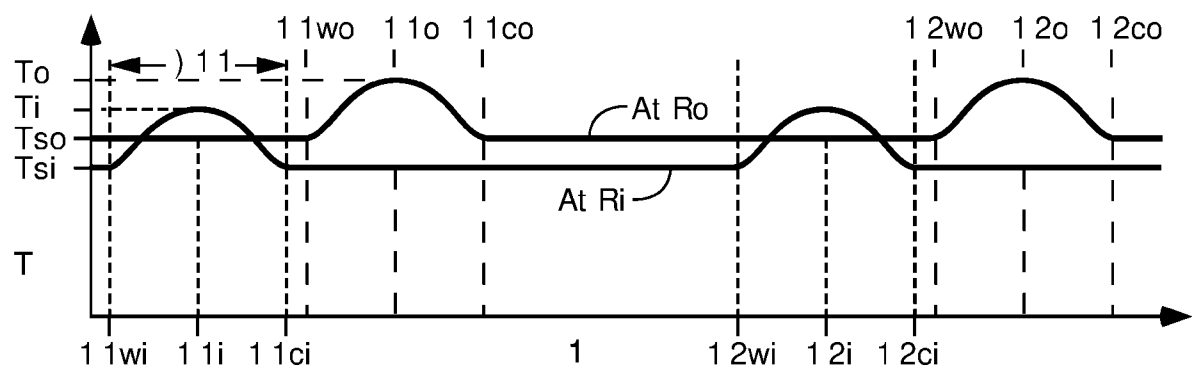
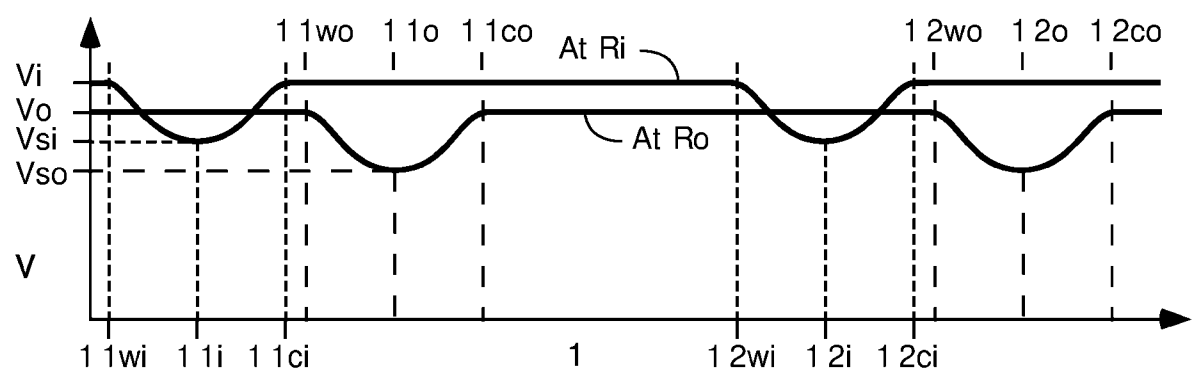


Fig. 5J



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Fig. 5K

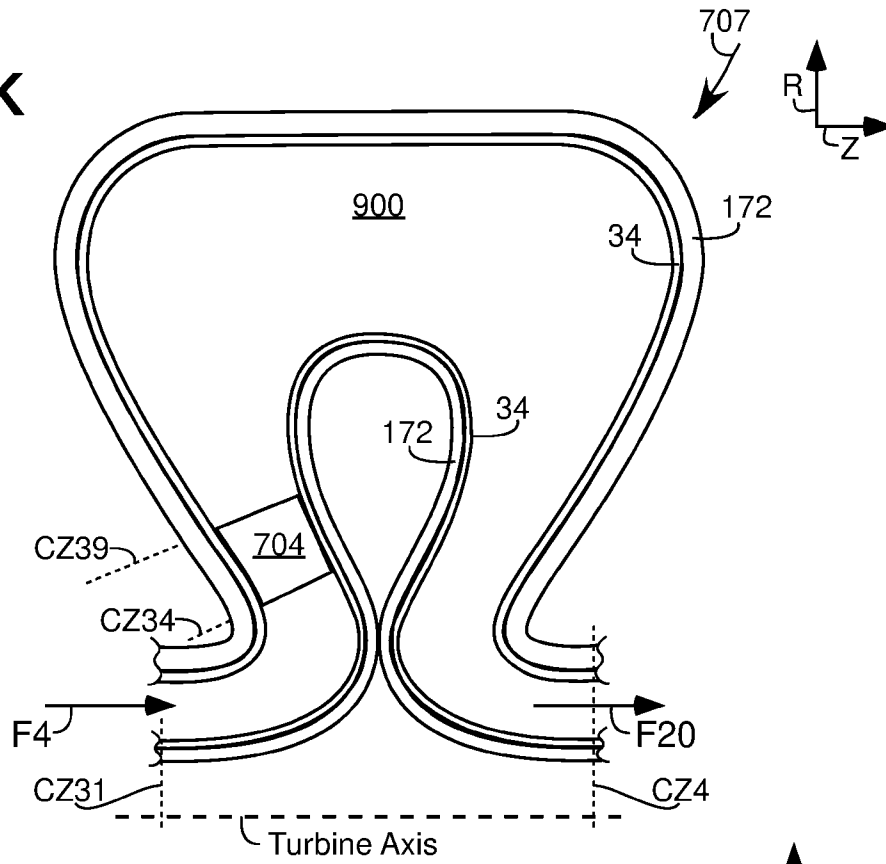
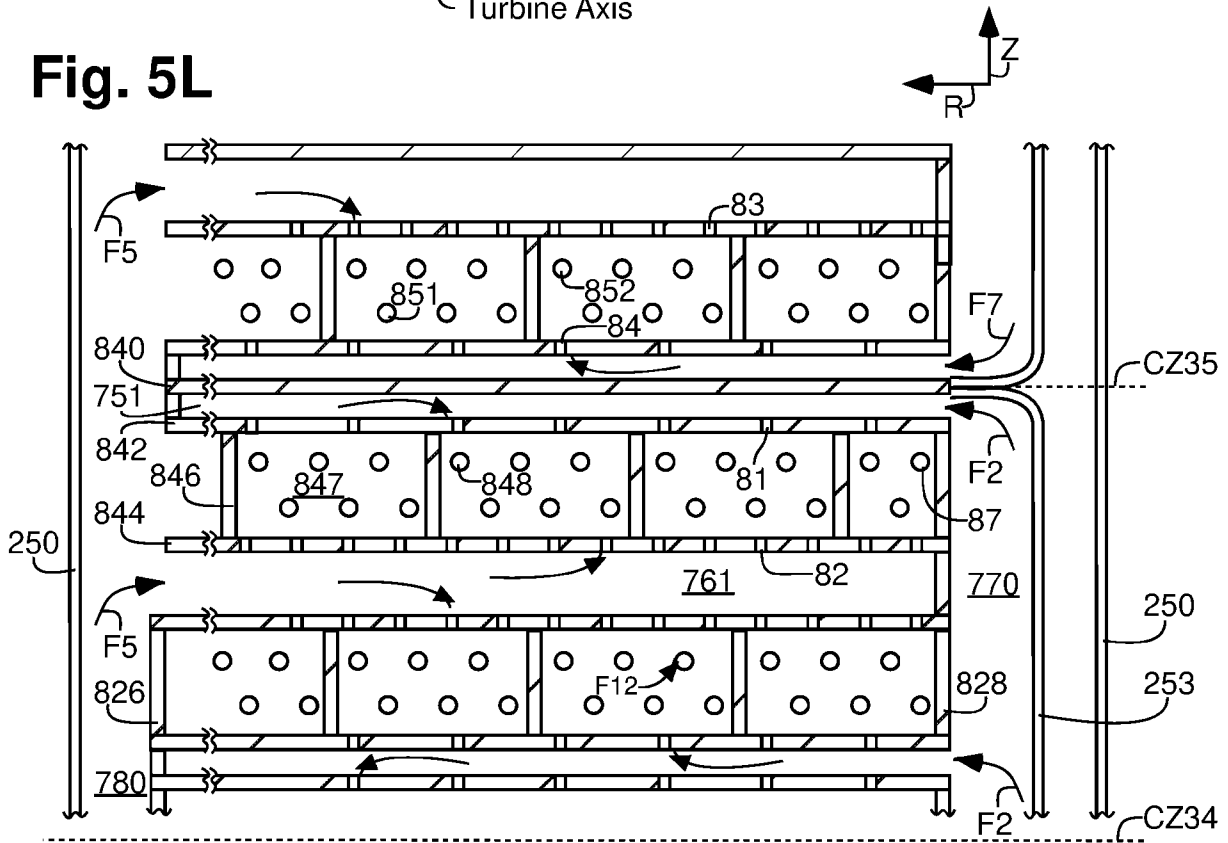
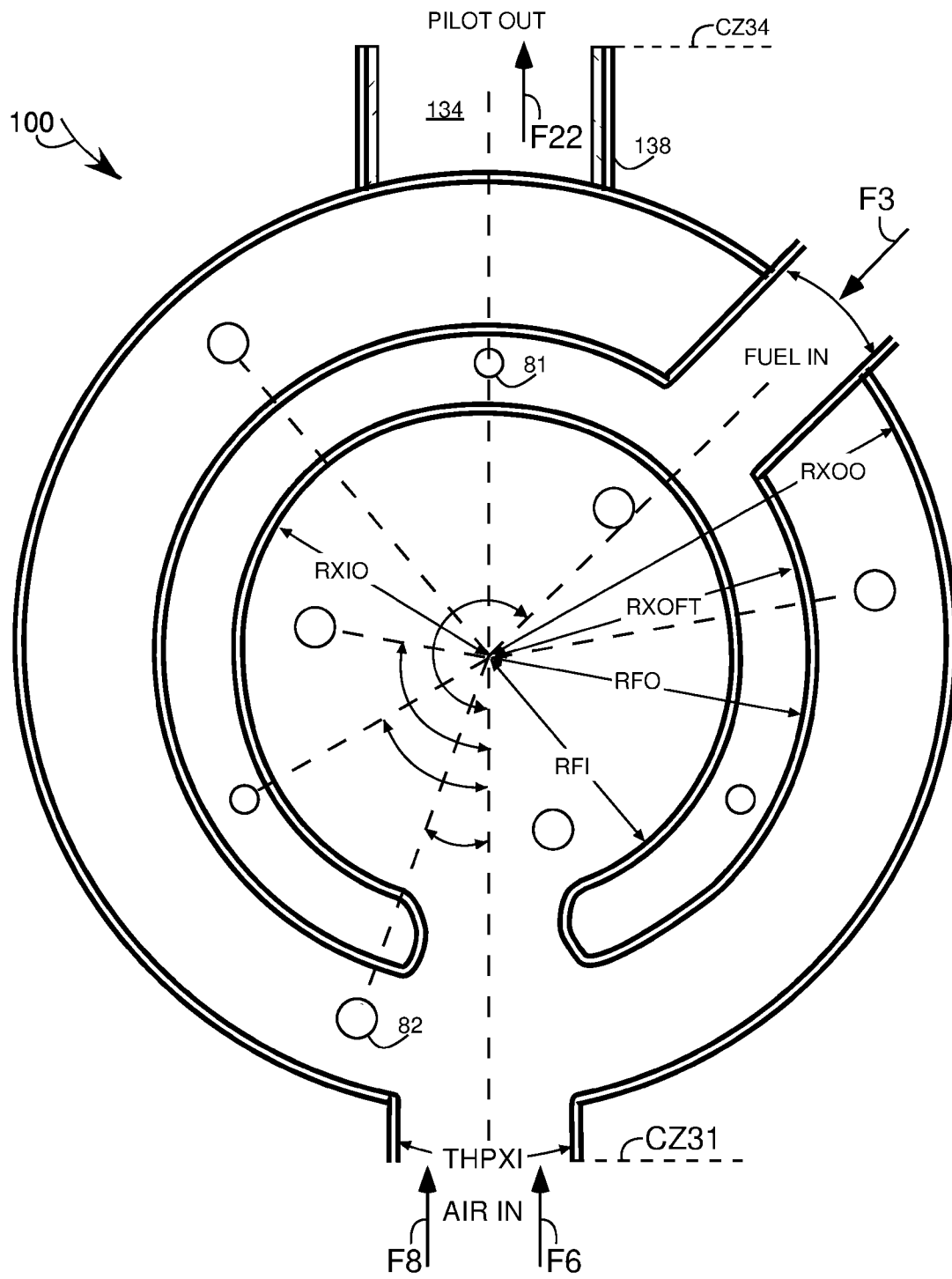


Fig. 5L



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Fig. 5M



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Fig. 5N

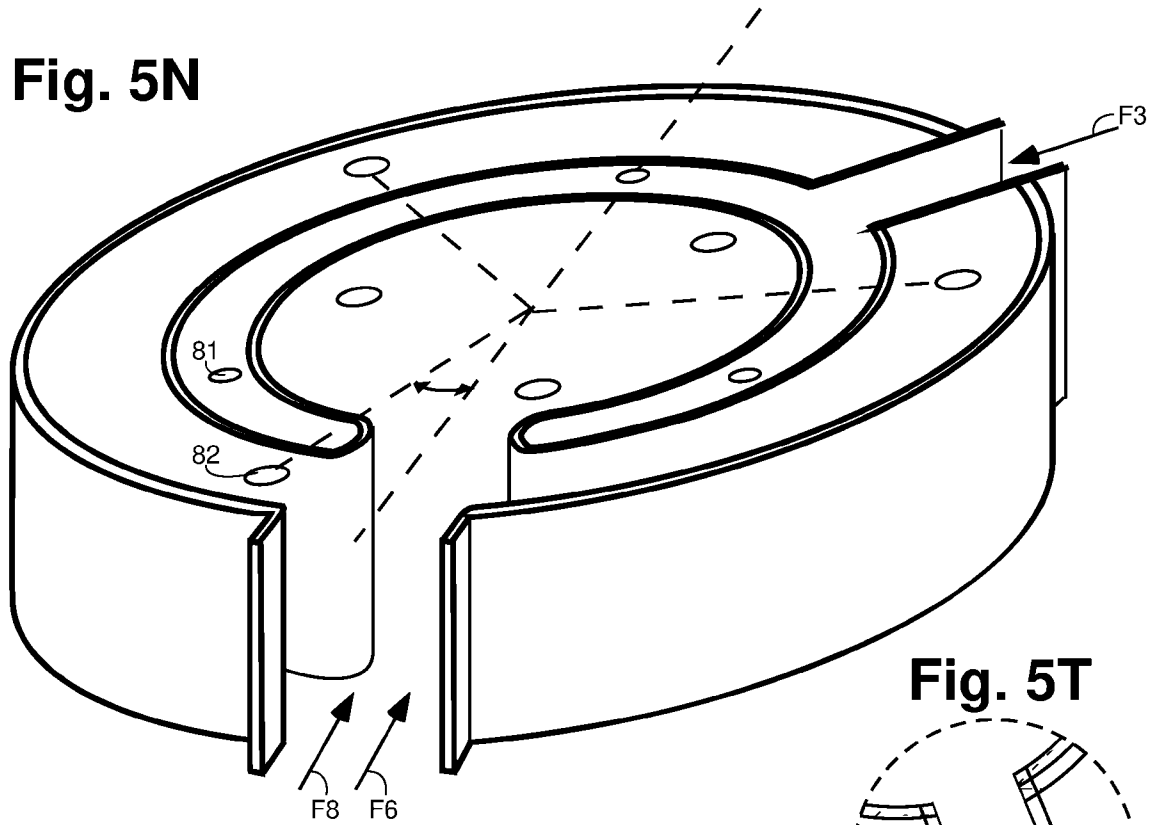


Fig. 5T

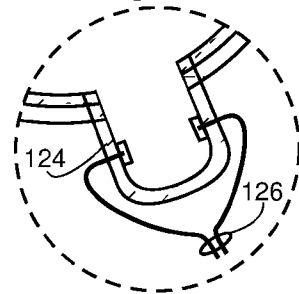


Fig. 5P

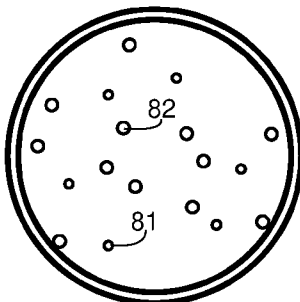


Fig. 5R

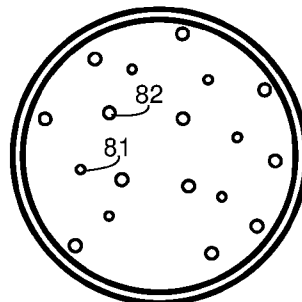


Fig. 5O

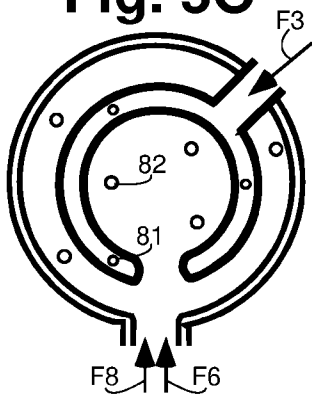


Fig. 5Q

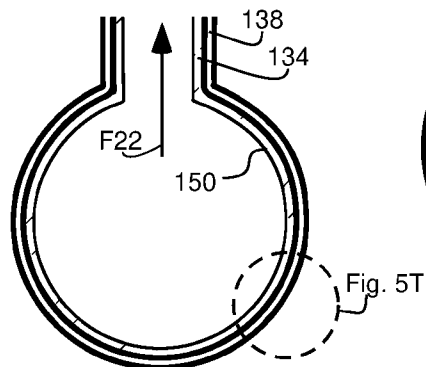


Fig. 5S

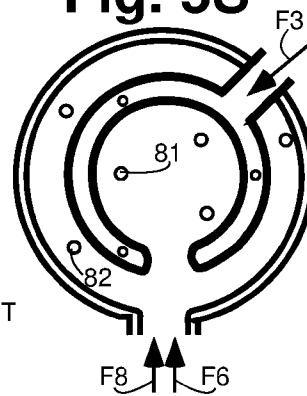


Fig. 5U

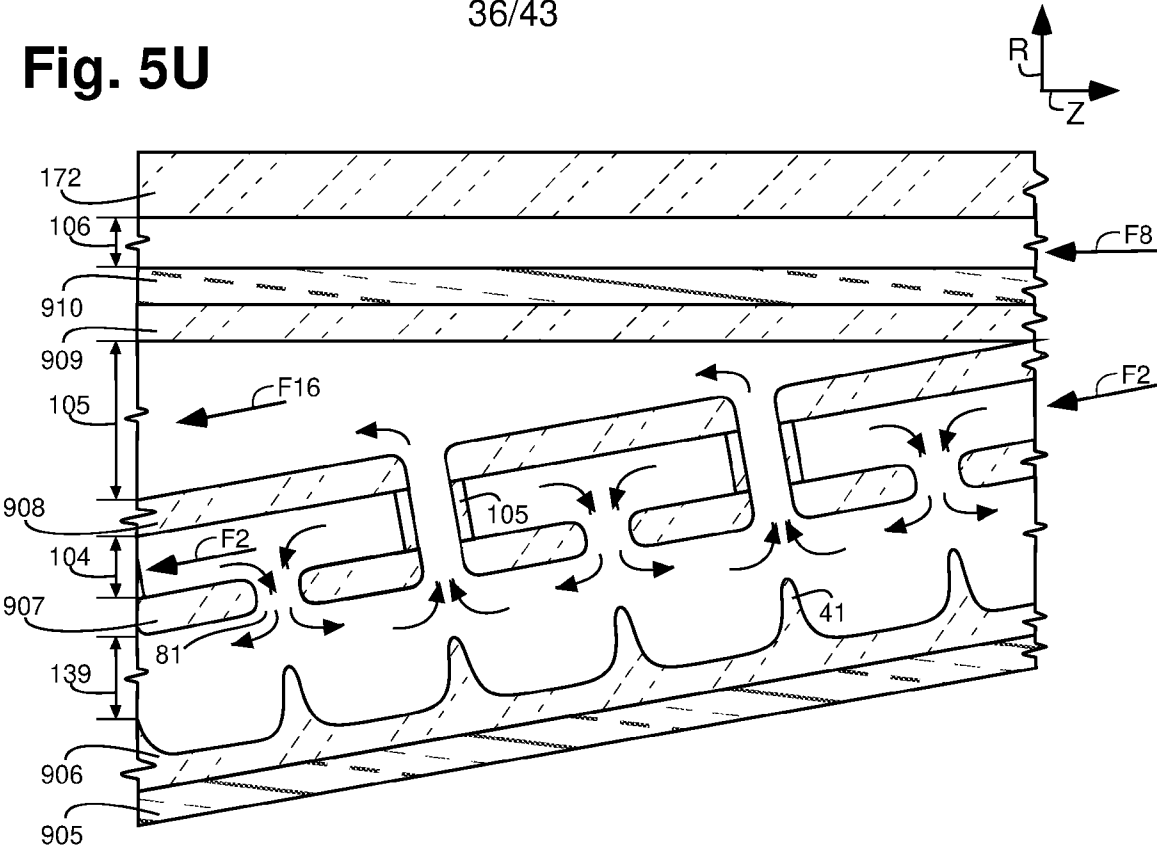
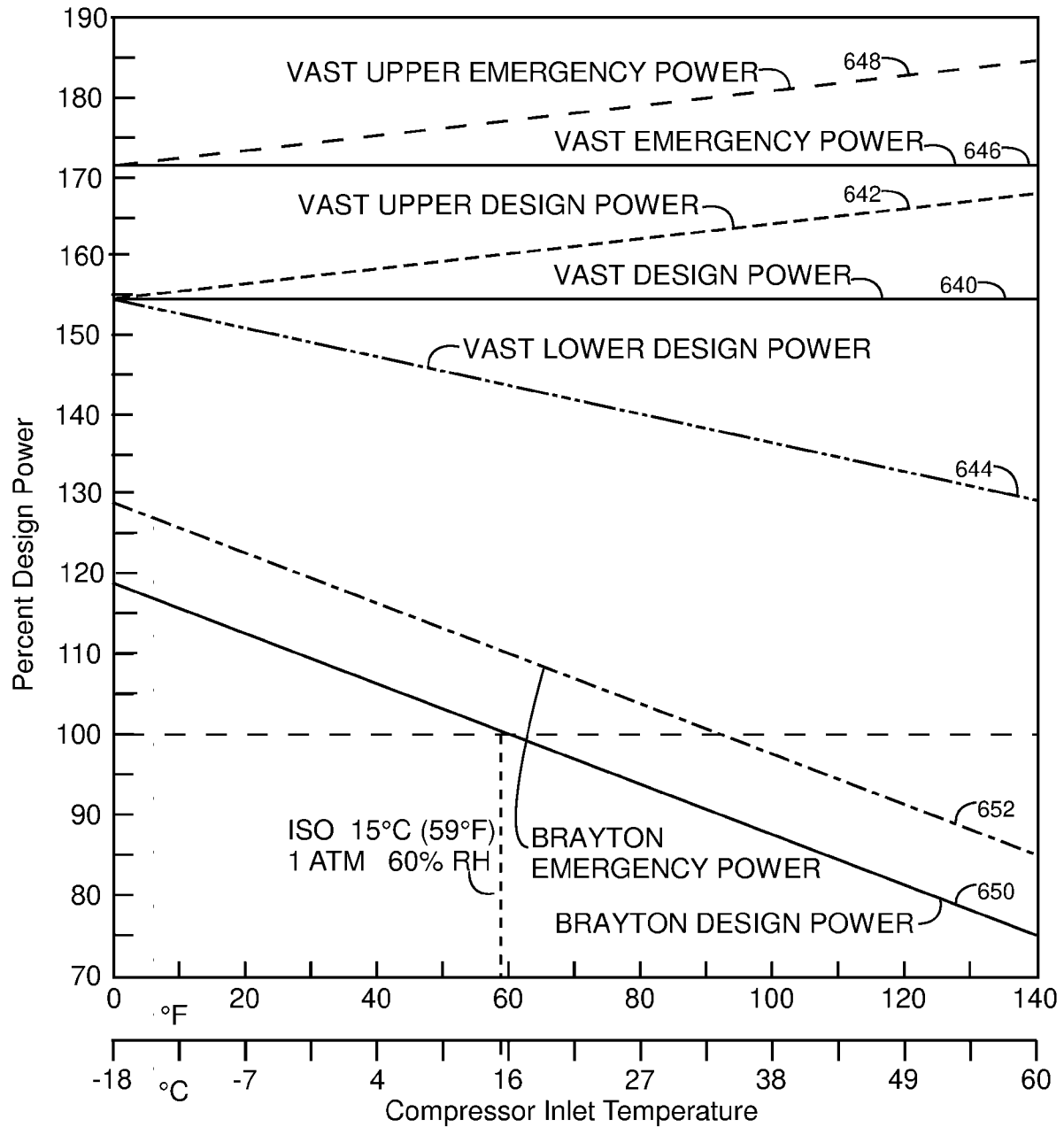


Fig. 5V



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Fig. 6A

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Fig. 6B

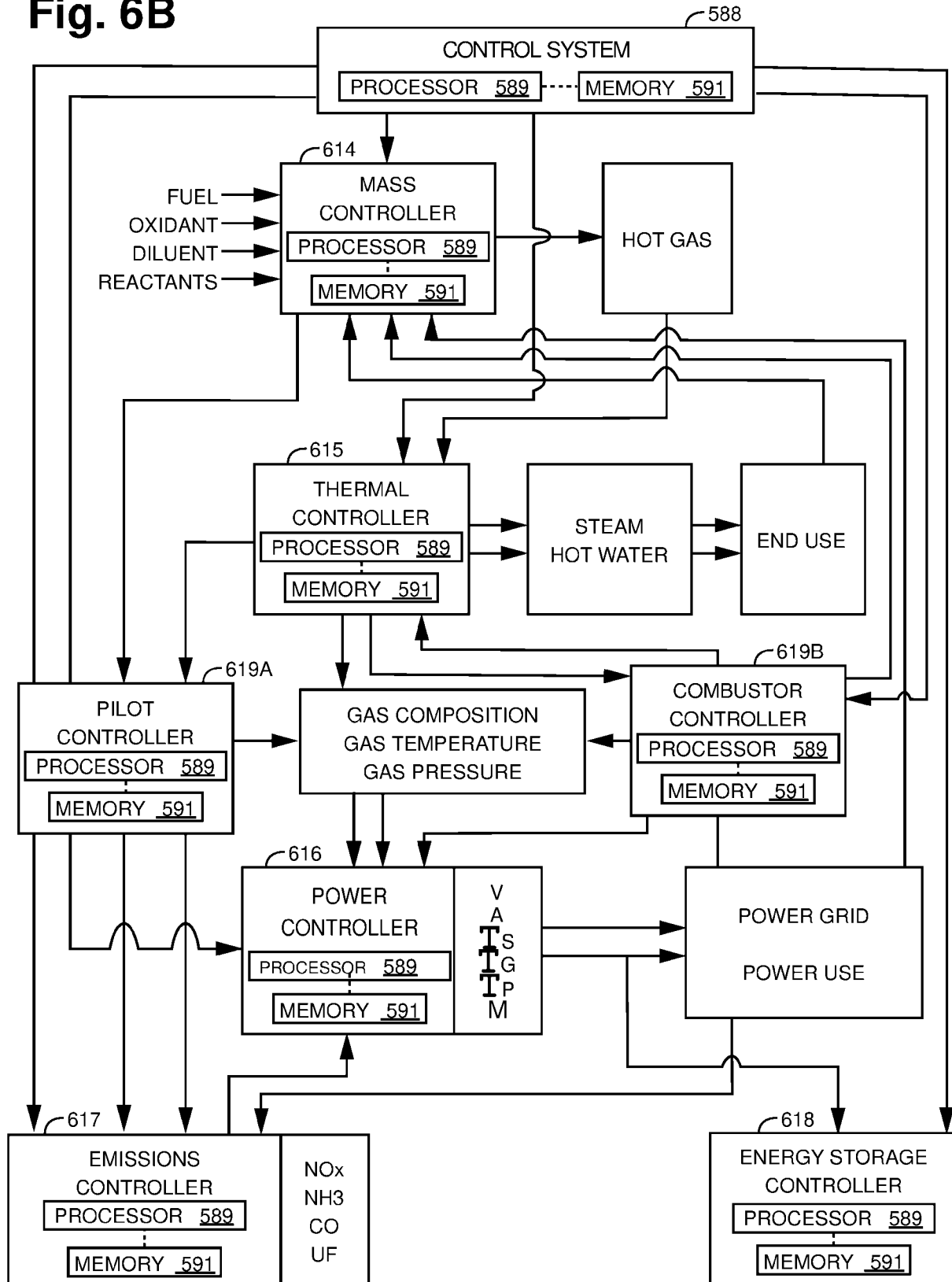
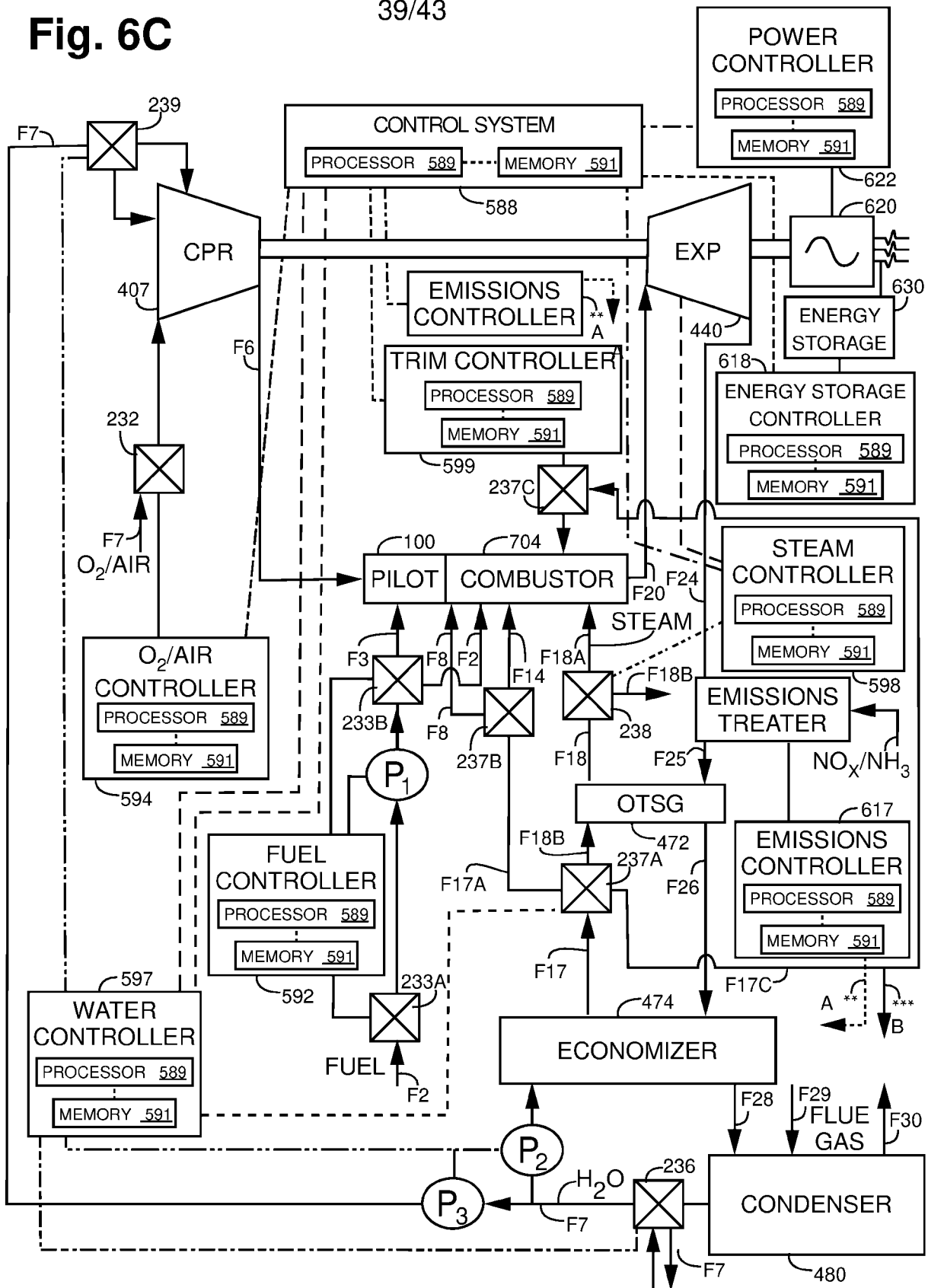


Fig. 6C

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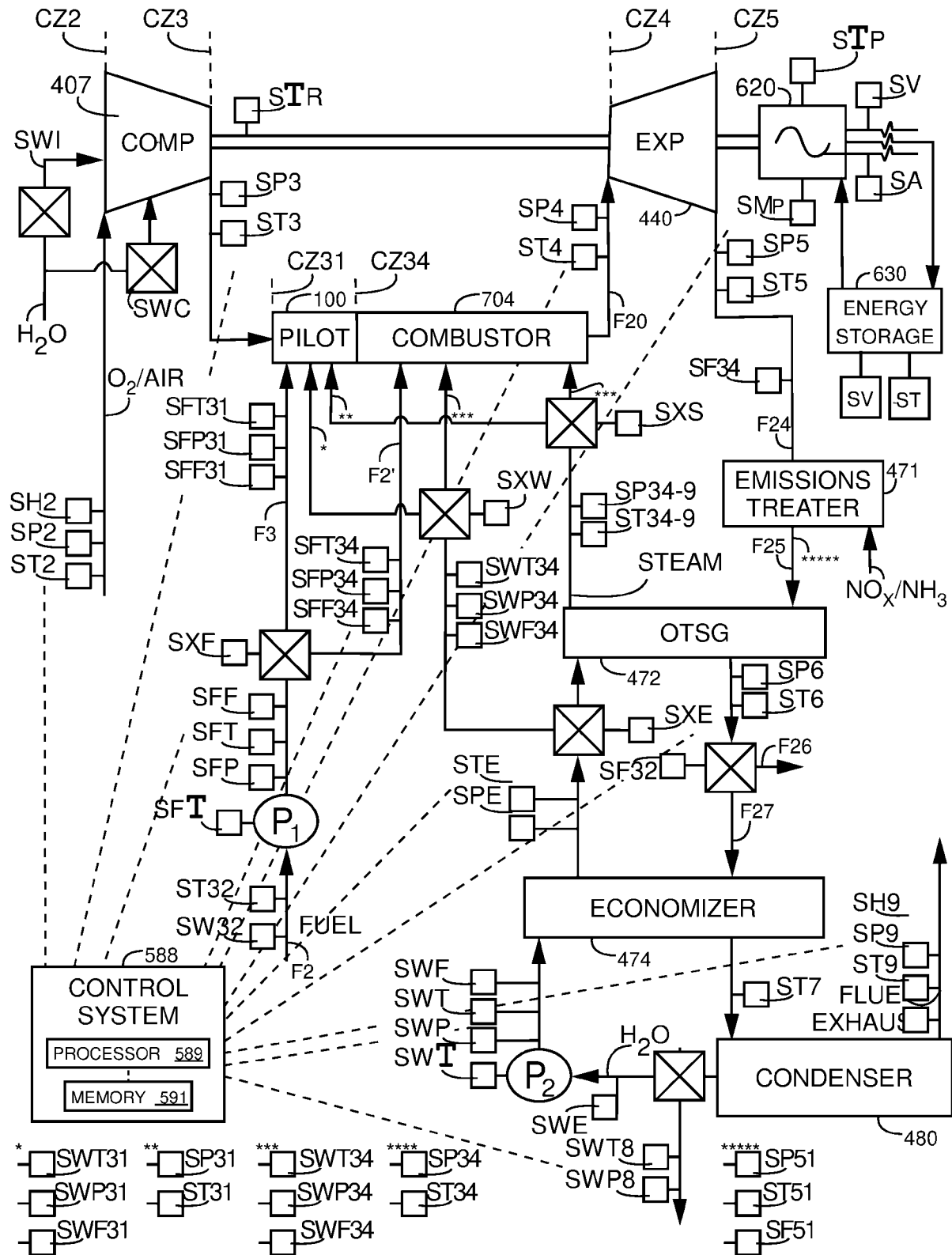
Fig. 6D

Fig. 6E

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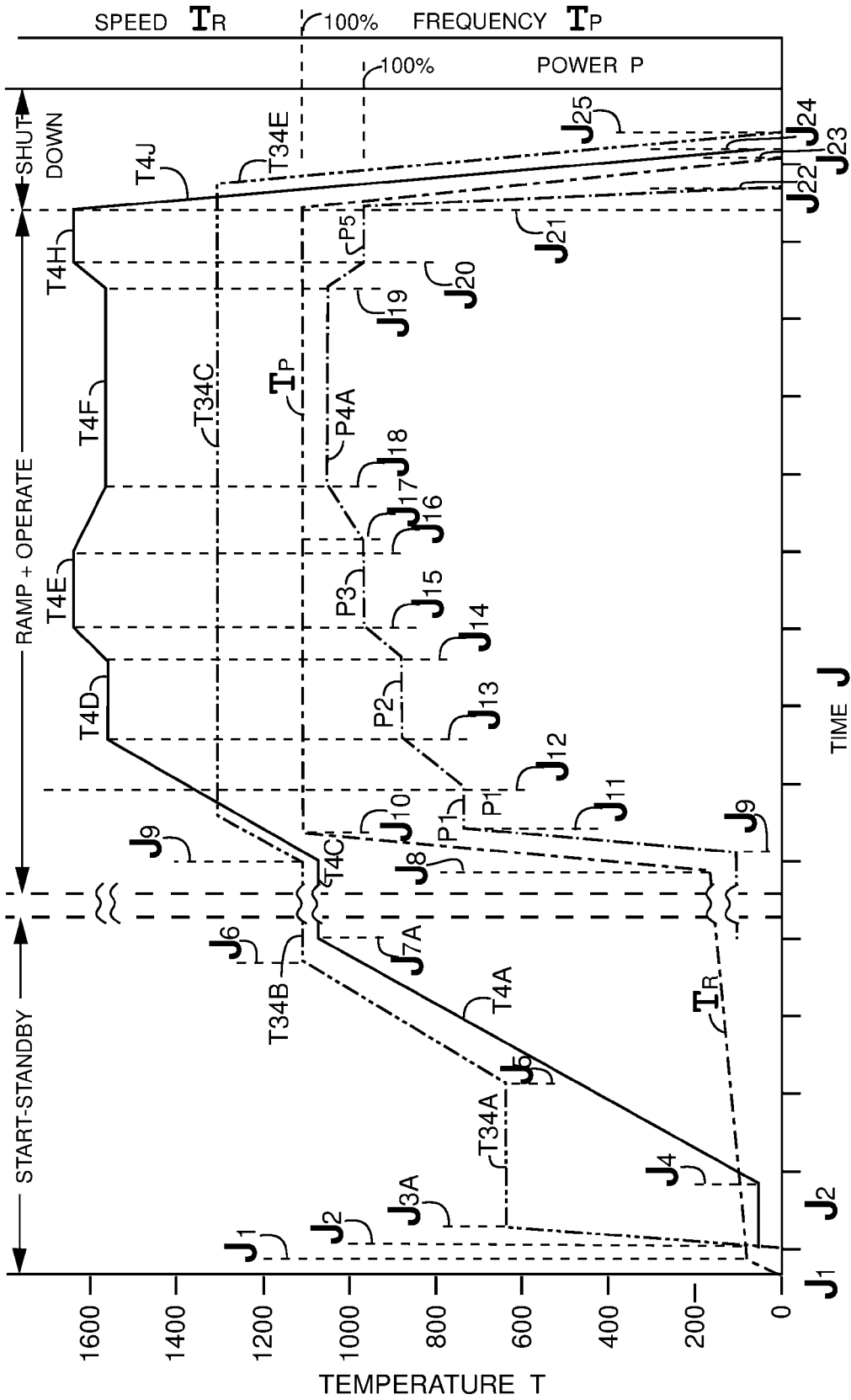


Fig. 6F

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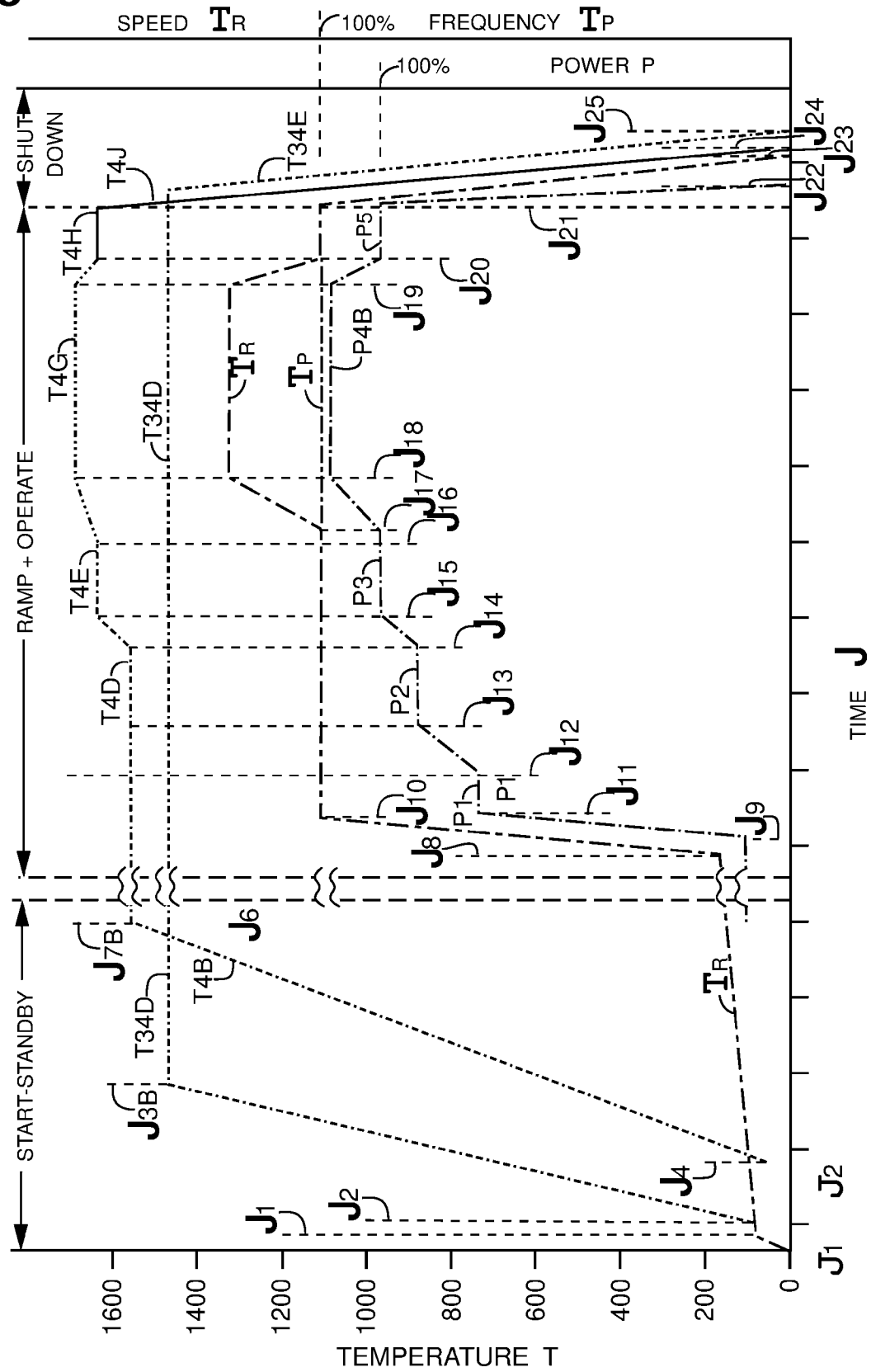
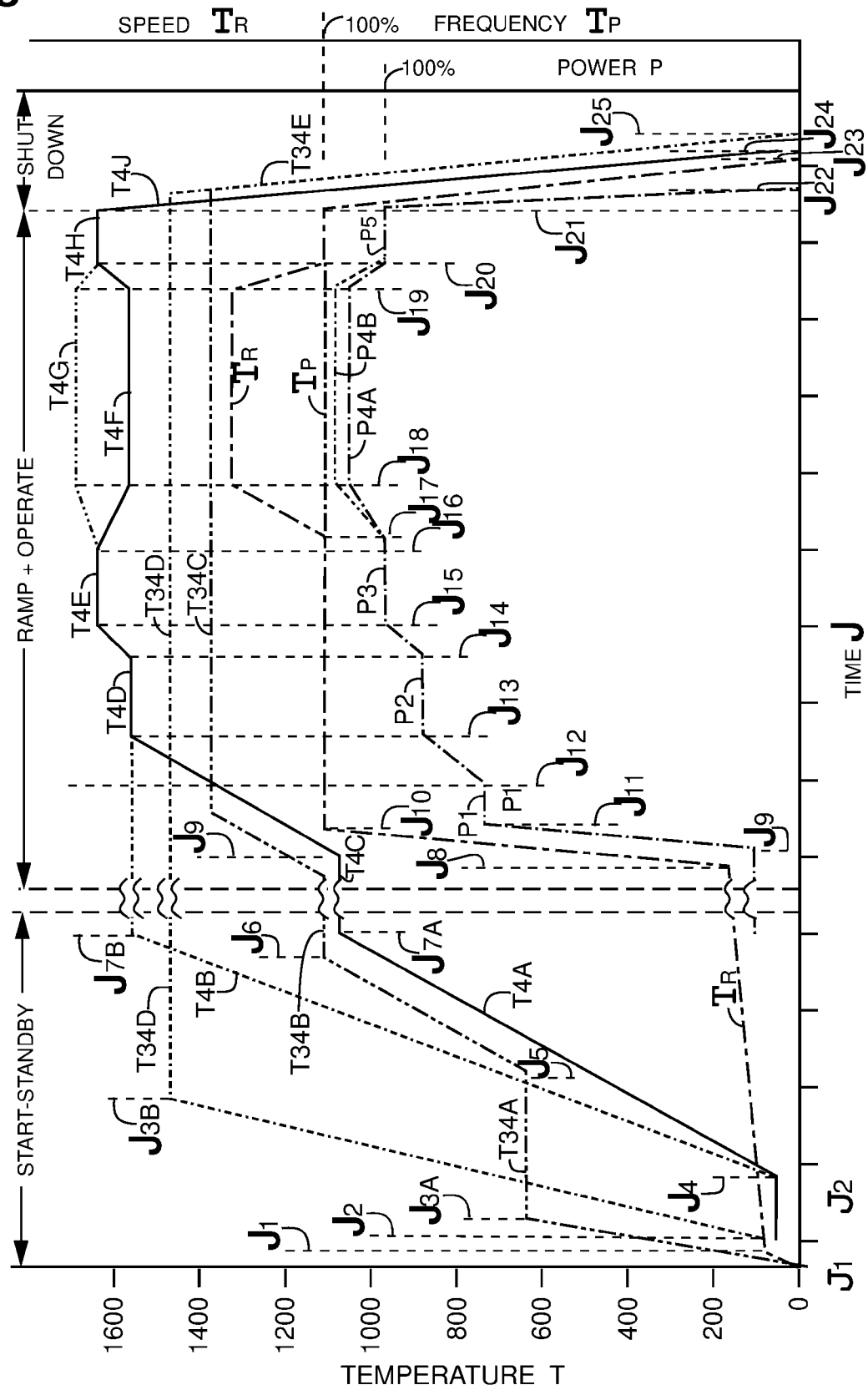


Fig. 6G

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/055262

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **F23N 1/00** (2025.01); **F02C 3/24** (2025.01); **F02C 9/28** (2025.01); **F23K 5/14** (2025.01); **F23R 3/34** (2025.01); **F23R 3/42** (2025.01); **F02C 3/30** (2025.01); **F23L 7/00** (2025.01); **F23R 3/06** (2025.01); **F23R 3/36** (2025.01)

CPC: **F23N 1/007**; **F02C 3/24**; **F02C 3/30**; **F23K 5/14**; **F23R 3/34**; **F23R 3/42**; **F23R 3/002**; **F02C 9/28**; **F23L 7/007**; **F02C 9/263**; **F23L 7/00**; **F23R 3/06**; **F23R 3/36**; **F23K 2203/105**; **F23N 5/006**; **F23R 3/36**; **F23L 2900/07004**; **F23L 2900/07006**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2022/0412557 A1 (8 RIVERS CAPITAL, LLC) 29 December 2022 (29.12.2022) Figs. 2, 3A; para [0007], [0060]-[0063], [0069]	1-13
A	US 2020/0263870 A1 (JOHNS MANVILLE) 20 August 2020 (20.08.2020) Fig. 2; para [0006]-[0012], [0043]-[0044], [0066]-[0068]	1-13
A	US 2009/0180939 A1 (HAGEN et al.) 16 July 2009 (16.07.2009) Figs. 55-56; para [0477], [0769], [0787], [0931]-[0932], [1563]	1-13
A	US 3,241,609 A (REZNOR) 22 March 1966 (22.03.1966) Fig. 1; col 2, ln 33-69	1-13



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance
“D” document cited by the applicant in the international application
“E” earlier application or patent but published on or after the international filing date
“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
“O” document referring to an oral disclosure, use, exhibition or other means
“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

06 February 2025 (06.02.2025)

Date of mailing of the international search report

20 February 2025 (20.02.2025)

Name and mailing address of the ISA/US

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Telephone No. **PCT Help Desk: 571-272-4300**

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1.

Group I: Claims 1-13, drawn to scalable combustor systems.

Group II: Claims 14-20, drawn to combustor systems with fluid feeders.

The inventions listed as Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features

Group II does not require a system comprising a plurality of fuel feeders comprising fuel orifices; and a plurality of oxidant feeders comprising oxidant orifices disposed about at least one of the first combusting chamber wall and the second combusting chamber wall; wherein the combustor is configured to deliver an oxidant fluid through the plurality of oxidant feeders and oxidant orifices, and to deliver a diluent fluid with at least one of the fuel fluid and the oxidant fluid through one or more of the plurality of fuel orifices, and through one or more of the oxidant orifices to combust the fuel with the oxidant in the combusting chamber; and wherein the combustor is configured to the combustor outlet, a radially opposed combusting chamber wall; and a combustion fluid comprising products of combustion, diluent, and residual oxidant; and a control system configured to control delivery of the fuel fluid, the oxidant fluid, and the diluent fluid, and to ignite the fuel with the oxidant by controlling one or more fluid delivery rates to maintain a combustion temperature in the combusting chamber above a combustion quench limit, as required by Group I.

Group I does not require a fluid delivery system configured to deliver a fuel fluid comprising a fuel, an oxidant fluid comprising an oxidant and a diluent fluid comprising a diluent into a combustor in fluid communication with the fluid delivery system, as required by Group II.

Shared Common Features

The only feature shared by Groups I and II that would otherwise unify the groups is the combustor comprising: a combusting chamber having an upstream flame authority; a first combustor wall; an opposed second combustor wall; a plurality of orifices in at least one of the first and second combustor walls; a plurality of fluid feeders feeding one or more of said fuel fluid, oxidant fluid, and/or diluent fluid, to said plurality of orifices; and a combustor outlet; wherein the first and second combustor walls are transversely elongated relative to a shallow spacing between the first and second combustor walls, along directions transverse and perpendicular to a streamwise flow direction through the combustor, and wherein a ratio of transverse elongation to shallow spacing is greater than 1.15. However, this shared technical feature does not represent a contribution over prior art, because the shared technical feature is anticipated by US 2022/0412557 A1 (8 Rivers Capital, LLC). 8 Rivers Capital, LLC discloses a combustor (para [0007]) comprising: a combusting chamber having an upstream flame authority (Fig. 2; para [0061], [0069], fuel nozzle cone, 281 a, for produce a flame-stabilizing vortex.); a first combustor wall (Figs. 2, 3A; para [0061], [0063], outer casing, 265, or first ribs, 263.); an opposed second combustor wall (Fig. 2, 3A; para [0061], [0063], opposing outer casing, 265, or second rib.); a plurality of orifices in at least one of the first and second combustor walls (Figs. 2, 3A; para [0060], [0062], diluent stream opening, 255 c, or perforations, 261.); a plurality of fluid feeders feeding one or more of said fuel fluid (Fig. 2; para [0061], fuel gas line, 215.), oxidant fluid (Fig. 2; para [0065], oxidant injector, 285.), and/or diluent fluid, to said plurality of orifices; and a combustor outlet (Figs. 2, 3A; para [0060], combustion outlet, 291.); wherein the first and second combustor walls are transversely elongated relative to a shallow spacing between the first and second combustor walls, along directions transverse and perpendicular to a streamwise flow direction through the combustor (Figs. 2, 3A; para [0061], [0063], outer casing walls, 265, shown in opposite relation with shallow spacing in transverse and perpendicular direction along combustion chamber, 273, at diluent stream openings, 255 c, or outlet, 291... further, adjacent ribs, 263, shown in opposite relation with shallow spacing in transverse and perpendicular direction.), and wherein a ratio of transverse elongation to shallow spacing is greater than 1.15 (para [0060], volume ratio of reaction and dilution chambers is up to 5.).

As the technical features were known in the art, this cannot be considered a special technical feature that would otherwise unify the groups.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/055262

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

Groups I and II therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: **1-13**

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.