

SCALABLE PRESSURE VESSEL, METHOD FOR FABRICATION THEREOF
AND USES THEREOF

5 Field of the invention

The present invention relates to storage and transport of fluids under pressure, such as storage and transport of liquid natural gas (LNG), liquid petroleum gas (LPG), liquid carbon dioxide (LCO₂), liquid hydrogen (LH₂), and in principle any other fluid to be stored at pressure higher than atmospheric pressure.

- 10 Specifically, the invention relates to small, medium, and large sized storage tanks and transport tanks for pressurized fluid based on a principle of repetitive, geometric scalability. Storage tanks and transport tanks must be designed for a specific purpose and application expressed in terms of size, shape and pressure; pressurized tanks are generally referred to as "pressure vessels". Key
- 15 performance parameters for pressure vessel concepts are thus that they can be designed for purpose for a variety of different conditions and applications while providing good performance in terms of safety, weight, cost and space efficiency.

20 Background of the invention and prior art

- When a pressurized fluid is to be stored or transported, several requirements and constraints must be met by the pressure vessel. The pressure vessel must be strong enough to handle the pressure and to sustain dynamic variations of the load on the tank over the operating ranges of the tank. In addition, certain
- 25 geometrical, size or shape related constraints associated with the field of use must be met. For example, a spherical tank or a cylindrical tank may be weight optimal for containing pressurized fluid, but the tank wall thickness can become too large and costly for practical fabrication. Moreover, due to their shape such shell type tanks usually have a very poor utilization of the surrounding space
- 30 such as when employed in a ship structure, under other circumstances when being placed within a confining space. Size limitation related to maximum acceptable shell thickness, shape limitations, need for multiple tanks to be installed for achieving required storage capacity, and space utilization inefficiency represent severe limitations for the use of traditional spherical and

cylindrical shell type pressure vessels.

The current invention has roots going back for more than two decades. “A system for storage or transport of compressed gas on a floating structure” with
5 Norwegian patent NO 319876, granted 2005.09.26, describes how pressurized gas, such as non-refrigerated natural gas under high pressure, can be stored by way of stacks of long sections of standard gas pipeline made of steel. Since the pipe wall thickness depends proportionally on pressure and radius the concept of pressurization without cooling has not become commercially
10 successful due to the required very high steel weight in relation to cargo weight and the inefficient in space utilization for clusters of cylinders. A further step of development was defined in Norwegian patent NO 321892, granted 2006.07.17, describing how bundles of cylindrical pressure vessels can be replaced by a much more compact, uniform, cellular structure. Related patents are NO
15 323091, NO 316958, NO322241 and NO316958.

The patents demonstrated how several forms of cellular structures, such as triangular and orthogonal cellular patterns, provide the same material efficiency as for cylinders. The cellular patterns described were in fact a first case of what may be termed a “lattice pressure vessel”. It was also shown how the outer
20 walls and corners enclosing the internal lattice may have a cylindrical shape providing deformations consistent with the deformations of the internal load bearing structure. Particularly important features of that invention were the in principle unlimited pressure vessel scalability and that the pressure vessel can have any box-like overall shape adaptable to geometric requirements of a given
25 confining space. Due to the principle of an internal load bearing structure, i.e. “a lattice”, to carry the forces of internal gas pressure rather than containing the pressure solely by on outer shell structure. A further development was double-walled box type pressure vessel with internal, lattice type load bearing structure, described in PCT/NO2005/00232, WO2006001711, and US 20070194051 A1.
30 All these inventions may be referred to as the “first generation” of lattice pressure vessels or LPV.

Later, the concept was further developed with a more flexible design for the internal load bearing structure at KAIST (Korea Advanced Institute of Science

and Technology) and described through a series of patents referenced as patent publications WO 2012148154, WO 2014073719, US10145508, WO2006001711 and US2007194051. These patents describe various forms of the outer geometry including rounded side walls, as well as
5 various types of structural components in the internal, three-dimensional load-bearing lattice structure. Notably, these patents do not describe a uniform internal load bearing structure but rather several forms of structural components that may vary throughout the internal space of the pressure vessel. This group of patents are hereby referred to as the
10 “second generation” of lattice pressure vessels and include improvements that make the LPV concept more suitable for moderate and low-pressure applications of pressure vessels. The second generation LPVs initially targeted pressure vessels for liquid natural gas (LNG) and have been implemented as LNG fuel tanks in ships. However,
15 it has later become clear that the technology also has great potential for other important gas containment applications, such as storage of ammonia, liquid hydrogen, liquid carbon-dioxide (LCO₂) and other fluids.

Even though the second generation LPVs represents state of the art in
20 size independent, shape independent and pressure independent pressure vessels, it would be very welcome if significant improvements are still possible with respect to reducing weight, increasing structural efficiency, easier and safer fabrication, and reducing overall cost of fabrication and operation.

25 The objective of the present invention is to provide even more favorable versions of pressure vessels, in particular relating to structural efficiency, total weight, ease of fabrication and overall cost. An important objective of the invention is to contribute towards a more sustainable environment and economy by providing pressure vessels that more efficiently can store and transport
30 gases and fluids and thereby facilitate better use of fuels with lower emissions than traditional oil fuels. Examples are liquid natural gas, liquid hydrogen and hydrogen carriers such as ammonia, and handling and storage of carbon dioxide in the CCS (Carbon Capture and Storage) chain, and more. Such pressure vessel would represent a significant enabler towards the green shift

with a particular potential for better handling of environmentally friendly energy carriers and carbon waste. The international community is at a crossroad regarding developing and implementing climate and environmentally friendly energy solutions. In particular, the international shipping industry is facing new
5 emission regulations and requirements that demand that shipping converts to “no” or “low” emissions fueling or, alternatively, onboard carbon capture and storage of emissions from exhaust. Introduction of carbon tax and demands for cleaner transportation by customers also facilitate the transition toward cleaner ship transport. Along with this, new market opportunities are emerging
10 regarding ship transport of environmentally friendly fuels and liquid carbon-dioxide (LCO₂). Similarly, new on-land infrastructures for dealing with the green transition are also being developed; these also involve storage and transportation of huge amounts of gas under pressure. Accordingly, there will be increasing needs for efficient containment systems that are space efficient,
15 scalable and cost efficient with applications to gases such as low carbon fuels, ammonia, hydrogen and LCO₂. A main goal for the current invention is to provide new and better solutions to these challenges and thereby contribute towards the green transition and a more sustainable economy.

20 Summary of the invention

The present invention meets the objectives by providing a size, shape and pressure scalable pressure vessel comprising an outer pressure shell that is leak-tight for containment of a pressurized fluid during operation, and at least one opening through the outer pressure shell for loading and unloading of the
25 fluid. With reference to a Cartesian coordinate system with an x-axis, a y-axis and a z-axis, the pressure vessel is distinguished in that it further comprises:

- a plurality of internal parallel tension panels (flat plates) oriented orthogonal to the z-axis and being in tension under operation by carrying and balancing pressure on opposing outer pressure shell parts that connect with the periphery of the parallel tension panels,
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- a plurality of internal parallel tension beams oriented parallel to the z-axis and connecting with and being in tension under operation by carrying and balancing pressure on opposing outer pressure shell parts meeting the ends of said tension beams,

- preferably also comprising longitudinal stiffeners inside the outer pressure shell parts connected to the internal stiffened tension panels, wherein the longitudinal internal stiffeners extend in the z-direction,
- 5 - preferably also comprising transverse stiffeners inside the outer pressure shell parts connected to the internal tension beams, wherein the transverse stiffeners extend in the x and/or y direction,
- preferably also comprising intermediary stiffeners connecting longitudinal stiffeners with transverse stiffeners
- 10 - preferably also comprising stiffeners on the internal tension panels, preferably arranged as extending orthogonally in x and y directions.

Preferable pressure vessel embodiments are as defined in dependent claims, in
15 the detailed description or are as evident from the illustrations.

The combination of features described above, in the further description, in the claims and as illustrated, provide in principle pure tension stress only internally in the pressure vessel when subjected to internal pressure, with a minimum of
20 structure, possible to scale and optimise to different pressure merely by adjusting thicknesses of pressure shell plates, internal panels and stiffeners, adjusting tension beam cross area, distance between internal panels, distance between internal tension beams and/or distance between and/or height of internal stiffeners. For many embodiments, including much repetitive structure,
25 for simplification and cost reduction, optimising within wide ranges of pressure can for example be merely by adjusting a distance between internal tension panels, a distance between internal tension beams, and optionally also a distance between internal stiffeners on the outer pressure shell, as will be clear from the following description. The possibility of optimizing the pressure vessels
30 of the invention with respect to weight, performance, and ease of fabrication, is an important feature of the current invention.

The pressure vessel does not have to be a cylindrical or a spherical shell. More preferable, for better utilization of space and easier fabrication, is a box-like containment like an orthogonal hexahedron or cuboid comprising in principle 6

outer surfaces, like a dice, wherein two opposing pressure shell surfaces cross the x-axis orthogonally, two opposing pressure shell surfaces cross the y-axis orthogonally and two opposing pressure shell surfaces cross the z-axis orthogonally. Transition pressure shell surfaces can be included in addition,
5 such as for taking up curvature and double curvature while avoiding stress concentrations at the joining sections between outer planar shell surfaces. Other shapes of the outer pressure shell, and thus the shape of pressure vessel of the invention, can be wedged, skew, polygonal, single curved, double curved, and in principle any other shape, with or without "shave offs" or other
10 irregularities in the shape.

However, the always essential structure, for all embodiments, is the internal load bearing structure inside the outer pressure shell, namely the parallel internal tension panels and the internal tension beams, oriented and arranged
15 orthogonally as defined in claim 1. For many embodiments, comprising stiffeners inside the outer pressure shell, how said stiffeners are arranged and is connected to the always essential internal structure and function together with the always essential internal structure, provide further uniqueness and advantage of the pressure vessels of the invention, as will be duly described
20 and clarified. The essential internal structure takes up pressure between structurally connected opposing parts of the outer pressure shell, by a minimum of structure and weight.

A repetitive, optimized, orthogonal internal structure as defined, allowing for
25 structural adaptations relating to shape, supports and technical installations. Small deviations from this are allowable within the scope and context of the invention, while the advantages over the "second generation" LPVs as described above are still retained with respect to cost and/or weight. Internal tension panels mean in substance flat plate structures, flat within an acceptable
30 margin. Oriented in general orthogonal to the z-axis, means that the panels are in the x-y plane, perpendicular to the z-axis, within an acceptable margin. Internal tension beams, as fully fabricated and installed in operation in the pressure vessel, is a continuous structure in tension, structurally connecting outer pressure shell parts or intermediate structure so as to balance the

pressure on opposing outer surfaces. Internal tension beams are straight and aligned within an acceptable margin of fabrication. Strict geometrical control is essential for providing mainly pure tension internal in the pressure vessel in all three spatial directions, for taking full advantage of the invention.

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Additional openings for access of personnel and pressure equalization, and possibly strengthening structures around the openings, are often included through or on internal tension panels. The distance between internal tension panels is preferably regular and is preferably, but not limited to, any real number within the range 0,6 to 3 m. The distance between internal tension beams is preferably even and is preferably, but not limited to, any real number typically within the range 1 to 4 m. If assuming fixed thickness, cross-section dimension, i.e. fixed structural strength for each element, the required number of internal panels and internal tension beams thereby follows logically from the size and design pressure of the pressure tank. There may be exceptions to the distances indicated above; particularly for very small tanks that can be fabricated without requirement of human access.

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Preferably, all obligatory features, including all obligatory structural members, the orientation and connections thereof, and dimensions, are modelled mathematically for finding an optimal design with respect to weight, strength and external constraints. This includes analytical and numerical modelling of stiffeners with thickness and height or width of the stiffeners, as well as the distance between the stiffeners, and outer pressure shell parts, for optimization for the intended use since unnecessary structure is not wanted and not too weak structure either. Basing the design and fabrication on using limited number of equal or similar structural components enables optimization, simplifies fabrication, and reduces overall cost and is thereby preferable.

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The detailed description provides enabling disclosure and presumably clear understanding of the meaning, purpose, and effect of the features.

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The invention also provides a method for fabricating the pressure vessel of the invention, distinguished by comprising the steps to fabricate and join the

following structure or parts or preassembled combinations thereof:

an outer pressure shell that is leak-tight, for containing a pressurized fluid during operation, including to fabricate or arrange at least one opening through the outer pressure shell for loading and unloading of the fluid,

5 a plurality of internal tension beams,

a plurality of internal tension panels, wherein each internal tension panel comprises openings or connecting structure for internal tension beams, wherein the number and positioning of said openings or connecting structures correspond to the number and positioning of internal tension beams, and

10 with reference to a Cartesian orthogonal x-y-z coordinate system:

to arrange the plurality of internal tension panels orthogonal to and along the z-axis and structurally connect the internal tension panels to outer pressure shell parts that connect with the periphery of the internal tension panels,

15 to arrange the plurality of internal tension beams or sections thereof in the z-axis direction, through corresponding openings or to connecting structure for internal tension beams in the plurality of internal tension panels, structurally connecting the internal tension beams between opposing outer pressure shell parts meeting the ends of said internal tension beams.

20 Although the invention can be fabricated by way of conventional production methods, such as block assembly as commonly used in shipyards, it also provides an alternative method of fabricating a pressure vessel according to the invention, hereby referred to as the "panel method", distinguished by comprising the steps to fabricate and join the following structure or parts or preassembled combinations hereby described for a case where the bottom and top panels are
25 parallel to the x-z plane, the side panels are parallel to the y-z plane, the internal tension panels are orthogonal to the z-axis, and the tension beams are parallel with the z-axis, as illustrated in Figure 1:

the fabricated stiffened bottom panel is completed in one piece or
30 assembled from several sections and laid out on supports that preferably are positioned consistently with supports for the LPV in its final use,

the fabricated stiffened tension panels are each completed in one piece or assembled from several sections and sequentially positioned and connected and fastened to the bottom panel while preliminary lateral support is provided, if

necessary,

the neighbouring tension panels are connected and fastened with the associated prefabricated tension beams which are either placed and fastened as sections in the designated positions in the opening space between the neighbouring tension panels or sections of tension beams are inserted through openings in the tension panels to which they then are fastened,

the end panels, the side panels and the top panel are each prefabricated in one piece or are prefabricated and assembled from several sections and fastened and connected with side panels in such a way that all connecting parts are joined together to provide a pressure vessel that is leak tight and complete in accordance with the description of the invention,

the sequence of assembly the parts described above may depend on factors such as available fabrication facilities such as welding robots and cranes, accessibility for machines and personnel, inspection and testing, equipment to be installed in the pressure vessel, and the like.

Further preferable method embodiments are as defined in dependent claims, in the detailed description or are as evident from the illustrations. Other methods of fabrication and assembly not directly described here are feasible and included in the scope of the method claims but may include adjustments depending on the fabrication site and facilities. For example, when very large tanks are to be transported and/or placed onboard a ship or floating facility, the totality of the pressure vessel may be fabricated in several large sections and finally assembled at the final installation site.

As a suggested reference classification, small sized pressure vessels are in general of size in the range 0,5 to 10 m³, medium sized pressure vessels are in the size range 10-500 m³ while large pressure vessels have the size above 500 m³. The pressure vessel of the invention can easily be scaled to any of said sizes.

The invention also provides use of the pressure vessel of the invention, for storage and/or transport of liquid natural gas (LNG), liquid petroleum gas (LPG), liquid carbon dioxide (LCO₂), liquid hydrogen (LH₂), liquid ammonia, or in

principle, any other fluid that should be stored at pressure higher than atmospheric pressure, or any fluid that should be stored and/or transported more cost effectively.

- 5 The current invention represents a significant improvement over previous inventions associated with cellular and lattice type internal load bearing systems. This particularly relates to modularity, repetitiveness and simplicity of design, the capabilities for structural optimization, and ease and efficiency of fabrication. Multiple studies have confirmed that the pressure vessel of the
- 10 invention is at least 20-30 % less expensive to build, weights at least 20 – 30 % less and is much easier to fabricate than earlier prismatic type pressure vessel designs, which already are favorable compared to other known pressure vessels, all of which is surprising and non-obvious. Accordingly, studies have revealed that the current “third generation” of LPVs can provide as much as 20
- 15 to 25 or 30 percent savings in both of weight and cost compared with the previous generations of LPVs. Improved health, safety and environment (HSE) is also provided, by safer and easier fabrication, and reduced material consumption.

20 Figures

Figure 1 illustrates an embodiment of a pressure vessel of the invention with x-y-z reference coordinate system.

Figure 2 illustrates a pressure vessel of the invention completed with an external thermal insulation system.

- 25 Figure 3 illustrates corner solutions between outer pressure shell panels.

Figure 4 illustrates joining parts between internal tension panels and stiffened outer pressure shell side and top panels.

Figure 5 illustrates sections of stiffened, internal tension panels with internal tension beams and manholes.

- 30 Figure 6 illustrates positioning of support system that allows for thermal contraction and expansion.

Figure 7 illustrates how the lean LPV concept may be adapted to a wedge type tank shapes.

Figure 8 illustrates further adaptations to skew sides and composed geometries

between skew parts and regular box shapes.

Figure 9 illustrates first steps of assembly by the proposed panel assembly method.

Figure 10 illustrates how tension beams may be inserted between internal
5 tension panels and attached to these.

Figure 11 illustrates further steps of assembly by the panel assembly method leading to full enclosure of the entire pressure vessel.

Figure 12 illustrates that the invention also can be assembled by alternative methods such as block type assembly methods.

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Detailed description

Reference is made to Figure 1, illustrating somewhat simplified a preferable embodiment of a pressure vessel 1 of the invention with a defined, associated Cartesian x-y-z coordinate system. For descriptive purposes the reference
15 coordinate system has x and y coordinates parallel to the outer shell end panels 5, (outer shell means outer pressure shell, parts thereof are also termed end panel, side panel, top panel or bottom panel), and the internal tension panels 4 indicated inside the outer pressure shell 2. The two outer (pressure) shell side panels visible, one in the x-z plane (top) and one in the y-z plane (side), are
20 indicated with 6. Further, the outer (pressure) shell single curved joining sections are denoted with 7 and the eight outer shell doubly curved corners are marked with 8. It is to be noted that the y-axis may not necessarily be oriented in the same direction as the direction of gravity; for instance, the x-y plane could be horizontal whereas the z axis could point in the vertical direction.

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A more extensive illustration of an embodiment of the invention is shown in Figure 2. The pressure vessel 1 is shown comprising an outer shell barrier 2 inside which pressurized fluid is contained during operation, and at least one opening with pipe connection 10 through the pressure shell for loading and
30 unloading pressurized fluid, here extending from a so-called pipe dome structure 11. 9 indicates lateral support attachments on the shell surface. For clarity, one end panel of the pressure shell, and parts of top, bottom and sides of the pressure shell towards said end panel, have been removed to reveal the internal structure of the pressure vessel. The internal structure comprises a

plurality of parallel internal tension panels 4, arranged for taking tension forces in the x and y spatial directions, further comprising a plurality of parallel internal tension beams 12, arranged perpendicular to the parallel panels for taking tension in the third spatial direction z. Figure 2, shows that the parallel tension

5 beams 12 connect continuously and aligned through and attached to the parallel panels 4. This may be done by way of premade passage openings 13 in the tension panels, one opening in series for each panel for each beam; however, usually more preferable, sections of the internal tension beams can be attached directly to the surface or to stiffeners of the tension panels without

10 making openings in the internal tension panels, for example as illustrated in Figures 10a and 10b. This requires precise positioning of the attachment parts to avoid misalignment and unwanted bending stresses. The internal tension beams, as completed, are continuous and structurally connected and aligned from one outer end panel 5 to opposite end panel of the pressure shell, taking

15 up and balancing pressure induced tension between said pressure shell end panels 5.

The parallel, internal tension panels 4 are fastened on all sides to the outer pressure shell panels 6, thereby ensuring that the internal pressure on opposite

20 outer pressure shell panels 6 is transferred and balanced by way of tension in the tension panels. The stress in the internal tension panels in the x and y directions originating from the internal gas pressure is equal regardless the relative external dimensions of the prismatic tank; the stress in the tension panels only depends on internal pressure, distance between tension panels and

25 thickness of the tension panel including possible stiffeners. Equal stressing of the tension panels in its two directions implies that the plate load bearing capacity is optimally utilized. A key result of the present invention is that the thickness and stress of the internal load bearing structure is not dependent on the overall size of the tank, only on pressure and distance between tension

30 panels. A noticeable consequence is accordingly that any degree of scaling in the three spatial directions is feasible simply by making the tension panels larger in size and their number larger. This is clearly a major difference from traditional spherical and cylindrical pressure vessels for which the shell thickness is directly proportional with the size of the radius of curvature. In

essence, the invention describes a modular system with equal modular units that can be extended repetitively in the x and y directions and also extended repetitively in the z direction to provide a box-like pressure vessel of any size.

- 5 The outer pressure shell or “skin” 2 is the barrier for internal fluid pressure and as such takes the internal pressure on the inside of the outer pressure shell by the internal tension panels, in x and y direction, and by the internal tension beams in the z-direction, thereby balancing internal pressure between opposing pressure shell parts, here following the coordinate system of Figure 1. Clearly,
- 10 internal pressure leads to bending of the outer panel structures since the pressure load must be transferred from the inside of the shell 2 onto the adjacent tension panels, and likewise for the internal tension beams. The problem of pressure transfer to the internal tension panels is efficiently dealt with by introducing longitudinal stiffeners or ribs 14 in the z-direction spanning
- 15 between the tension panels whereby the combined strength and stiffness transfer provides the required load bearing capacity. For simplicity, Figure 2 only shows such stiffeners associated with the modular positions of the tension beams, whereas stiffeners 14 will in the rule be introduced also in between these positions as indicated in Figure 1. The overall dimensions of the
- 20 longitudinal stiffening and plate thickness of outer shell panels depend only on internal pressure, distance between internal tension panels, and distance between longitudinal stiffeners, and not on the overall size and dimensions of the pressure vessel itself. Again, this differs principally from traditional shell type pressure vessels where the size of the tank expressed in terms of radius
- 25 determines the shell thickness and thereby becomes a severe, practical limitation to scaling up the size of the pressure vessel.

- External stiffeners are possible, in addition or instead of internal stiffeners, but expectedly not preferred for cryogenic, cold or warm fluid operation since they
- 30 can form heat bridges through outer insulation and increase the total outer space required for the LPV.

The “lean” and simple geometry of the invention provides many advantages. It implies that it is possible and preferable to optimize the load bearing geometry

- and weight of a tank for a given pressure merely by varying distance between internal tension panels, distance between stiffeners, outer pressure shell plate thickness, height of stiffeners and thickness of stiffeners, and internal tension beam dimensions and distribution. Notably, the total amount of material (sum)
- 5 required for the tension panels is in principle independent of the distance between these, however, there will be a minimum plate thickness for the tension panels and the stiffening clearly depends on internal tension panel spacing. The spacing between tension panels is preferably chosen to be of the same order or nearly the same as the distance between tension beams. For large tanks such
- 10 distance will typically be between 0.6 and 3 meters where the minimum distance is associated with providing human access. As described, unidirectional stiffening of the outer shell panels in the z direction is optimal since additional, perpendicular stiffening for the spans between tension panels will have very little effect on the local load bearing capacity. The stiffening of the
- 15 end panels may be similar in the x and y directions or the stiffening on the end panels may be denser in one direction than the other. In sum, these matters distinguish the current invention significantly from prior art.
- 20 Figure 3a illustrates that the corners between joining external panels are rounded with quarter-cylinder geometry 8 with radius indicated as R. The reason for this smooth transition rather than sharp corners is to avoid severe stress concentrations. The radius R may be chosen to be about equal or of the same order as for the distance between longitudinal stiffeners; however, it can
- 25 also be chosen to be significantly larger, particularly for large size tanks for which high deformational flexibility at the corners may be preferable. In most embodiments there is no need for stiffening on the cylindrical sections adjacent to the end panels; however, there are cases where curved stiffening will be applied on the cylindrical sections, particularly in connection with system lines
- 30 associated with the positions where the tension beams meet with the end panels. There may also be transverse stiffening applied to the sides of these cylindrical sections where the longitudinal stiffening is discontinued next to the

cylindrical sections.

Logically, and as seen in Figure 3b, 1/8 spherical and doubly curved geometry with same radius R as for the cylindrical corner sections is implemented at the 8
5 corners where three outer panels meet.

The outer shell end panels 5 are connected to the external side panels and anchored to the opposite end panel by means of the internal tension beams 12 which balance pressure on the opposite pressure shell end panels, see Figure
10 2. Longitudinal stiffeners 14 on the external side panels are extended to the end panels such that they form a grid of crossing stiffeners. The anchoring of internal tension beams 12 is strengthened by a grid of strong stiffeners 15 that connect between the positions of the incoming tension beams. Intermediary longitudinal stiffeners 14 from the side panels extend to a cross-grid inside the
15 outer shell end panels. In some embodiments of the invention the stiffening on the end panels only requires plate stiffening in one direction spanning the stronger stiffeners 14 in the other direction, as illustrated in Figure 1.

The stiffeners on the inside of the pressure shell may be simple plates with
20 uniform beam height, or plates with welded flanges, or having variable beam height, or being other types rolled or extruded beam profiles. With reference to the defined global x-y-z system these stiffening beams run in the z-direction inside the walls in the x-z planes and y-z planes. In all cases these beams are continuously welded or joined otherwise to the adjacent outer pressure panels.

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The internal stiffener cross-grid on the end panels may in preferred cases consist of some stiffeners with greater stiffness and strength than others where the stronger stiffeners are positioned where the tension beams attach to the end panels. In some cases, particularly for small tanks, it may be sufficient for the
30 end panels to employ stiffening in only one direction between the cross-grid of stronger stiffening connecting with the attached tension beams.

The height and thickness of stiffeners and the distance between the stiffeners are subject to analytical and mathematical optimization and depends on the

further structural elements, the operation pressure of the pressure vessel and the material used. Some typical examples for a medium to large sized pressure vessel may be panel, cylindrical corner, stiffener and tension beam plate thicknesses of 6 to 35 mm, stiffener and tension beam heights/widths of 200 to 1000 mm, distance between stiffeners of 300 to 1000 mm, and distance between tension panels and tension beams of 600 to 4000 mm. Note that these quantities are interconnected and optimized with respective size, shape, pressure and material properties. Stiffeners may have variable heights and/or flanges.

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Notice that the term internal tension beam is used, irrespective if it is a single beam, sections of beams that are joined, or/and includes intermediate structure between beams sections, such as structure on internal tension panels, such as stiffeners or extended stiffeners used for connection in tension through the internal tension panels, such as structure including seats extending through to opposite sides of the tension panel, for receiving and joining tension beam sections on opposite sides, all of which, in any combination, provide tension in the tension beam under operation balancing out pressure as described, without any significant bending disturbing the tension.

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The internal tension panels are not fluid-tight but rather contain a multiple of openings to ensure that the liquid level is the same across all sections between internal tension panels and the gas pressure remains the same across all sections, see Figure 4. Rat-hole type openings 16 in the panels should preferably be implemented along the connections between all internal tension panels 4 and the surrounding outer shell enclosure 2 as shown in the figure or they could be separate, round holes at a small distance from the joints between the tension panels and the outer shell. A particular objective with these edge openings is to ensure that fluid or gas does not get trapped when emptying the tank. Further, larger openings 17, such as man-holes type access openings, are preferably implemented in all of the internal tension panels. At least one such opening should be implemented per tension panel as they are of importance to provide access for people and machinery during construction assembly and during inspections and repair operations. Typical dimensions of manhole type

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openings are 400 to 600 mm. The effect of weakening of the tension due to these cut-outs can be compensated by common type edge reinforcement of the openings as is common in many types of structures.

- 5 Figure 5 provides some further insight into the matter of internal tension beams that carry most of the pressure loading on the external end panels and must be dimensioned accordingly. A general principle is that the cross-section of the tension beam should preferably be double-symmetric to avoid eccentricities and, as result, occurrence of bending stresses. Double-symmetric cross-
- 10 sections also have the advantage of being well suited for connecting with stiffeners on the tension panels. Figure 5a show tension beams with so-called X-type cross-section 18; this may be referred to as an X-beam. Such X-beams may be fabricated by rolling, extrusion, welding of plate strips or joining angle-type cross-sections. The figure also shows possible manholes 17 for access
- 15 and passage between internal tension panels. The dotted lines 20 indicate natural locations for tension panel stiffening that can be one-sided or two-sided relative to the plate part of the panel. Similarly, Figure 5b show an alternative embodiment where the tension beam has a square, tubular cross-section 19. This solution is also easy to implement; however, particular attention should be
- 20 paid to avoid trapped fluid in hollow cross-sections. Many other alternatives may be considered including solid round bars, pipes, I-beams and heavy flange beams that are also feasible with the current invention. The X-beams perfectly matching the orientation of crossing stiffening in x and y direction, are preferable, since they can be welded directly to crossing stiffeners without any
- 25 intermediate structure in between and will not trap fluid.

- Internal pressure in pressure vessels implies elastic expansion whereas cooling of the stored fluid implies contraction. For a large tank the expansion or contraction can be significant. For simplified illustration, assuming a thermal
- 30 coefficient of expansion equal to $14 \cdot 10^{-6}$ per degree K the case of 200 degrees cooling gives a contraction of 2.8 mm per m. For a large tank this case may mean several cm of actual contraction from one end to the other. Clearly, the support must be designed for sliding to avoid severe stressing due to external constraints against motion. Fortunately, well-proven technologies are available

for sliding type supports, for example use of laminated woodblocks that additionally also provide some degree of thermal insulation. Woodblock supports have been extensively used for type A and Type B (international gas code classifications) prismatic tanks without significant internal pressure. Such known support solutions can easily be implemented for the current invention. Figure 6 illustrates an example of support system for the current invention where woodblocks 21 are placed at a number of locations under the internal tension panels. These locations represent particularly strong and stiff structural parts of the pressure vessel, such as being centred under tension panels with locally further strengthening. Figure 6a shows a view from the side whereas Figure 6 b shows a view from below. The double arrows indicate that the supports have a guidance that allows sliding only in the direction of the double arrows, The support in the middle 22 is a fully fixed support. Given significant cooldown of the pressure vessel the contraction, and expansion, at all other support points is constrained towards the fixed support 22.

The simple, faceted geometry of the invention with rounded corners or sides makes it suitable for applying thermal insulation for pressure vessels with a cold internal fluid. Combination of pressurization and cooling is employed for many fluids such as LNG, LPG, LCO₂, ammonia and LH₂. Well proven insulation systems for A and B type tanks are easily available, such as foam block type and spray-on foam systems. Thermal insulation of liquid hydrogen at temperature -253 °C (20 K) is particularly challenging because it requires vacuum insulation to avoid freezing of air or gas in the insulation layer. The embodiment of pressure vessel 1 of the invention illustrated in Figure 2 also comprises a vacuum insulation system with porous insulation blocks 23 with gaps between 24 attached to the outer shell surface 2 of the pressure vessel. A continuous, flexible, air-tight membrane 25 is attached to the outside of the insulation blocks where the membrane has corrugations 26 in two directions allowing for significant contraction due to compression when the inner pressure vessel is cooled down. The geometry of the corrugations is unique in that the compression at the corrugations and their crossing points can take place elastically without plastic yielding stresses in the membrane. The insulation system includes at least one opening and coupling to a vacuum pump for

providing vacuum in the insulation. The vacuum insulation is fully scalable, as is the pressure vessel of the invention. Further reference is made to patent publication WO 2022050848, the contents of which is incorporated herein by reference.

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For very flat tanks for which the height is very much smaller than the two other external dimensions of the tank a preferred solution may be that the side and end walls degenerate to be pure cylindrical surface without flat parts. Still, tension panels and longitudinal stiffening of the top and bottom panels are

10 applied as described.

Although the geometry of a pressure vessel of the invention so far has been referred to as a box-like tank with rounded corners or sides with a repetitive, uniform load carrying structural system inside, the invention allows for other shapes that can better fit an irregular surrounding space, such as holds inside a ship where the space designated for the tank has walls that are oriented at an angle in relation to the orthogonal reference coordinate system. Figure 7a shows a “wedged” tank where the bottom panel 27 has a slope in relation to the horizontal plane. For simplicity the figure does not show the rounded corners or the cylindrical parts

20 between outer flat panel parts. As shown in Figure 7b, also this case can be dealt with using the regular internal load carrying system described earlier with tension panels 4 and tension beams 12. One obvious problem arising for the case shown is that the lower row of tension beams 28 must be terminated when they reach the skew bottom panel, see Figure 7c. Although this connection will not be described in detail here because it depends on the specific case, it turns out this problem can be dealt efficiently provided the connection point to the outer panel lies within the proximity of a tension panel.

30 Figure 8a shows a case where two outer side panels 29 are oriented at a skew angle in relation to the orthogonal reference coordinate system. Clearly, the same problem with connected tension beam as described for Figure 7c can occur for the skew sides; this can be dealt with in the same way as described above. Figure 8b shows a case with three skew

outer panels 27 and 28, and the principle of solution remains the same. Finally, Figure 8c shows a tank geometry that consists of one part that is box-like connected with one wedged part with three skew sides.

Combining the box solution with a wedged part as in Figure 8b is rather
5 straight-forward. This shows that even though the main principle of the invention is that the internal load carrying part of the pressure vessel is fully regular, it is feasible to design for tank shapes that can be irregular and thereby can fit into any given, constraining surrounding space.

10 A key feature of the present invention is that it implies high repetitiveness and is conducive to structural optimization. In most pressure vessel cases the gas pressure is the dominating load component whereas the passive, gravitational (“hydrostatic”) liquid pressure on the tank walls is normally much smaller. The side walls in relation to the vertical direction can thus be optimized for gas
15 pressure plus gravitational fluid pressure, whereas top plate can be optimized for gas pressure and the bottom for gas plus gravitational pressure. For some applications, such as tanks onboard ships, it may also be necessary to account for additional pressures contributions from pressures generated by motion, e.g. ship roll, or accidental load conditions. In all cases it may be a benefit to keep
20 the geometry and spacing as repetitive as possible for ease of fabrication. Even more important, the extensive repetitiveness allows for efficient structural optimization where the key variables are distance between internal tension panels and tension beams, plate stiffener spacing and dimensions or thickness thereof. The primary optimization parameter or objective function will normally
25 be tank weight and material cost whereas it is also possible to include parameters relating to cost and ease of fabrication, such as total length of welding.

In some embodiments, it may be preferable to add stiffening to the internal
30 tension panels, to reduce their flexibility in relation to variable pressure on the two sides, for instance, from dynamic motion of tank and fluid onboard a ship. In such cases the stiffening should preferably align with the positions of the

tension beams crossing the tension panels.

- Further, support for personnel, ladders and platforms can preferably be attached to or fixed onto the panel stiffening and tension beams. Said structures
- 5 for easy access and improved work positions for personnel can be permanent inside the pressure vessel or employed primarily during the construction phase.

- In addition to playing an important structural role the internal tension panels play a significant role in reducing rapid fluid motion and sloshing when applied for
- 10 transport purposes. This is particularly important for large tanks onboard ships. In fact, the current tank geometry with tension panels practically eliminates fluid sloshing and thereby also reduces the risk of fatigue and crack growth significantly.

- 15 The parallel panels are preferably repetitive and identical panels. Depending on the size of the tank the panels may be made from one steel or metal plate, or by joining several plates together by welding. Very large internal tension panels may be assembled from several sections and joined during the overall assembly process of the tank. Also, very large side panels and end panels may
- 20 be assembled by joining sections by welding during assembly.

- The tank will in most cases be supported on multiple support blocks that are positioned in a way that is consistent with the location of the tension panels and structural outline of the underlying structure, such as a stiffened ship deck.
- 25 Normally, wood blocks that provide fixed or sliding support are used for thermally insulated tanks. Additionally, lateral supports at the sides and at the top panel can be employed to provide lateral stability during normal and accidental load conditions such as forces during collisions, grounding, heeling, and flooding of surrounding compartments for tanks onboard ships. Since
- 30 supports introduce concentrated forces onto the outer and inner panels additional strengthening of the adjacent parts can be introduced without significant modification of the overall design concept of the invention.

The tank of the invention can be made with any material suitable in terms of

strength, joining, assembly and usage requirements. For most applications it is foreseen that a type of carbon steel or alloyed steel, such as low temperature stable austenitic steel, may be preferable. However, other materials or metals may also be employed in connection with special requirements, such as use of

5 aluminium for low weight. The chemical properties and temperature of the pressurized fluid also play a decisive role for choice of material; for instance, for containments for liquified gases such as liquid natural gas (LNG), liquid petroleum gas (LPG), liquid ammonia, liquid carbon dioxide (LCO₂), and liquid hydrogen (LH₂). The international gas code (IGC) sets specific requirements for

10 approval of tank materials depending on temperature, chemical composition, and design pressure. The code requirements may also extend to use of specific welding techniques and weld testing, and to heat treatment of the welded tank assembly. Requirements may also extend to maximum plate thickness. Final approval normally requires pressure testing. Unlike for traditional spherical and

15 cylindrical shell type pressure vessel the current concept provides size scalability without increase of material thickness.

Pressure vessels of the current invention may be fabricated by specialized pressure vessel manufacturers or, particularly for large ship tanks, by shipyards

20 and offshore yards that have necessary qualifications and certificates.

Preferably, structural parts, with or without stiffeners, and any additional structure, may to a large extent be prefabricated by automated cutting and by welding or other joining method feasible for automation, and preferably using fixtures or jigs for holding prefabricated components or parts in position before

25 or during joining in the pressure vessel. Ladders and work platforms or support structure for use during the assembly or being of permanent nature for later inspection, can easily be supported by or attached to the regular tension panel, tension beam and stiffener system, temporarily and/or permanently.

30 The pressure vessels of the invention are fully scalable with respect to pressure. However, most embodiments will not have to exceed 2 MPa (20 atm. or barg) as design pressure, often the design pressure is lower, seldom higher.

Traditional ship building methods are usually based on a so-called block

assembly principle in which three-dimensional structural parts are prefabricated and placed sequentially and joined with its neighboring blocks to make up the total structure. The current invention is comprised only of repetitive components of following types; external side panels, also termed outer shell panels, including bottom panel, side panels and top panels, and outer end panels; internal tension panels, and internal tension beams. This concept implies that the prefabrication by parts comprises internal panels or sections of internal panels, and internal tension beams or sections of internal tension beams, including outer pressure shell parts and/or internal stiffeners or parts thereof, or not. Although the block assembly principle may be suitable for some tank fabricators of the current invention a rather unconventional approach, here denoted "the panel method" is hereby proposed and may be preferable. Figure 9a shows a first step where the bottom panel is prefabricated in one or several sections which are laid out on preliminary supports 30 and joined. Since this is mainly a flat, regular, stiffened plate it is feasible to join very large plate sections and use extensively robot welding.

Figure 9b shows next steps in which prefabricated stiffened tension panels 4, or sections of tension panels, sequentially are lifted into place and attached to the bottom panel. Clearly, preliminary, lateral supports will be required in the initial phase of this assembly process. The placing of the tension panels includes that they are connected to their neighbours with tension beams 12. This can essentially be done in one of two ways as shown in Figure 10: (a) sections of tension beams 31 corresponding to the space between neighbouring tension panels are accurately positioned and welded to the stiffened tension panels, or (b) sections of the tension beams 32 are inserted through corresponding openings in the tension panels with the same cross-section as the tension beams and thereafter welded to the tension panel. Approach (a) is in the rule preferable for practical reasons while it requires good accuracy to ensure that the tension beam sections are correctly aligned. Figure 10a indicates by an arrow how a section of tension beam 30 can be inserted between tension panels and accurately placed on supports, such as brackets 33 or other forms of strengthening and position guidance, and thereafter welded to the stiffeners of the tension panels. Approach (b) may have some disadvantages in that the

tension panels with stiffeners will have to be cut open and the threading of tension beams through narrow openings may be difficult to carry out in practice. Alternatively, continuous sections of tension beams may be inserted in a two-step process in which the tension panels are horizontally sectioned at the

5 crossing with the tension beams and placed from above into cut, fitted openings in the tension panel for the lower half section of the tension beams. Following this, a next layer of tension panel with fitted openings for the upper part of tension beams may be placed and fixed on top of the tension panel section and tension beam below.

10

The next stages of the proposed assembly process are designed for easy access for people and machinery, such as welding robots and testing equipment combined with that internal lattice of tension panels and tension beams provide a continuous scaffolding for such purpose. Figure 11a illustrates

15 further steps in the proposed assembly process where prefabricated end panels may be attached to the bottom panel and to the lattice grid as whole pieces or as end panels sections. This process may include attaching extra stiffening and reinforcements next to the end panels. Having openings from the sides provides and easy access for people and machinery. Figure 11b show further steps that

20 lead to full enclosure of the lattice pressure vessel. This process implies attachment of prefabricated side panels and top panels. For large tanks it may be necessary to carry out this assembly by subsections of the full panels while letting at least one panel section being open to the very last in order to provide internal access. The sequence of this process will depend on what gives best

25 access and what provides the best accuracy and precision.

Figure 12 shows an example of a prefabricated three-dimensional substructure representing a part of the internal load bearing structure where 33 may be termed "a block". The size of such structure may typically depend on cranes

30 and other equipment available at the production site. A block can also include parts of the outer panel structure. Thus, the entire pressure vessel may alternatively be assembled from blocks.

Variations of the method described are feasible considering size of the pressure

vessel, and deformations and tolerances of parts associated with handling and welding. It is evident that the work can include prefabrication by automated cutting, forming, and joining techniques such as robot welding. The proposed assembly procedure allows for personnel and machinery to work inside the
5 structure during assembly; this results in a far easier fabrication process than for earlier prismatic pressure vessel designs. The quantity of materials used is also reduced, and many difficult fabrication steps have been eliminated or made much easier. Very large plate sections, such as large, rolled steel plates from the manufacturer, can be used for the various panels; this reduces the amount
10 of welding work and reduces the possibility for crack formation.

The cost of fabricating a complete pressure vessel of the invention is typically 20 to 30 % lower than for prior art prismatic pressure tank designs, such as what has been referred to as the "second generation" lattice pressure vessels.
15 The efficient scalability with fully repetitive geometry even makes it weight competitive with traditional cylindrical and spherical pressure vessels because it can replace a battery of traditional pressure vessels with a single prismatic pressure vessel according to the invention. In some applications the prismatic space efficiency can imply that the fluid cargo capacity onboard a ship can be
20 doubled for a given, surrounding storage space, such as for low density fluids such as LH2 and LNG. The resulting weight of a pressure vessel of a specific size is also reduced by typically 20 to 30 % allowing for more cargo or load. The total monetary advantage is thus very significant, and the result is facilitating the shift to a more sustainable economy and enabling the transporters using the
25 pressure vessels of the invention to achieve an advantage both with respect to economy, energy efficiency, and reduced impact on environment and climate.

Summary of advantages of the invention

Based on foregoing descriptions the following unique properties are associated
30 with the current invention, partly as separate features, partly by combination of features, and can be summarized as follows:

1. Shape flexibility: The pressure vessel may have a rounded corner, box-like (hexahedron) shape with any ratio of dimensions in the three spatial

directions.

2. Uniformly scalable: The fully repetitive structure of the internal and external parts of a pressure vessel according to the invention implies that very large tanks can be designed and fabricated with the same dimensions of the basic components as for much smaller tanks. This implies great savings in the design and manufacturing processes.
3. Adaptable to various pressures: A design according to the invention is fully adaptable to various pressures, such as from 2 to 30 barg and beyond, by means of specifying only a few design parameters such as outer shell and tension panel plate thickness, distance between internal tension panels, stiffener dimensions, and distance, and tension beam dimensions.
4. Weight and cost optimization: The fact that the design involves only a low number of design parameters makes it feasible to carry out structural optimization by way of mathematical optimization methods or simply by systematic variation of design parameters whereby stresses can be estimated by simple formulas and compared with design code requirements. The objective function of the optimization may include parameters such as material weight and cost, and fabrication cost based on parameters such as welding lengths.
5. Shape flexibility: The invention allows for shape adaptations beyond the three-dimensional, orthogonal, box-like geometry by which outer, enclosing stiffened panels can be arranged such that the tank may have a shape with one, two, three or more skew walls in relation to the orthogonal reference coordinate system. Further, a tank of the invention may be composed of combinations of parts that have different shapes including combinations of orthogonal boxes skew box parts.
6. Sloshing: The regular pattern of internal tension panels at distance typically from 0.6m to 3m efficiently dampens dynamic, internal fluid motion and sloshing during transportation, such as onboard ships. No particular concern is associated with partial filling of liquid. This has great benefits for reducing crack growth and increasing fatigue life and it provides better operation flexibility by allowing partial filling.
7. Thermal insulation: The simple geometry with large, external flat panels

makes it easy to insulate with convention insulation techniques. It also makes it easy to employ recent inventions for vacuum insulation which are thermally very efficient and enables storing cryogenic fluids such as liquid hydrogen.

- 5 8. Supports: Conventional support systems that provide thermal insulation and allow for thermal or pressure expansion and contraction are easily employable with a pressure vessel of the invention.
9. Fabrication: The simple, repetitive geometry of a pressure vessel of the invention lends itself to automatized production methods such as cutting and welding by robots. Large parts of the overall tank, such as outer
10 panels, internal tension panels, and tension beams can be prefabricated fully or by sections before assembly.
10. Alternative assembly method: Manufacturing of structures, particularly within the shipping and offshore industries, are usually based on
15 assembly of three-dimensional substructures, called blocks, that are joined together to provide the final, total structure. Such process can also be used for the current invention. Beyond this, an alternative assembly process is developed for the current invention referred to as “the panel method”. This technique implies that prefabricated outer panels, tension
20 panels, and tension beams, or sections of these, are assembled in a sequential way which provides easy access for people and machinery during most of the assembly process while parts of the outer shell are kept open as long as possible.
11. Accessibility within the tank space: The open lattice geometry of the
25 invention provides a type of skeleton or scaffolding that enable easy access to form a during and after fabrication for purposes such as welding, inspection, testing and repair. Ladders and platforms can easily be attached to the lattice skeleton on temporary and permanent basis. Openings in the tension panels enable movement from one to another
30 compartment between tension panels.
12. Enabler for the green transition: The so-called green transition for climate and environment, to which most countries are highly committed, are faced with a series of highly challenging technical problems for which the current invention may provide some significant solutions. Some

examples: (a) The invention may be used for efficient transportation and storage of lower-carbon fuels such as LNG and LPG. Although these energy fuels are not ideal, they may provide intermediary solutions in the time period towards using entirely clean fuels. (b) The invention may be used for efficient transportation and storage of no-carbon fuels such as liquid hydrogen and ammonia. Transport and storage of liquid hydrogen will require very large tanks to enable an efficient infrastructure for the future hydrogen society. (c) Carbon capture, utilization and storage (CCS/CCUS) is deemed to become part of the solution for reducing carbon emissions to the atmosphere. Many millions of tons of CO₂ must be dealt with on a yearly basis to make any sensible impact. Liquid CO₂ requires cooling and significant pressurization, and the current invention provides a fully scalable solution for transportation and storage for LCO₂. The pressure vessels of the invention are very different from the conventional pressure vessel technology using cylindrical pressure vessels. For LCO₂ a typical range of pressure is 8 to 30 barg or higher, which for cylinders limits practical tank size and diameter significantly. Need for large storage volumes thereby requires many more pressure vessels than for the present invention, implying higher cost and less safety.

25

CLAIMS

1.

5 A pressure vessel (1) comprising an outer pressure shell (2) that is leak-tight for containment of a pressurized fluid during operation, and at least one opening (10) through the outer pressure shell for loading and unloading of the fluid, and with reference to a Cartesian coordinate system with an x-axis, a y-axis and a z-axis,

characterized in that the pressure vessel further comprises:

- 10 - a plurality of internal parallel tension panels (flat plates) (4) oriented orthogonal to the z-axis and being in tension under operation by carrying and balancing pressure on opposing outer pressure shell parts (6) that connect with the periphery of the parallel tension panels,
- 15 - a plurality of internal parallel tension beams (12) oriented parallel to the z-axis and connecting with and being in tension under operation by carrying and balancing pressure on opposing outer pressure shell parts (5) meeting the ends of said tension beams,
- 20 - preferably also comprising longitudinal stiffeners (14) inside the outer pressure shell parts connected to the internal tension panels, wherein the longitudinal internal stiffeners extend in the z-direction,
- 25 - preferably also comprising transverse stiffeners inside the outer pressure shell parts connected to the internal tension beams, wherein the transverse stiffeners extend in the x and/or y direction,
- preferably also comprising stiffeners on the internal tension panels, preferably arranged as extending orthogonally in x and y directions.

2.

30 The pressure vessel of claim 1, wherein the geometry of the outer pressure shell surface consists of planar panels and single and doubly curved pressure shell parts connecting the planar panels,

- wherein the single curved pressure shell parts consist of a multiple of single curved pressure shell parts with radius of curvature R , connecting planar panels at sides where two planar panels meet,
- wherein the doubly curved pressure shell parts consist of a multiple of

spherical pressure shell parts with radius of curvature R , connecting planar panels at corners where three planar panels meet.

3.

- 5 The pressure vessel of claim 1 or 2, wherein the internal tension beams (12) are structurally connected to the opposing outer pressure shell parts (5) meeting the ends of said tension beams, via transverse stiffeners at positions where stiffeners extending in x and y directions are crossing (15) or via transverse stiffeners extending in one of x or y direction if not both of transverse stiffeners
10 in x and y direction are present.

4.

- The pressure vessel according to any one of claim 1-3, wherein the internal tension beams extend through corresponding openings in the plurality of
15 internal tension panels and/or comprises sections that are joined together, including structure for tension beams in the plurality of internal tension panels.

5.

- The pressure vessel according to any one of claim 1 - 4, wherein the outer
20 pressure shell comprises six flat panels (flat plates) orthogonal to the x-axis, y-axis and z-axis, respectively, twelve quarter circular cylindrical single curved parts where two flat panels meet, and eight $1/8$ spherical double curved corner parts where three flat panels meet.

25 6.

The pressure vessel according to any one of claim 1-5, wherein the internal parallel tension panels are distributed evenly along the z-axis, and the internal parallel tension beams, oriented parallel to the z-axis, are distributed evenly
30 apart.

7.

The pressure vessel according to any one of claim 1-6, comprising one or more outer pressure shell parts that are irregular, such as one or several outer panels at skew angle in relation to the orthogonal reference system, or up to the entire

pressure vessel comprising dissimilar, connected outer pressure shell parts with seamlessly connected outer pressure shell parts.

8.

- 5 The pressure vessel according to claim any one of claim 1-7, wherein the pressure vessel is designed in accordance with all applicable code and regulatory requirements using simplified design formulas as well as advanced, computerized analysis tool to determine main geometric parameters, such as shell plate thickness, distance between internal tension panels and distance
10 between internal tension beams, dimensions and distance between stiffeners, by way of systematic, parametric variations or by way of mathematical optimization, to determine the optimal design solution with respect to objective functions such as weight and material used, and cost of fabrication.

15 9.

Method for fabricating the pressure vessel of claim 1, **characterized by** comprising the steps to fabricate and join the following structure or parts or preassembled combinations thereof:

- an outer pressure shell that is leak-tight, for containing a pressurized fluid
20 during operation, including to fabricate or arrange at least one opening through the outer pressure shell for loading and unloading of the fluid,
a plurality of internal tension beams,
a plurality of internal tension panels, wherein each internal tension panel comprises openings or connecting structure for internal tension beams, wherein
25 the number and positioning of said openings or connecting structures correspond to the number and positioning of internal tension beams, and
with reference to a Cartesian orthogonal x-y-z coordinate system:
to arrange the plurality of internal tension panels orthogonal to and along the z-axis and structurally connect the internal tension panels to outer pressure
30 shell parts that connect with the periphery of the internal tension panels,
to arrange the plurality of internal tension beams or sections thereof in the z-axis direction, through corresponding openings or to connecting structure for internal tension beams in the plurality of internal tension panels, structurally connecting the internal tension beams between opposing outer pressure shell

parts meeting the ends of said internal tension beams.

10.

The method of claim 9, further comprising to weld or join otherwise:

- 5 internal longitudinal stiffeners in the z-direction on pressure shell parts connected to internal tension panels,
 internal transverse stiffeners on pressure shell parts connected to internal tension beams, and
 intermediary stiffeners inside single curved pressure shell parts in
10 between.

11.

- The method according to claim 10, wherein the internal tension beams are connected structurally to the pressure shell parts by connecting the internal
15 tension beams to the transverse stiffeners extending in x and y directions in positions where said stiffeners are crossing, or connecting the internal tension beams to transverse stiffeners extending in x or y direction if not both of said stiffeners are present on the pressure shell parts.

20 12.

- Method according to any one of claim 9-11, comprising prefabricating and assembling the pressure vessel by three-dimensional parts, modules or blocks of the pressure vessel, wherein the division into blocks is made in accordance with ease of fabrication considering access and use of automated production
25 methods in the production of each block and thereafter each block is sequentially lifted into its designated place and joined together with its neighbouring blocks to compose the entire pressure vessel with all its defined structure.

30 13.

The method according to any one of claim 9-12, whereby the totality of the entire pressure vessel is assembled and joined together using a panel method approach, whereby the fabrication process is based on prefabricated substructures being the whole or parts of the stiffened panels comprising the

bottom panel, the tension panels, the end panels, the top panel, the side panels and the tension beams during which process the prefabricated sections or parts are sequentially joined together to comprise the entire pressure vessel as prescribed.

5

14.

Method according to any one of claim 9-13, for fabrication of large pressure vessels that are too heavy to lift and fabricate in one piece, whereby the pressure vessel is fabricated in two or more main sections or parts to be

10 transported and lifted into final location, such as onboard a ship, whereafter these main sections are joined together for providing the entire pressure vessel, followed by outfitting and testing.

15.

15 Use of the pressure vessel of any one of claim 1-8, for storage and/or transport of liquid natural gas (LNG), liquid petroleum gas (LPG), liquid carbon dioxide (LCO₂), liquid hydrogen (LH₂), liquid ammonia or in principle any other fluid that should be stored at pressure higher than atmospheric pressure, and/or any fluid that should be stored and/or transported more cost effectively.

20