A LANNDD Investigation
(Liquid Argon Neutrino and Nucleon Decay Detector)

Introduction

The LANNDD detector[1] requires a very large cryogenic vessel of a particular aspect ratio. The 100,000 metric tons (tonne, t) Liquid Argon (LAr) largest considered case would require a volume of 70,000 m^3. As a vertical axis, right circular, 1:1 height to diameter (aspect) ratio cylinder, the required diameter and height would be 45m. The site location, important to LAr transportation and soil bearing considerations, is Duluth MN.

Vessels of this volume and up to 2X larger are routinely fabricated for the storage of Liquefied Natural Gas (LNG) at their source and receiving terminals at aspect ratios of ca. 1:3 aspect (height to diameter) ratio in the largest sizes. Source terminal vessels collect the LNG product preparatory to shipboard transport loading and receiving terminals store the shipboard transport LNG quantities to supply the local pipeline energy demand. Highly industrialized countries without national energy resources and that can't reasonably be served by a Natural Gas (NG) pipeline, e.g., Japan and Korea, have LNG terminals with storage vessel volumes up to 200,000 m^3 and plan to develop even larger and more economical storage tanks.

The transport ships[2] that move the LNG from the source terminals to the receiving/distribution terminals commonly have total volumes up to 135,000 m^3. The ocean-going ships natural aspect ratio and vessel construction techniques require multiple LNG vessels of individual volumes up to 27,000 m^3. It should be noted that larger ship designs are being developed and still larger ships are being considered. These developments are being driven by a general increase in demand and a favorable economy of scale.

This study investigates the potential of the LNG technology to provide a suitable LAr vessel (tank), considers the attendant constraints of that choice, estimates the capital and operating costs and identifies items that will require further study and/or development.

LNG (Methane), LAr and LN_2

1 See, e.g., an early rendition in the figure in Appendix A.
2 See, e.g., Appendix C.

The important differences in the thermophysical properties of LNG (mainly Methane) and LAr are summarized in the following table. Nitrogen has been included in Table 1 for comparison and as the leading candidate for vessel purging.

Fluid	MW	T_{NBP}	rho $_L$	rho $_V$	rho $_G$	^2H_V	V_V/V_L	V_G/V_L
Units		K	kg/m3	kg/m3	kg/m3	kJ/kg		
Methane	16.04	111.6	423	1.82	0.717	510	232	590
Nitrogen	28.01	77.3	808	4.62	1.25	199	175	646
Argon	39.95	87.3	1395	5.77	1.79	163	242	779

Table 1. Select CH_4, N_2 and Ar properties. rho$_G$ and V_G are taken at 0˚C.

Most notable of the LNG and LAr similarities are the heat of vaporization per unit volume, the product of rho$_L$*ΔH_V, 215,730 and 227,385 kJ/m^3, despite widely different densities, 423 and 1395 kg/m^3 respectively, in the above table. That means that their volumetric boiloff rates are comparable for a given vessel insulation but that significantly more structural material is required to contain the 3.3 times greater LAr vessel liquid head.

Vessel Construction Types

The smaller vessels types found on transport ships are predominantly individual spherical and integrated, generally rectangular, Invar membrane. The spherical vessels (usually Al) are structurally self-contained double walled vessels, not unlike those built on land, and are carried in multiples of 4 or 5 inside and protruding above the ship's holds like cargo. The membrane tanks, on the other hand, use the ship's structure to contain the vessel liquid head pressure through a thick insulation layer. Their integrity is characterized by safety considerations that require a drip pan for the spherical vessel, but a redundant membrane for the membrane vessels to deal with the potential for inner LNG vessel leaks. These shipboard considerations are a measure of the anticipated reliability of each system by the users.

The land based LNG vessels come in a multitude of sizes[3] and types born of the fact that the vessel is stationary and the shipboard beam dimension and tank weight constraints don't apply. Reinforced (RF) concrete is used to reinforce stationary inner walls and for outer and containment walls or both. Some of the

[3] See, e.g., Appendix B.

largest stationary tanks are built below ground or have built-up earthen walls for added structural hoop strength and insulation reasons.

The inner shell materials of the largest vessels are nickel steel (Fe-9Ni, A-553, Type I) butt-welded plate or 304SS (A-240) embossed membrane sheet. The Fe-9Ni plate is full penetration butt-welded, 100% radiographed and typically provides the vessels full hoop strength and a complimentary structure is not required. The inner membrane type provides the vessels liquid containment lining but relies upon a separate outside structure for the vessel's hoop strength. The embossed sheet construction allows the membrane to move axially and circumferentially to accommodate the differential thermal contraction (ca. 300x10-5 $\Delta l/l$) of the 304 SS when it replaces low thermal expansion but more expensive Invar. The hoop stress is transferred outward to a separate hoop stress structure (typically RF) through an intermediate insulation layer.

The high purity and expensive (>$2.00/gallon at the source, see the later LAr cost discussion) LAr, static storage detector application was immediately judged to require the reliability of the Fe-9Ni full penetration butt-welded construction by those fabricators answering the question[4]. The only open issue was the material plate type: 9% nickel steel or 304SS. Stress level[5] and the cost of the required material would easily chose between them, but the 9% nickel steel has not yet been qualified for the LAr application plate thickness required by the 70,000 m^3, 1:1 aspect ratio, liquid head in the model studied here. The large LAr density and increased vessel height combine to create a hoop stress greater than the currently largest qualified (55mm) thickness, see the later discussion.

Basic LNG Vessel General Characteristics

Large LNG type inner vessels are, in their simplest form, effectively bathtubs, i.e., open at the top. A second concentric shell and a domed structural roof contain the LNG vapor. Insulation is provided by foam glass blocks at the bottom, product gas filled Perlite[6] insulation in the annular space and by insulation (Fiberglass) on a deck hung from the dome in the vapor space above to suspend just above the tank

---

[4] One fabricator, CBI, of Fe-9Ni tanks, CBI, claims that every membrane tank built leaks at some level to the annular insulation space.

[5] The 304 SS requires a material thickness greater the 9% nickel steel by the ratio of the allowable stresses at –320 K: 22.26 kg/mm^2/15.83 kg/mm^2 = 1.406.

[6] Perlite, 5-6 lb/cf, approaches the conductivity of gas of lading and stops the radiation.

wall. A standard boil-off value[7] for this configuration is ca. 0.1%/d for LNG or LAr, i.e., 0.1% of 100 kt = 100 t/d LAr in the case studied.

Note that this simple, low positive pressure, construction provides no ability to evacuate the vessel and that the typical design positive pressure is 1-2 psi[8]. That means the vessel will have to be dried of the (necessary and required) hydrostatic test residual water and of the air's oxygen constituent by purging or other non-evacuation means. For LNG this has meant GN_2 purging to avoid the flammability limits 5.1-15% in air by volume. In the LAr detector case it will mean purging to some GO_2 level and may mean post processing of the GN_2 to further reduce the vessel oxygen before the introduction of the LAr. Recall that the ultimate LAr goal is $\leq$ 0.1ppb O_2 contamination.

Double Containment LNG Vessel

The next level of improvement upon the single containment vessel described above is called a double wall or double containment vessel[9]. It differs in that it adds an inner tank vapor tight dome. That change allows the following improved operating characteristics:

1). The annular and roof insulation space can now be purged with a gas other than the gas of lading, GAr here. The purge-gas-of-choice[10] in this case would be GN_2.
2). The insulation space purge gas can be continuously monitored for air or stored product intrusion (leaks). Note that a positive purge system and pressure source[4] is required.
3). There is a positive mechanical separation of the insulation region (fiberglass cold wall lining and bulk Perlite) from the stored LAr liquid and vapor.

LNG Type Vessel Governing Code

There are a number of local codes that have been applied worldwide, but the most universal of the non-Asian codes available are the British and American codes.

---

7 See the lower specific CBI boil-off quotation later in this study.
8 Limited to the product of the pressure and the projected roof area < the weight of the roof structure, i.e., buoyancy and roof lift.
9 See, e.g., Appendix D.
10 LN_2 is the obvious stored refrigeration (emergency condition) choice and the LN_2 dewar storing the refrigeration can function to provide a LP source of GN_2.

Vessels tend to be built to the prevailing local government code. When an LNG type vessel is built in the US it will undoubtedly be built to the American Code: API 620, Appendix Q. API stands for the American Petroleum Institute, 620 is the Standard's designation and appendix Q applies to the type of LNG vessel[11] described above.

The full titles are API Standard 620, Design and Construction of Large Welded, Low Pressure Storage Tanks[12], Appendix Q, Low-Pressure Storage Tanks for Liquefied Hydrocarbon Gases. Note that the latter title is not meant to be exclusionary, no one seems to have anticipated a LAr vessel of this size and type before now.

The table of contents of API Standard 620 is provided below as a measure of its extent and to demonstrate its ASME section VIII type organization.

API 620 Contents

11 Appendix Q Low-Pressure Storage Tanks for Liquefied Hydrocarbon Gases. Liquefied Hydrocarbon is defined as liquefied ethane, ethylene and methane.

12 Available from Global Engineering Documents, global@his.com, (800) 854 7179.

General LAr Cost, Transportation

It is impossible for any of the major LAr suppliers to predict product prices into the future. Inflation, the attendant labor costs and energy costs aside, no one can predict with any certainty the future business climate, i.e., market demand at any point in the distant future. The context of the investigation was the current price of LAr of different purity (implies different source locations, transportation) delivered to Duluth MN.

I spoke to LAr marketing manager at all of the major LAr producers: Air Liquide, Air Products, BOC and PraxAir. Some were more helpful than others were but none seriously contradicted the market generalities of the others. They said that the price of standard LAr is ca. \$2.00/100cf (one gallon of LAr is 105 cf, i.e., \$2.10/gal.). That price is for standard LAr typically defined[13] as ca. 2 ppm O_2. There are 0.5-1, <0.5, and 0.1 ppm O_2 quantities that can be purchased at a premium. When asked how much more the 0.1 ppm might cost, the answer varied but averaged ca. +50%. One knowledgeable LAr representative offered that while the nation's LAr capacity is ca. 1,000,000 t/year, the production capability of 0.1 ppm LAr is no more than 25-50,000 t/year. If that indeed is the case, there is no hope of buying 0.1 ppm at the rate required to fill in one year in consideration of the contracts for that purity now (and then) in place, unless the highest purity[14] LAr production capability is dramatically increased.

As important as anything else learned is this short business lesson, if you insist on buying a product at a rate that exceeds its ready availability the price will go up. More than one industrial gas company representative scratched his head about whether there should be a volume discount or a scarceness premium. There must be a purchasing strategy there somewhere.

The transportation cost to Duluth MN caused more than one representative to suggest consideration of moving the site to a more central (for his company) location. This discussion was all over the lot and for good reason. Some producers are closer (only one is within 500 miles) and some much farther away from Duluth, some price the transportation by the truck trailer mile and others by a \$/100cf premium. Still

[13] The Compressed Gas Association (CGA) has a set of industry standard Grade purity definitions, but the suppliers routinely guarantee a lower than minimum value for a given Grade contaminant.

[14] Not one of the major industrial gas suppliers would talk about LAr with substantially better then 0.1 ppm GO_2.

others (PRAX AIR) spoke of rail as the obvious and economic transport solution[15]. I will report what was said, but the reader should understand that until a delivered contract price is formally solicited for a fixed quantity over some period of time and the allowed delivery rate variation possibilities are discussed in detail, its pretty loose talk.

The basic trouble is that most[16] of the Air Separation (and thus LAr) capacity is located on the coasts: east, west and gulf. Not one of those locations is convenient to Duluth. It was suggested that trailer freight might cost $2.00/mile, and a two thousand-mile one-way trip $4,000. At 21-22 t/trailer load that's about a $0.94/100scf premium. Another suggested with reference to St. Louis (careful of capacity here) that a $0.67/100cf premium might be sufficient.

At this point I would use a budget price of $3.00/100cf or $0.83 liter as a target value delivered in Duluth. That's a total of 70,000,000 *$0.8322 = $58.25 million for the delivered liquid, excluding availability price pressure. If the delivery rate is kept too high for the availability conditions the producers can name their price. Ah capitalism.

The LANNDD project, once it decides what it thinks it wants to purchase (careful here), should send out a LAr specification, delivery destination and required deliver rate to all the major industrial gas producers and ask for anticipated available capacity and budgetary cost advice. If must be made clear that a partial capacity response is welcome.

PRAXAIR Conference Call

PraxAir showed much more interest in supplying the LAr than any of the other major suppliers and aggressively pursued the LANNDD inquiry. Subsequent to the initial PraxAir contact and LAr requirement description, a conference call was arranged between PraxAir's Kate Loritz, Chis Benesch, and Jack Solomon, and Kirk McDonald and the author. A PraxAir proposal was promised, has since been received and that information reflected in this report.

[15] This might have something to do with the fact that PraxAir has the most developed rail distribution system.

[16] PraxAir's large East Chicago plant (near Chicago, IL) is a significant exception to the rule.

The full teleconference note set is found elsewhere, but the important highlights of that discussion are found here and form the basis for the introduction to the topic of Purity Processing. The PraxAir main LAr producing plants are in East Chicago, IL, and Houston, TX. The distribution costs from one was stated to be approximately equal to the other. PraxAir claims to have a ca. 40% share of the LAr national market of 20 billion cf/yr[17], or ca. 5 billion cf/yr. East Chicago supplies ca. 30% of the PraxAir capacity: 2 billion cf/yr or 100,000 tons/yr. (The PraxAir arithmetic leaves something to be desired.)

LAr, ppm (v/v)	C	D	E	F
Carbon Dioxide	1.0	0.5	0.5	0.5
Nitrogen	20.0	10.0	5.0	10.0
Oxygen	5.0	2.0	1.0	2.0
Hydrocarbon	1.0	0.5	0.5	0.5
Water	10.5	3.5	1.5	1.0
Dew Point, ÞC	(60.0)	(67.8)	(73.3)	(75.6)

Table 2. CGA G-11.1-1998, Maximum contaminant levels for Liquid Argon by CGA LAr grade.

Quality Verification Levels	Typical Uses (not all inclusive)
C	General Industrial, shield gas, heat treating.
D	Heat treat, sintering, shield gas, AOD appl.
E	High Purity applications.
F	Semiconductor applications.

Table 3. CGA G-11.1-1998, Typical uses by CGA Grade.

PraxAir could provide an Industrial Grade[18] LAr (see Table 2. C for the corresponding CGA values) fill of 100,000 tons for the LANNDD in one year. If Ultra High Purity[19] (UHP) LAr (better than Table 2. E) were required it would take 100% of their product for 6 years. LAr delivery trailer-trucks haul 420,000-cf

17 The unit 100 cubic foot, 100 cf, is a standard in the industrial gas industry. 100 cf Ar is equal to 10.34 lb. 1 metric ton = 21,302 cf. And 20 billion cf/yr = 0.938 million metric tons/yr.

18 PraxAir Standard Industrial Grade: 5 ppm O_2, 4-ppm moisture.

19 The PraxAir Semiconductor specialist, Jim Borkman, was mentioned in the context of the Ultra High Purity LAr. We should find an excuse to meet and talk to Mr. Borkman at our earliest convenience.

and RR tank cars 1.3-1.6 million-cf. PraxAir has ordered and will soon receive 30 new 1.9 million-cf capacity RR tank cars[20].

PraxAir lobbied for the whole LANNDD LAr contract or, failing that, the logistical coordinator role of all suppliers for the entire quantity. They are the LAr market leader (they claim 40%) and were making the point that they were unquestionably in the best position, by a factor of two in capacity over the nearest competition, to service this contract. There was more than a little unabashed salesmanship at work.

The important question of how best to obtain the required 0.1-ppb O_2 contamination level was raised in the PraxAir conference call. The context of the discussion was where, how and to what purity should the oxygen removal be addressed. The discussion was preliminary at best, especially without Mr. Borkman (PraxAir semiconductor industry gas specialist), and none were prepared to make much more than hand-wringing contributions[21]. Argon purity and its maintenance when introduced into the vessel (or subsequent processing) are critical problems that will no doubt require a complete development. An example of the "receive industrial or semiconductor grade[22] LAr and pre-process it on the LANNDD site" strategy requires processing LAr (perhaps as warm gas) at the same rate it is delivered 100,000 t/365 d = 274 t/d. When that process is defined and implemented, imagine what happens if the plant goes down for few days; 274/22 = 13 trucks/day will have to find another place to drop their LAr each day until processing can resume.

In answer to the question of LN_2 availability to the Duluth MN area, PraxAir identified Blake, MI and Inver Groove, MN as the nearest sources.

There was some discussion about the rare gases, Ne, Xe and Kr and their availability. It turns out that PraxAir has more Xe than customers for the moment, an opportunity waiting for someone. Moreover, the LAr/GAr market is over-supplied for

[20] It would take 1053 1.9 million cf zero loss RR cars to deliver the 2 billion cf LANNDD needs. That's almost three deliveries a day to deliver it all in one year.
[21] The lowest LAr lowest O_2 level PraxAir has delivered is 0.08 ppm. Cost information is found the PraxAir budgetary proposal.
[22] PraxAir Semiconductor grade: maximums in ppm by volume, O_2: 2, CO and CO_2: 0.5, H_2: 1, N_2: 10, H_2O: 1, and Hydrocarbons: 0.5.

the moment and the gas industry is aggressively looking for customers. Storage of the LAr is not an option; site bulk storage of 18,000 gallons[23] was mentioned.

See the next section: PraxAir Proposal.

[23] Standard tanks (dewars) of ca. 20,000 gallons in size are very popular because they are the largest tanks that can be conveniently, w/o special road permits/routes, be delivered. So cryogenic tankage is often modulo 20,000 gallons.

PRAXAIR LAr Supply Proposal

The proposal received on June 26, 2002 included a letter report and a Power Point presentation, each with essentially the same information and the same qualified values in each case. Christopher Benesch, LAr national product manager signed the cover letter, and Kate Loritz, account manager, authored the included letter report and PP presentation. The following tables are excerpted from the proposal.

Component	Industrial	Semiconductor	LANNDD
Min. Purity	0.999970	0.999985	0.999985
Oxygen	5 ppm	2 ppm	0.5 ppm
Moisture	10.5 ppm	1 ppm	0.5 ppm
Nitrogen	20 ppm	10 ppm	20 ppm
Hydrogen		1 ppm	
Carbon Dioxide	1 ppm		1 ppm
CO and CO_2		0.5 ppm	
Hydrocarbons	1 ppm	0. 5ppm	1 ppm

Table 4. The general LAr purity specifications. (PraxAir) (The last column was added according to the PraxAir text treatment and the LANNDD specification definition contained there.)

The PraxAir text defines the LANNDD purity as "<0.5 ppm O_2 and <0.5 ppm H_2O, and all other contaminants meet (the) CGA industrial specification". Table X. has been extended to include the PraxAir LANNDD specification for ease of comparison.

The detector fill period could become a function of the purity if the number of facilities producing the higher purity LAr grades were to shrink so that the sum of their available production capacity limited the delivery rate. Here PraxAir states that down to "LANNDD purity", as previously defined, it can deliver in 12 to 24 months. We might need to ask some fine structure questions.

Purity -->	CGA Ind.	SEMI	LANNDD
Fill Time, months	12 to 24	12 to 24	12 to 24
LANNDD Capacity	2 BCF	2 BCF	2 BCF
Facility Product	Any	Many	Limited

Table 5. Estimated time to fill the LANNDD. (PraxAir)

The following table is provided with the following PraxAir caveats: 1). "… given the delivery time frame", 2). "… all budgetary pricing is based upon current supply and demand conditions, and 3). "Pricing can be impacted by market conditions at the time (the) project starts.

Purity -->	CGA Industrial	SEMI	LANNDD
$/100 cf	$3.50	$4.50	$5.50
LANNDD Cap.	2 BCF	2 BCF	2 BCF
Estimate, USD	$70 Million	$90 Million	$110 Million

Table 6. Cost model for USA LAr for 2 BCF purchased and delivered over a 12 to 24 month period. (PraxAir)

The PraxAir contacts Kate Loritz[24], Christopher Benesch[25] and Jack Solomon[26] offered to arrange "a tour of one of our argon production facilities[27]" for those addressed Kirk McDonald and G. T. Mulholland.

PRAXAIR La Porte TX Facility Visit

Kirk McDonald and the author visited the Praxair facility in La Porte TX, ca. 30 mi. east of downtown Houston and near the Houston Ship Canal at the invitation of Chris Benesch, the Praxair national argon product manager.

A separate report[28] describes the tour and the facility as described with an emphasis on the LAr product purity and the potential for improvement of the dual Air Separation plants. Notable here the LAr production capability of 40 t/d/plant, half at 1-ppm O_2 and half at 0.1-ppm capability, two 50,000 gallon LAr storage dewars, and a RR siding especially for the transport of the more expensive LAr. Important to the purity issue is 10% decrease in yield to gain the 0.1-ppm O_2 purity level and the fact that Praxair has contracted for 0.1-ppm O_2 and 0.08-ppm H_2O certified deliveries.

[24] Account Manager, North Region, Inver Grove Heights, MN 55077, 651 437 9499, X231
[25] National LAr Product Manager, Danbury, CT 06813, 203-837-2475
[26] Director of Technology Planning, Danbury, CT 203-837-2164
[27] That is, Houston, TX and East Chicago, IN (near Chicago, IL).
[28] Praxair La Porte Facility Visit, August 7, 2002, G. T. Mulholland.

The La Porte plant included two large, 0.2%/d, liquid storage dewars of the double-walled, Perlite insulated, construction type: 150 Mscf LO_2 and 200 Mscf LN_2. The liquid supplies the liquid trailer delivery requirement and backs-up the production pipeline feed. If the Plant or Plants go down the liquid is vaporized and heated and supplied to the pipeline until exhausted or the plants can be brought back on-line.

Praxair was asked to investigate the technical and cost feasibility of providing 0.01 ppm O_2 LAr in production quantities. Our host agreed to pursue the matter with Jim Borkman (high purity gas specialist) of Praxair's Tonawanda NY facility. The requested schedule for that work was the week of September 9. 2002.

Real World Vessel Parameters and Costs

The leaders in the field of LNG ship fabrication seem to be (by web LNG presence) Mitsubishi, Kawasaki and Hyundai. By the same search process the large stationary tank fabricators seem to be Kawasaki, Mitsubishi, Hyundai, Nissan and Chicago Bridge and Iron (CBI).

Jack Sondericker, BNL, agreed to query Kawasaki w/re a budgetary quote for a 100,000 t, 1:1 aspect ratio, 45m diameter and 45m high LAr vessel. Jack had recently project managed and successfully completed the CERN acceptance of the ATLAS central cryostat fabricated by Kawasaki. Kawasaki has responded with interest and agreed to provide a budgetary price for the exact vessel specified.

Initial Kawasaki's Y. Numasawa's initial response:

45m diameter, 45m high
304SS:
Low point of the side wall 92 mm @ 15.83 kg/mm^2
9% Nickel Steel:
Low point of the side wall 66 mm @ 22.26 kg/mm^2

Trouble is only 55 mm 9% nickel steel qualified (NDT) to date.
NDT qualification of 66 mm would be a development cost.

Insulation:
Bottom: Perlite Concrete
Sides: glass wool blanket next to Ni-Fe, balance Perlite powder

Top: Perlite powder
Heat load: 153,000 kcal/h = 177.8 kW
Boil-off: 95 t/d, 0.104%/d

Kawasaki offered an alternate 70-m diameter and 18.5-m high, but that was not encouraged for aspect ratio reasons.

Kawasaki has been asked for a Budgetary quote for:
SS304 and 9% nickel steel in the standard model,
and if they would, a SS304 membrane tank of the same size in-ground?

Kawasaki Budget Estimate response

Jack Sondericker coordinated our request for a budgetary estimate to Kawasaki's Y. Numasawa.

The response quoted the cost of three Asian jobs comparable in scope to the current project's requirements. The most recent two values, Kawasaki scaled to the current project, for double walled metal construction (9% Ni steel inner and Carbon steel outer) averaged $24.21 million. We were asked to carefully note that these costs include local conditions, regulations and local contractors construction costs in rapidly developing Asian countries. The Duluth, MN disposition of these issues will influence the site particular quoted values.

See the rationalization of the vessel quotations later in this report.

Chicago Bridge and Iron (CBI)

Jack Blanchard of CBI worked up the technical information and Ray Moen provided a preliminary technical description and budgetary cost estimate upon request, attached. A double walled 117.7' (35.88 m) high and 165' (50.3 m) diameter, 1-m thick Perlite insulated vessel with 0.05%/d boil-off was quoted for erection in Duluth MN for $16,300,000.00, with a short list of qualifications. The height and diameter dimensions changes result from the acceptance of two current practice material constraints: 1). The limitation of weld qualified 9% nickel steel to 55 mm in thickness (LAr head), and 2). the loading of foundation insulation (LAr head). The total volume of 70,000 m^3 was preserved in the 35X50' diameter design quoted.

The vessel Hydrotest is proposed with the water supplied at LANNDD's expense. The vessel is dried of residual water with a GN2 purge (from a liquid source). The purge can continue to reduce the O_2 content in the tank (to only ca. 5% for methane). The quote is importantly conditioned upon an 11,000 psf foundation soil rating that will require mostly rock or a significantly hardened soil (piles, etc.). This will likely lead to a quotation cost adder.

The Enraf, a standard product brand, servo controlled level gauge displacer is lowered into the liquid until the apparent weight of the displacer changes as measured by the tension on the cable. This device is meant to sense density differences in LNG and may be eclipsed by a simpler device for the LAr application.

Note that characteristic of the LNG class vessels the negative pressure relief is nominally 3/4 ounce per square inch.

See the rationalization of the vessel quotations later in this report.

Rationalized Vessel Quotes

The Kawasaki and CBI quotes can be rationalized as follows.

There is a large uncertainty associated with the Kawasaki quote with respect to the local site costs, but we have no direct means to measure that for the moment. We have little choice but to accept the Kawasaki exact geometry bid at face value: $24.21 million, for the moment.

The CBI bid, on the other hand, doesn't have that concern. It does need an aspect ratio correction (the elevation increase requires a greater (45/30 X) shell wall thickness, and the increased head requires a new higher load strength floor material (the existing material is at the its limit at ca. 35 m). I f we say that these fundamental shell material increases, insulation loading upgrade replacements and the almost certain ground loading improvements will cost an additional 20%, the CBI bid becomes $19.56 million.

The average of the two rationalized quotations is $21.89 million. At that value the Kawasaki bid is 10% higher, and the CBI bid 10% lower than the rationalized average of $21.89 million.

Quotation Technical Comparisons

To extent the vessels details have been provided, the only clear technical difference in base technical proposals is the vessel boil-off rate: Kawasaki lists 0.104%/d and CBI 0.05%/d. That discrepancy would have to be addressed in a specification, in all probability in favor of the lower value. Fortunately it is one of the easier parameters to improve.

Real World Refrigerator Costs

Cosmodyne has been contacted as the leading manufacturer of engineered modular air separation, nitrogen and oxygen liquefaction equipment in the approximate capacity range of interest, i.e. condense 0.1%/d*100,000 LAr t = 100 LAr t/d at ca. 87.4K.

While Cosmodyne was working toward an equipment solution and budgetary cost estimate on the basis of a 1%/d boil-off requirement, CBI called to say that the boil-off specification for the GN_2 purged Perlite insulation space they provided in their quotation should be 0.5%/d. At this point the apparent factor of two in refrigerator capacity over load should be taken as an operating margin.

Note that the Nitrogen Refrigerator equipment type from Cosmodyne will have a significant nitrogen shaft seal leakage. We will need to compare the capital and operating costs (to include makeup LN_2) of the A/S system with those costs for the competing “closed” (essentially loss-less) helium refrigerator based system. The outcome of that cost comparison is not immediately apparent, in part because the closed helium systems are generally more expensive on a $/W basis and would require the equipment for a third fluid, i.e., storage tank, inventory, etc.

Cosmodyne Proposal

George Pappagelis[29] provided the following budget information for a Cosmodyne[30] 100 tpd argon reliquefier. The 100 tpd reliquefier rating corresponds to a 100,000 t vessel boil-off rate of 0.1%/d.

Nitrogen Refrigerator General Specification:
100 tpd LAr Reliquefier
Power Consumption: 1.8 MW (Cost = $432/(d*$0.01/kWh))
(Multiply by the actual rate: $/kWh to get the daily operating cost.)
Nitrogen make-up gas (low loss seals): 120 nm^3/h
(LN_2: 3.6 tons/d = 1,178 gpd, Cost @ $0.25/gal. = $294/d))
Capital Cost Budget Price: $2.9 million.

Nitrogen Refrigerator Attributes:
1. Cold Box Module w Factory installed insulation.
2. Dual, high efficiency, ACD turboexpander module.
3. Recycle compressor with low loss seals.
4. Booster Compressor for nitrogen liquefier feed.
5. Control system.
6. Module interconnecting wiring and piping.

[29] Cosmodyne technical representative, (310) 320 5650, pappg@cosmodyne.com.
[30] www.cosmodyne.com

Oxisorb, MG Industries

Frank Tamandl[31] of MG Industries (MESSER is the parent) in Allentown, PA, was contacted w/re the standard Oxisorb units available. He responded with the specifications[32] for their largest standard low-pressure cartridge, the R20.

Model Oxisorb, R20 Room Temperature specifications:

1. Maximum flow rate: 100 m^3/h, ca. 3500 cfh
2. Maximum inlet pressure: 20 bar, ca. 290 psia
3. Maximum adsorption cap.: 65 liters, ca. 2.3 scf O_2
4. Net weight: 36 kg, ca. 79.2 lb.
5. Guaranteed outlet < 0.1 ppm by volume

Model Hydrosorb, R20 Room Temperature specifications:

- Maximum adsorption cap. 430 liters, ca. 15.2 cf water vapor

When it was made clear that the cartridges were sent back to Germany for reactivation, it became apparent that LANNDD should require cartridges that can be regenerated locally. When special considerations were raised I was directed to Dick Betzendahl[33] in Malvern, PA.

Mr. Betzendahl has been contacted and has had preliminary discussions with Mr. Frank Dimmers[34], the Messer Oxisorb Export business manager, in Germany. After discussing the issue a bit we concluded that I should contact Mr. Dimmers directly. I will set about to do that essentially immediately.

When I asked for catalog specification sheets for the available cartridges I was referred to the web site: www.mgindustries.com/gts/SpecGasEquip.Filtration.pdf

***

[31] MG Industries, 5275 Tilghman St., Allentown, PA, Tel: (610) 530 5342, FAX: (610) 398 0398.

[32] Strangely provided in long hand. I'll call for copies of R20 Oxisorb and Hydrosorb printed materials.

[33] MG Industries, Malvern PA, (610) 695 7400.

[34] Frank.dimmers@messe.de, (011) 49208 8509 210.

References

1. F. Sergiampietri, *On the Possibility to Extrapolate Liquid Argon Technology to a Supermassive Detector for a Future Neutrino Factory*, presented at NuFACT'01 (Tsukuba, Japan, May 26, 2001), http://www.hep.princeton.edu/~mcdonald/nufact/nufact01.pdf

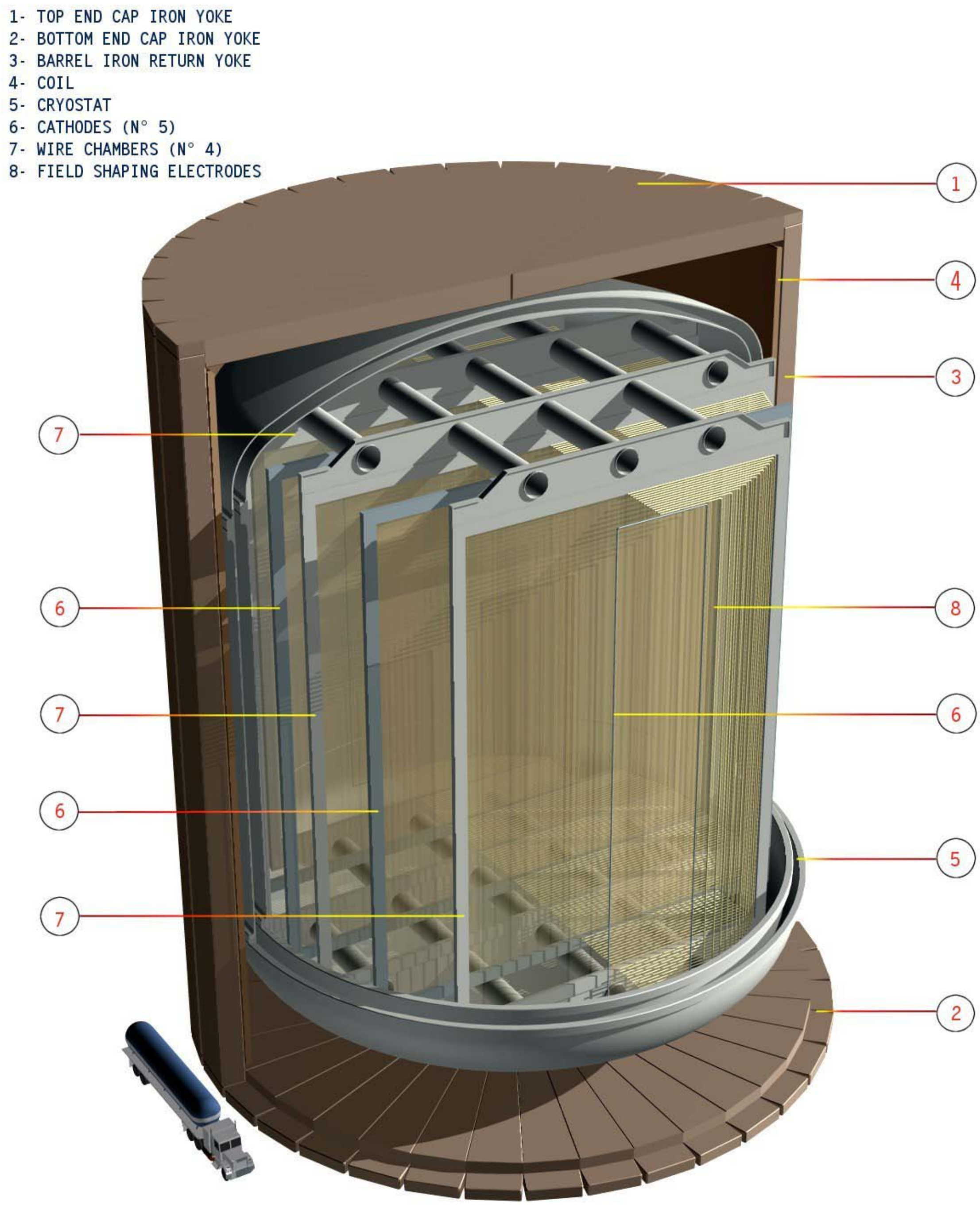
2. D.B. Cline, F. Sergiampietri, J.G. Learned and K.T. McDonald, *LANNDD, A Massive Liquid Argon Detector for Proton Decay, Supernova and Solar Neutrino Studies, and a Neutrino Factory Detector*, presented at NuFACT'01 (Tsukuba, Japan, May 24, 2001), http://xxx.lanl.gov/abs/astro-ph/0105442

3. K.T. McDonald, *A Strategy for Accelerator-Based Neutrino Physics in the USA* (May 1, 2002), http://xxx.lanl.gov/abs/hep-ex/0204037

Other Consulted Sites

1. http://pcnometh4.cern.ch/Proposals/t2400doc_lowres.pdf
2. http://www.chicago-bridge.com
3. http://www.grc.nasa.gov/WWW/PAO/html/issradpb.htm
4. http://www.mhi.co.jp/tekken/e/index.htm
5. http://www.mhi.co.jp/tekken/e/lng_tank
6. http://www.mhi.co.jp/tekken/e/outline/main_03.htm
7. http://www.tokyo-gas.co.jp/techno/stp/99a1_e.html
8. http://www.osakagas.co.jp/rd/sheet/003e.htm
9. http://www.cmspanhandlecompanies.com/expansion_lng.asp
10. http://www.meisei-kogyo.co.jp/JobRecord_Tank.htm
11. http://www.transgasatlanico.pt/tank_concept.htm
12. http://www.mms.gov.mmab/policy-committee/Past%20Meeting/Fall01/Beale103101
13. http://wwwsecc.co.kr/e_secc/h_business/pet_inch.htm
14. http://www.takenaka.co.jp/takenaka_e/engi_e/a02/a02_1.html
15. http://www.khi.co.jp/tekkou/product/lng_e.htm
16. http://www.kogas.or.kr/english/lng/incheon7.pdf
17. http://www.skgas.co.kr/engskgas/e_lpginfo/e_shippingmap/e_shippingmap.jsp
18. http://wwwsantos.com.au/education/pt_bonython/pt_bonython.pdf
19. http://www.totalfinaelf.com/us/html/de/in/dein3-3.htm
20. http://www.bp.com/company_overview/technplogy/frontiers.fr02dec01/fr02lng.asp
21. http://pcnmeth4/pubs/nnn02.pdf

Appendix A.



LANNDD
Liquid Argon Neutrino and Nucleon Decay Detector

F. Sergiampietri-August 2000

Appendix B

Table 1: Nominal Capacity of Storage Tanks

Diameter	20 ft. (6.1 m) Ht. Capacity		30ft. (9.1 m) Ht. Capacity		40ft. (12.2m) Ht. Capacity		50ft. (15.2m) Ht. Capacity		60 ft. (18.3 m) Ht. Capacity		Diameter
Feet	Mbbls*	M^3**	Mbbls*	M^3**	Mbbls*	M^3**	Mbbls*	M^3**	Mbbls*	M^3**	Meters
20	1.1	178	1.7	267	2.2	356	2.8	445	3.4	534	6.1
25	1.7	278	2.6	417	3.5.	556	4.4	695	5.2	834	7.6
30	2.5	400	3.8	600	5.0	801	6.3	1001	7.6	1201	9.1
35	3.4	545	5.1	817	6.9	1090	8.6	1362	10.3	1635	10.7
40	4.5	712	6.7	1068	9.0	1423	11.2	1779	13.4	2135	12.2
45	5.7	901	8.5	1351	11.3	1801	14.2	2252	17.0	2702	13.7
50	7.0	1112	10.5	1668	14.0	2224	17.5	2780	21.0	3336	15.2
55	8.5	1346	12.7	2018	16.9	2691	21.2	3364	25.4	4037	16.8
60	10.1	1601	15.1	2402	20.1	3203	25.2	4003	30.2	4804	18.3
65	11.8	1879	17.7	2819	23.6	3759	29.5	4698	35.5	5638	19.8
70	13.7	2128	20.6	3269	27.4	4359	34.3	5449	41.1	6539	21.3
80	17.9	2847	26.9	4270	35.8	5693	44.8	7117	53.7	8540	24.4
90	22.7	3603	34.0	5404	45.3	7206	56.6	9007	68.0	10809	27.4
100	28.0	4448	42.0	6672	56.0	8896	69.9	11120	83.9	13344	30.5
110	33.8	5382	50.8	8073	67.7	10764	84.6	13455	101.5	16146	33.5
120	40.3	6405	60.4	9608	80.6	12810	100.7	16013	120.9	19216	36.6
130	47.3	7517	70.9	11276	94.6	15034	118.2	18793	141.8	22552	39.6
140	54.8	8718	82.2	13077	109.7	17436	137.1	21795	164.5	26154	42.7
150	62.9	10008	94.4	15012	125.9	20016	157.4	25020	188.8	30024	45.7
160	71.6	11387	107.4	17080	143.2	22774	179.0	28467	214.8	34161	48.8
180	90.6	14412	136.0	21617	181.3	28823	226.6	36029	271.9	43235	54.9
200	111.9	17792	167.9	26688	223.8	35584	279.8	44480	335.7	53376	61.0
220	135.4	21528	203.1	32293	270.8	43057	338.5	53821	406.2	64585	67.1
240	161.1	25621	241.7	38431	322.3	51241	402.8	64052	483.4	76862	73.2
260	189.1	30069	283.7	45103	378.2	60137	472.8	75172	567.3	90206	79.2
280	219.3	34873	329.0	52309	438.6	69745	548.3	87181	658.0	104618	85.3
300	251.8	40032	377.7	60048	503.6	80065	629.4	100081	755.3	120097	91.4
***Mbbls = 1000 API Barrels**			****M^3 = Cubic Meters**		**API bbl =42 gallons**				**1 M^3=6.29 bbls**		

Courtesy CBI.

Appendix C

LR is first choice for LNG ships

Transporting liquefied natural gas (LNG) by sea requires special engineering techniques and contingency measures to lower the risks arising from the hazardous nature of the cargo. At the forefront of LNG technology, LR has been associated with the development, approval and application of various cargo containment systems over many years. Our experience benefits the world's LNG operators – a market leading 29% of the global LNG fleet is classed by LR.

Besides providing through-life ship classification services, LR's unique marine operations simulation capability enables LNG operators to understand, address and lower the commercial risks to their business activities.

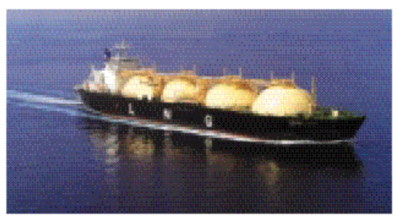
Leading operators benefit from LR's experience

LR's classification services – from preliminary design, through design appraisal, construction and in-service survey, continue to benefit the expanding world trade in LNG. LR has strong relationships with many owners and yards, and 14 LNG ships are currently on order to LR class.

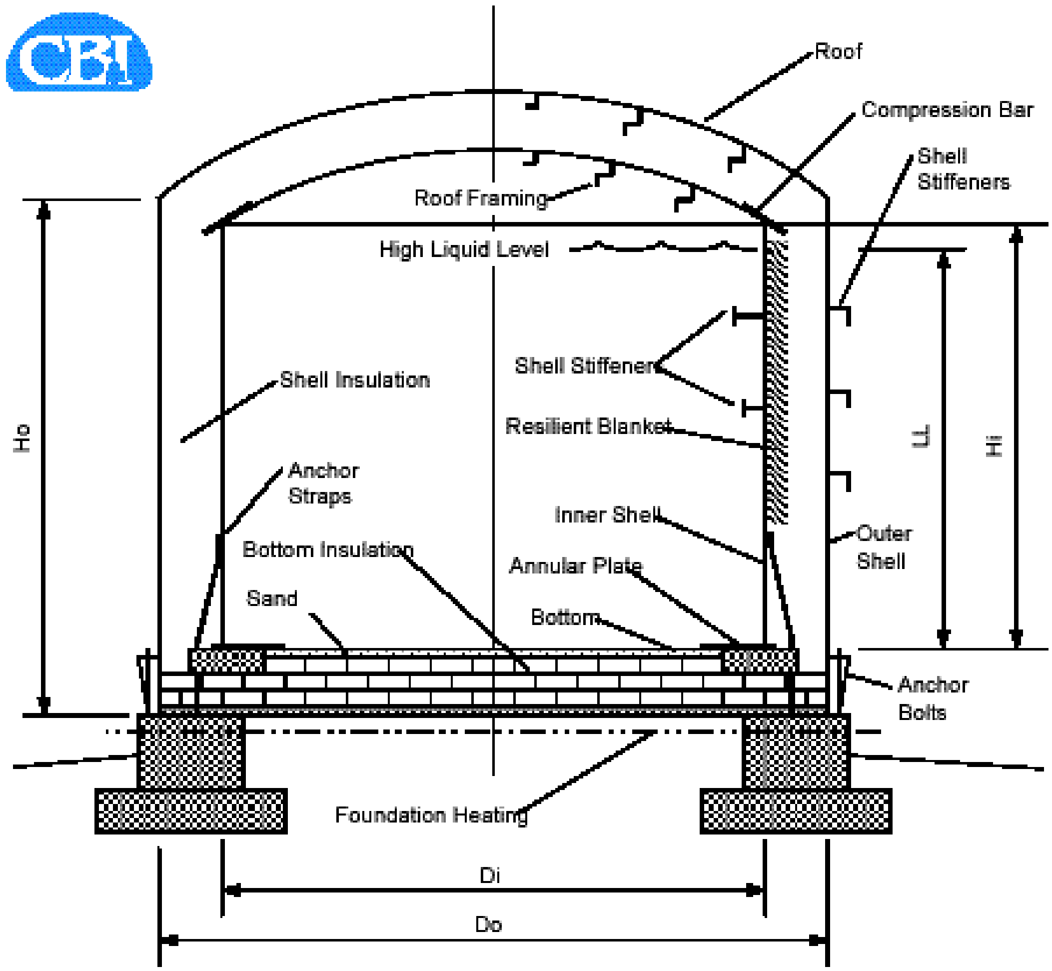
- For further information, please contact Chris Bale:
  Tel: +44 20 7423 2269
  Fax: +44 20 7423 2069
  Email: chris.bale@lr.org

Builder	Owner/project	Number of LNG ships	Containment system
Hyundai Heavy Industries	Nigeria LNG	3	Moss
Mitsubishi Heavy Industries	Shell Brunei	1	Moss
Mitsubishi Heavy Industries	Shell	2	Moss
Mitsubishi Heavy Industries	Petronas	2	Gaz Transport
Mitsui Chiba	Petronas	1	Gaz Transport
Puerto de Real	Enagas (EN Elcano SA)	1	Gaz Transport
Samsung	BP	2	Technigaz
Sestao	Enagas (Knutsen AS; Naviera F Tapias SA)	2	Gaz Transport

Breakdown of LNG-ships currently on order to LR class.



Appendix D

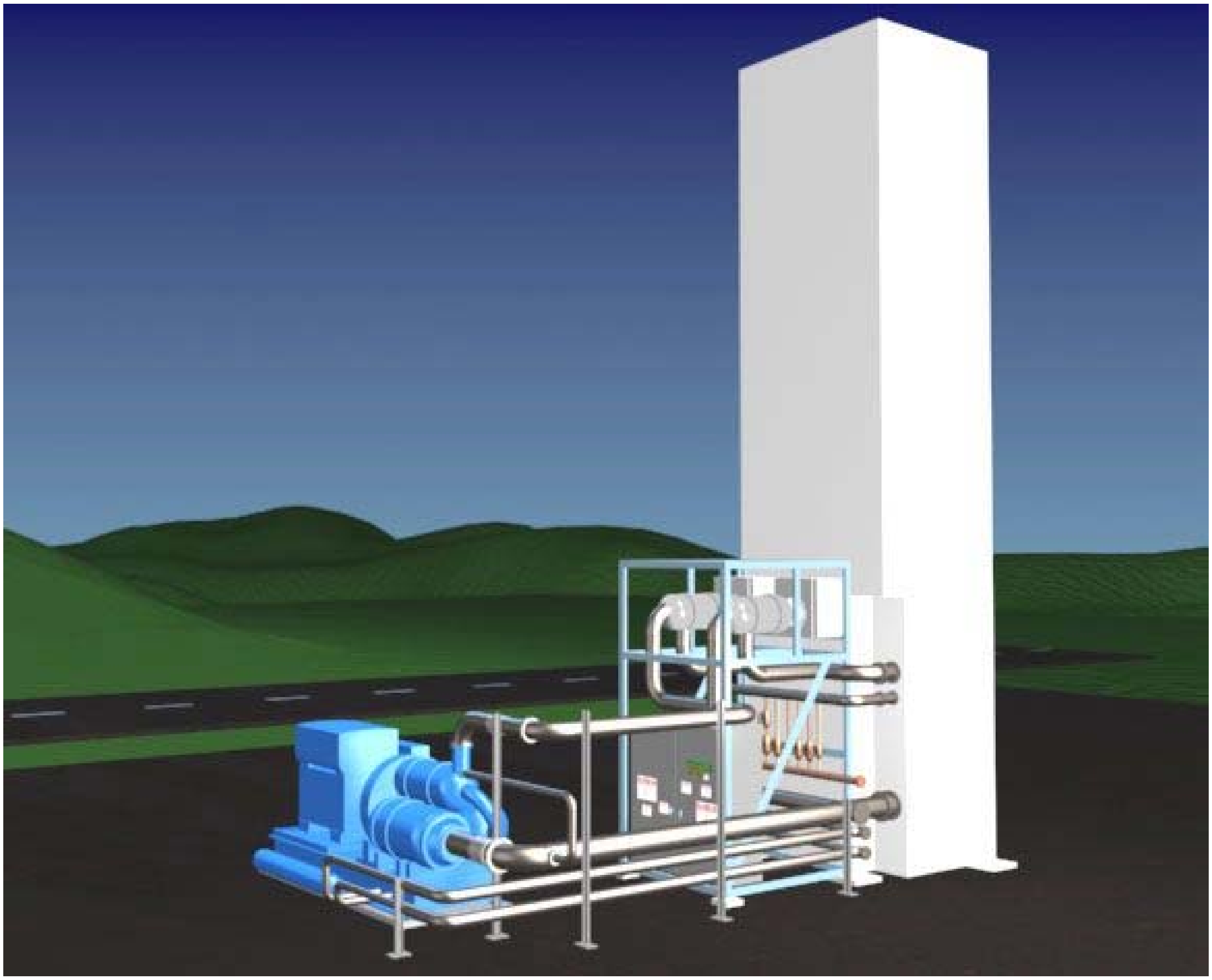


Double Wall & Double Roof Tank

	Feet
Di =	165
Hi =	117.9803
LL =	117.7303
Do =	173
Ho =	118.0443

Estimate Page ~ 3

Appendix E.



Courtesy of Cosmodyne.