Storing Petroleum Liquids in Large Aboveground Storage Tanks

PEMY Consulting LLC
Philip Myers

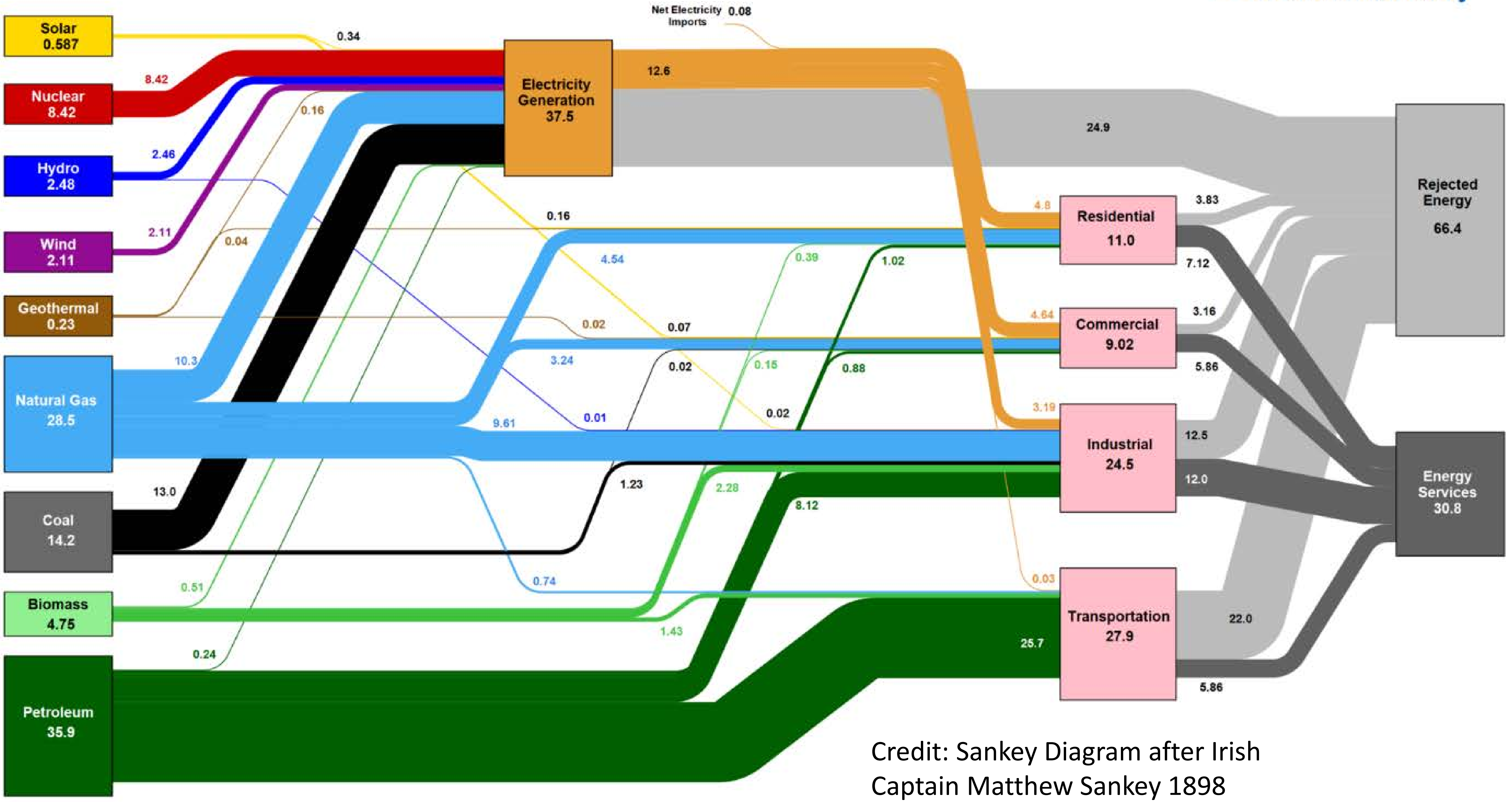
22nd Annual California CUPA Training Conference
THEME: "2020: PERFECTING OUR VISION"
DATES: Feb 3rd thru Feb 6th, 2020

U.S Energy Flow

- "Quad" 10^{15} BTU, equivalent of 183,000,000 bbls oil
- World energy consumption was 524 quads in 2019
- U.S. energy consumption in 2016 was 97 quads
- eia.gov
- https://www.eia.gov/state/maps.php

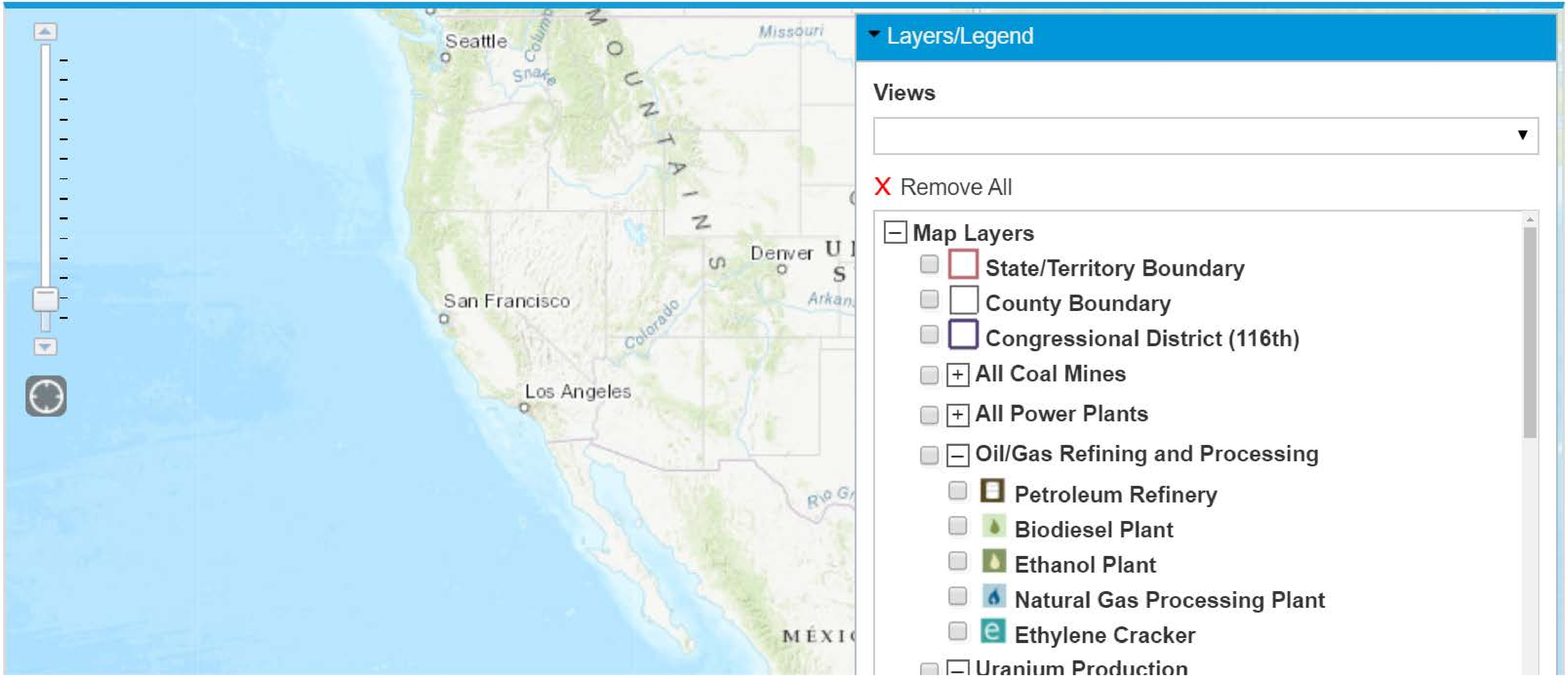
Wow – we use 20%!

Estimated U.S. Energy Consumption in 2016: 97.3 Quads

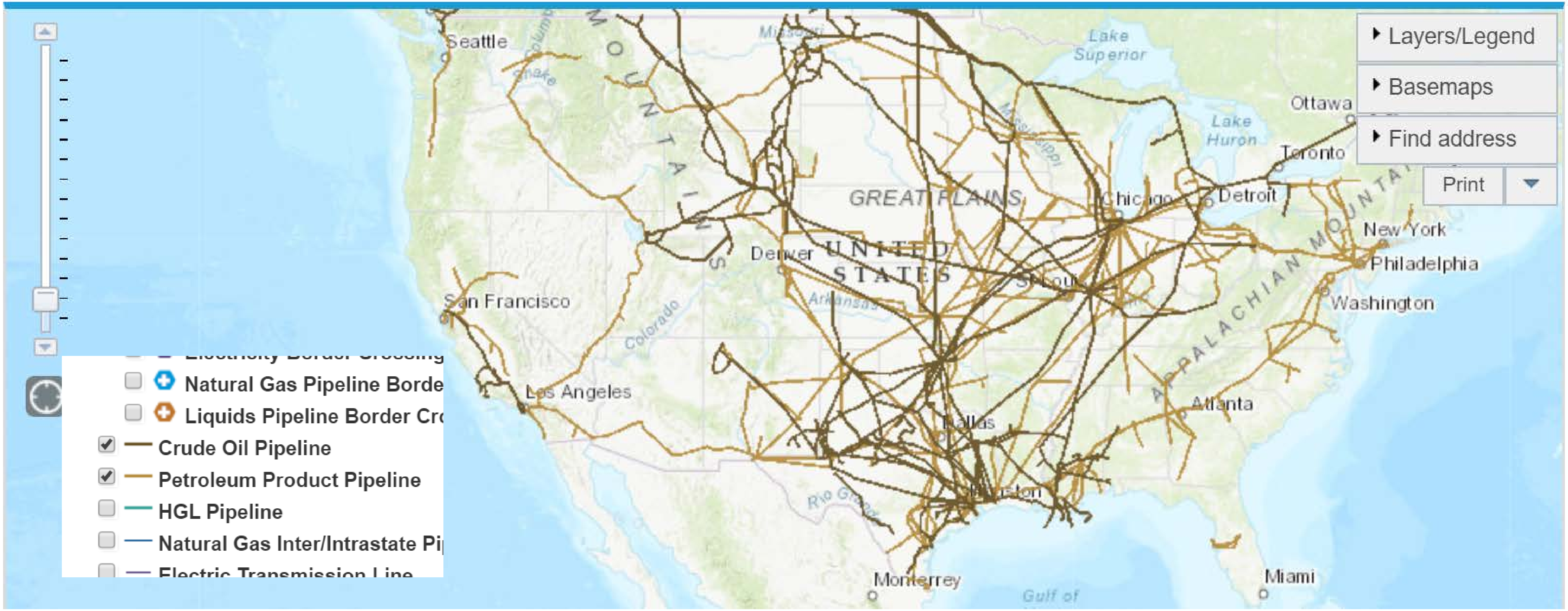


Credit: Sankey Diagram after Irish Captain Matthew Sankey 1898

U.S. Energy Mapping System



U.S. Energy Mapping System



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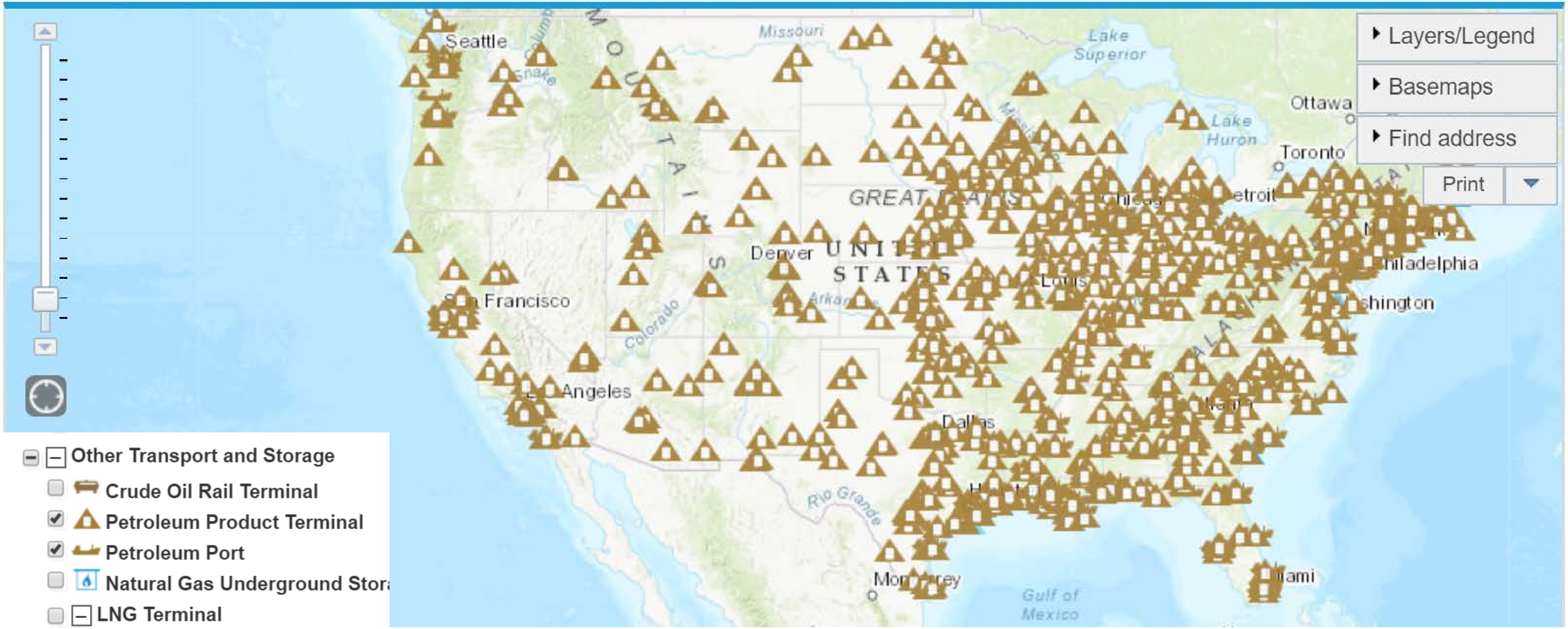

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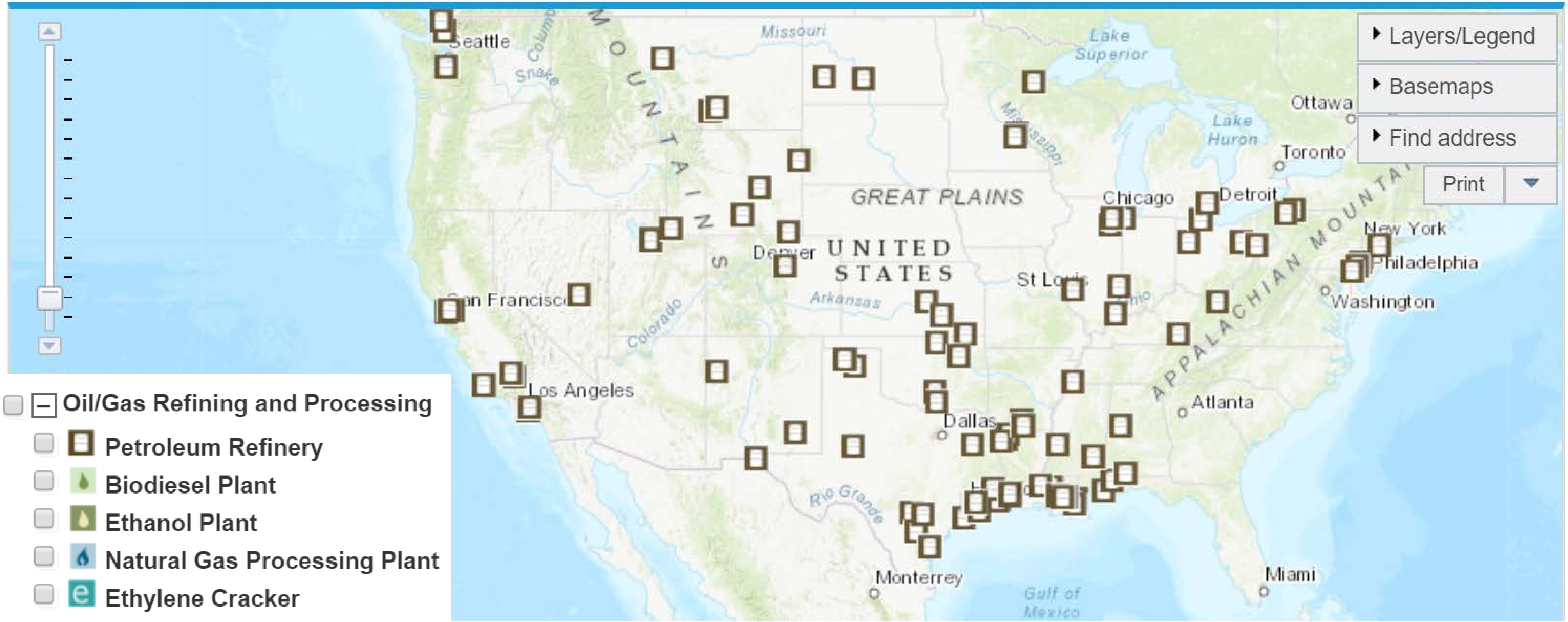
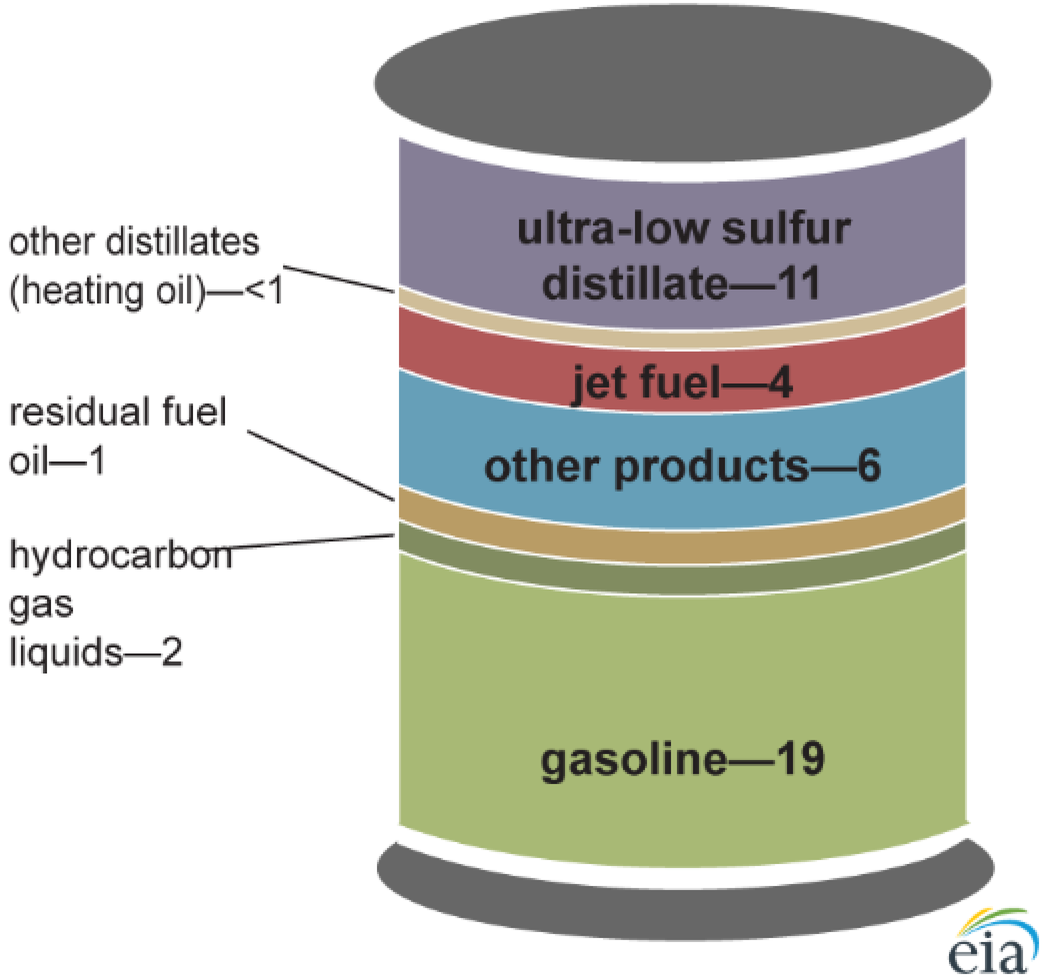


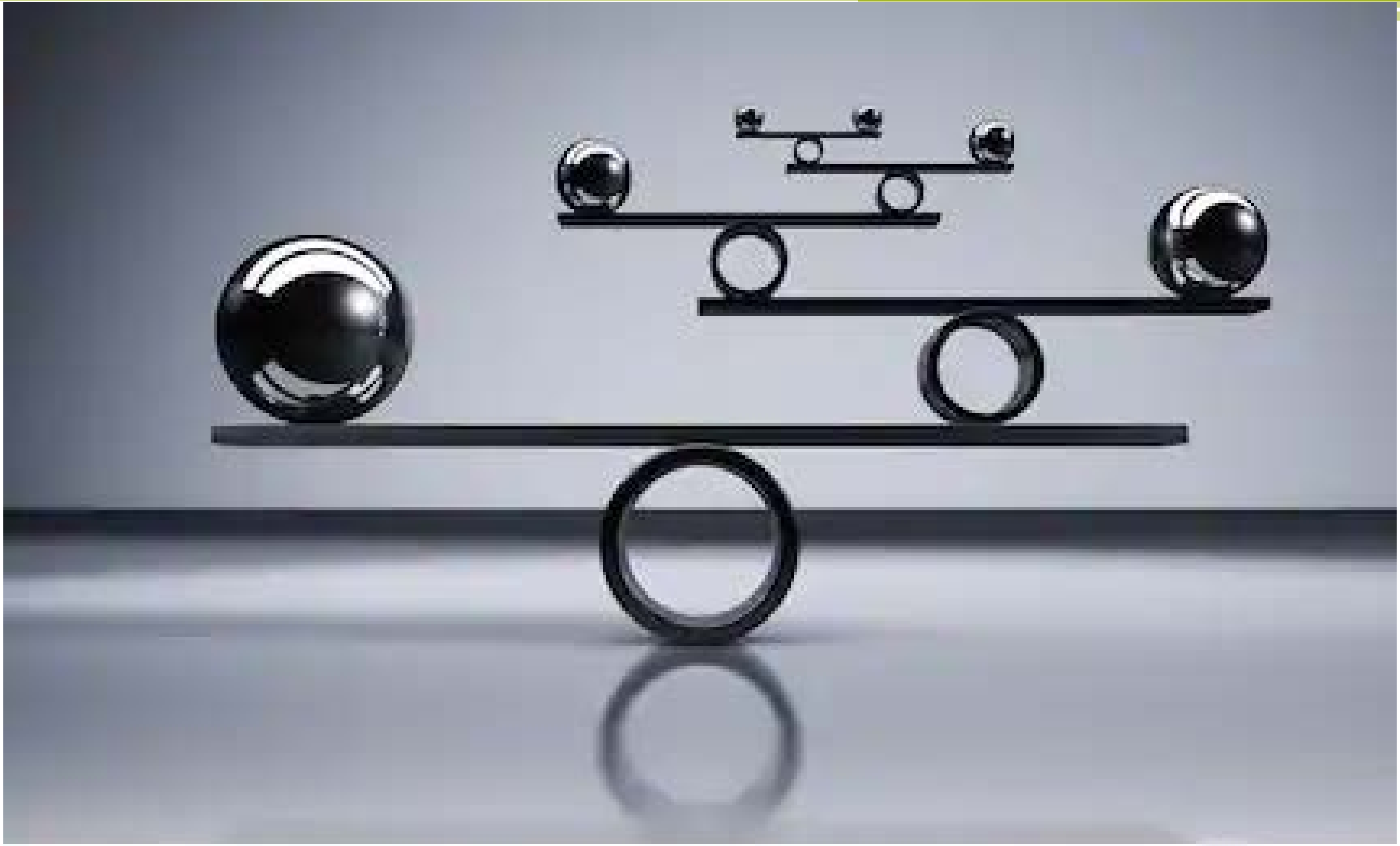
Petroleum products made from a barrel of crude oil, 2018

gallons



About ½ barrel of crude becomes gasoline – the rest -

Solvents	Diesel fuel	Motor Oil	Bearing Grease
Ink	Floor Wax	Ballpoint Pens	Football Cleats
Upholstery	Sweaters	Boats	Insecticides
Bicycle Tires	Sports Car Bodies	Nail Polish	Fishing lures
Dresses	Tires	Golf Bags	Perfumes
Cassettes	Dishwasher parts	Tool Boxes	Shoe Polish
Motorcycle Helmet	Caulking	Petroleum Jelly	Transparent Tape
CD Player	Faucet Washers	Antiseptics	Clothesline
Curtains	Food Preservatives	Basketballs	Soap
Vitamin Capsules	Antihistamines	Purses	Shoes
Dashboards	Cortisone	Deodorant	Footballs
Putty	Dyes	Panty Hose	Refrigerant
Percolators	Life Jackets	Rubbing Alcohol	Linings
Skis	TV Cabinets	Shag Rugs	Electrician's Tape
Tool Racks	Car Battery Cases	Epoxy	Paint
Mops	Slacks	Insect Repellent	Oil Filters
Umbrellas	Yarn	Fertilizers	Hair Coloring
Roofing	Toilet Seats	Fishing Rods	Lipstick
Denture Adhesive	Linoleum	Ice Cube Trays	Synthetic Rubber
Speakers	Plastic Wood	Electric Blankets	Glycerin
Tennis Rackets	Rubber Cement	Fishing Boots	Dice



Valuing: Health, Safety, Environment


8 covered tanks (2019 Dorian)


4 covered tanks (2019 Dorian)

What are impacts of these events?

- Business interruption
- Environment
- Reputation
- Good design
- Employee alignment
- Stay out of news
- Meaning of risk

Should society tolerate these events?


Society

Tanks Anyone?

Are these tanks?

Molten Steel
Storage - crucible

Acid
Storage

Are These Tanks?

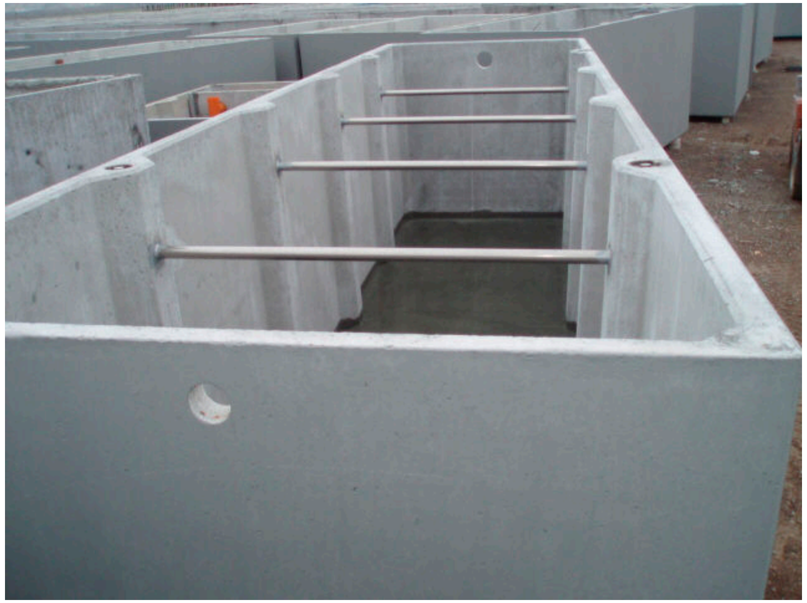
Is this a tank?


FUEL
FUEL
FUEL
ENGINES
LANDING GEAR
ENGINES
CONVENTIONAL DESIGN

Fuel Tanks


Lt 20
Lt 10
Lt 5


BOYD'S
EQUIPMENT




Ensign


GOEBEL

But What About Oil Storage Tanks?


Image courtesy of Nabucco Gas Pipeline International GmbH

Fixed Roof Tank (FRT)

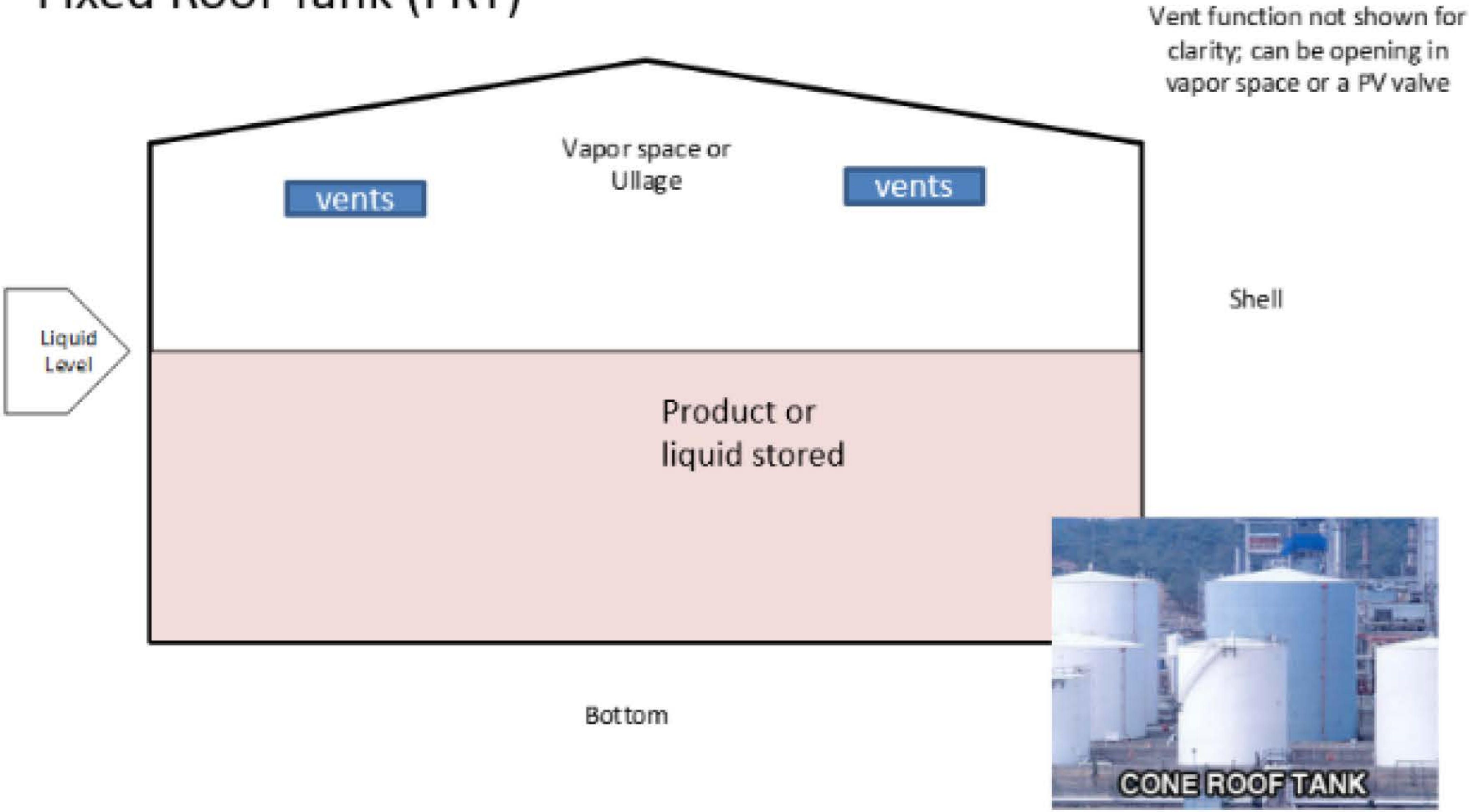


Figure 22 Fixed Roof Tank (FRT)

Covered or Internal Floating Roof Tank

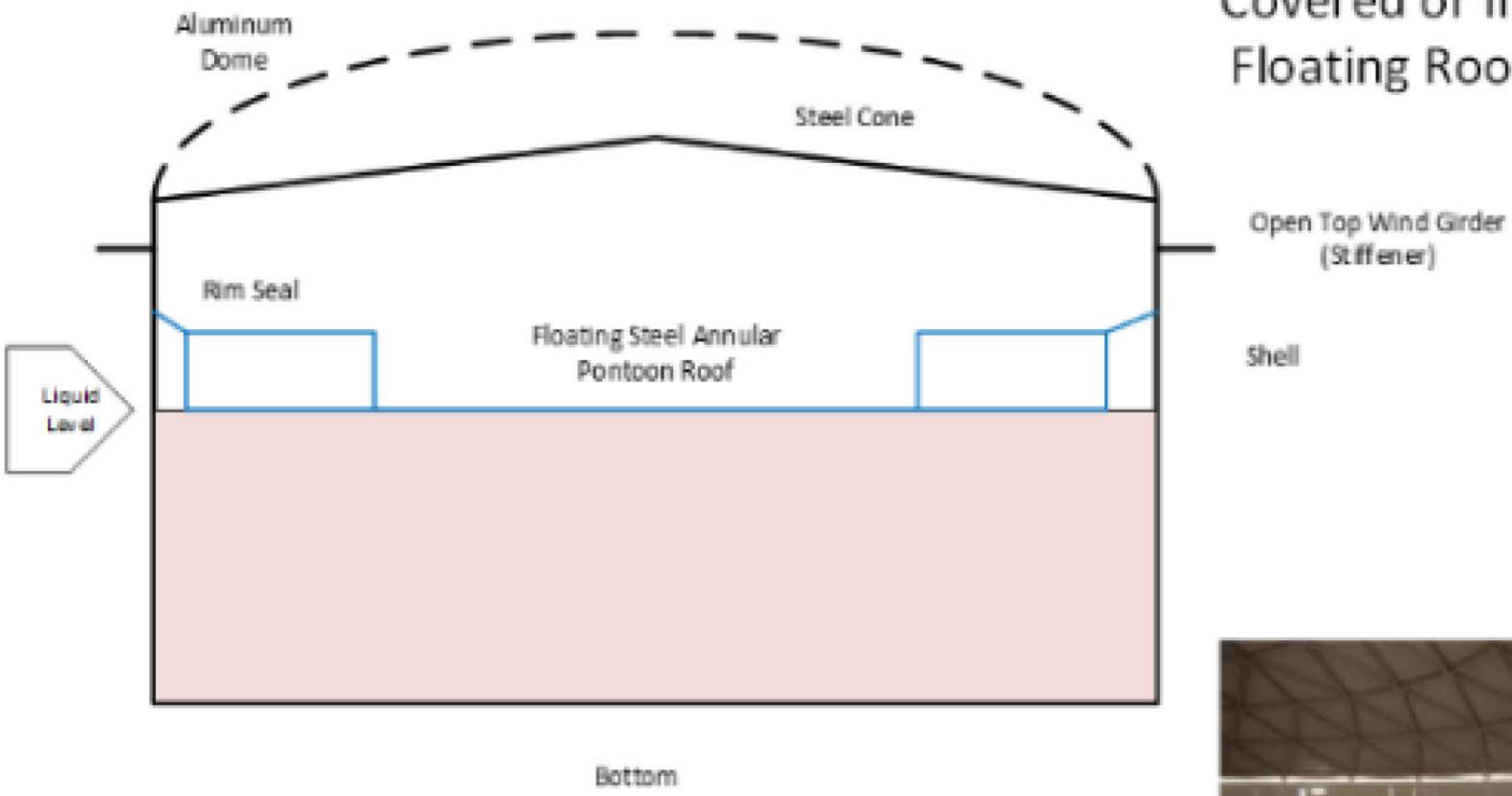
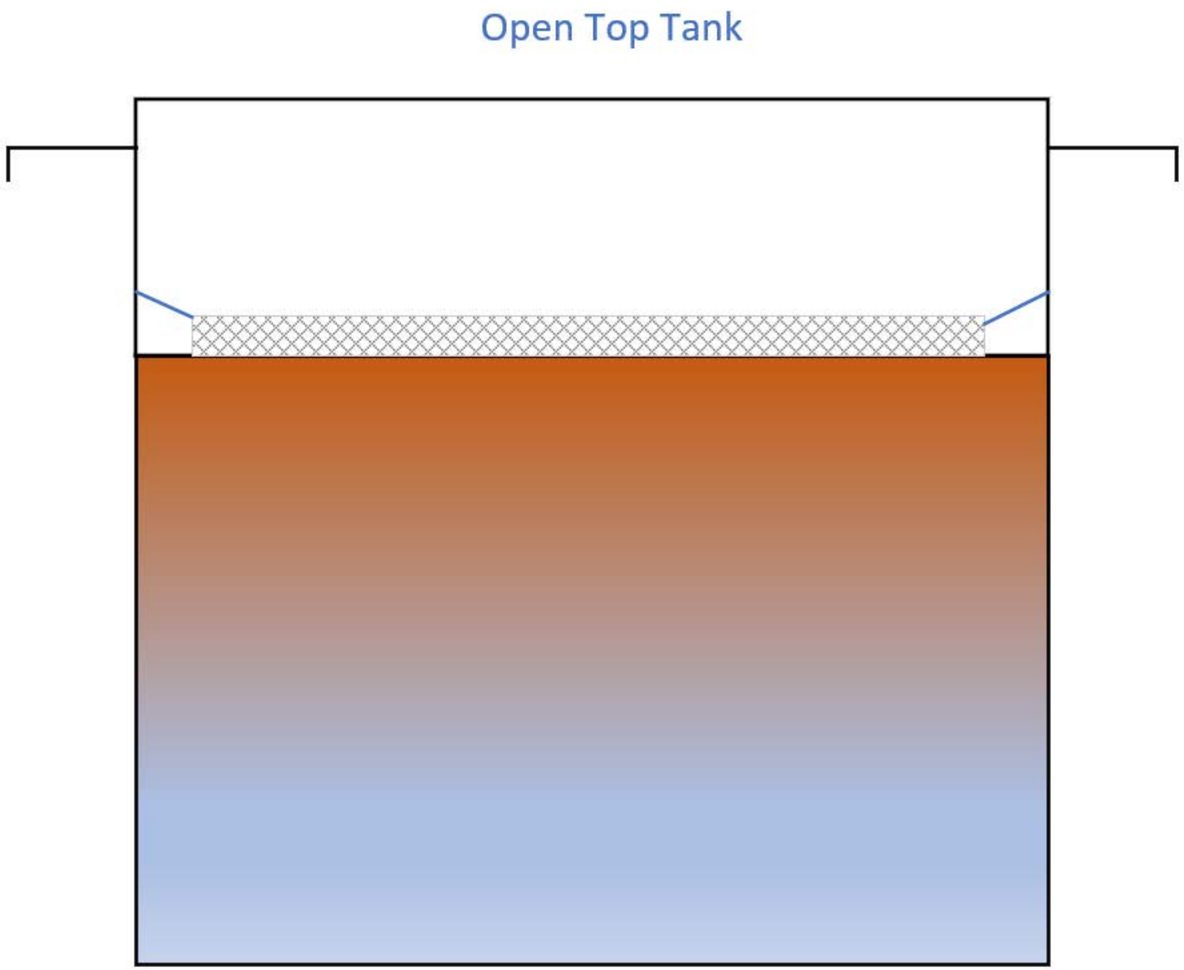


Figure 28: Internal floating Roof Tank (IFRT)

External Floating Roof Tank



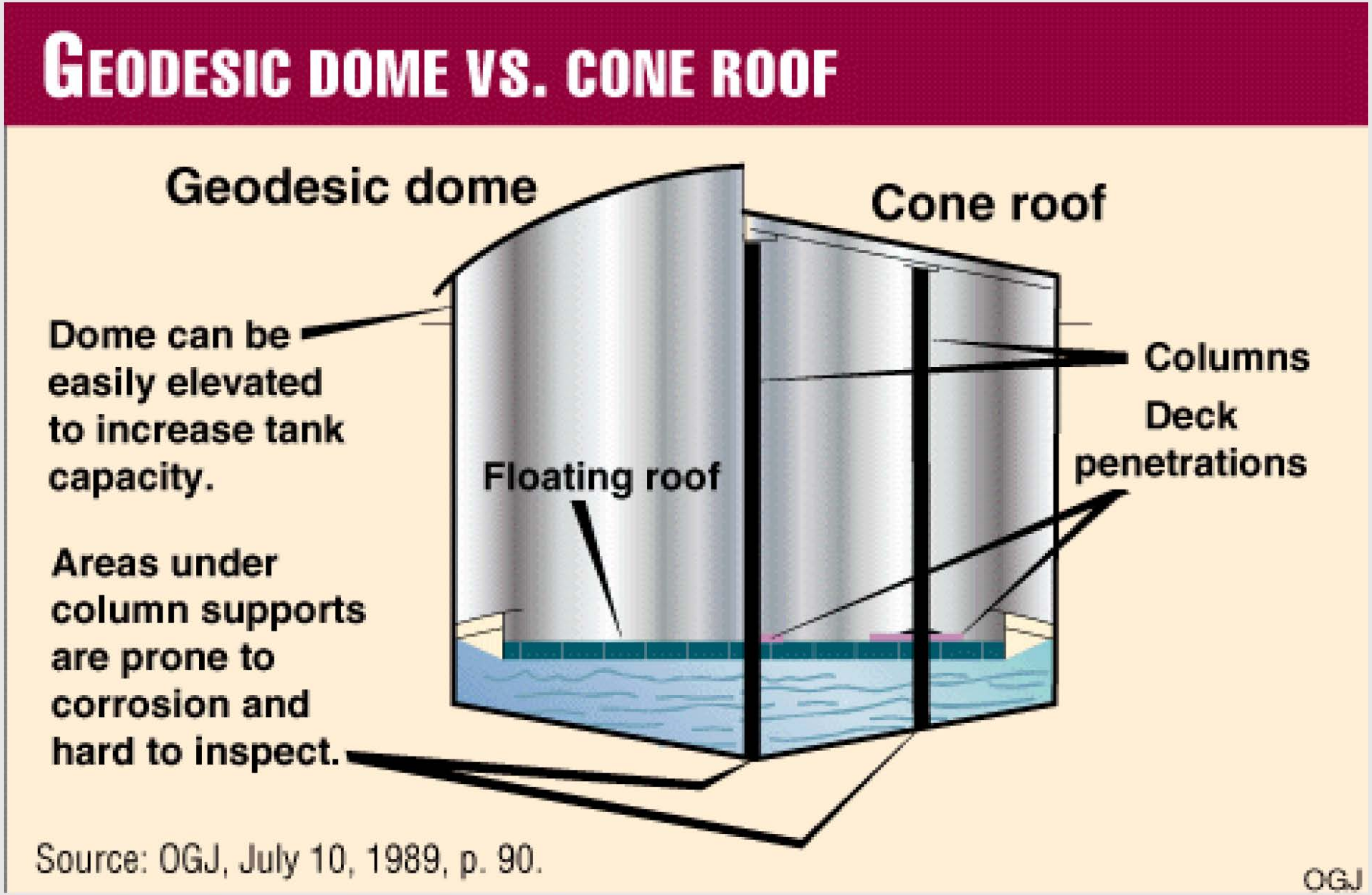


Figure 4 Contrast between geodesic and cone roofs

Quick Facts 3 Cone versus Dome Roofs

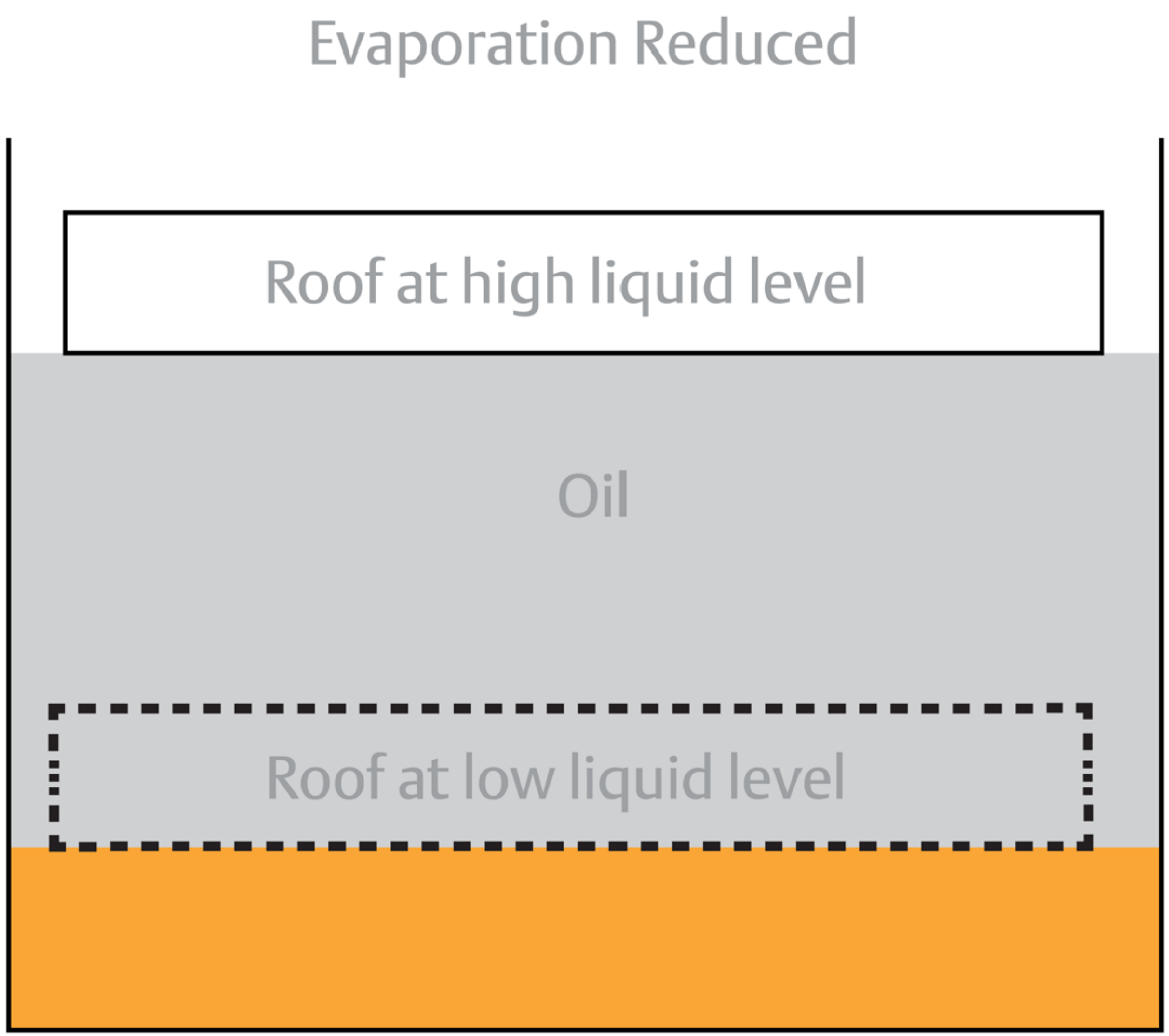


Figure 1 Conceptual diagram of floating roof tank

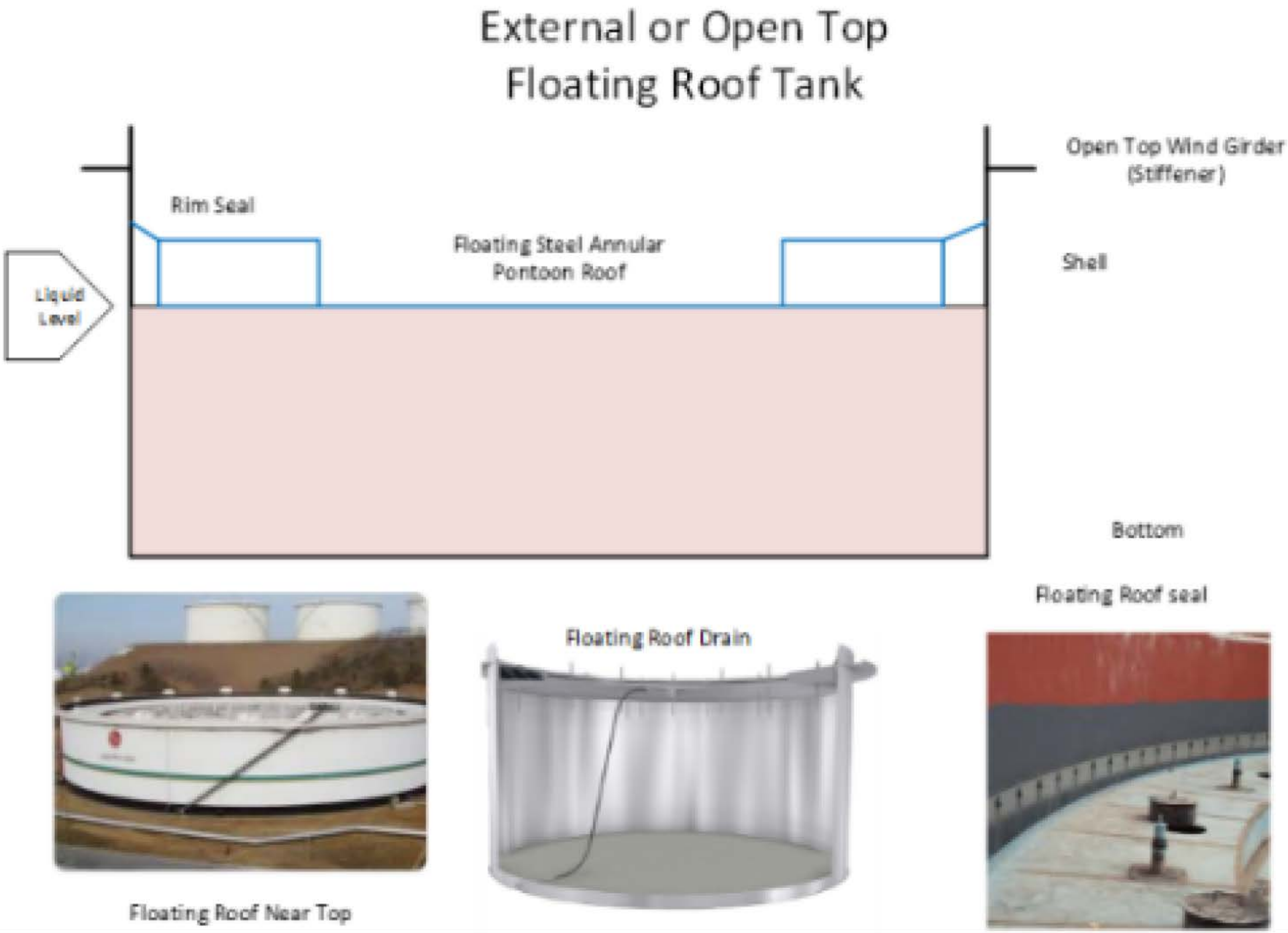


Figure 26 Open Top or External Floating Roof Tank (EFRT)

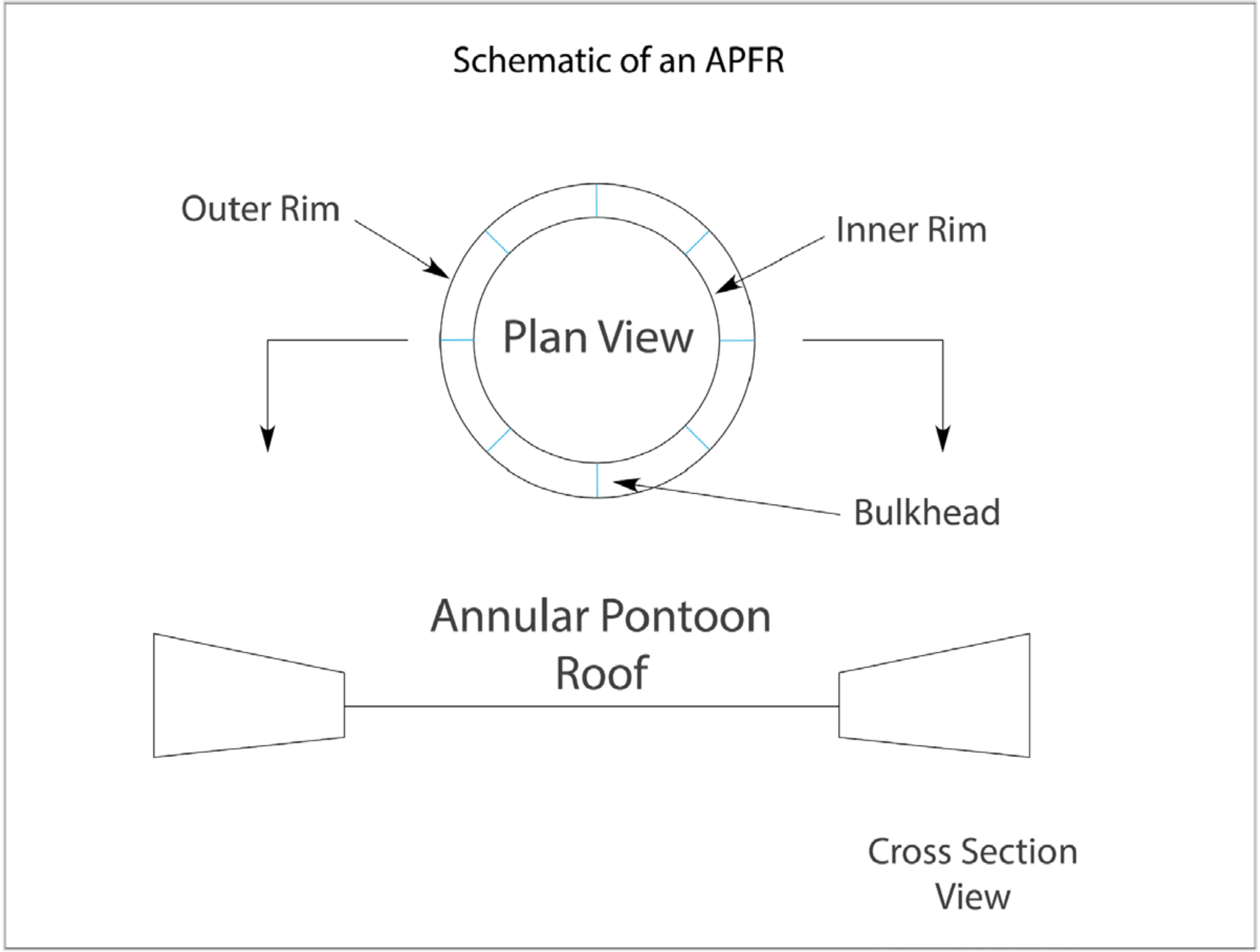


Figure 5 Schematic of an APFR

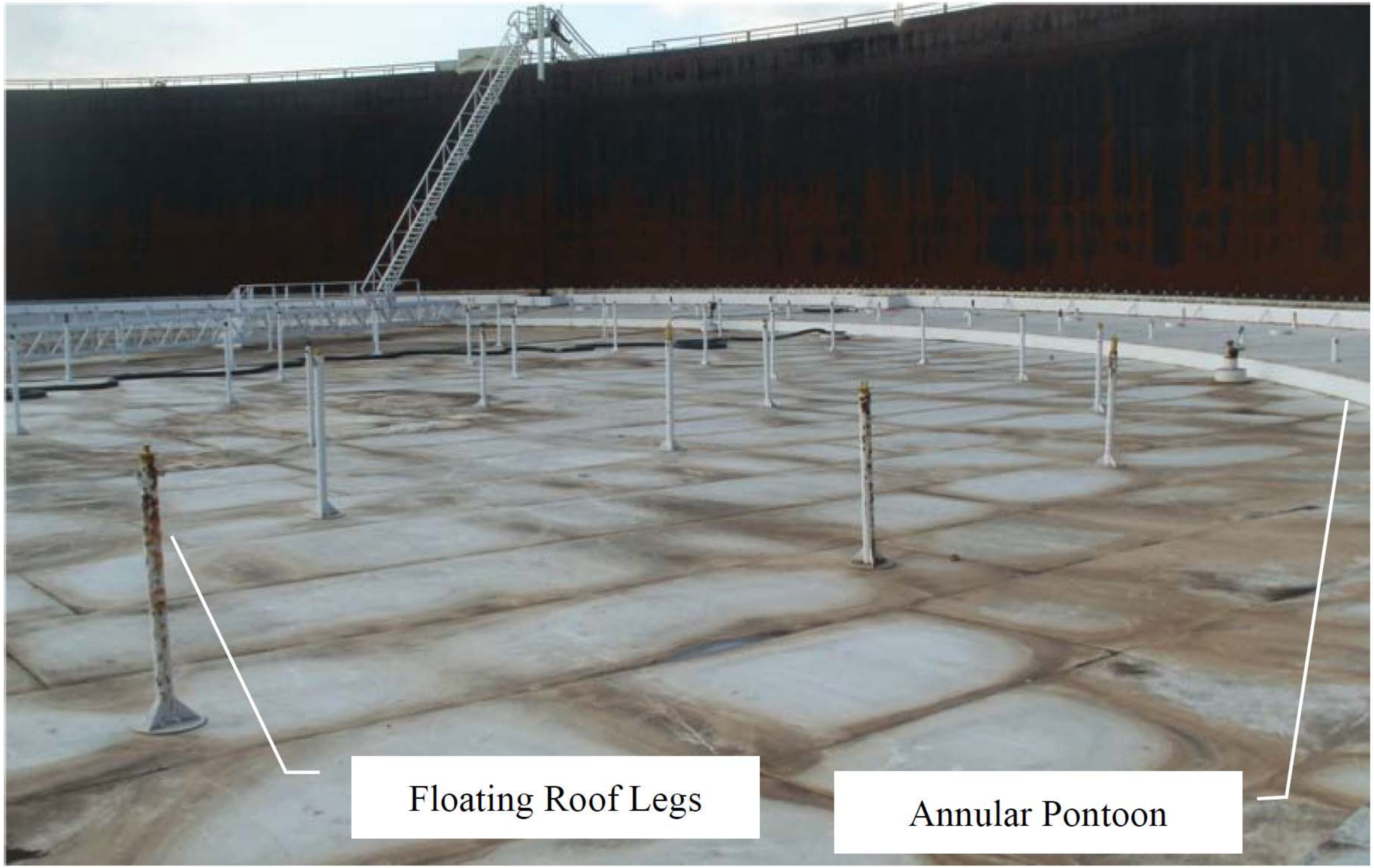
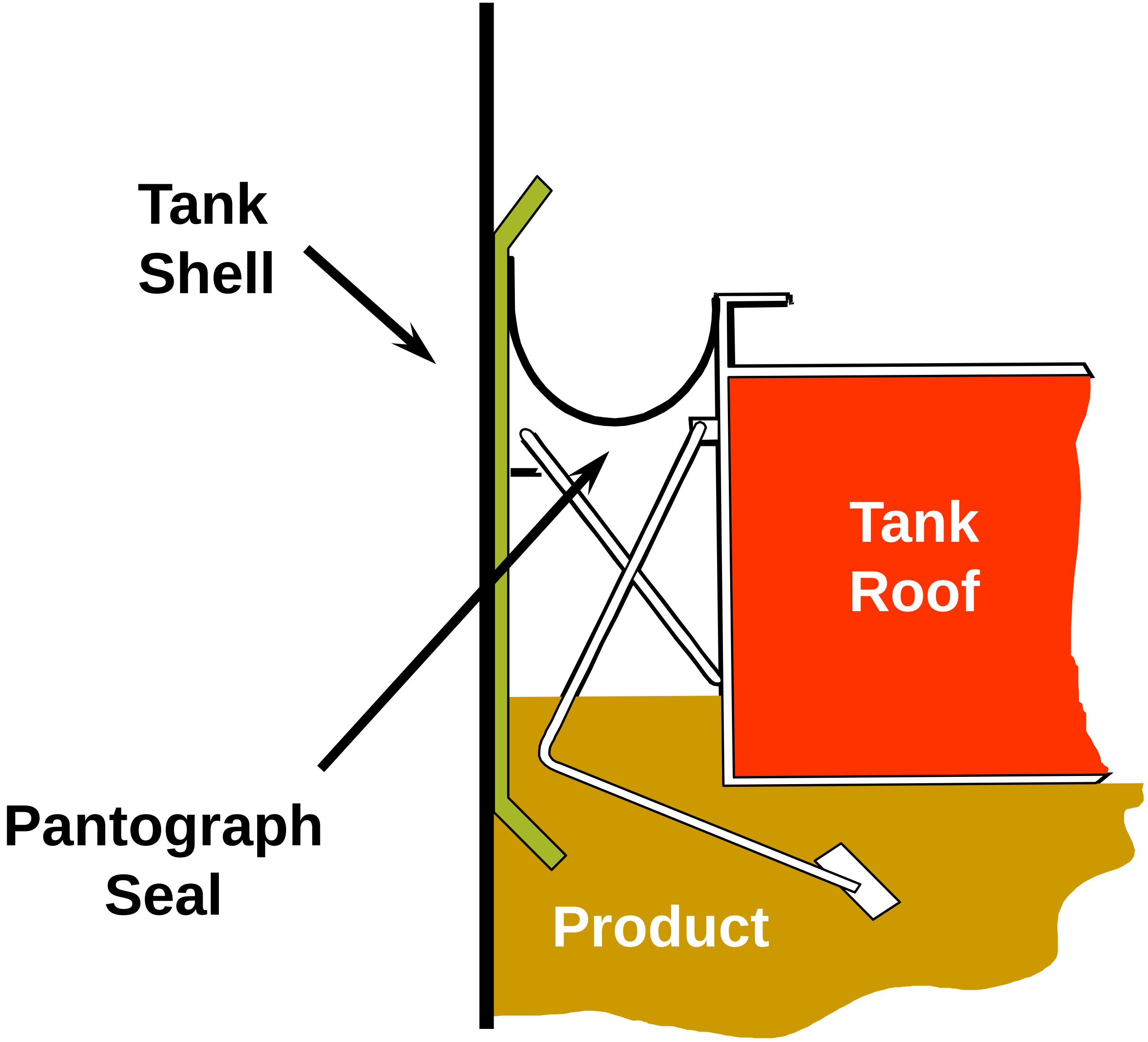


Figure 6 An overview of an APFR in application


Tank
Shell
Tank
Roof
Pantograph
Seal
Product

Storage Options for Bulk Liquids			
Product	FRT	EFRT	IFRT
Crude Oil (low vapor pressure)	Yes	Yes	Yes
Crude Oil (high vapor pressure)	No*	Yes	Yes
Gasoline	No*	Yes	Yes
Diesel Fuel	Yes	Yes	Yes
Ethanol	No	Yes	Yes

Table 1 Storage Tanks by Bulk Liquid

*In upstream tanks, volatile crude oil is often stored in small tanks (< 30ft diameter). When regulations require or when the owner must control vapors, then vapor recovery systems can be applied to these fixed roof tanks. If storing volatile organic liquids in a fixed roof tank, the pressure-vacuum or PV vent valve should be the vapor recovery system used.

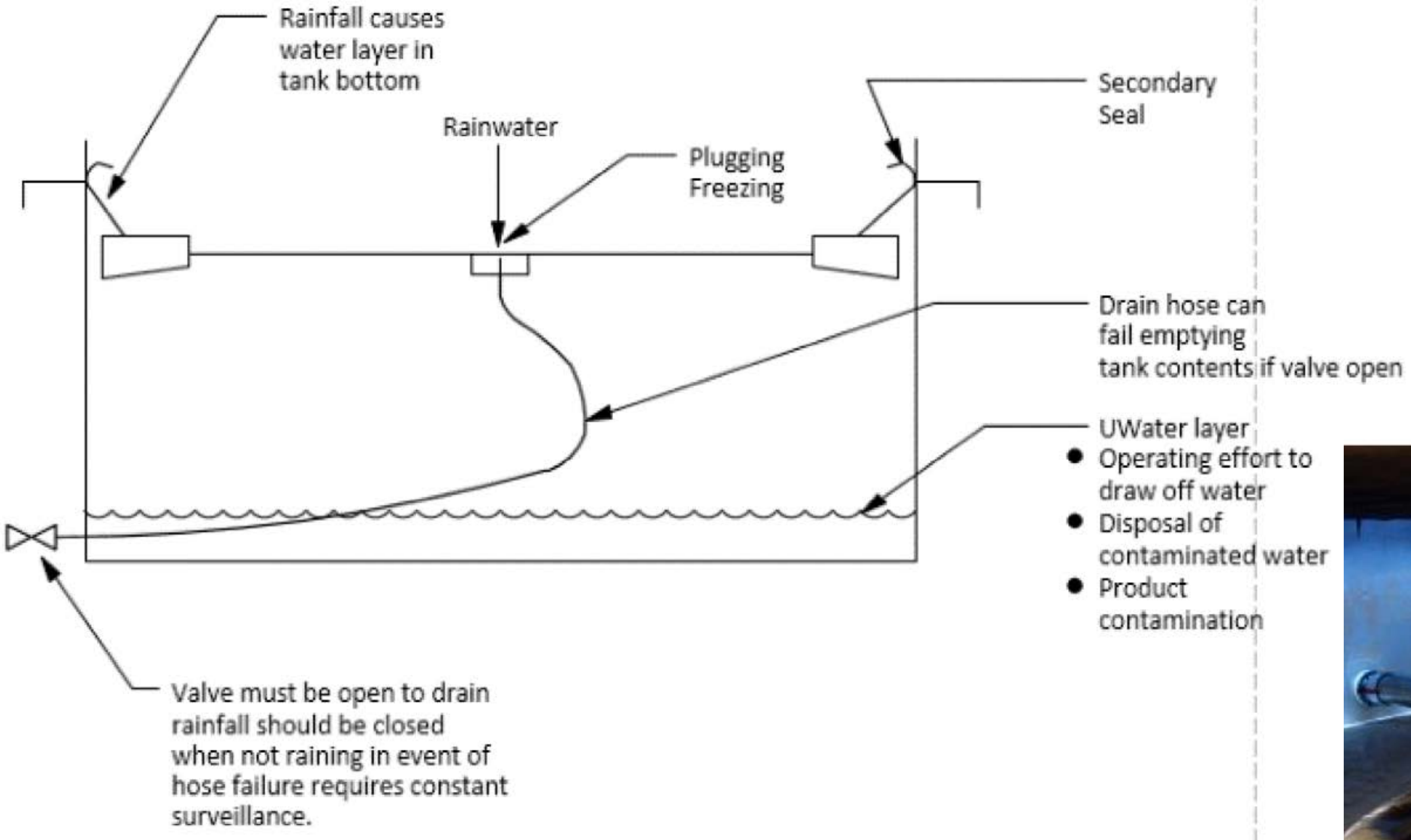


Figure 40 Schematic diagram of APFR drainage systems

Figure 39 Inadequate precipitation drainage

Why API 650?

- Uses
- Specifications
  - 650 v 653
- Types
  - FR, EFR, IFR
- How they differ from small tanks
  - horizontal, vertical, cylindrical, boxlike, etc,
- Moving parts: “foundation”, floating roofs, liquid level, venting devices, etc.
- The hazards: fire/explosion, spills, vapor clouds, air pollution, leaks, toxicity humans, plants, animals
- How to keep jack in the box

Aboveground v Belowground

- Pros and cons
  - corrosion
  - impact
  - fire
  - environmental
- Fire code spacing requirements

Where are API 650 Tanks Found

- Petroleum Terminals
- Pipeline Breakout Terminals
- Refineries
- Marine receiving facilities
- Chemical plants
- Bulk plants
- Lubricant Blending and Packaging Facilities
- Asphalt Plants
- Aviation facilities (and airports)
- Oil and Gas production facilities
- etc

Limits - but all have exceptions

- Diameter constraint not set by API – but by practical limits
  - No lower limit
  - No upper limit
- Thickness
  - 3/16 to 1.5 in
- Materials: mostly mild steel and some higher strength alloys (exceptions)
- Temperature: -20 to 200 (exceptions)
- Shape: vertical cylindrical flat bottom
- Spacing
- Stored liquid vapor pressure

Constructing Tanks – Which One?

- API 650
- API 653
- API 620
- UL 142
- STI SP001
- ASME BPV

Materials of construction?

- Mild steel
- Aluminum
- Stainless steel
- Plastic
- FRP
- Concrete
- Wood
- Glass

Big v Small?

- What factors govern thickness?
  - welding
  - general strength/handling
  - tank size (diameter, height, gas pressure on top of liquid)
  - pressure
- What about stress?

There are two kinds:
- primary
- secondary

Hoops stress and minimum thickness

Structural Difference Big and Small Tanks

- Show spreadsheet of required thicknesses

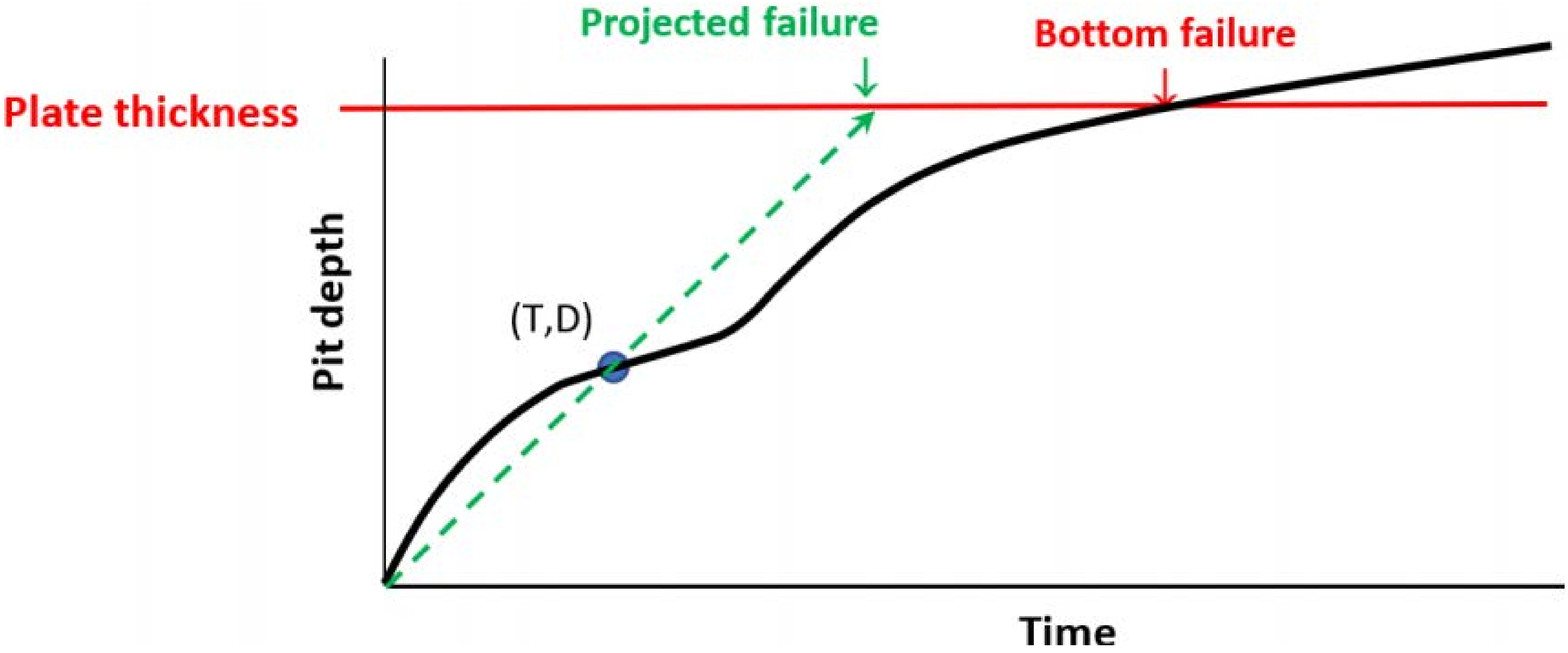
Shape

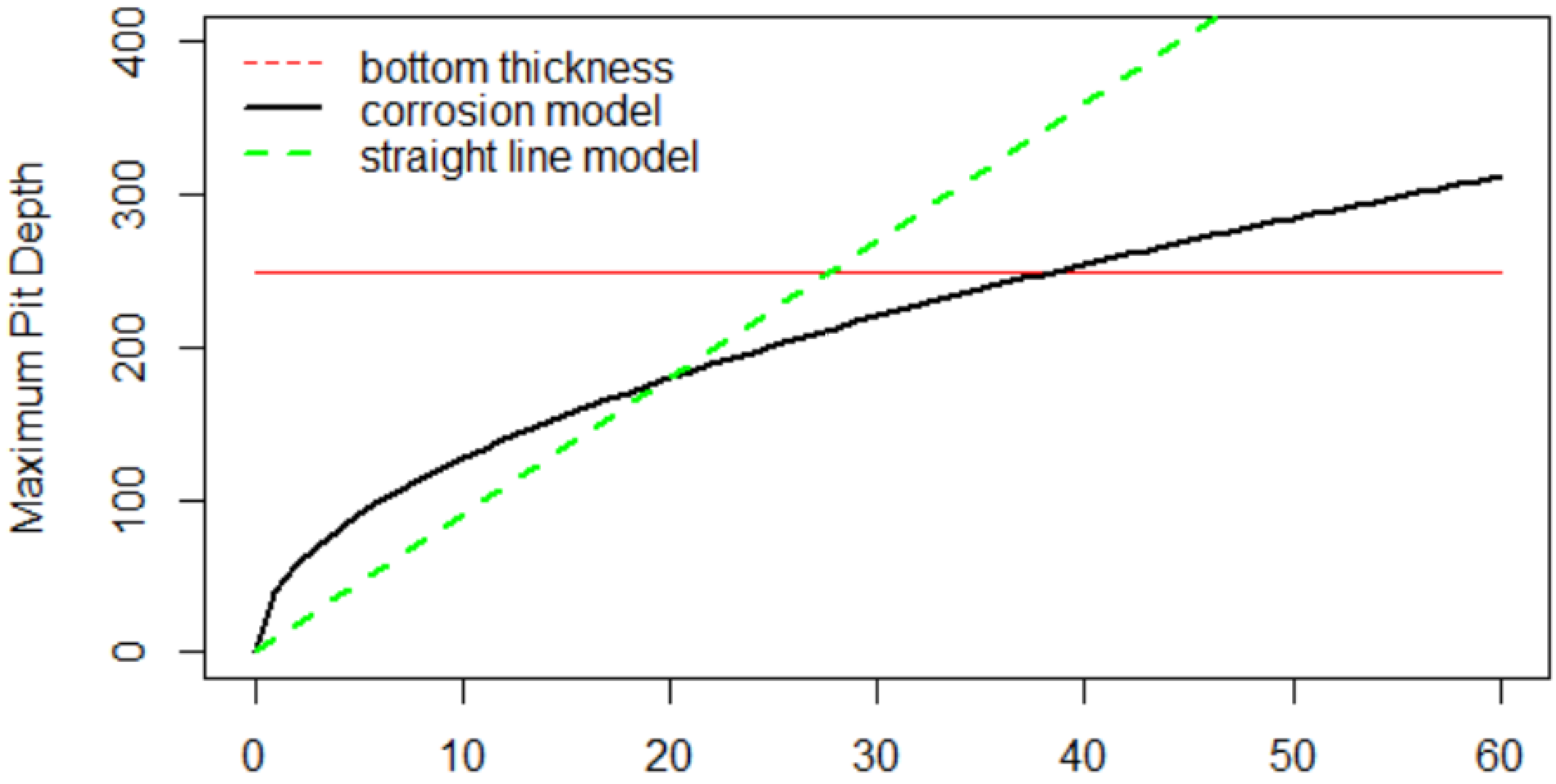
Check all that are true:

- ❑ cylindrical for large tanks
- ❑ horizontal for small tanks
- ❑ tanks with pressure have flat ends or closures
- ❑ vertical tanks may have conical or dished bottoms
- ❑ All tanks have fixed covers

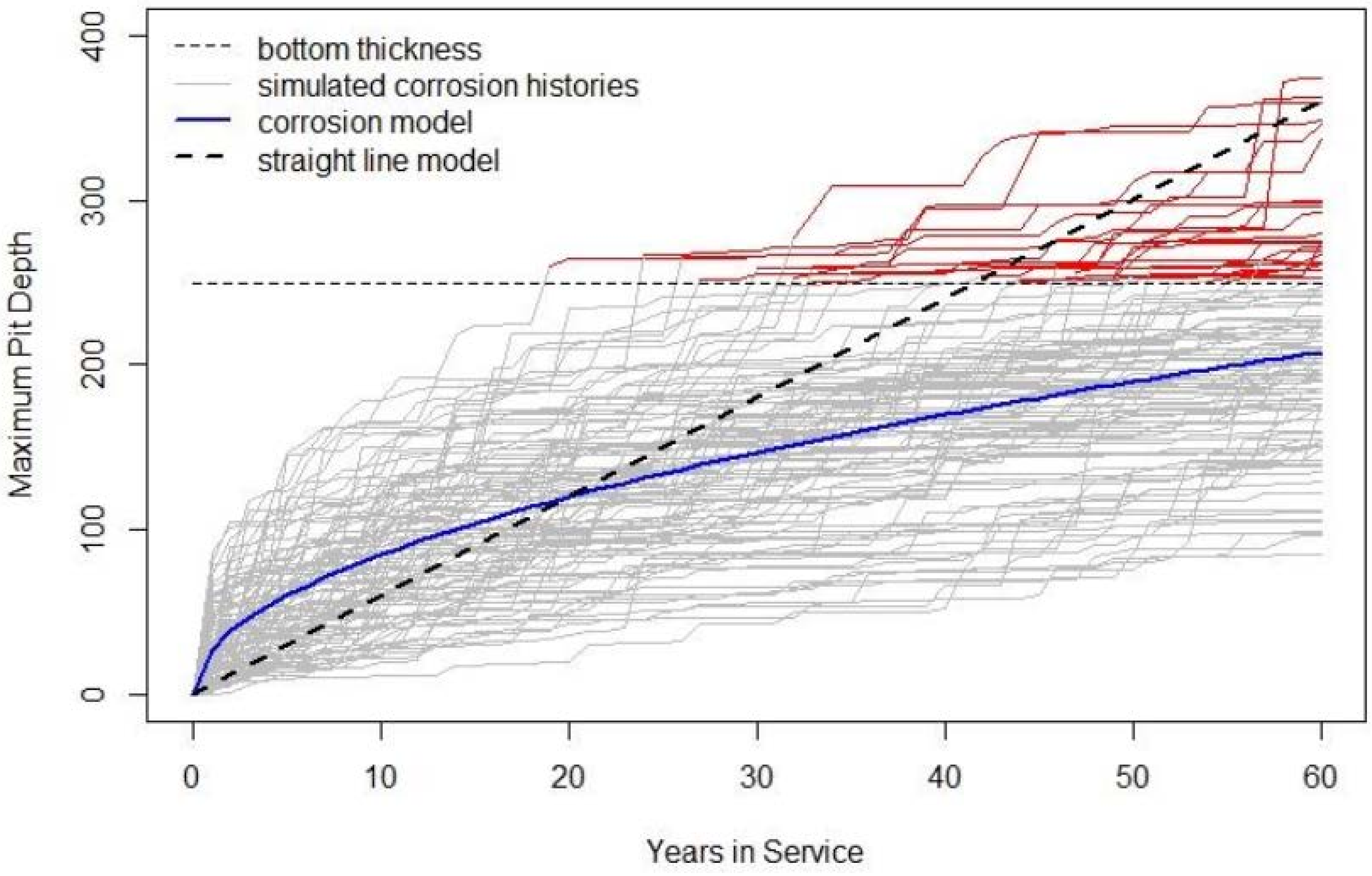
Then – and Now

- API 653 issued 1991
- Maximum Inspection interval was 20 yrs
- All tanks should have been inspected by now


Projected failure
Bottom failure
Plate thickness
Pit depth
(T,D)
Time


bottom thickness
corrosion model
straight line model
Maximum Pit Depth
0
100
200
300
400
0
10
20
30
40
50
60

Probabilistic Nature of Corrosion



Corrosion of Components - Rank

Vertical Tank

- bottom
- shell
- roof

Horizontal

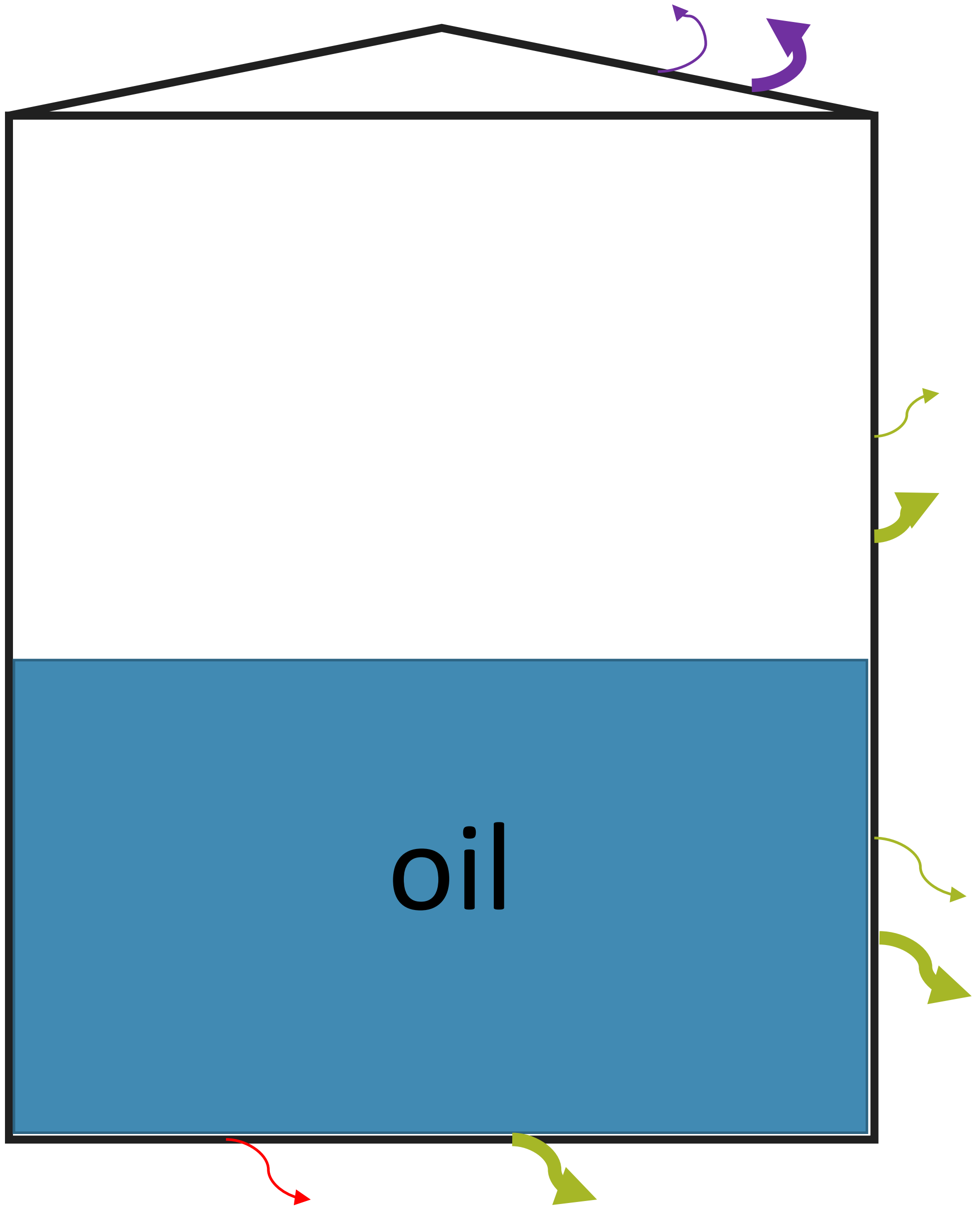
- bottom
- ends
- shell
- top

schematic picture of tank here

Corrosion – Rank Best to Worst

- aviation gasoline
- heated tank (180F) in refinery service
- lube oils
- gasoline
- crude oil
- diesel

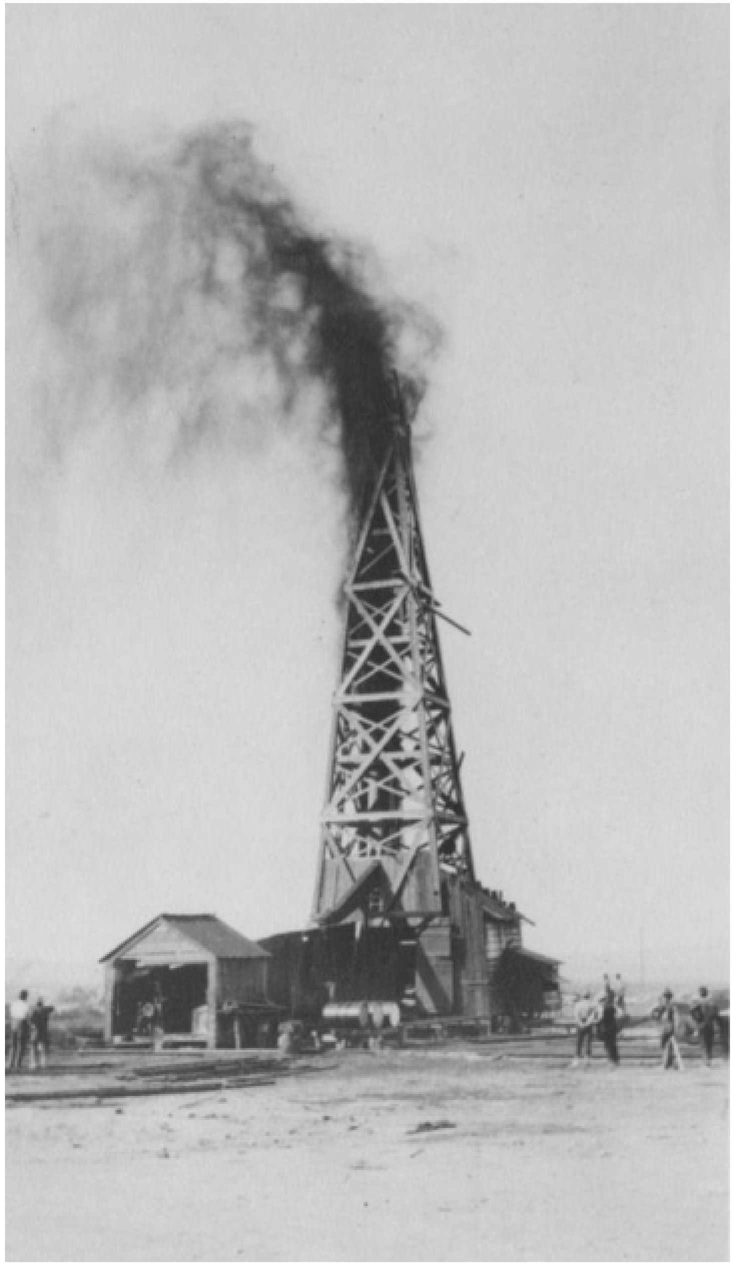
Leak Causation?



Leaks – which are
worst?
best?
detectable?

Finding Leaks

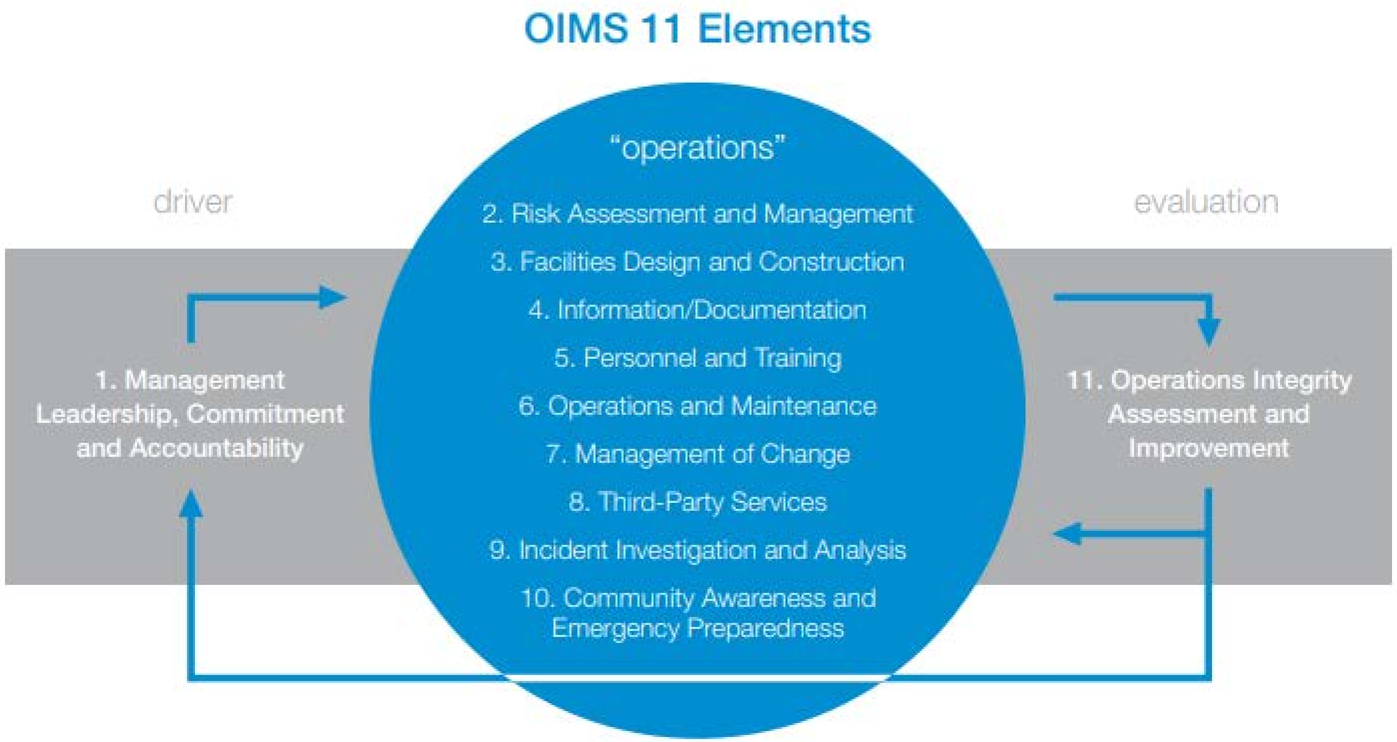
- API 653 Monthly walk around
- API 653 Formal External Inspection
- API 653 Formal Internal Inspection



So What's Really Important for Large ASTs

- API 653 program (verifiable, audiable, and robust)
- Tank overfill protection program API 2350

How to Keep Jack in the Box



Mini-Mgmt System for Tanks

- Use industry standards for design, construction, operation
  - API 650
  - API 2610
- Use industry best practices for inspection, repairs, maintenance
  - API 653
  - API 579
- Prevent leaks:
  - Track and understand corrosion data (and insist on it from inspection suppliers)
  - Use stock loss methods
  - Minimize internal inspections

Then – and Now

- Before 1991 – R you kidding me? You wanna inspect a tank?
- Serious incidents in the 70s and 80s resulted in numerous calls for regulations
- The Ashland Incident along with other pushed API to draft API 653
- The aximum Inspection interval was 20 yrs
- All tanks should have been inspected by now

- The next talk by Brock Trotter will cover tank airborne emissions from storage tanks.

Tank Emissions Calculations

How to use API EPA AP 42

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ckground

The US EPA requires companies that store, handle, and transport liquid
petroleum products must report the emissions associated. The EPA
provides calculation methodologies for a variety of scenarios in AP 42.

The EPA published a modeling software for tank emissions on their
website but they state specifically, "***The model will remain on the website
to be used at your discretion and at your own risk. We will continue to
recommend the use of the equations/algorithms specified in AP-42 Chapter
7 for estimating VOC emissions from storage tanks. The equations specified
in AP-42 Chapter 7 (https://www.epa.gov/ttn/chief/ap42/ch07/index.html)
can be employed with many current spreadsheet/software programs.***"

eference Standards

- **API MPMS Ch 19.1 – Evaporative Loss from Fixed-Roof Tanks**
- **API MPMS Ch 19.2 – Evaporative Loss from Floating-Roof Tanks**

- EPA AP 42 (General Document)

eneral Concept

$$E = A \times (EF) \times \left(1 - \frac{ER}{100}\right)$$

$$E = emissions, A = activity\ factor, EF = emissions\ factor,$$
$$ER = overall\ emissions\ reduction\ efficiency\ \%$$

Activity factor determined by the physical properties of the liquid/vapor

Emissions factor determine by the piece of equipment through testing

PI MPMS Ch 19.1_4.1 – Fixed-Roof Tanks – General

Total routine losses from fixed roof tanks are equal to the sum of the standing loss and working
s:

$$L_T = L_S + L_W \quad (1\text{-}1)$$

ere:

L_T = total routine losses, lb/yr
L_S = standing losses, lb/yr, see Equation 1-2
L_W = working losses, lb/yr, see Equation 1-35

PI MPMS Ch 19.1_4.2 – Standing Losses

oveground and Underground Tanks

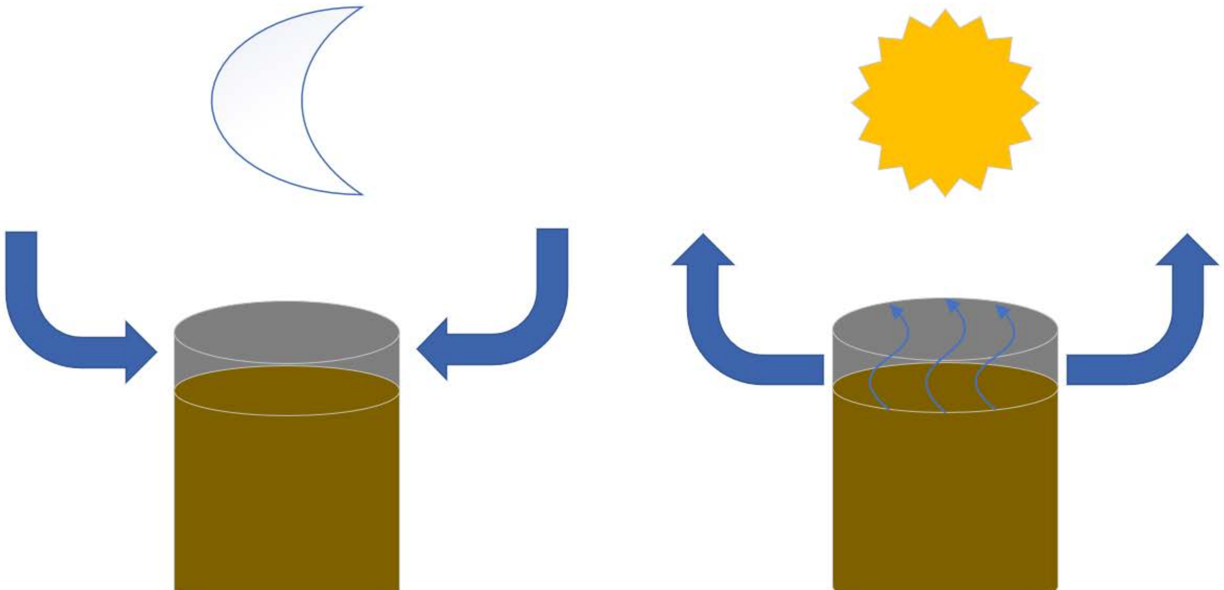
oveground tanks, the standing loss L_S (lb/yr) is:

$$= 365(\pi D^2/4)\ H_{VO}\ K_S\ K_E\ W_V \quad (2)$$

H_{VO}, K_S, K_E, and W_V are determined in 4.2.2 through 4.2.6, respectively;

he constant 365 has units of days/yr.

lerground tanks, assume no standing loss occurs (L_S = 0) because the insulating nature of the earth
liurnal temperature change.



I MPMS Ch 19.1_4.2.3 – Vapor Space Outage Cont.

apor Space Outage H_{VO}

oor space outage H_{VO} (ft), the height of a cylinder of diameter D whose volume equals the vapor olume of a fixed-roof tank, is:

ertical tanks (see Figure 1):

$$H_{VO} = H_S - H_L + H_{RO} \quad (4a)$$

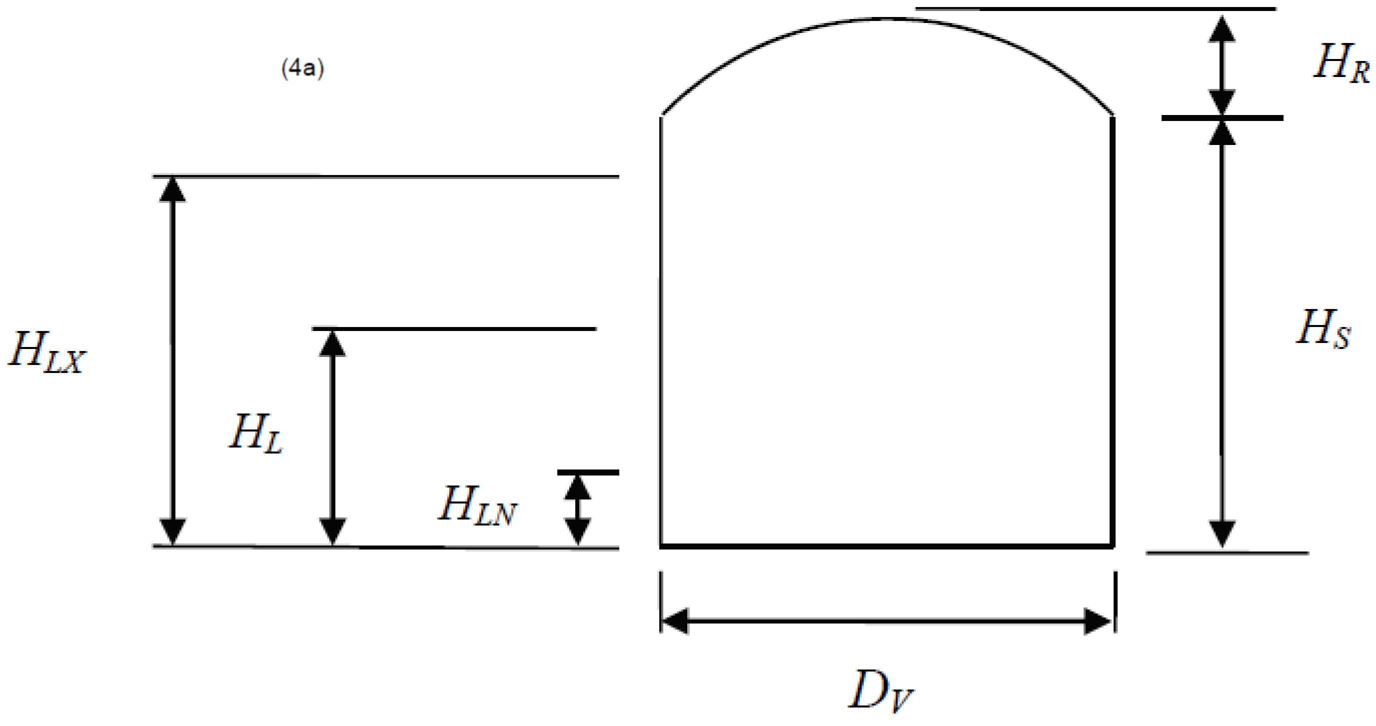


Figure 1 — Fixed-Roof Tank Geometry

PI MPMS Ch 19.1_4.2.4 – Vented Vapor Sat. Factor

ed Vapor Saturation Factor K_S

vapor saturation factor K_S (dimensionless) accounts for the degree of stock vapor saturation in apor:

$$1/(1 + 0.053 P_{VA} H_{VO}) \quad (7)$$

is determined in 4.2.3;

constant 0.053 has units of 1/(psia-ft).

is the stock true vapor pressure (psia) at the average liquid surface temperature T_{LA}

API *MPMS* Ch. 19.4, 3rd Edition, Section 4.2 to determine vapor pressure P_V at a given perature T)

re

T_{LA} is the daily average liquid surface temperature (°R), which may be determined as follows:

$$T_{LA} = 0.44 T_{AA} + 0.56 T_B + 0.0079 \alpha I \quad (8)$$

$$T_{AA} = (T_{AX} + T_{AN})/2 \quad (9)$$

nt – High P_{VA}

Heavy – Low P_{VA}

I MPMS Ch 19.1_4.2.4 – Vented Vapor Sat. Factor Cont.

on below for estimating liquid bulk temperature is based on the assumption that the product is in uilibrium. The time required for the liquid bulk to achieve thermal equilibrium with ambient however, would result in the stock typically not being in thermal equilibrium for much of the riod. Therefore, it is highly preferable to use measured values for the liquid bulk temperature. If values are unavailable, T_B may be estimated as:

$$T_B = T_{AA} + (6\alpha - 1) \quad (12)$$

where

α is the tank surface solar absorptance (see API *MPMS* Ch. 19.4, 3rd Edition, Section 4.8);

I is the daily total insolation on a horizontal surface (Btu/(ft^2 day)) (see API *MPMS* Ch. 19.4, 3rd Edition, Table 1);

The constants 6 and 1 have units of °R.

owest α

Highest α

I MPMS Ch 19.1_4.2.5 – Vapor Space Expansion Factor

4.2.5 Vapor Space Expansion Factor K_E

The vapor space expansion factor K_E is nominally dimensionless but is assigned units of (1/day) because it describes the expansion of vapors in the vapor space that occurs due to the diurnal temperature cycle, and thus it pertains to a daily event.

a) For stocks with $P_{VA} \leq 0.1$ psia and $\Delta P_B \leq 0.063$ psi (see Equation 18), the vapor space expansion factor K_E (1/day) is approximately:

$$K_E = 0.04 \tag{13a}$$

K_E may be estimated more accurately for this case as follows:

$$K_E = 0.0018 \Delta T_V \tag{13b}$$

where

The constant 0.0018 has units of 1/°R.

ΔT_V is the daily vapor temperature range (°R), which may be determined as follows:

I MPMS Ch 19.1_4.2.5 – Vapor Space Expansion Factor Cont.

For stocks with $P_{VA} > 0.1$ or ΔP_B > 0.063 psi (see Equation 18):

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_A - P_{VA}} \geq 0 \qquad (13c)$$

ere

P_{VA} is determined in 4.2.4;

ΔT_V is determined in 4.2.5a);

T_{LA} is determined in 4.2.4;

$\Delta P_V - \Delta P_B$ is the daily exceedance (psi) of the vapor space pressure range beyond the vent setting range;

ΔP_V is the daily stock vapor pressure range (psi), and may be determined using either of the following methods:

I MPMS Ch 19.1_4.3 – Working Losses

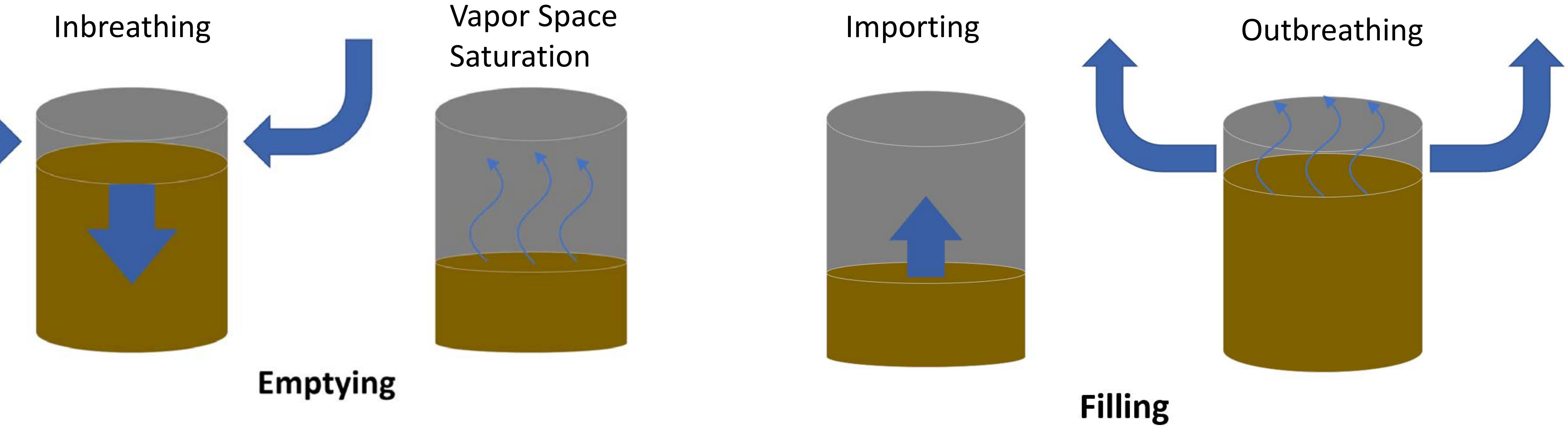
orking Loss L_W

General

loss occurs when the liquid level in the tank increases. The working loss L_W (lb/yr) is:

$$L_W = V_Q \, K_N \, K_C \, K_B \, W_V \qquad (21)$$

$_Q$, K_N, K_C, and K_B are determined in 4.3.2 through 4.3.5, respectively, and W_V is determined in 4.2.6.



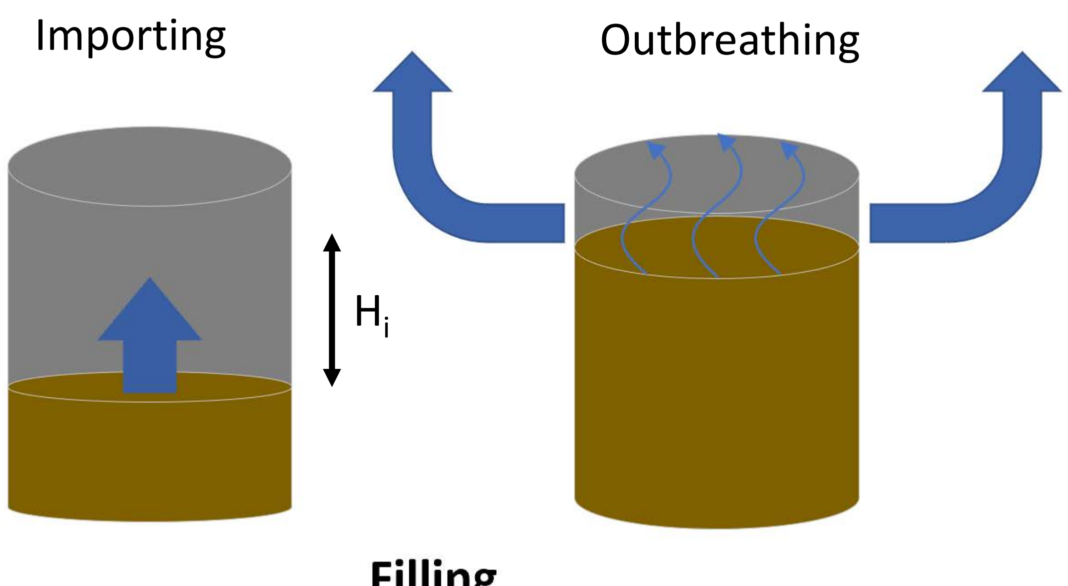
I MPMS Ch 19.1_4.3.2 – Net Working Loss Throughput

Net Working Loss Throughput V_Q

orking loss throughput (ft^3/yr) is:

$$V_Q = (\Sigma H_Q)(\pi D^2/4) \quad (22a)$$

H_Q is the annual sum of the increases in liquid level (ft/yr). If ΣH_Q is unknown, V_Q can be estimated as:



I MPMS Ch 19.1_4.3.3 – Turnover Factor K_N

Turnover Factor K_N

rnover factor (dimensionless) is:

$K_N = 1$ for $N \leq 36$ (23a)

$K_N = (180 + N)/(6N)$ for $N > 36$ (23b)

The constant 180 has units of turnovers/yr.

N is the stock turnover rate (turnovers/yr) =

$\Sigma H_Q / (H_{LX} - H_{LN})$ (24a)

Dimensionless variable responsible for accounting for the frequency of tank turnovers

I MPMS Ch 19.1_4.3.4 – Product Factor K_C

4 Product Factor K_C

product factor accounts for the effect of different stocks on evaporative loss during tank working. The
duct factor (dimensionless) is:

$K_C = 0.75$ for crude oil stocks (26a)

$K_C = 1.0$ for refined petroleum stocks (26b)

$K_C = 1.0$ for single component petrochemical stocks (26c)

Dimensionless variable responsible for accounting for the product and its respective evaporative loss contribution

I MPMS Ch 19.1_4.3.5 – Vent Setting Correction Factor K_B

ent Setting Correction Factor K_B

eather vent pressure setting range ΔP_B (determined in 4.2.5b)) is less than or equal to the typical ±0.03 psig, $K_B = 1.0$. If ΔP_B is significantly greater than ±0.03 psig:

$$\frac{P_{BX} + P_A}{P_O + P_A} \leq 1.0,$$

$$K_B = 1.0 \qquad (27a)$$

K_N is determined in 4.3.3;

P_A is the atmospheric pressure at the tank site (see 4.2.5b)2);

P_{BX} is the breather vent maximum pressure setting (see 4.2.5b)2);

P_O is the normal operating pressure (psig) = $(P_{BX} + P_{BN})/2$ (28)

s://www.youtube.com/watch?v=YA3XUEIcXA0

onclusion Fixed-Roof Tank Emissions

Emissions governed by both thermal fluctuations and liquid level changes

The product determines the physical properties associated with the iquid/vapor equilibrium in the vapor space.

Dark tanks absorb more solar energy and have greater emissions

The EPA does not endorse its prior emissions software and companies must be able to defend values chosen when calculating tank emissions

I MPMS Ch 19.2_4.1 – Floating-Roof Tanks – General

General

e total loss L_T is the sum of the standing loss L_S and the working loss L_W:

$$L_T = L_S + L_W \quad (1)$$

Exact same contributions as Fixed-Roof tanks

PI MPMS Ch 19.2_4.2 – Standing Losses

Standing Loss L_S

Overview

ding loss pertains to evaporative loss of stock liquid from beneath the floating roof while it is floating.
standing loss L_S can be estimated as follows:

$$L_S = (F_r + F_f + F_d)\, P^* \, M_V \, K_C \quad (2)$$

is the total rim-seal loss factor, in pound-moles per year,

is the total deck-fitting loss factor, in pound-moles per year,

is the total deck-seam loss factor, in pound-moles per year,

is the vapor pressure function, dimensionless,

is the average molecular weight of stock vapor, in pounds per pound-mole,

is the product factor, dimensionless.

PI MPMS Ch 19.2_4.2 – Standing Losses Continued

Table 1—Rim-Seal Loss Factors

Tank Construction and Rim-seal System	Average-fitting Seals							Tight-fitting[a] Seals						
	Zero-wind Speed Loss Factor	Wind-dependent Loss Factor	Wind-dependent Loss Exponent	Rim-seal Loss Factor K_r (lb-mol/ft-yr)				Zero-wind Speed Loss Factor	Wind-dependent Loss Factor	Wind-dependent Loss Factor	Rim-seal Loss Factor K_r (lb-mol/ft-yr)			
	K_{ra} (lb-mol/ ft-yr)	K_{rb} [lb-mol/ (mph)^n-ft-yr]	n (dimension-less)	0 (mph)	5 (mph)	10 (mph)	15 (mph)	K_{ra} (lb-mol/ ft-yr)	K_{rb} [lb-mol/ (mph)^n-ft-yr]	n (dimension-less)	0 (mph)	5 (mph)	10 (mph)	15 (mph)
Welded Tanks														
Mechanical-shoe seal														
Primary only	5.8 [b,c]	0.3 [c]	2.1 [c]	5.8	15	44	94	1.5	0.4	1.9	1.5	10	33	70
Shoe-mounted secondary	1.6	0.3	1.6	1.6	5.5	14	24	1.0	0.4	1.5	1.0	5.5	14	24
Rim-mounted secondary	0.6	0.4	1.0	0.6	2.6	4.6	6.6	0.4	0.4	1.0	0.4	2.4	4.4	6.4
Liquid-mounted seal														
Primary only	1.6	0.3	1.5	1.6	5.0	11	19	1.0	0.08	1.8	1.0	2.4	6.0	11
Weather shield	0.7	0.3	1.2	0.7	2.8	5.5	8.4	0.4	0.2	1.3	0.4	2.0	4.4	7.2
Rim-mounted secondary	0.3	0.6	0.3	0.3	1.3	1.5	1.7	0.2	0.4	0.4	0.2	1.0	1.2	1.4
Vapor-mounted seal														
Primary only	6.7 [d]	0.2	3.0	6.7	32	210	680	5.6	0.2	2.4	5.6	15	56	139
Weather shield	3.3	0.1	3.0	3.3	16	100	340	2.8	0.1	2.3	2.8	6.9	23	54
Rim-mounted secondary	2.2	0.003	4.3	2.2	5.2	62	340	2.2	0.02	2.6	2.2	3.5	10	25
Riveted Tanks														
Mechanical-shoe seal														
Primary only	10.8	0.4	2.0	11	21	51	100	[e]	[e]	[e]				
Shoe-mounted secondary	9.2	0.2	1.9	9.2	14	25	44	[e]	[e]	[e]				
Rim-mounted secondary	1.1	0.3	1.5	1.1	4.5	11	19	[e]	[e]	[e]				

Notes:

[a] "Tight-fitting" means that the floating roof is maintained with no gaps more than 1/8 in. wide between the rim seal and the tank shell.

[b] When no specific information is available, a welded tank with an average-fitting mechanical-shoe primary seal only can be assumed to represent the most common or typical construction and rim-seal system in use on domed EFRTs.

[c] When no specific information is available, a welded tank with an average-fitting mechanical-shoe primary seal only can be assumed to represent the most common or typical construction and rim-seal system in use on EFRTs.

[d] When no specific information is available, a welded tank with an average-fitting vapor-mounted primary seal only can be assumed to represent the most common or typical construction and rim-seal system in use on IFRTs.

[e] No evaporative-loss information is available for riveted tanks with consistently tight-fitting rim-seal systems.

PI MPMS Ch 19.2_4.2 – Working Losses

Working Loss L_W

Overview

g, or withdrawal, loss pertains to the evaporation of stock liquid that clings to the tank shell (and any oof support columns) while the stock is withdrawn (i.e. while the liquid level is decreased). The g loss L_W can be estimated as follows:

$$L_W = \frac{0.943 Q_N C_L W_L}{D}\left(1 + \frac{N_{fc} D_C}{D}\right) \quad (19)$$

Q_N is the net stock throughput associated with decreasing the liquid level in the tank (bbl/yr), - Throughput

C_L is the clingage factor (bbl/1000 ft^2), - Clingage Loss

W_L is the average stock liquid density at 60°F (lb/gal), - Liquid Density at ST

N_{fc} is the number of fixed-roof support columns (dimensionless),

D_C is the effective column diameter (ft),

- Volume Loss through support column

D is the tank diameter (ft).

PI MPMS Ch 19.2_4.3.3 – Clingage Factor

4.3.3 Clingage Factor C_L

The clingage factor C_L is given in Table 7.

Table 7—Clingage Factors C_L for Steel Tanks (bbl/1000 ft^2)

Product Stored	Shell Condition		
	light rust	dense rust	gunite lining
gasoline	0.0015	0.0075	0.15
single-component stocks	0.0015	0.0075	0.15
crude oil	0.0060	0.030	0.60

chnical Conclusion Floating-Roof Tank Emissions

- Emissions governed by both thermal fluctuations and liquid level changes
- The product determines the physical properties associated with the iquid/vapor equilibrium in the vapor space.
- Simpler to calculate than Fixed-roof tank calculations due to Emissions factor charts
- The EPA does not endorse its prior emissions software and companies must be able to defend values chosen when calculating tank emissions

g Picture Conclusions

- Depending on regional windiness, covered tanks have significantly less emissions that open top tanks.
- More frequent internal inspections to check seals not necessarily a good dea: tank cleaning emissions are huge (i.e. in the order of a year of operating emissions plus solid wastes). Detail seal inspections should be checked when the tank is out of service for internal inspections.
- Minimal inspections can be conducted anytime.
- The public and the regulatory agencies can and should write letters to API to effect change. This can be done through inquiries on specific standards as well as writing directly to API. They will act on it.