NFOGM
NORWEGIAN SOCIETY FOR OIL AND GAS MEASUREMENT

Data Reconciliation in LNG Tank Farm Allocation

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6th June 2016

Tekna

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This talk focusses on issues encountered in using data reconciliation for LNG tank farm allocation

First, an introduction to the world's largest LNG storage facility

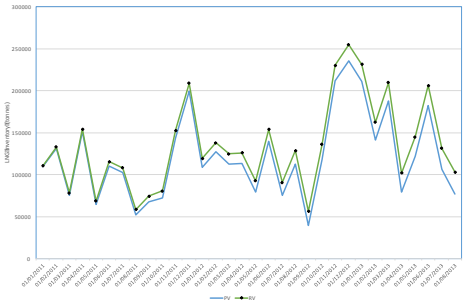
minimise:

$$J(\hat{y},\hat{z}) = (y-\hat{y})V^{-1}(y-\hat{y})$$

subject to:

$$f(\hat{y},\hat{z}) = 0$$
$$g(\hat{y},\hat{z}) \geq 0$$

Explore why data reconciliation was used within the allocation



Issues & lessons learned

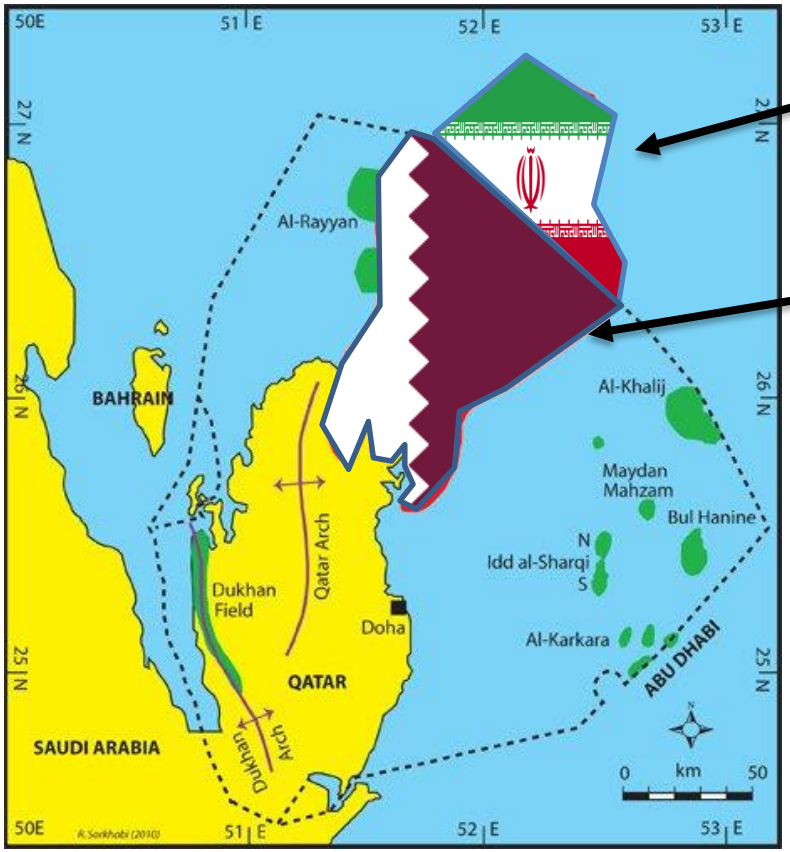
The world's largest LNG facility is based in one of the world's smallest countries, Qatar

In a population of just over 2 million, only 16% are Qataris

Nearly 1.7 million expats are there to support the oil & gas industry…

…and construction for the 2022 FIFA World Cup

The 1,800 TCF of North Dome/South Pars field is shared between Qatar and Iran

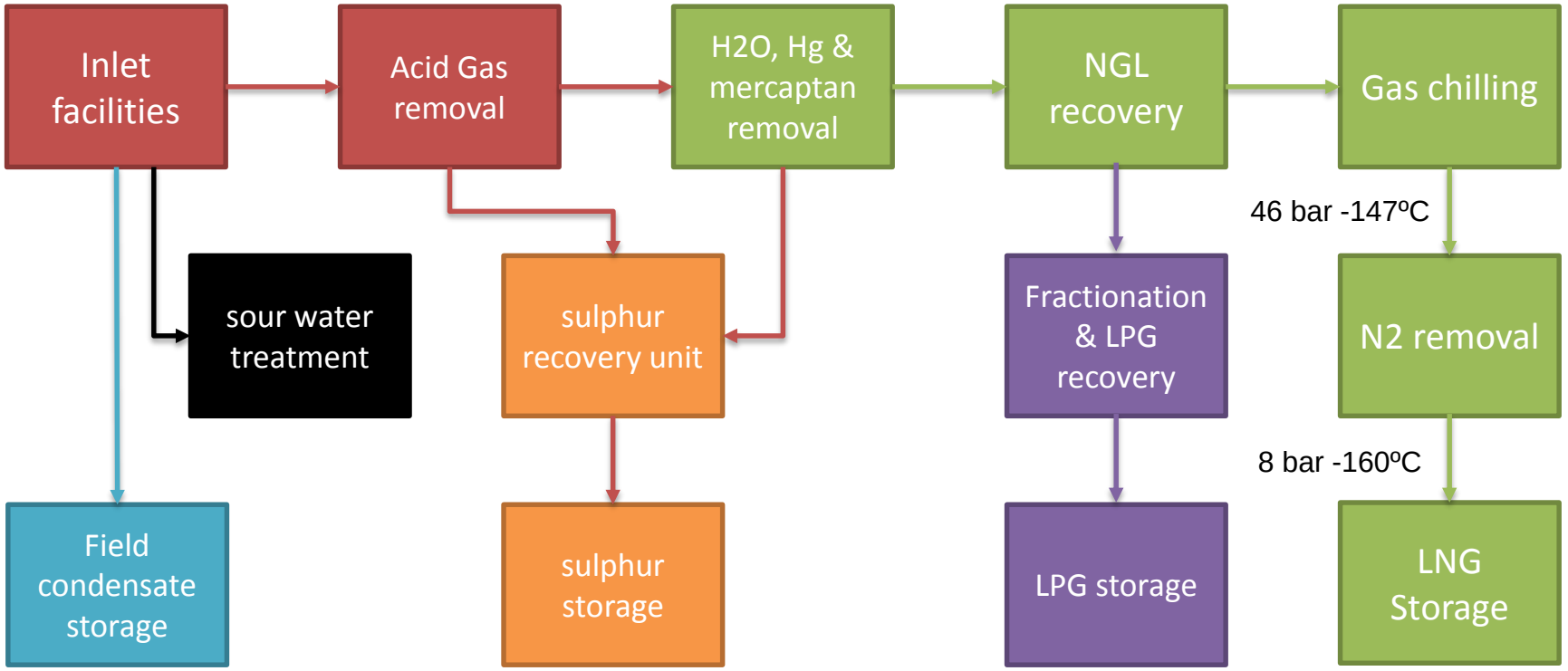


South Pars ~ 38%

North Dome ~ 62 %

With a land mass of less than 4% of Norway, Qatar has 10% of world's gas reserves

Natural gas and liquids are transported onshore for processing and gas liquefaction at Ras Laffan



Liquefaction reduces the volume of the gas to 1/600th for ease of transportation to overseas markets

There was little demand for gas domestically due to cheap electricity

Initially, two companies at Ras Laffan produced **rich** LNG for export to the Asian market

Each company owned and operated its own trains and product storage facilities which included condensate, LPG, helium and sulphur

65% Qatar Petroleum
10% Exxon-Mobil
10% Total
7.5% Mitsui
7.5% Marubeni

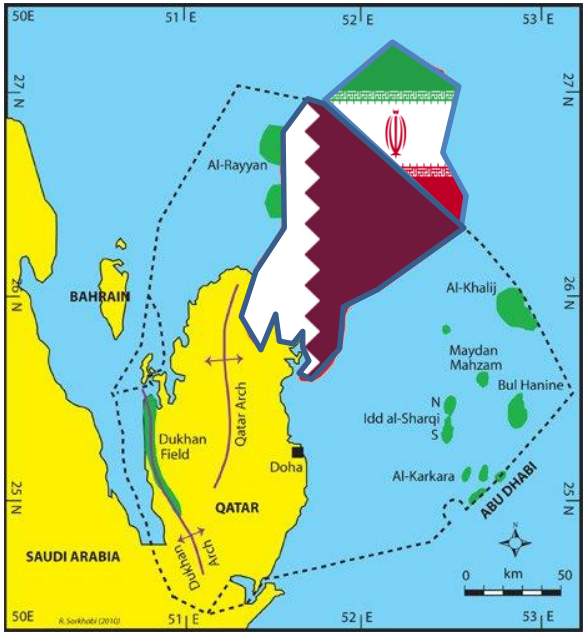
70% Qatar Petroleum
30% Exxon-Mobil

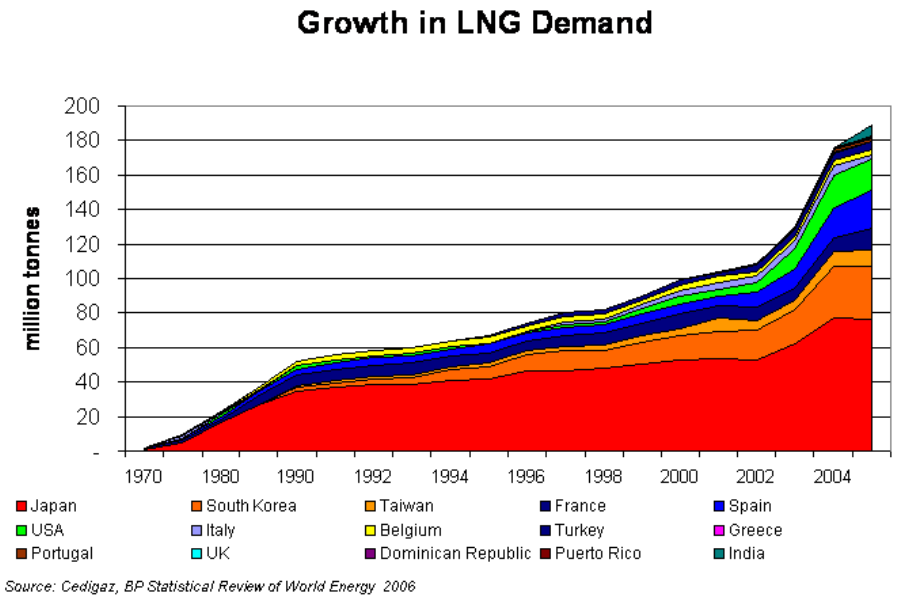
Each train has a production capacity of ~ 3.2 to 3.3 Mtpa giving a total of approximately 16.6 Mtpa

At this point, there was no requirement for product allocation

In 2004, there was only the rich LNG plants and a dedicated berth each for QG1 and RL1

Rapid expansion of the LNG industry was spurred by global demand & geopolitical considerations





Source: Cedigaz, BP Statistical Review of World Energy 2006

By 2011, 5 more ventures were developed to produce **lean** LNG for the European and US markets

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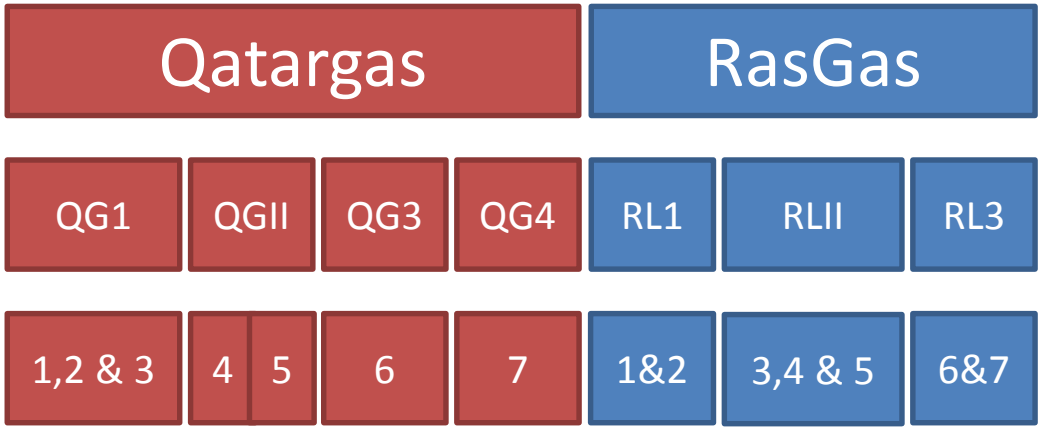
Plans for expansion led to the Common Facilities' Projects to realise benefits of operational synergies

CSP
Common Sulphur Storage & Loading

CLLNG
Common Lean LNG Storage & Loading

CCSL
Common Condensate Storage & Loading

CLPG
Common LPG Storage & Loading



Mega trains 7.8 Mpta

RL II capacity 4.7 Mtpa each

Total capacity: 77 Mtpa


Bahrain
Ash Shamal
QG2QG 3/4
Ras Laffan Industrial City
Al Khor
Al Khor
Al Daayen
Umm Salal
Doha
Qatar
Doha
Al Rayyan
Al Wakrah
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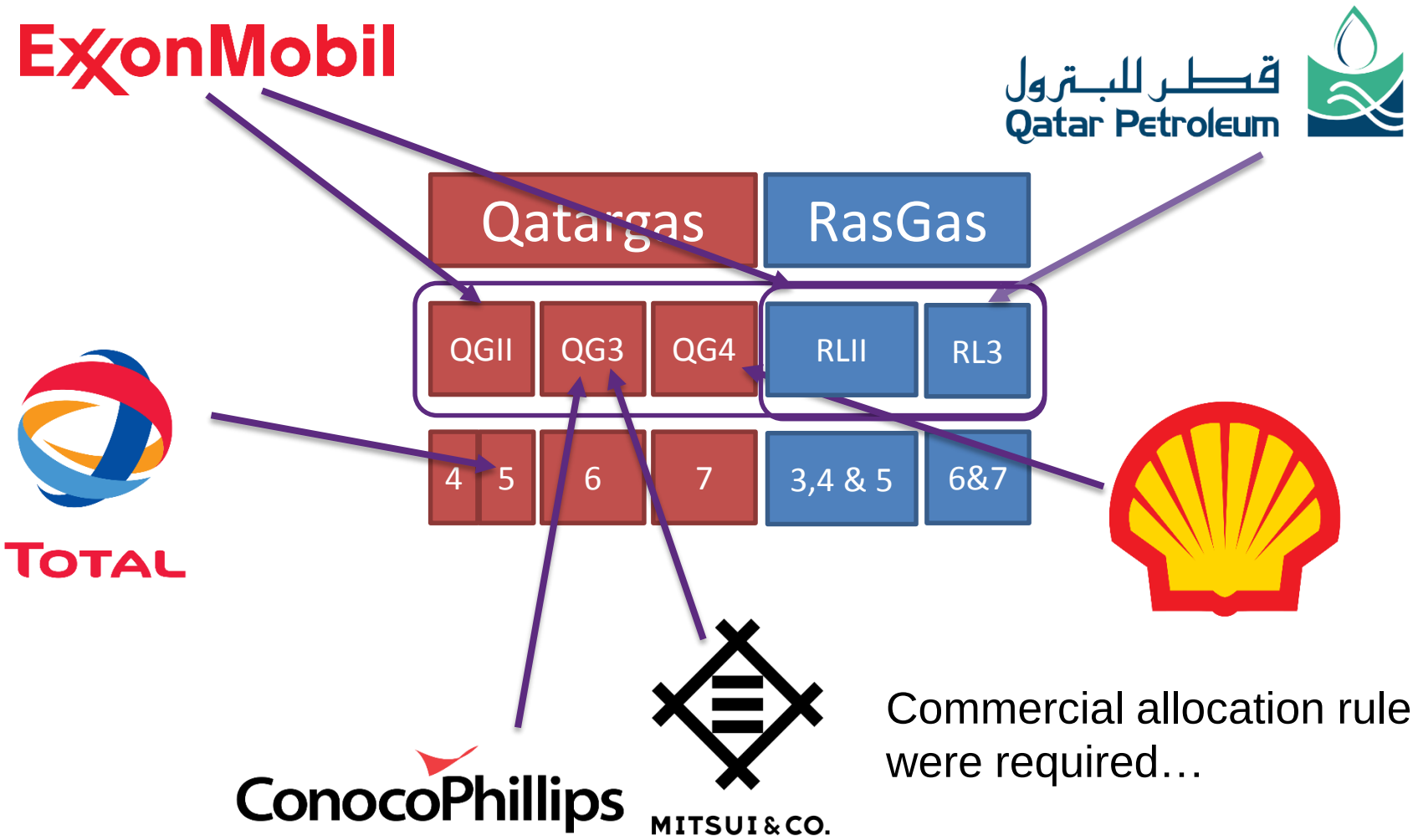
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
US Dept of State Geographer
Google earth

At maximum capacity, a Q-Max vessel is loaded every 17 hours at each berth

Approximately 1 Q-Max = UK gas consumption per day

CLLNG would store Lean LNG for multiple & different shareholders within the new Joint Ventures



Commercial allocation rules were required…

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The CLLNG facility is spans a huge area and is over 5km across – excluding berths

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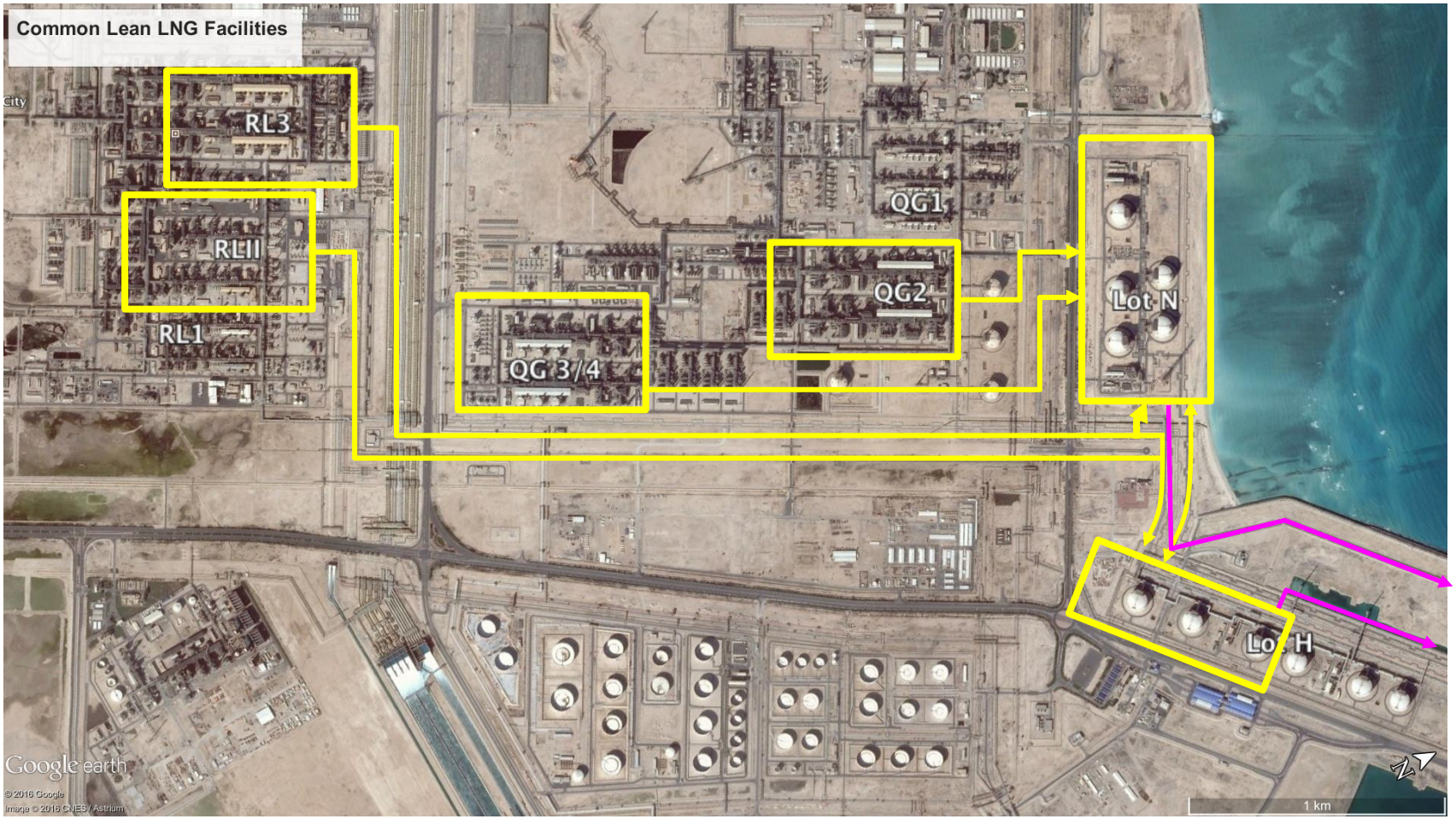
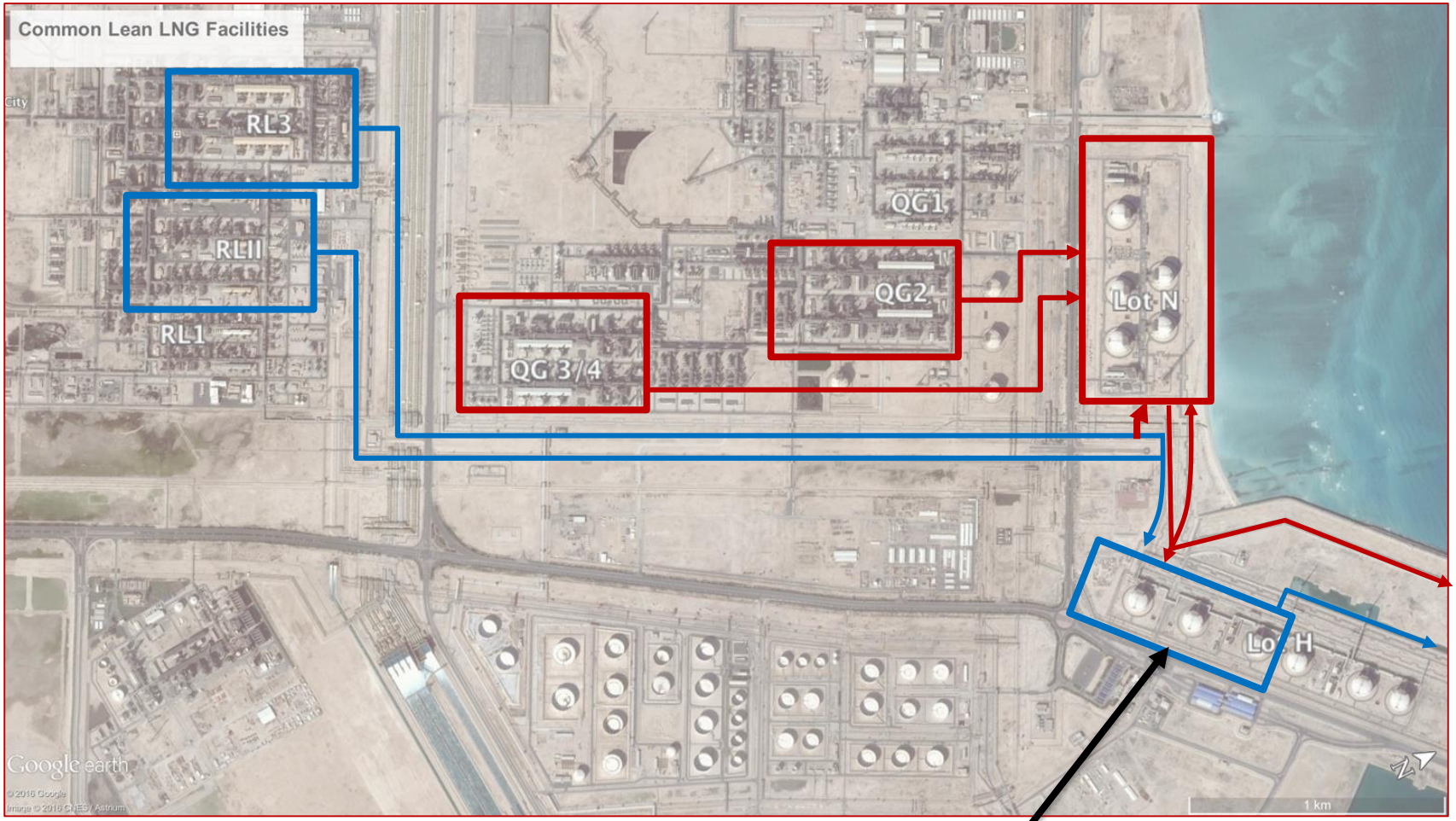
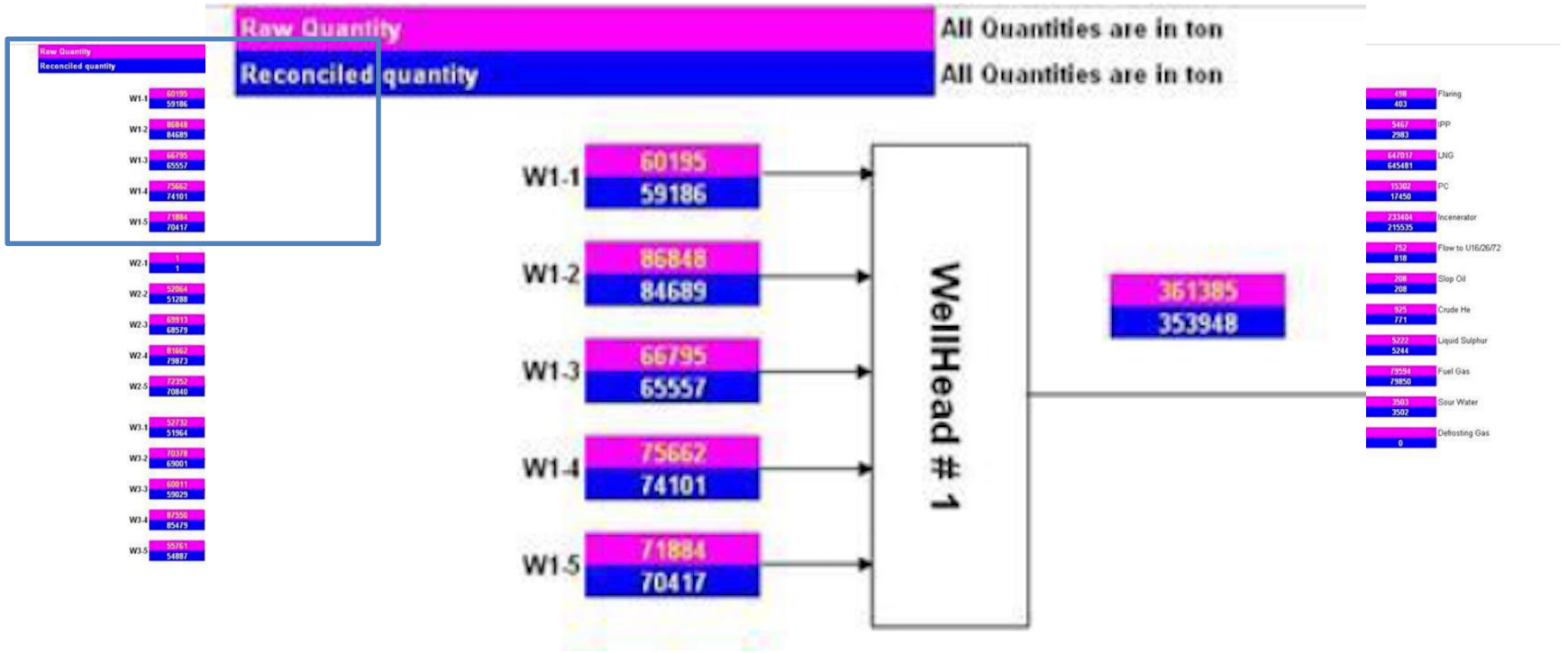


Operated by Qatargas & RasGas, this posed challenges including agreeing loss allocation and daily management



Only the Lean Lot H tanks were part of CLLNG

RasGas used DRS on trains and upstream facilities to help identify gross errors and apportion loss to wells



The raw Process values are shown along with the Reconciled values

The use of data reconciliation was supported by stakeholders within CLLNG and written into the AMP

The Allocation & Measurement Procedure details the allocation of each JV (Owner Group)'s inventory

$$inventory_{close}^{OwnerGroup} = inventory_{open}^{OwnerGroup} + production^{OwnerGroup} - BOG_{total}^{OwnerGroup}$$
$$- LNGloaded^{OwnerGroup} \pm transfer^{OwnerGroup}$$

Due to DRS there is **no allocation of losses**

The calculations are done in **Mass & Energy**

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$$- LNGloaded^{OwnerGroup} \pm transfer^{OwnerGroup}$$

BOG is boil-off gas vapour from the tanks which is compressed and returned to the trains for fuel

This is allocated based on a **theoretical** calculation that uses the N_2 content and rundown rates of LNG into the tanks

The Allocation & Measurement Procedure details the allocation of each JV (Owner Group)'s inventory

$$inventory_{close}^{OwnerGroup} = inventory_{open}^{OwnerGroup} + production^{OwnerGroup} - BOG_{total}^{OwnerGroup}$$
$$- LNGloaded^{OwnerGroup} \pm transfer^{OwnerGroup}$$

Transfer captures the production that is moved between the two tank farms via the transfer line

The Allocation & Measurement Procedure details the allocation of each JV (Owner Group)'s inventory

$$inventory_{close}^{OwnerGroup} = inventory_{open}^{OwnerGroup} + production^{OwnerGroup} - BOG_{total}^{OwnerGroup}$$
$$- LNGloaded^{OwnerGroup} \pm transfer^{OwnerGroup}$$

34 Sales & Purchasing Agreements each had a different method for calculating energy content of sales LNG…

LNG loaded is the **reference** quantities of LNG loaded to ship, Purge & Cooldown and Normal Loading Losses

Normal Loading Loss is based on loading quantity and the characteristics of the vessel

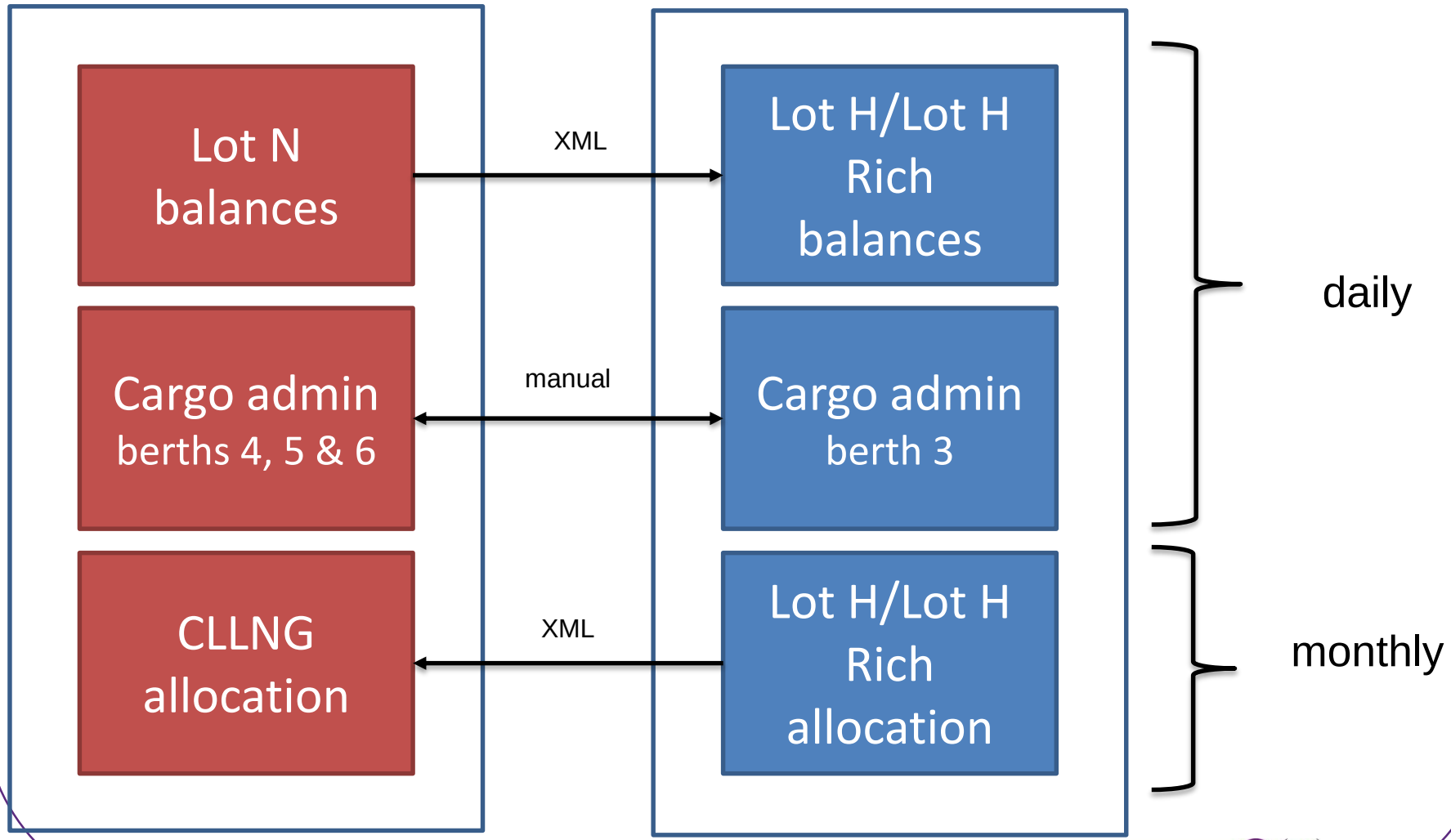
The Allocation & Measurement Procedure details the allocation of each JV (Owner Group)'s inventory

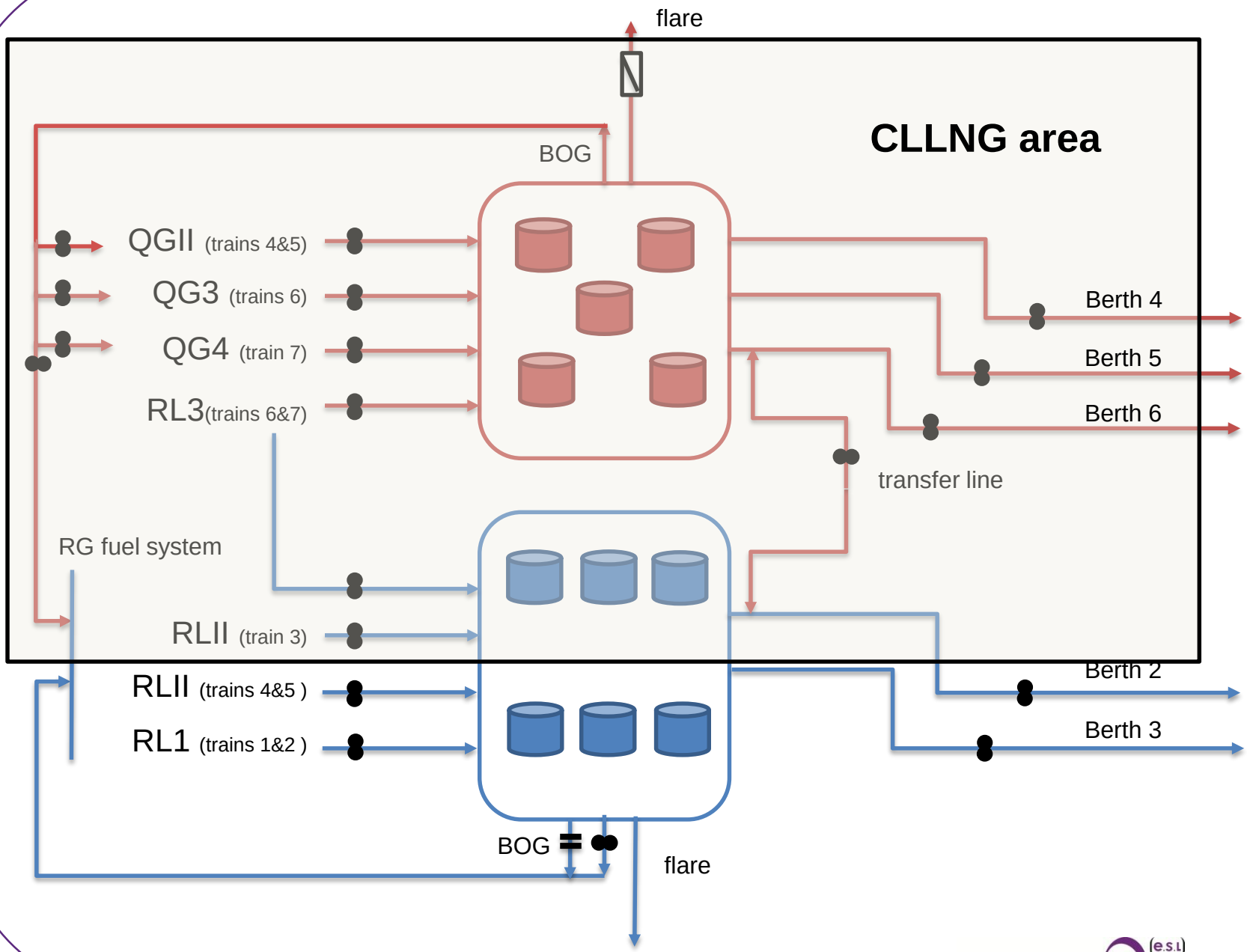
$$inventory_{close}^{OwnerGroup} = inventory_{open}^{OwnerGroup} + production^{OwnerGroup} - BOG_{total}^{OwnerGroup} - LNGloaded^{OwnerGroup} \pm transfer^{OwnerGroup}$$

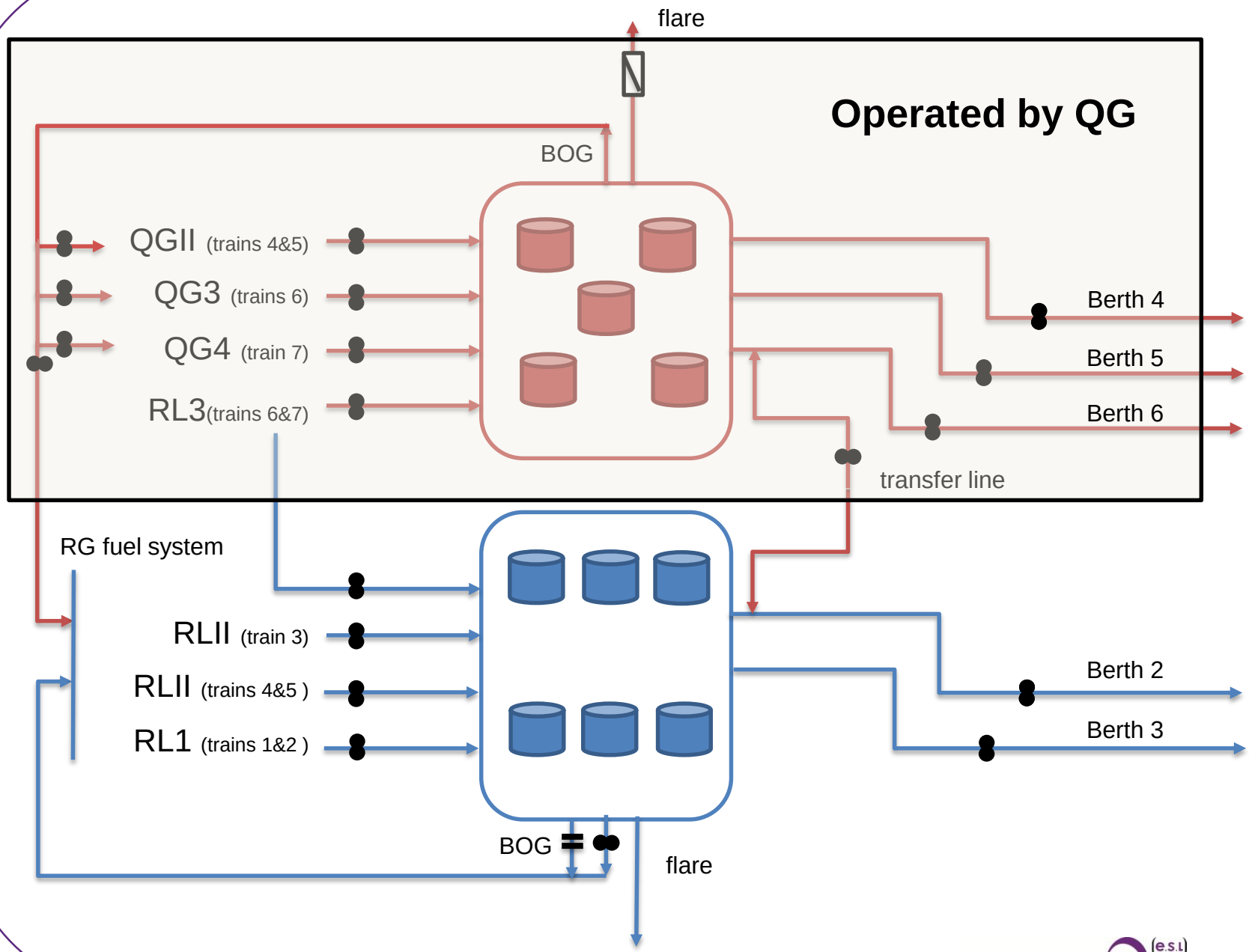
Production is deemed to be the sum of the daily reconciled **values** from the balances

Despite a very simple equation, this is quite a convoluted process!

RasGas & Qatargas perform different parts of the process with Qatargas as overall Operator




flare
CLLNG area
BOG
QGII (trains 4&5)
QG3 (trains 6)
QG4 (train 7)
RL3(trains 6&7)
Berth 4
Berth 5
Berth 6
transfer line
RG fuel system
RLII (train 3)
RLII (trains 4&5)
RL1 (trains 1&2)
Berth 2
Berth 3
BOG
flare


flare
Operated by QG
BOG
QGII (trains 4&5)
QG3 (trains 6)
QG4 (train 7)
RL3(trains 6&7)
Berth 4
Berth 5
Berth 6
transfer line
RG fuel system
RLII (train 3)
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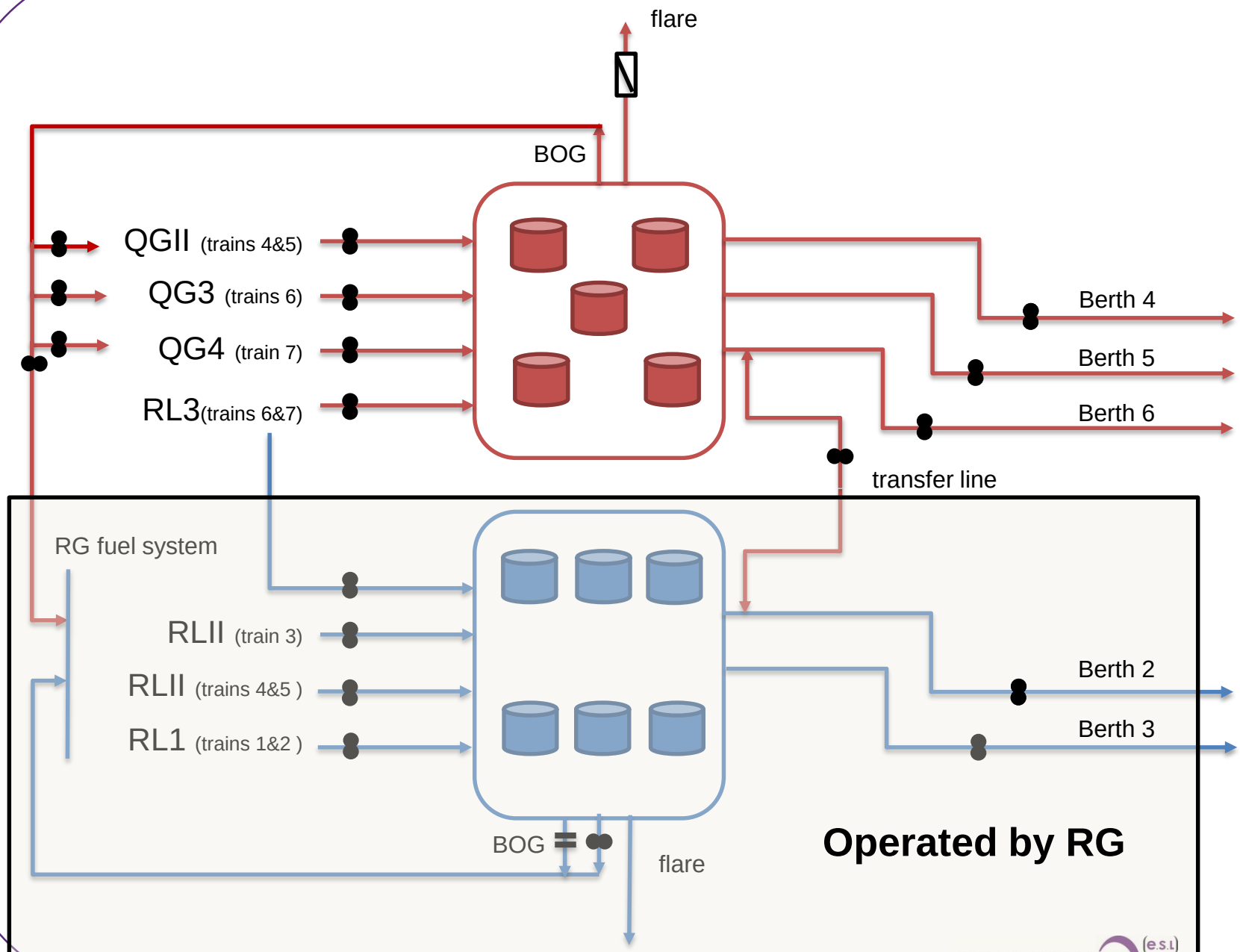
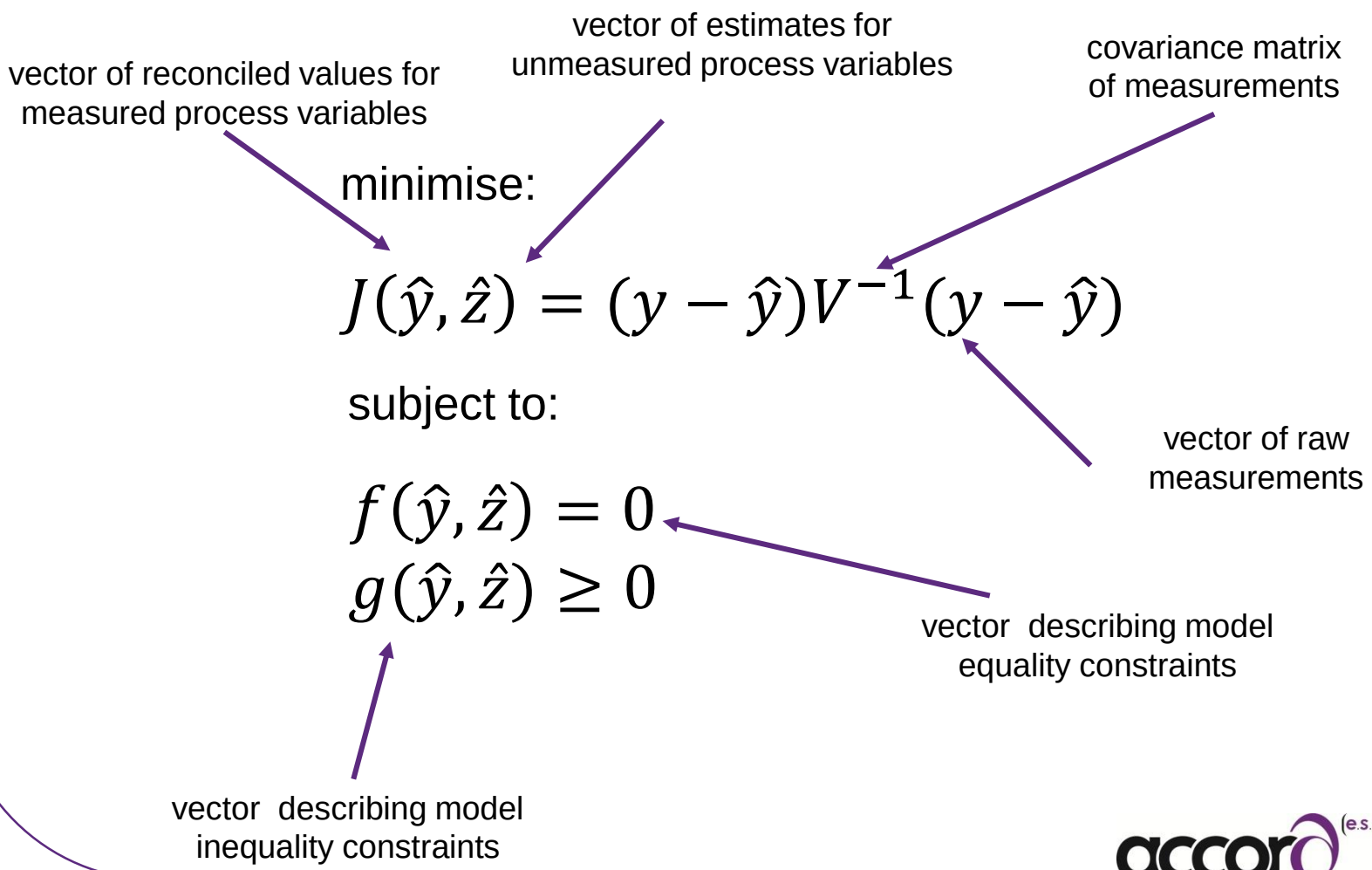
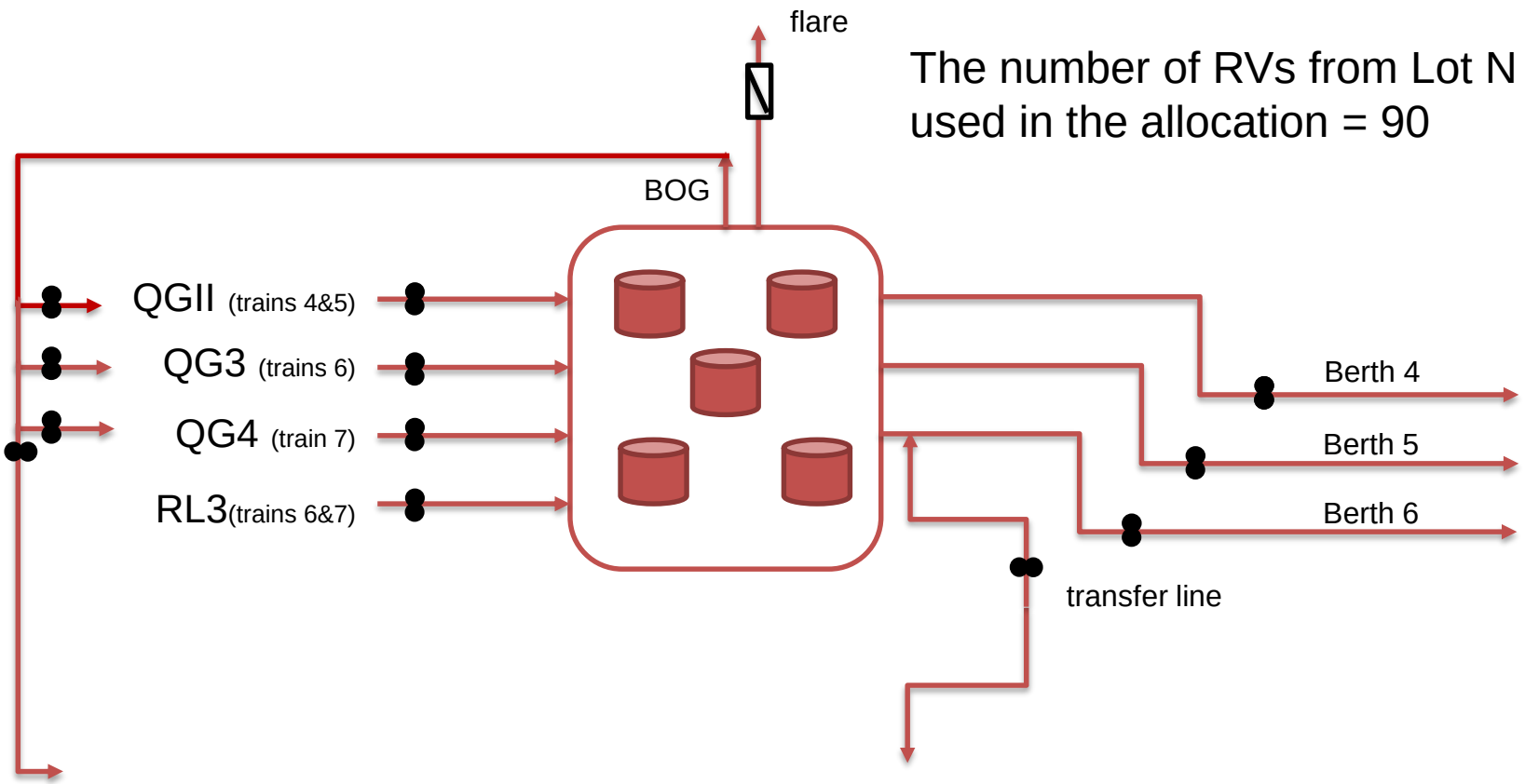
RL1 (trains 1&2)
Berth 2
Berth 3
BOG
flare


flare
BOG
QGII (trains 4&5)
QG3 (trains 6)
QG4 (train 7)
RL3(trains 6&7)
Berth 4
Berth 5
Berth 6
transfer line
RG fuel system
RLII (train 3)
RLII (trains 4&5)
RL1 (trains 1&2)
Berth 2
Berth 3
BOG
flare
Operated by RG

Sigmafine was used to do the daily reconciliations based on established techniques



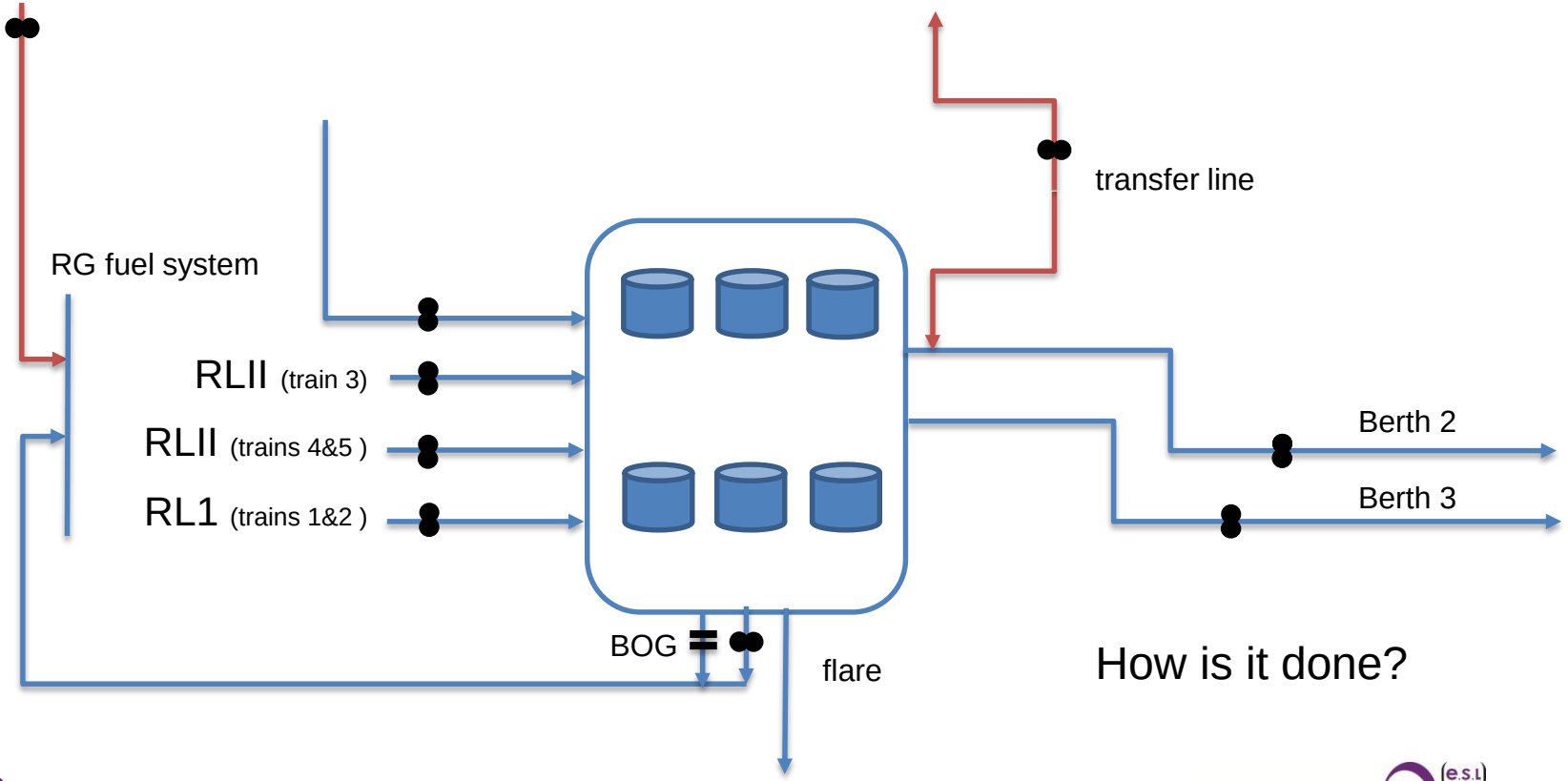
Separate daily component mass and energy balances are carried out for Lot N



The number of RVs from Lot N used in the allocation = 90

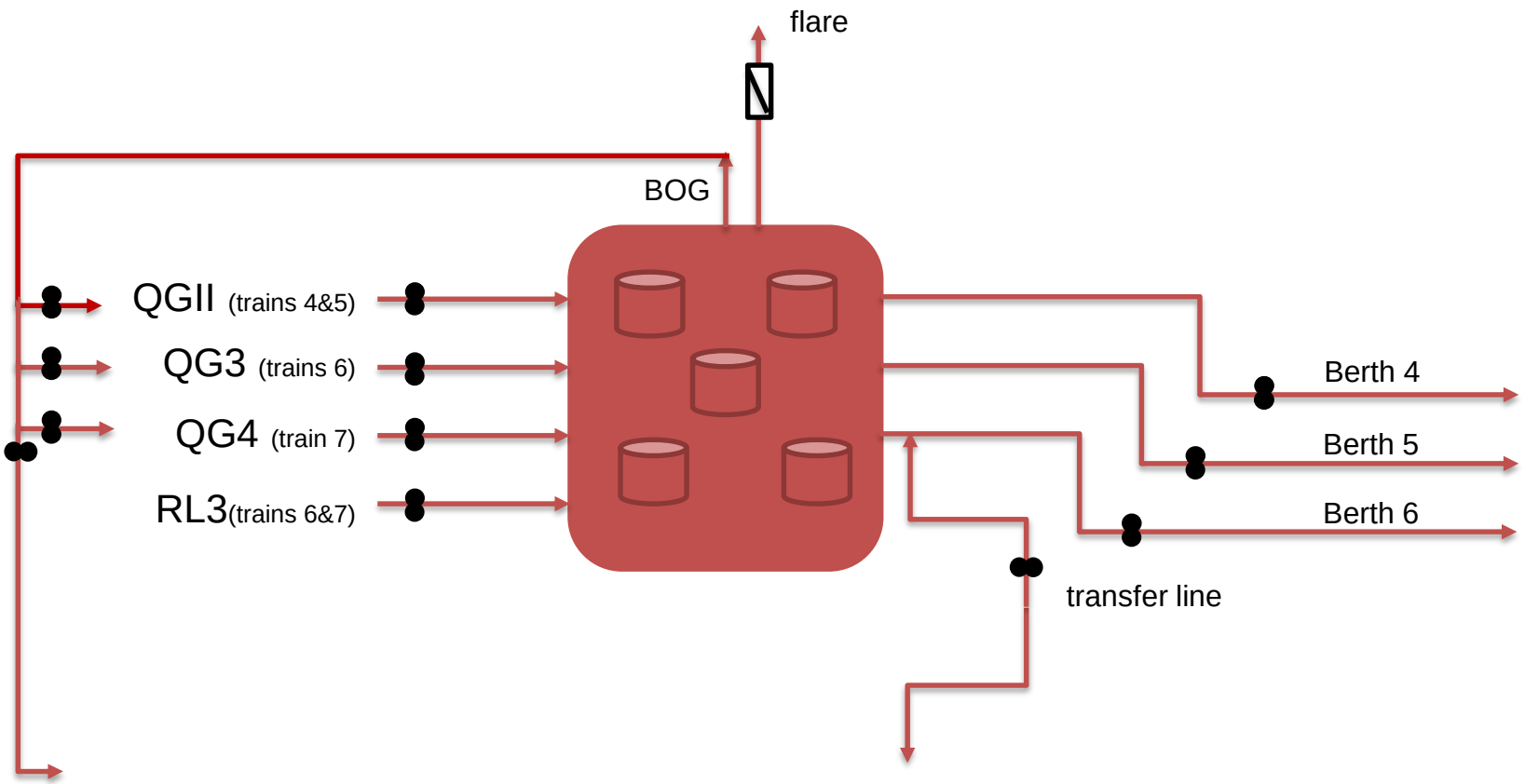
These results would be sent to RasGas via XML to feed into the Lot H mass and energy balances

The number of RVs from Lot H used in the allocation = 48



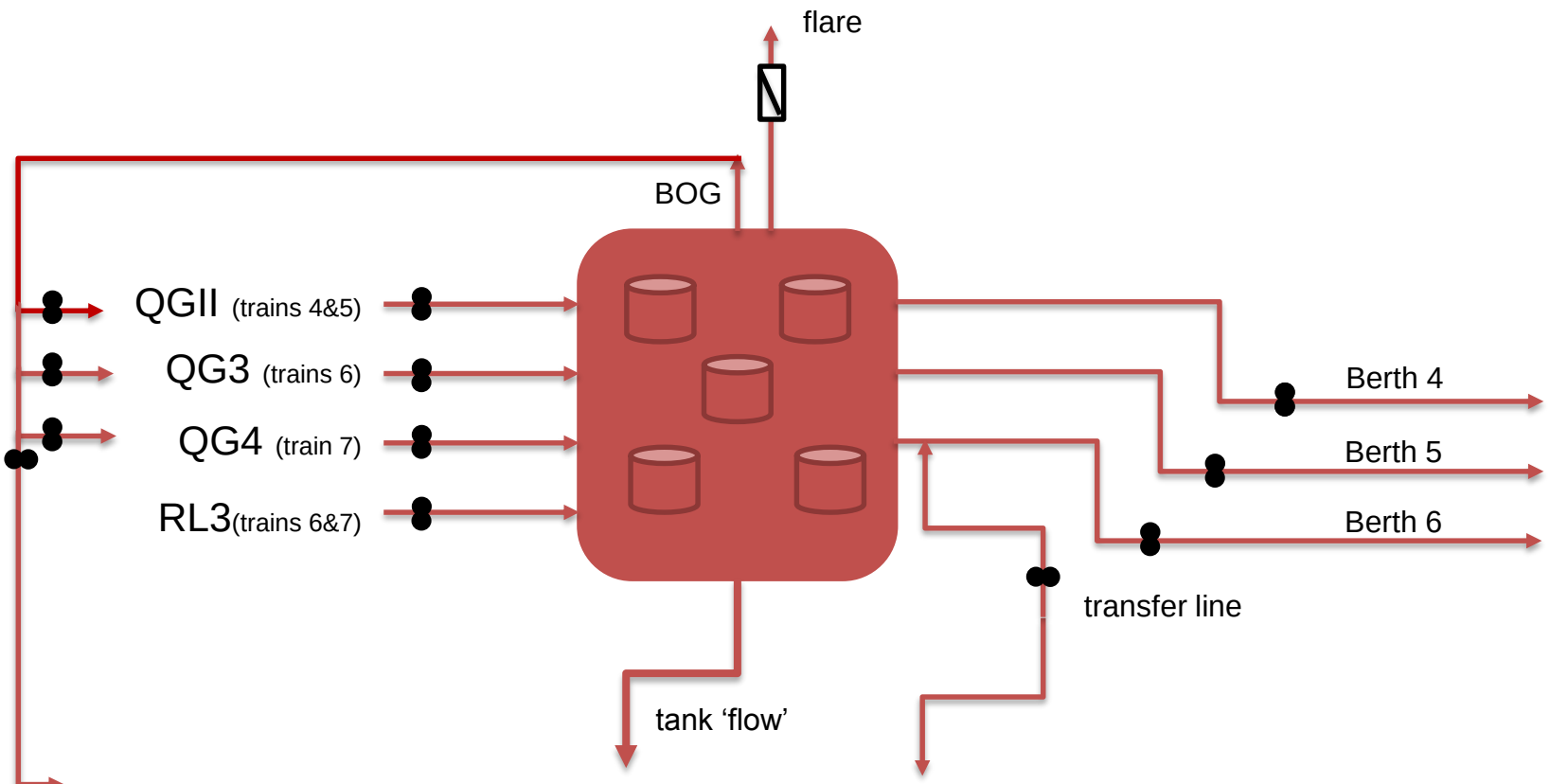
How is it done?

The facility can be simply modelled using flows and a node for the tanks



All measured flows in and out of the node are denoted by x_i

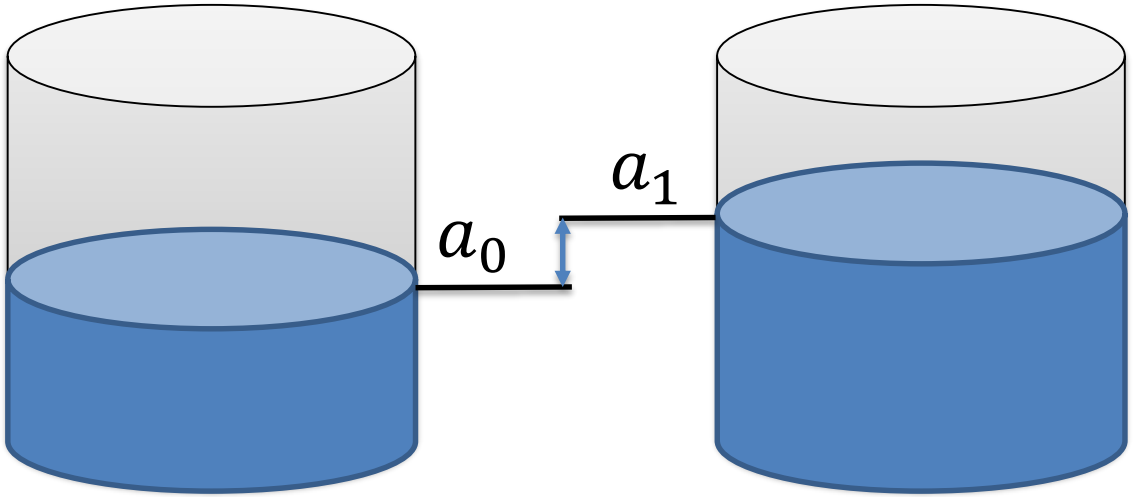
The model calculates a flow from the change in tank levels which is used in the reconciliation



For clarity we shall refer to the tank change flow as y_i

The model calculates a flow from the change in tank levels

$$y_1 = a_1 - a_0$$



The uncertainties in measurements ***a*** give an uncertainty in ***y*** which allows the model to compute a reconciled value

$$\hat{y}_1 = y_1 + \varepsilon_1$$

The reconciliation adjusts the mass or energy flows so there is a balance across the facility

The model adjusts the measured variables according to the magnitude of the associated uncertainties to give the reconciled estimates

$$\sum x_i + y_i \neq 0$$

becomes:

$$\sum \hat{x}_i + \hat{y}_i = 0$$

Loss would be appropriately attributed to the Owner Groups' LNG rundown each day and gross errors flagged up

So, what was the problem?

The monthly allocation sums the daily balances and expects a perfect balance

$$inventory_{close}^{OwnerGroup} = inventory_{open}^{OwnerGroup} + production^{OwnerGroup} - BOG_{total}^{OwnerGroup} - LNGloaded^{OwnerGroup} \pm transfer^{OwnerGroup}$$

For the monthly allocation, the total balance is given by:

$$\sum_{n=1}^{m} \hat{x}_{i,n} + \sum_{n-1}^{m} \hat{y}_n = 0$$

We need explicit reporting of tank levels so we need to get back to the opening and closing inventories for the month, a_m and a_0

The monthly allocation sums the daily balances and expects a perfect balance

m days

$$\sum_{n=1}^{m} \hat{x}_{i,n} + \sum_{n=1}^{m} \hat{y}_n = 0$$

substitute to give

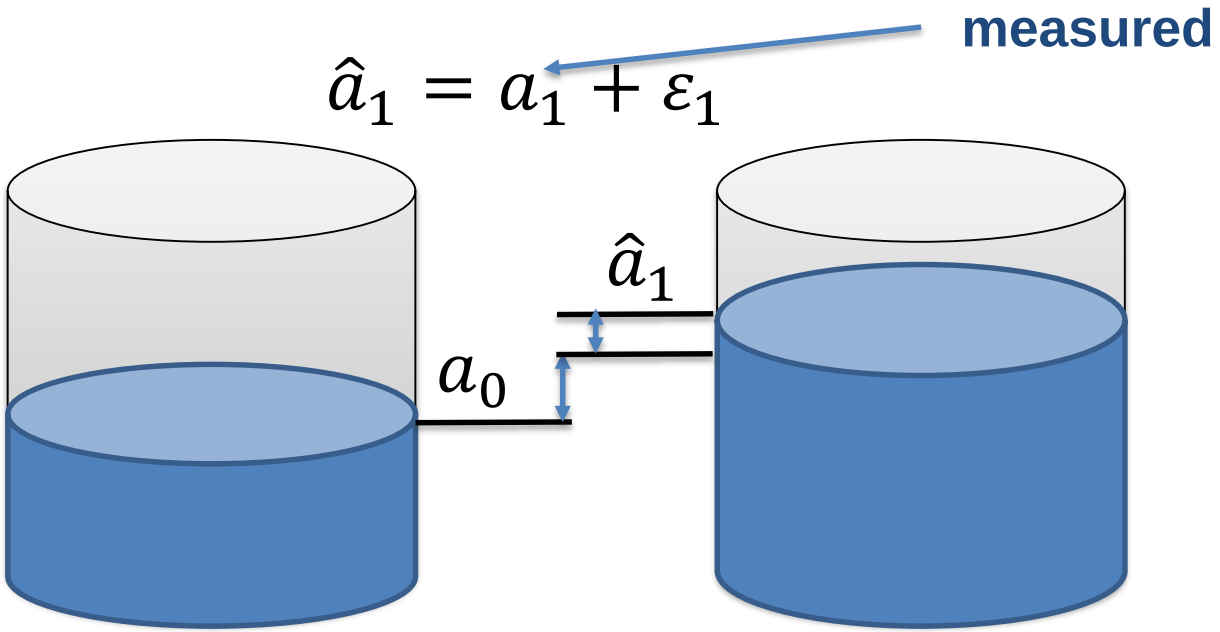
$$\sum_{n=1}^{m} \hat{x}_{i,n} + \sum_{n=1}^{m} (y_n + \varepsilon_n) = 0$$

Expanding and simplifying gives an imbalance:

$$\sum_{n=1}^{m} \hat{x}_{i,n} + a_m - a_0 = \sum_{n=1}^{m} \varepsilon_n$$

So to have a **zero** imbalance, reconciled tank levels had to be used in the daily reconciliations and monthly allocation calculations

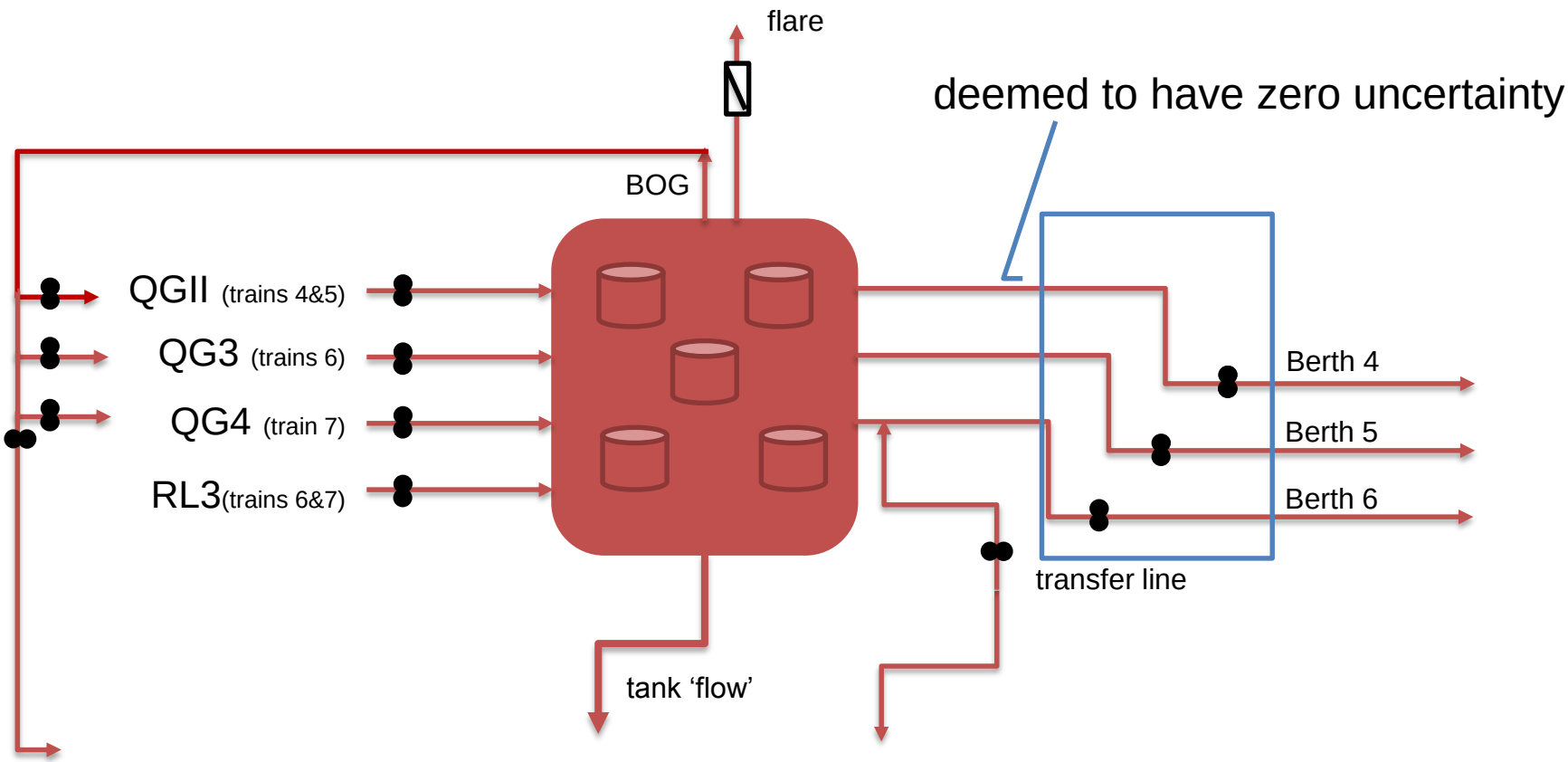
The closing inventory was reconciled by adding the adjustment, ε_n, to the measured level



This reconciled closing stock is now used as the opening stock for the next day's reconciliation. Now, there is monthly mass balance:

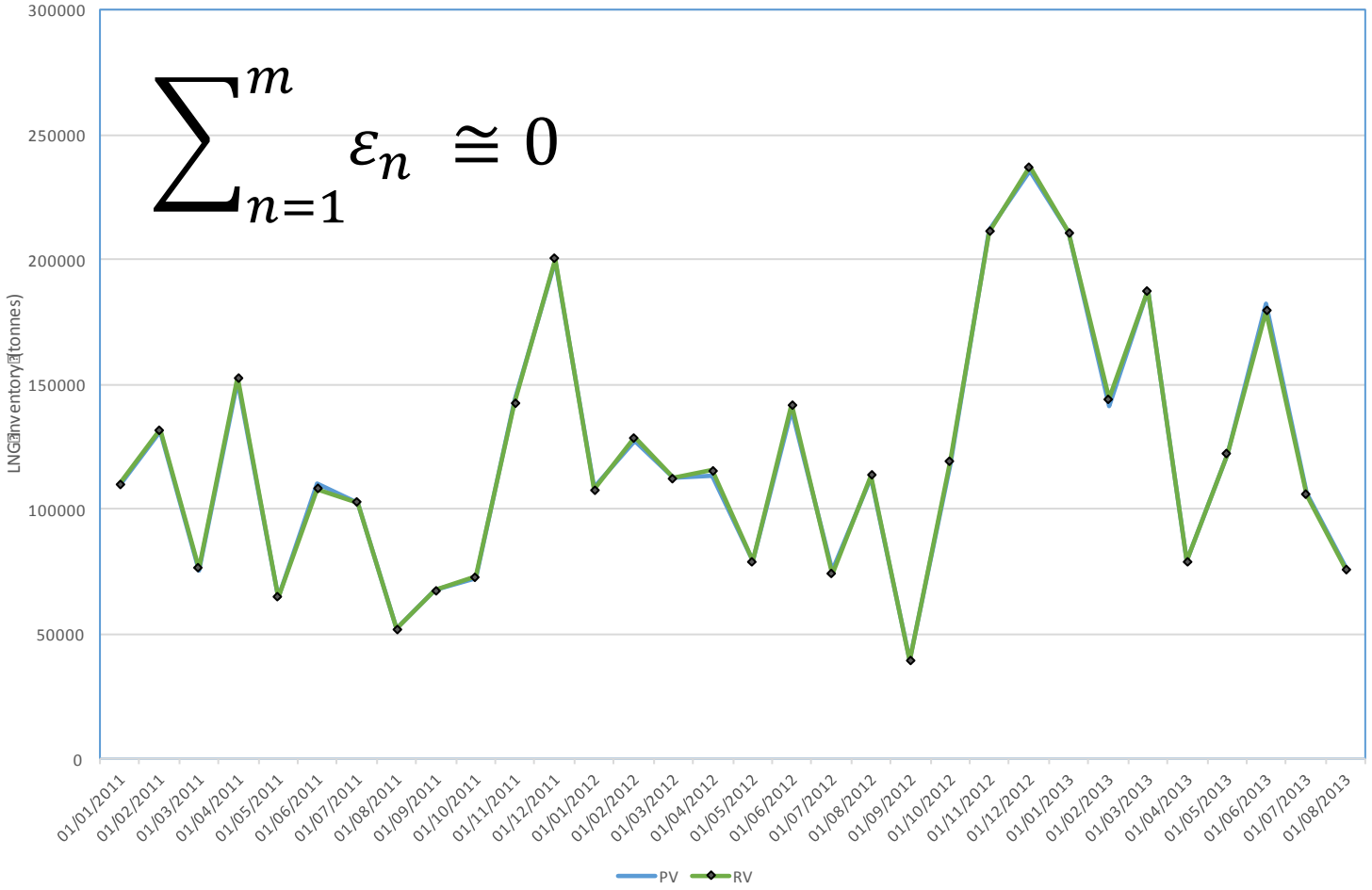
$$\sum_{n=1}^{m} \hat{x}_{i,n} + \hat{a}_m - \hat{a}_0 = 0$$

The allocation agreement means imbalances are not attributed to all measurements

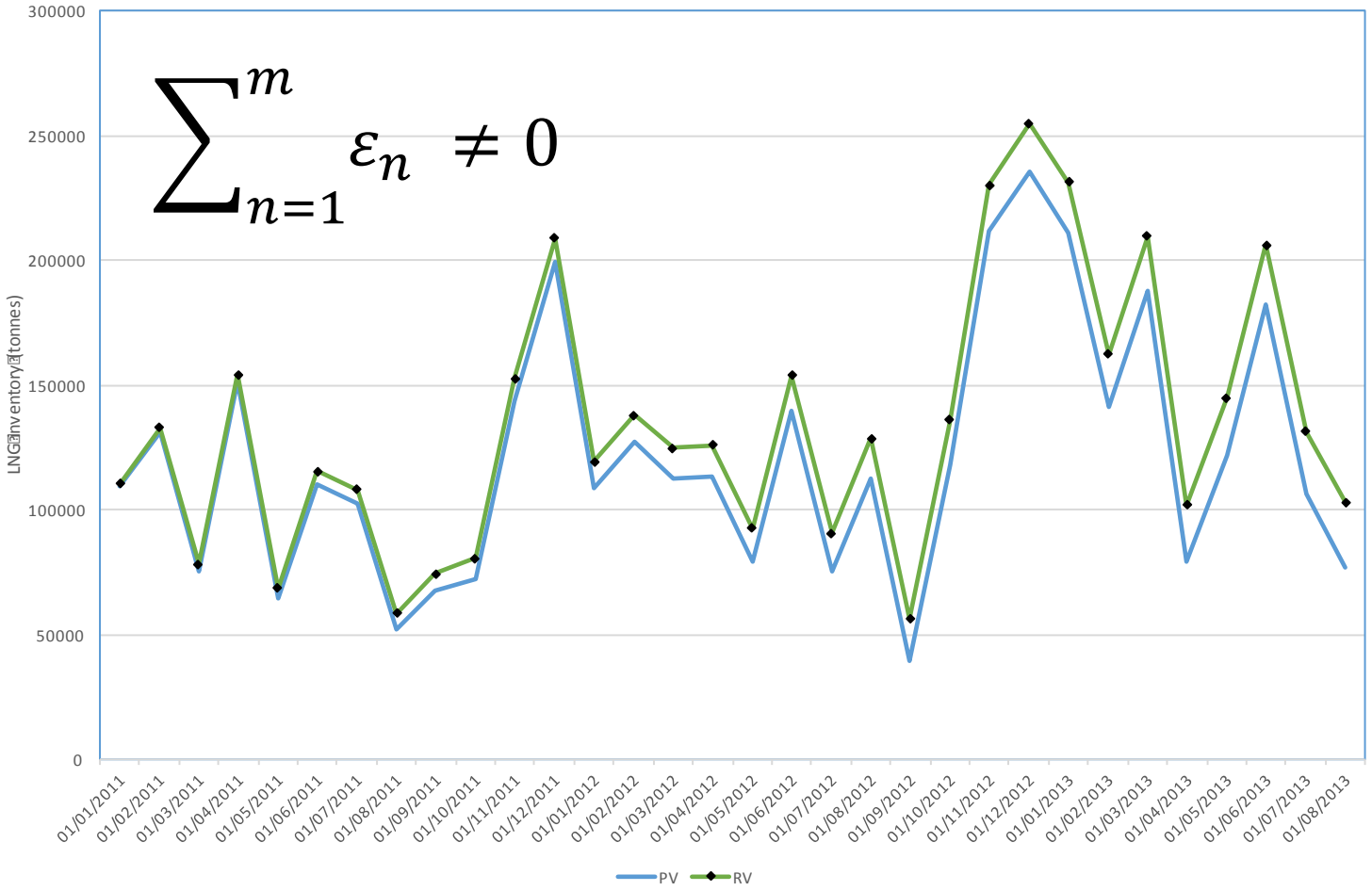


This meant that the imbalance was forced to the tanks, rundown meters and BOG, fuel & flare

Over time, the difference between reconciled & measured inventory should be very small

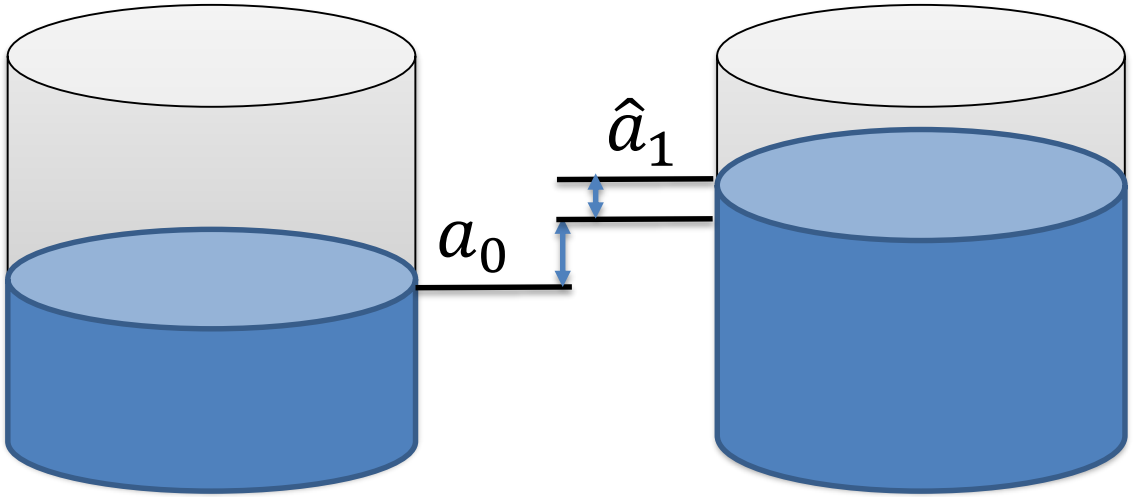


With a systematic bias, the measured inventory drifts from reconciled inventory



The measured and reconciled tank levels showed drift over time

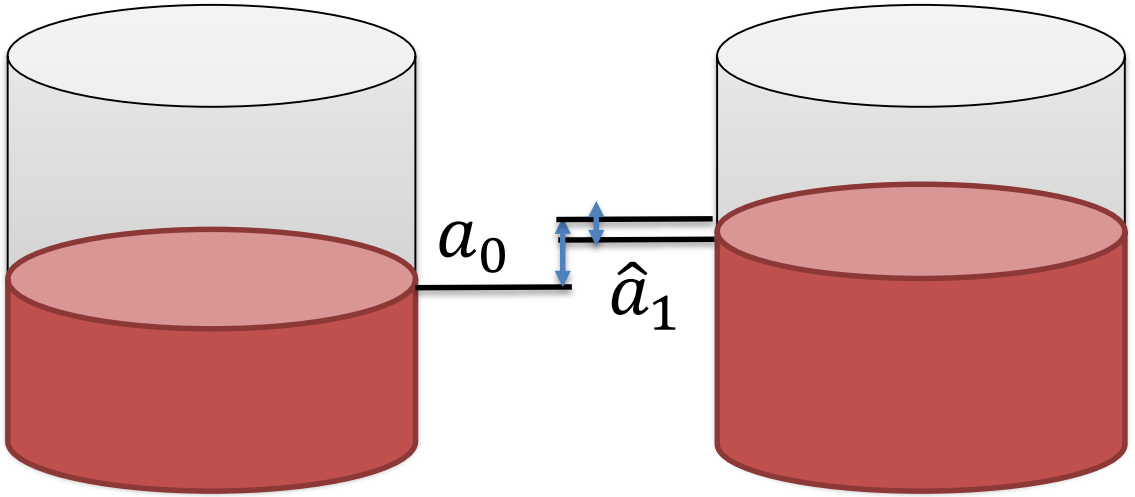
$$\hat{a}_1 = a_1 + \varepsilon_1$$



This was handled in other common facilities by periodically writing down of reconciled stock to match physical stocks

The reconciliation for energy exhibited a different bias

$$\hat{a}_1 = a_1 + \varepsilon_1$$



This resulted in a drift in energy density of tank inventory when performing simultaneous mass and energy allocation

Thus the allocation was done in energy first with an adjustment in the mass allocation to maintain the tank energy density

Key learnings from the first year of operation allowed the process to be refined & improved

The change to **‘energy is king’** allocation resulted from user experience and analysis of allocated results

Measurement uncertainties were now source data in the allocation process and required a step change in measurement expertise & support

Handling of **mismeasurements** matured to dispense with the historical rerunning of daily balances which had to be run sequentially

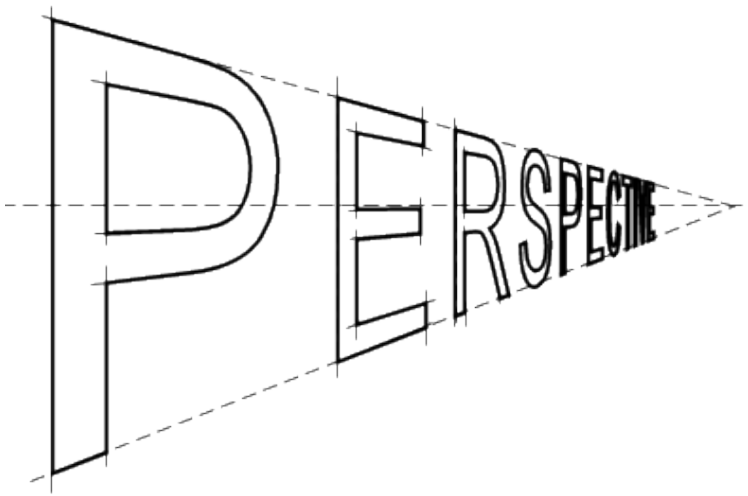
Was it the right thing to do?

purism v. pragmatism

A better understanding of data reconciliation techniques now gives us a different perspective

What could we use to improve the reconciliation?

Kalman filters?



Baysian statistics?

nonlinear data reconciliation?

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6th June 2016

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accord (e.s.l)


accord
(e.s.i) delivering energy solutions


Qatargas Slugcatchers
2-300m
Google earth
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