“Reliably Tracking Carbon & Losses”

(Data Reconciliation & Validating Measurements)

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Cost of Carbon (CO2) on Margin ($ per Unit of Capacity)

- Depending on the carbon tax and your plant's carbon intensity, the impact on your margins can vary considerably as shown below for the oil-refining sector
- Therefore, accurately measuring, tracking and accounting for your CO2 emissions, etc. is obviously important to properly manage your plant's profitability – but how?

"In God we trust, all others bring data" – W. Edward Deming

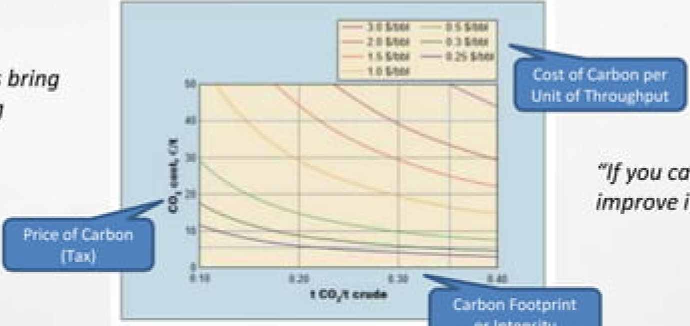

Figure 1 Impact of carbon cost on refinery margin

"If you can't measure it, you can't improve it" – Peter Drucker

J. Mertens, "Assessing Impact of Carbon Pricing on Refinery Profitability", *Petroleum Technology Quarterly*, Q2, 2012.

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"All models are wrong, some models are useful" (G.E.P. Box)

- Corollary … "All measurements are **inaccurate**, some are **consistent**"

- Measurements are always corrupted by ***random*** errors (Normally distributed) and ***systematic*** errors (e.g. zero and span biases)
- Data Reconciliation attempts to ***validate measurement *consistency**** using known conservation of matter laws for material, energy and momentum
  - Uses optimization and statistics with engineering relationships (flowsheet) to find a consistent set of measurements and can highlight bad measurements
  - These relationships can be volume, mass, component balances, etc.
  - Since carbon tracking involves liquid and gas streams, accounting will likely be mass and component balances
  - It is commercially available software

* *"Data Reconciliation is a technique to optimally adjust measured process data so that they are* ***consistent with known constraints***." Crowe, C.M., Data Reconciliation – Progress and Challenges, *J. Proc. Contr.*, **6**, 89-98, (1996).

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Inconsistent measurements result in inaccurate accounting / tracking

- Assertion … Inaccurate accounting / tracking results in poor planning and scheduling and ***ultimately poor business decisions*** ☹

- Types of accounting / tracking in various industries:
  - *Production, Yield and Weight-Loss Accounting* in Oil-Refining and Petrochemical Industries
  - *AMIRA P754 Metal Accounting and Reconciliation* in Mining and Metallurgical Industries
  - *ISO 14051:2011 Material Flow Cost Accounting (MFCA)* in other Process Industries such as Food & Beverage, Bulk & Specialty Chemicals, Discrete-Parts Manufacturing, etc.
  - *Royalty Payments* to technology licensors, governments, etc. as well as *custody transfers*
  - *Carbon (CO2) Footprint and Green House Gas (GHG) Emissions Tracking* potentially required in all Industries for carbon taxation - "Cap and Trade" based on these accounting practices as well

- Five (5) Attributes of a Solid Data Foundation: ***accuracy***, *authenticity, integrity, context and timeliness* (ARC Report: Optimization: The Road Ahead for the Process Industries, May 2017).

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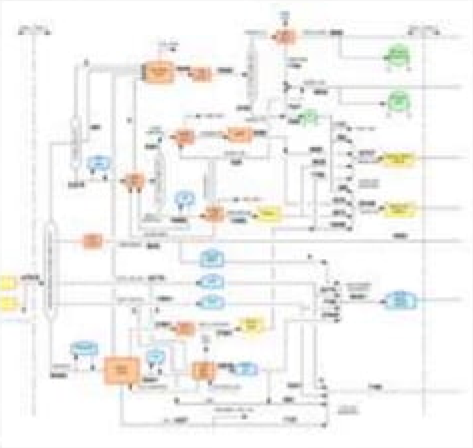
Industry Observations and Issues over Past 20-Years

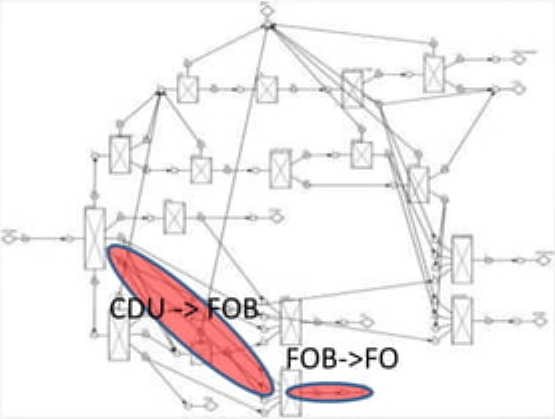
"If you don't eat yer meat, you can't have any pudding!" (Another Brick in the Wall, Pink Floyd, 1979)

- Assertion … If you are not using statistical data reconciliation and its gross-error diagnostics, **then bad measurements exist (period)**
- The *most common complaint* of plant-wide production accounting is that **"we can't close the daily material balance"**
  - This means that many individual material balances have significant and unexplainable imbalances / inconsistencies - *because there are too many gross-errors!*
- The *most difficult data gathering requirement* is **logging time-varying flows** such as tank-to-tank transfers and other temporary line-ups / movements
- The *most difficult modeling requirement* is **building and maintaining the large plant-wide flowsheet** (i.e., engineering relationships)
- The *most difficult management requirement* is to understand that failure to close the material balance means **failure to fully manage your business** as effectively as possible

Oil-Refinery Example (Volume Only)

- Showed that ***worst*** **"(RAW–RECONCILED)/RAW"** metric is only 30% accurate at detecting gross-errors whereas gross-error statistics are 100% accurate!





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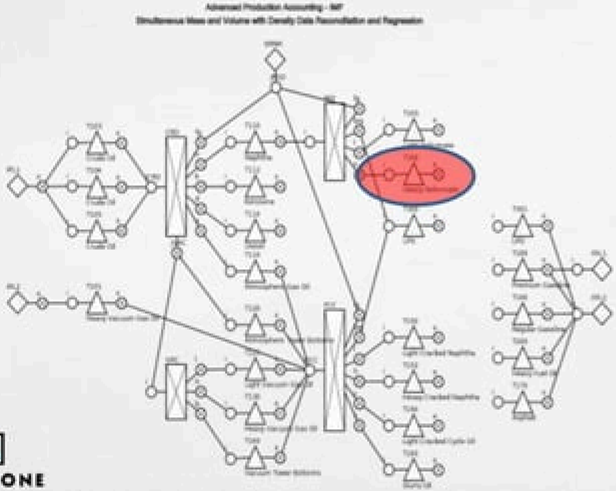
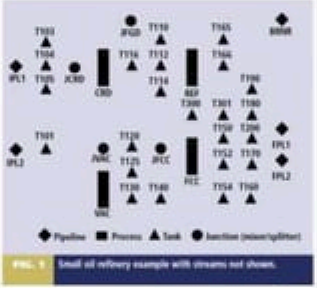
Oil-Refinery Example (Volume, Mass, Density)

- Detected bad density measurement for T300
- Shows importance of reconciling all three variables together





Modeling Objects

- **Perimeters – Supply/Demand Points or Sources/Sinks**
- **Pools – Inventory or Holdup**
- **Continuous-Processes – Blenders, Splitters, Separators, Reactors , Fractionators & Black-Boxes**
- **Port-In – Flows into a Unit (similar to a nozzle).**
- **Port-Out – Flows out of a Unit**

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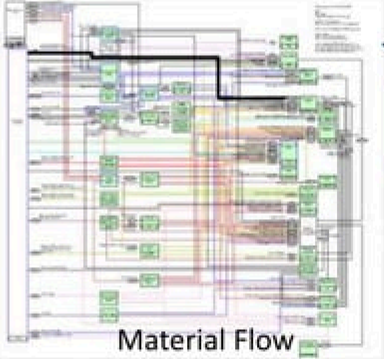
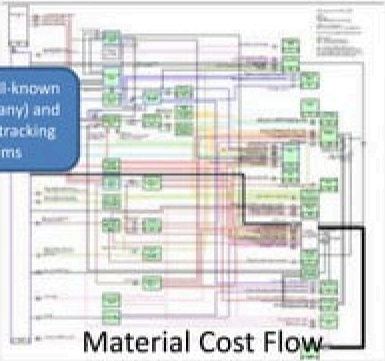
Material Flow and Cost Accounting (Mass, Cost)

- Reconciles material flows and simulates costs, tracks contaminants and largest measurement uncertainties / gross-errors as well as inefficiencies and losses
  - "MFCA is a management tool to better understand the potential environmental and financial consequences of material and energy practices - it does so by assessing the physical material flows in a value-chain and assigns adequate associated costs to these flows"



Material Flow

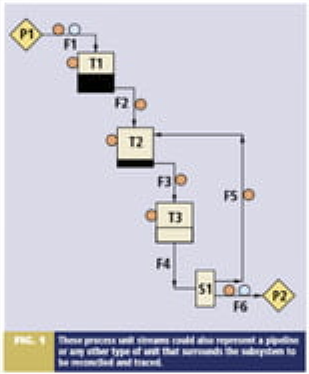
MFCA is very well-known in Europe (Germany) and Asia (Japan) for tracking waste streams

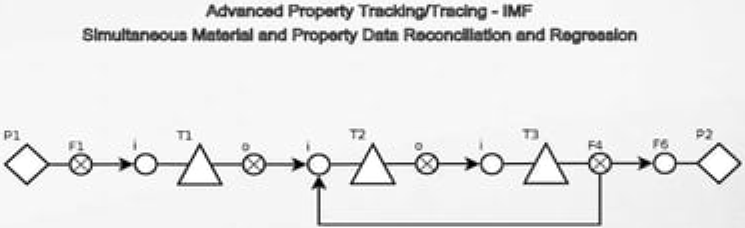


Material Cost Flow

Cascading Tank Example (Volume, Property)

- Trace qualities in all running-gauge tanks with recycle on a sub-hour basis; useful for composition and property tracking especially feeds / products before blending





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Heat Exchanger Network (Flow, Temperature)

- Reconcile cold and hot fluid (energy) flows and temperatures including estimating **heat transfer coefficients** (U) to trend **fouling factors** (f) over time using temperature, pressure and density corrected flows.

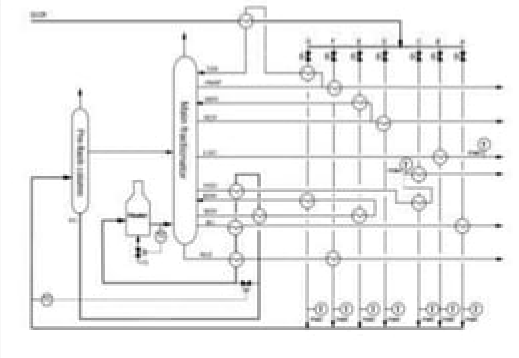
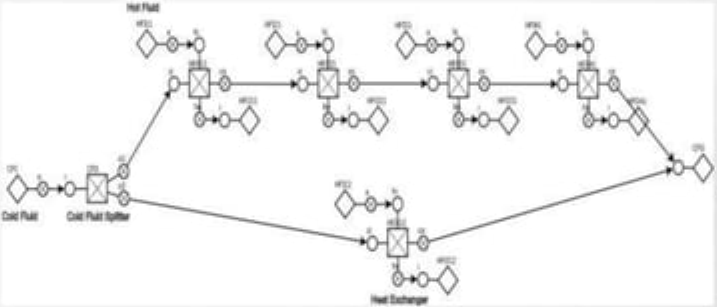


Figure 2: Simplified crude unit overview.



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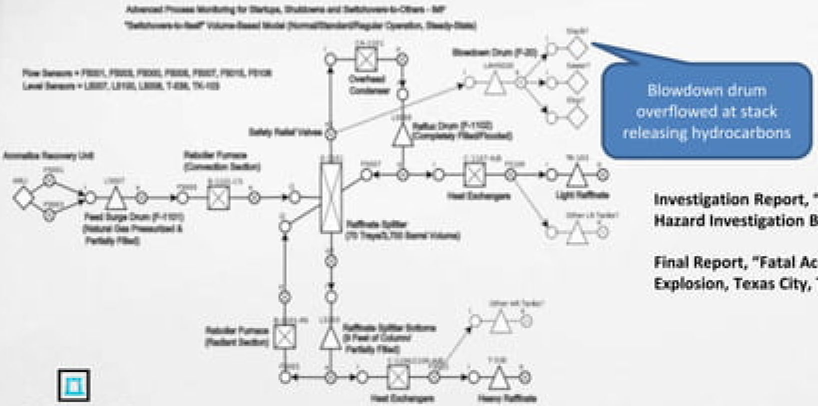
Material Balances during Startups / Shutdowns

- BP Texas City Raffinate Splitter (Isomerization Unit) Incident
  - Page 78, Investigation Report: "Start up of a unit is a time when **material balances** should be calculated."
  - Page 86 Final Report: "The Day Shift Board Operator stated that he was performing a mental **material balance** every few minutes, but the actions taken are inconsistent with this."



Investigation Report, "Refinery Explosion and Fire", U.S. Chemical Safety and Hazard Investigation Board, Report Number: 2005-04-I-TX, March, (2007).

Final Report, "Fatal Accident Investigation Report: Isomerization Unit Explosion, Texas City, Texas, USA", December, (2005).

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Material Balances during Standbys ("Safe-Park")

- XOM Torrance FCCU Electrostatic Precipitator Incident
  - Page 39, Investigation Report: "Tubes in a heat exchanger connected to the FCC unit developed holes during extended operation, causing an increased main column pressure that contributed to hydrocarbons flowing to the ESP."

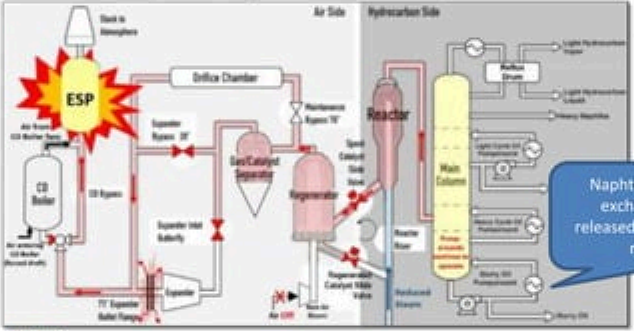

FIGURE 17

When steam flow rate was reduced through the reactor riser, reactor pressure could no longer prevent hydrocarbon backflow from the main column. Hydrocarbons leaked through closed SCSV, through FCC unit air side piping and equipment, and to the energized ESP. A hydrocarbon/air mixture ignited inside of the ESP.

Investigation Report, "ExxonMobil Torrance Refinery Electrostatic Precipitator Explosion", U.S. Chemical Safety and Hazard Investigation Board, Report Number: 2015-02-I-CA, May, (2017).

Naphtha/slurry oil heat exchanger tube leak released hydrocarbons into reactor, etc.

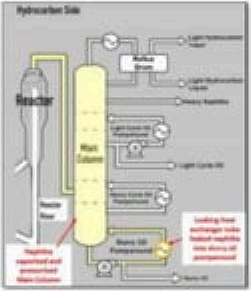

FIGURE 28

Leaking heat exchanger tube allowed light naphtha to enter main column.

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Getting ready for carbon pricing and carbon footprint tracking …

- Our unique on-line and automated approach ("The How")
  - Step 0: Build process unit-operation flowsheet model ***(In – Out = 0)***
  - Step 1: Monitor ***key process unit tags for steady-state*** i.e., flows, temperatures, pressures, levels, concentrations, compositions, etc.
  - Step 2: Include upstream and downstream process unit holdup / level tags and automatically estimate ***fill and draw rates*** for these inventory vessels to increase "software redundancy" (hardware redundancy is more physical measurements)
  - Step 3: Perform ***steady-state data reconciliation*** when process unit is at steady-state; this will minimize apparent gross-errors due to unaccounted accumulation
  - Step 4: Report ***measurement adjustments and gross-errors*** as auxiliary ***diagnostic* tags** when above critical value i.e., 95% and 99% confidence intervals
  - Step 5: Plot measurement diagnostic tags over time to identify ***persistent measurement defects* or outliers** (non-random +ve and –ve adjustments / deviations) to increase "temporal redundancy"

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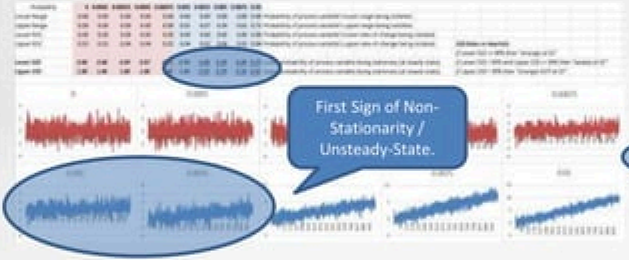
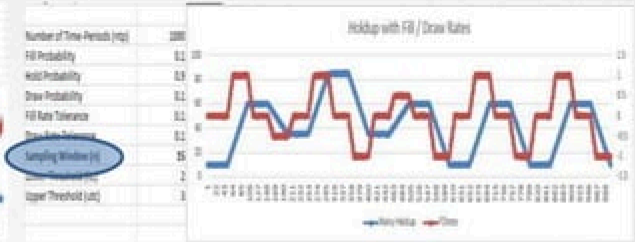
Highlighting some details …

- Step 1: Steady-State Detection (SSD)

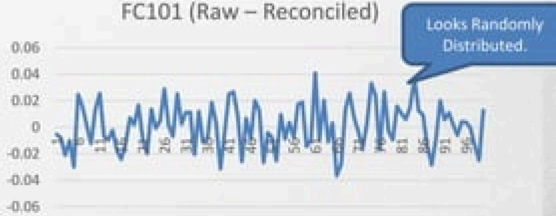


Step 2: Fill & Draw Rate Estimation



- Steps 4 & 5: Reporting and Monitoring

Tag	Raw	Reconciled	Statistic
FC101	100.1	97.6	7.78 (Bad)
PT202	35.9	34.6	5.21 (Bad)
TI303	339.2	340.5	2.10 (Good)
AI404	6.45	6.67	1.93 (Good)



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Summary

- Validating measurements for consistency is a requirement before using process and production data for any purpose especially tracking carbon and losses ☺
- The most reliable and accurate technique to screen process and production data for statistically significant gross-errors or defects is data reconciliation
  - Not Machine Learning, not Extended Kalman Filtering, not Neural Networks
- On-line / real-time data reconciliation applied in an automated fashion is the most effective and efficient way to deploy data reconciliation - results can then be easily displayed in a dashboard, emailed as alerts, historized, etc.
- Off-line / daily data reconciliation using a plant-wide flowsheet deployed in spreadsheets and other business intelligence software **should be augmented with on-line data reconciliation to pre-screen for sub-day measurement defects** and other process anomalies (leaks, mis-logging, losses)

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Implementations

- First data reconciliation engine installed at the PetroCanada Edmonton Refinery to replace their "Volumetrics" inside Honeywell's Production Balance (PB)
  - Honeywell PB (now PAR) installed in over 300 sites world-wide in many different process industries including mining, metals and minerals, chemicals, petrochemicals, etc.

- Current data reconciliation engine installed in STAN2 software (www.stan2web.net) from the Vienna University of Technology with over 9,000 registered users – also being used for MFCA in Finland's agricultural industries
  - Requested help to solve their types of problems with an extreme number unmeasured variables (non-observable flows) as most industries do not have a lot of measurements i.e., waste-water treatment facilities

- Ready to be deployed on-line using simple API / SDK connected to any OPC server ☺

Conclusions

- In anticipation of carbon pricing, companies need to start collecting and analyzing their process and production data and confirming its accuracy, consistency and reliability
- This will establish a baseline as well as identify where additional instrumentation is required to increase both the hardware and software redundancy of the system
- This will also identify existing measurements with systematic errors which can be investigated further i.e., re-calibrate, repair, re-purpose, etc.
- In addition, consider a material flow cost accounting (MFCA) exercise to quantify the economic value of each co-feed, co-product and by-product of your plant including emissions, effluents and utilities

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