# EFRC Training Workshop

## Control of Emissions in Reciprocating Compressor Systems

**Introduction Emissions of Reciprocating Compressor Systems**

André Eijk– TNO

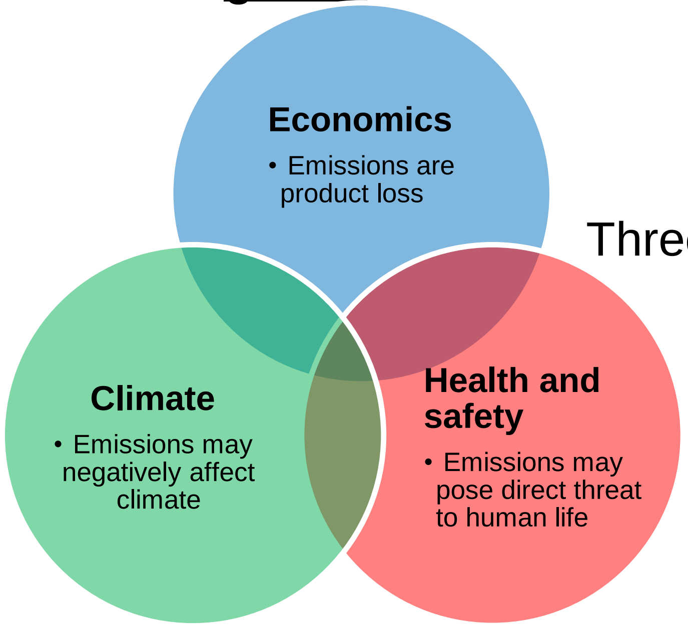
Delft, The Netherlands

# CONTENTS

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

# INTRODUCTION

- ‘To emit’ is to send outward substance, light, gas, noise, heat, fine particles, etc.
- Compressor emissions fit in many of these categories, yet the pre-defined focal point of this presentation study is the emission of gases.
- Why, do these emissions matter?




Three reasons to reduce emissions

**Economics:**

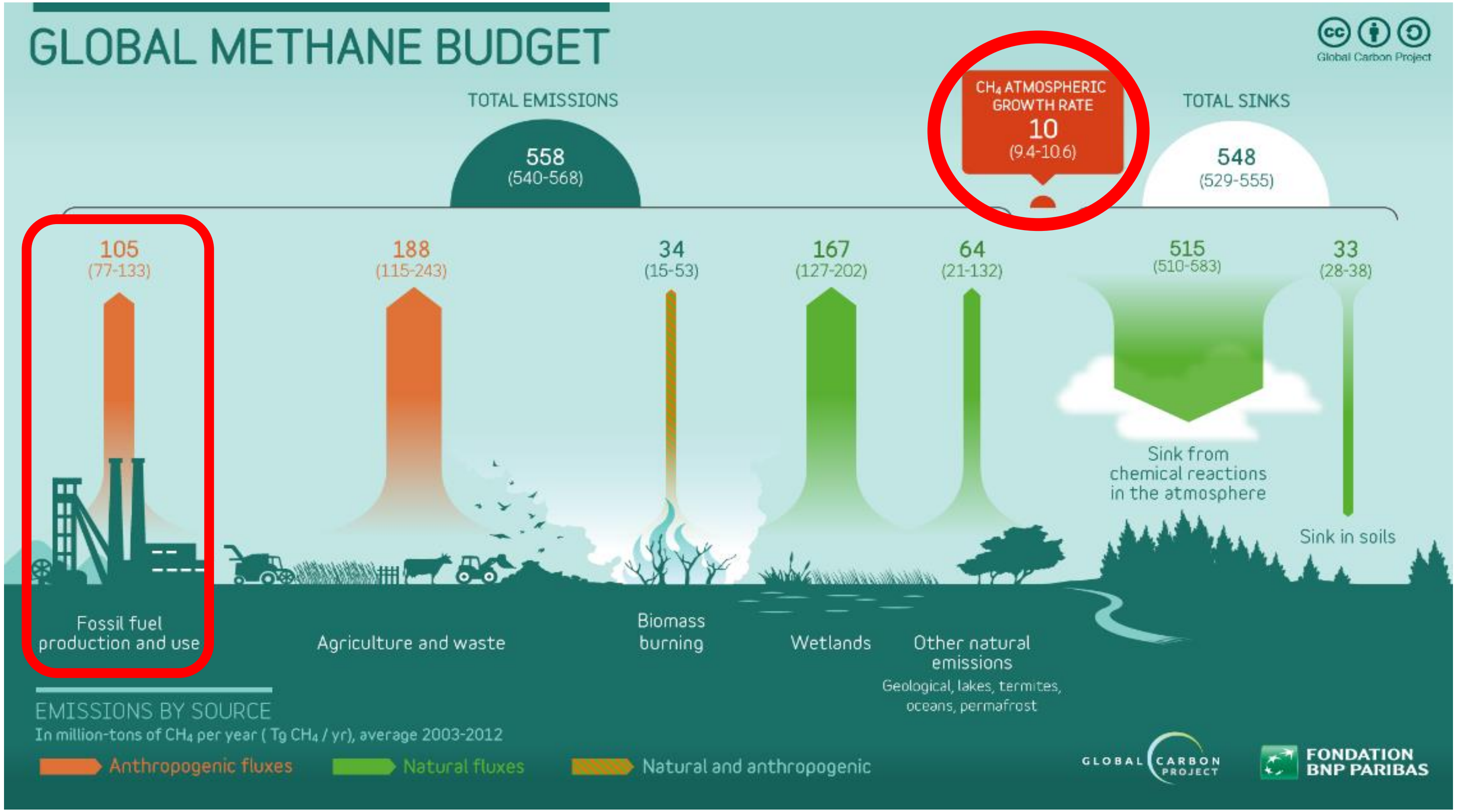
- Loss of sealable product
- Benefit if the penalty of $CO_2$ emissions -> costs of reduction measures
- No benefit if the product losses are lower than the costs of reduction measures

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

**Health and Safety**

- Substance may be toxic, asphyxiant (unable to breathe), flammable, or explosive
- Volatile Organic Components (VOC's):
  - Organic chemical components which evaporate under normal atmospheric conditions of temperature and pressure (EPA, 2017) (acetaldehyde, benzene, formaldehyde, methylene chloride, naphthalene, toluene, and xylene)
- Indoor VOC's: Can create health problems (inhalation)
- Outdoor VOC's: Some create smog, ozone, fine particles (traffic)
- Biological VOC's (plants, trees; terpene) sources emit ≈ 8X more than anthropogenic (caused by human) VOC's and is the dominant source (85%)
- Non-toxic VOC's (CO, CO2, CH4, C2H6, many fluor carbons) are excluded from EPA's (**E**nvironmental **P**rotection **A**gency) VOC definition
- Methane is defined by the EPA as a VOC but is (in general) not health threatening

## Climate




Global Methane cycle schematic, in million-tonnes of $CH_4$ per year, average 2003-2012 (Global Carbon Project, 2016)

# INTRODUCTION

## Climate

- Global Warming Potential (GWP):
  - Is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to Carbon Dioxide (CO2)
  - Is the ratio of the amount of heat trapped by a certain mass gas and CO2 (GWP of CO2 is standardized to 1)
  - A GWP is calculated over a specific time horizon, commonly 20, 100, or 500 years
  - Methane has a lifetime of 12.4 years and with climate-carbon feedbacks a global warming potential of 84 over 20 years and 28 over 100 years in response to emissions
  - Is used to calculate the emissions of as gas to a CO2 equivalent value (CO2e)
- GWP depends on:
  - the absorption of infrared radiation by a given species
  - the spectral location of its absorbing wavelengths
  - the atmospheric lifetime of the species

# INTRODUCTION

| | | GWP | |
|---|---|---|---|
| | Lifetime (yr) | Cumulative forcing over 20 years | Cumulative forcing over 100 years |
| $CO_2$ | b | 1 | 1 |
| $CH_4$ | 12.4 | 84 | 28 |
| $N_2O$ | 121.0 | 264 | 265 |
| $CF_4$ | 50,000.0 | 4880 | 6630 |
| HFC-152a | 1.5 | 506 | 138 |

Global Warming Potentials from the IPCC's 5th assessment report (AR5) (IPCC 2014)

Example: $GWP_{100}$ of CH4 = 28

1 tonne $CH_4$ = 28 tonne $CO_2$ equivalent

| VOC Common name | Chemical formula | Other name | GWP, 100 year time horizon |
|---|---|---|---|
| dimethylether | $CH_3OCH_3$ | | 1[a] |
| methylene dichloride | $CH_2Cl_2$ | Dichloromethane | 10[a] |
| methyl chloride | $CH_3Cl$ | Chloromethane | 16[a] |
| methyl bromide | $CH_3Br$ | Bromomethane | 5[a] |
| methylchloroform | $CH_3CCl_3$ | 1,1,1-Trichloroethane | 144[a] |
| HCFC-22 | $CHClF_2$ | Chlorodifluoromethane | 1,780[a] |
| HCFC-123 | $CHCl_2CF_3$ | Dichlorotrifluoroethane | 76[a] |
| HCFC-124 | $CHClFCF_3$ | Chlorotetrafluoroethane | 599[a] |
| HCFC-141b | $CH_3CCl_2F$ | Dichlorofluoroethane | 713[a] |
| HCFC-142b | $CH_3CClF_2$ | Chlorodifluoroethane | 2,270[a] |
| HCFC-225ca | $CHCl_2CF_2CF_3$ | Dichloropentafluoropropane | 120[a] |
| HCFC-225cb | $CHClFCF_2CClF_2$ | Dichloropentafluoropropane | 586[a] |
| HFC-23 | $CHF_3$ | Trifluoromethane | 14,310[a] |
| HFC-32 | $CH_2F_2$ | Difluoromethane | 670[a] |
| HFC-125 | $CHF_2CF_3$ | Pentafluoroethane | 3,450[a] |
| HFC-134a | $CH_2FCF_3$ | 1,1,1,2-Tetrafluoroethane | 1,410[a] |
| HFC-143a | $CH_3CF_3$ | 1,1,1-Trifluoroethane | 4,400[a] |
| HFC-152a | $CH_3CHF_2$ | 1,1-Difluoroethane | 122[a] |
| HFC-227ea | $CF_3CHFCF_3$ | 1,1,1,2,3,3,3-Heptafluoropropane | 3,140[a] |
| HFC-236fa | $CF_3CH_2CF_3$ | 1,1,1,3,3,3-Hexafluoropropane | 9,500[a] |
| HFC-245fa | $CHF_2CH_2CF_3$ | 1,1,1,3,3-Pentafluoropropane | 1,020[a] |
| HFC-365mfc | $CH_3CF_2CH_2CF_3$ | 1,1,1,3,3-Pentafluorobutane | 782[a] |
| HFC-43-10mee | $CF_3CHFCHFCF_2CF_3$ | 1,1,1,2,3,4,4,5,5,5-Decafluoropentane | 1,610[a] |
| HFE-449s1 | $CH_3O(CF_2)_3CF_3$ | | 397[a] |
| HFE-569sf2 | $CH_3CH_2O(CF_2)_3CF_3$ | | 56[a] |
| [illegible] | [illegible] | | [illegible] |
| ethane | | | 8.4[b] |
| propane | | | 6.3[b] |
| butane | | | 7.0[b] |
| ethylene | | | 6.8[b] |
| propylene | | | 4.9[b] |

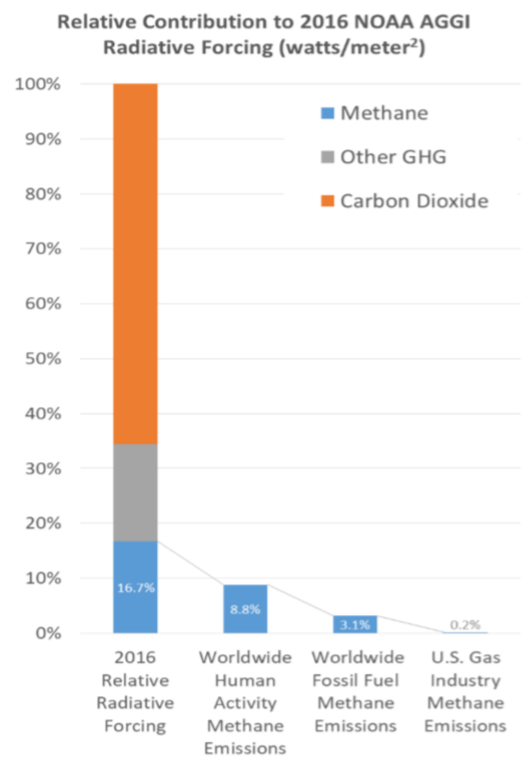
Global Warming Potentials of some common VOC's

# CH4 EMISSIONS IN THE NATURAL GAS INDUSTRY

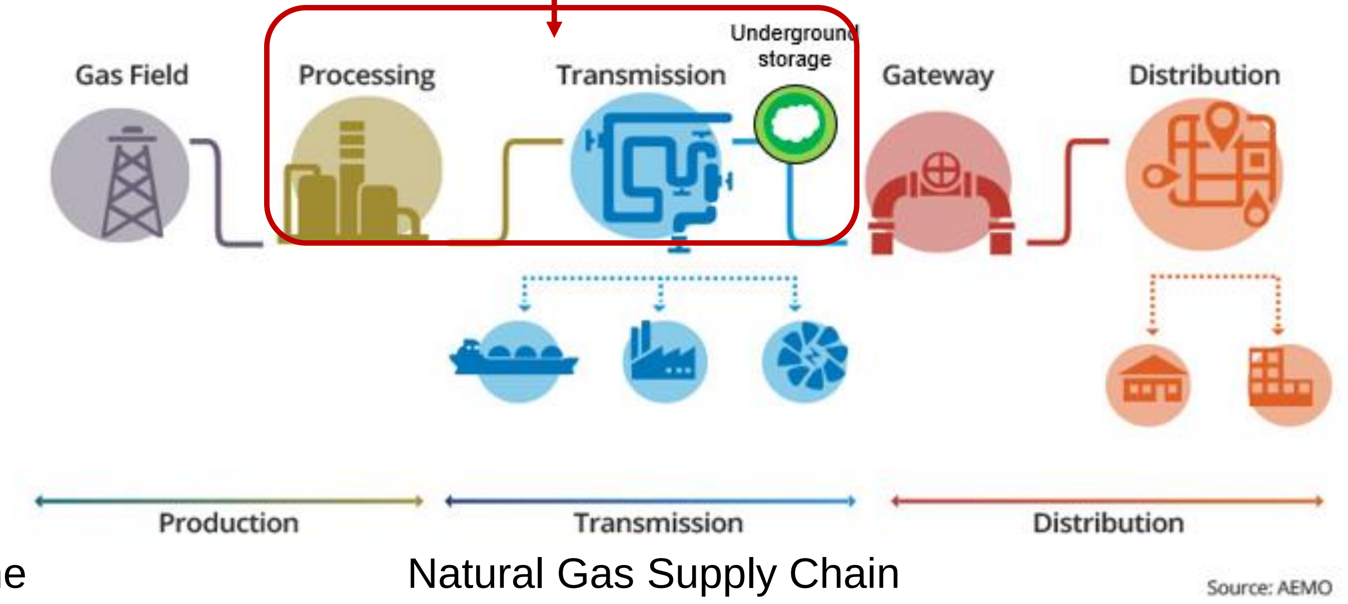
EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Most information on methane emissions is found in the USA
- Knowledge and available emission data is increased considerably caused by Shale Gas production

- Each sector is associated with different activities, pressures and natural gas compositions, and therefore different emissions
- Compressors are most used in processing, transmission and storage sector
- Compressor emissions are different in each sector



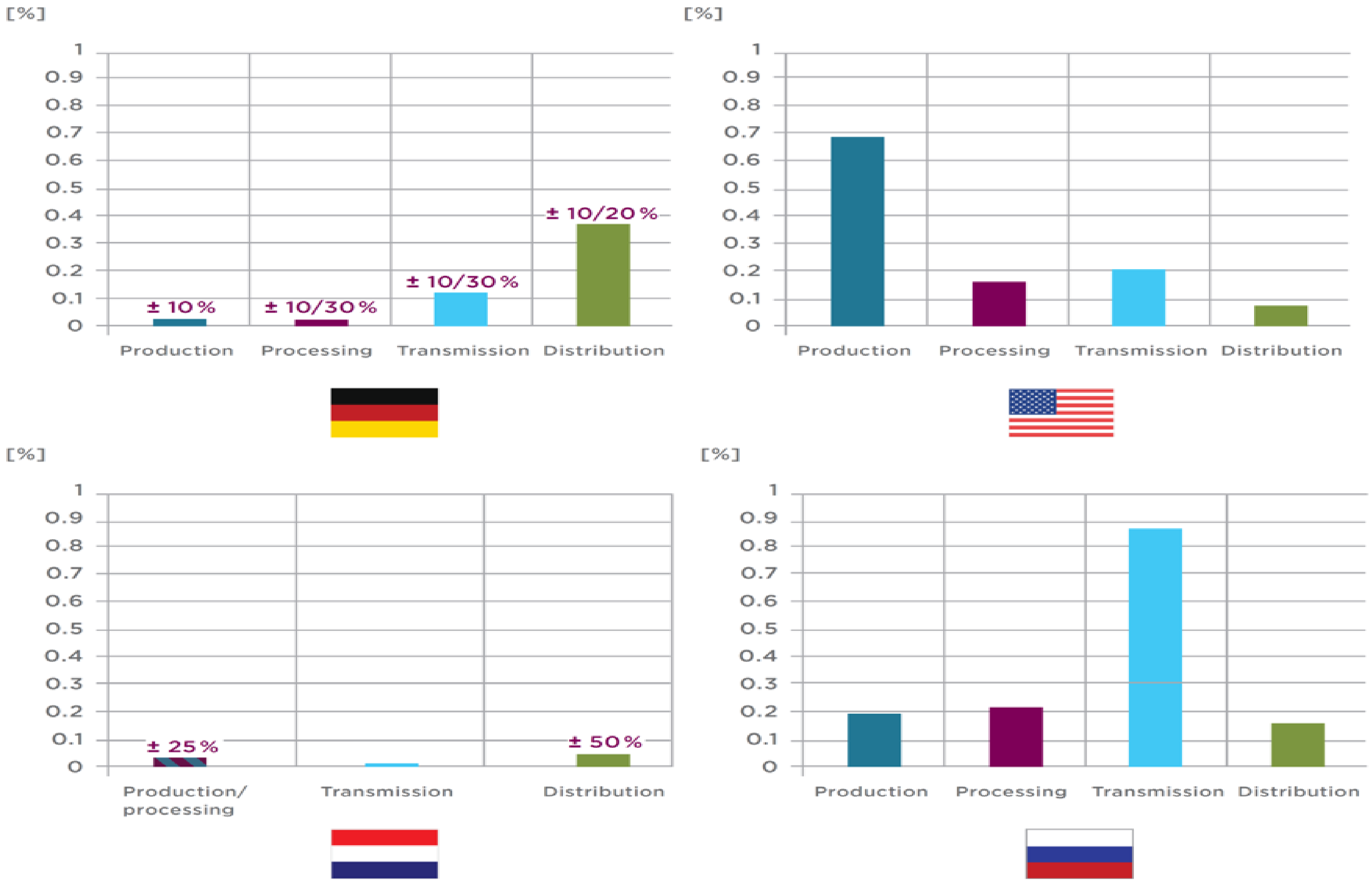

Global GHG relative compared to USA methane




Natural Gas Supply Chain

# CH4 EMISSIONS IN THE NATURAL GAS INDUSTRY

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

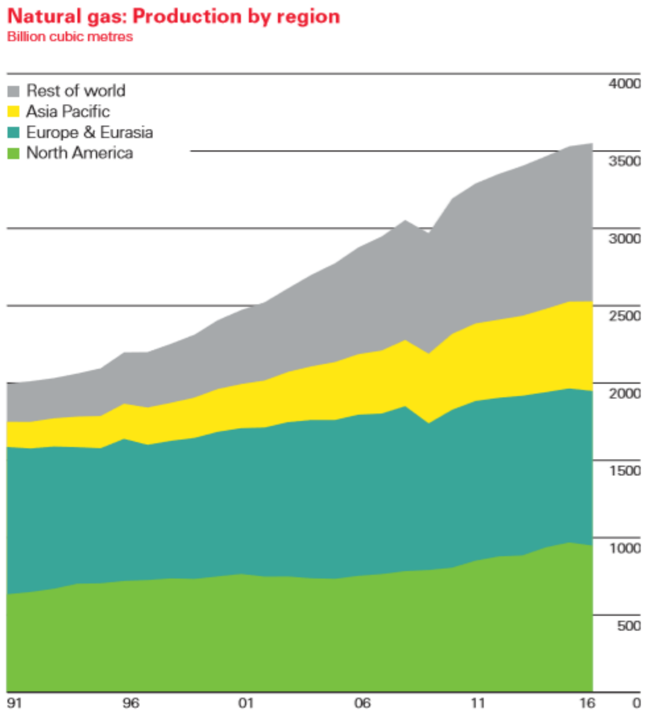



Methane leakage rates from natural gas systems in Germany, the Netherlands, Russia and the US (% of total gas handled) (Source: Cremonese & Gusev, 2016, p. 23)

# CH4 EMISSIONS IN THE NATURAL GAS INDUSTRY

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Methane emissions are classified as fugitive or vented emissions:
  - Fugitive emissions: unintentional leackage
  - Vented emissions: intentional leackage
- Most information on CH4 emissions is found in the USA:
  - EPA's (**E**nvironmental **P**rotection **A**gency)
- Knowledge and available emission data is increased considerably caused by Shale Gas production in the USA
- Some facts and figures of CH4 (total) emissions in O&G industry:
  - Worldwide: 11%
  - USA: 32% of total USA emissions
  - EU: 8% of total EU emissions
  - Energy sector of NL: 4% of national CH4 emissions and 0.4% of total national GHG

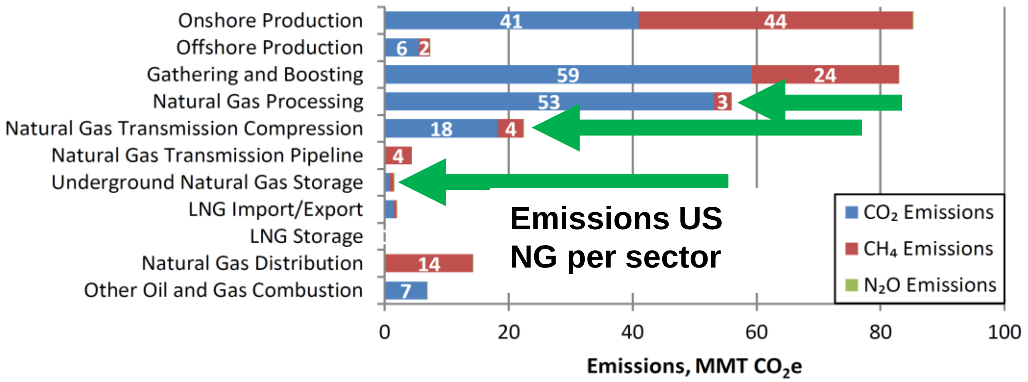


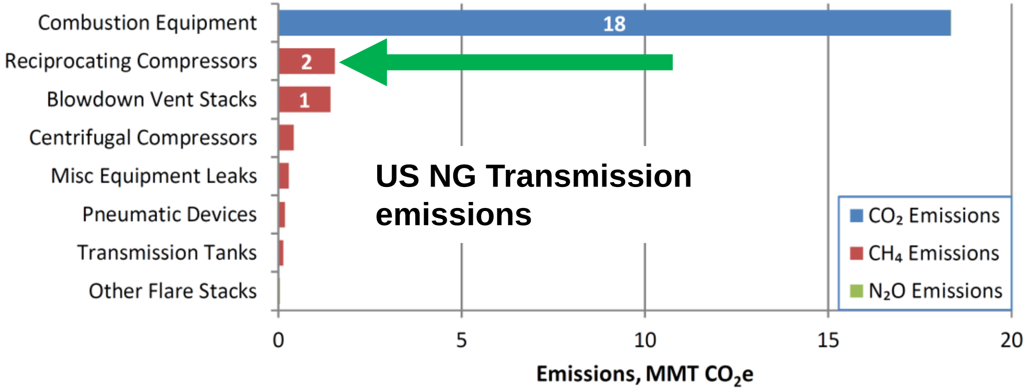

Worldwide NG production, sorted by region. Timescale: 1991 to 2016. NG quantity in billion $m^3$

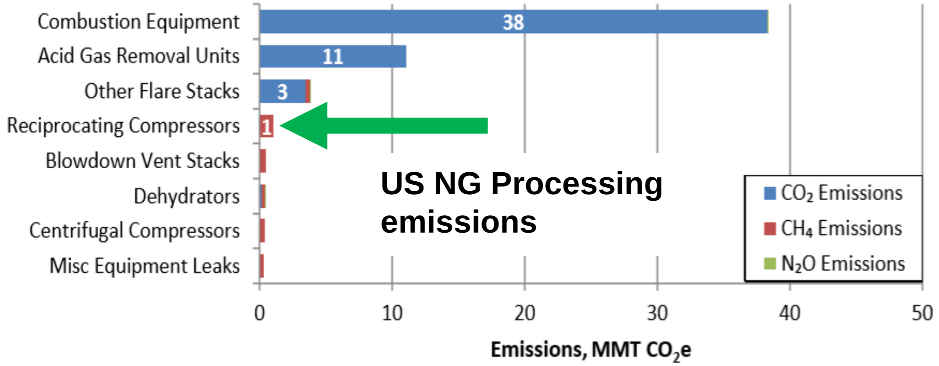
# CH4 EMISSIONS OF RECIPS IN THE NATURAL GAS INDUSTRY

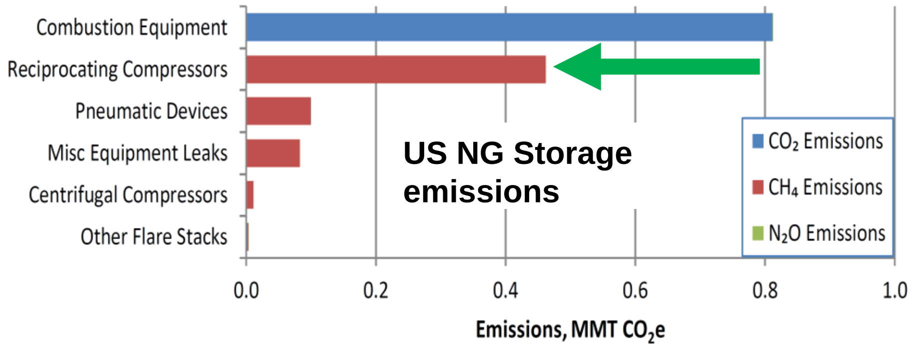
EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Some facts and figures of CH4 (total) emissions of reciprocating compressors
- Source: EPA’s Greenhouse Gas Reporting Program (GHGRP):
  - GHGRP is mandatory for large emitting facilities >25.000 tones $CO_2$ equivalent




Emissions in Million Metric Tons (MMT) per sector

# CH4 EMISSIONS OF RECIPS IN THE NATURAL GAS INDUSTRY

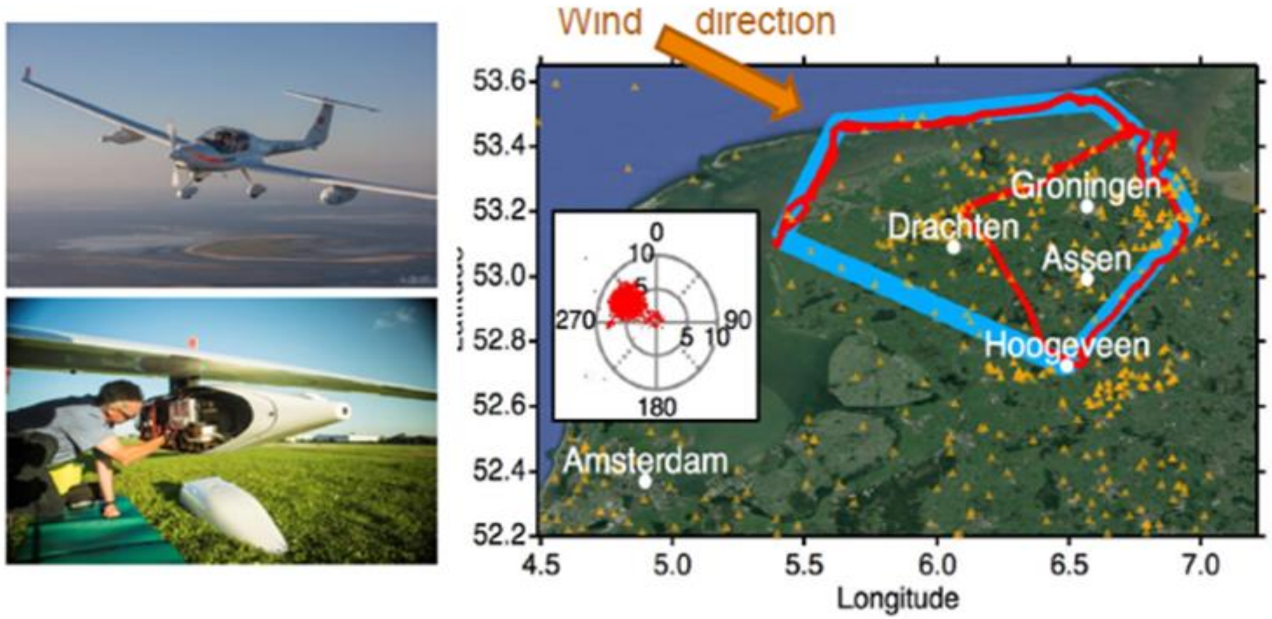
EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Studies have shown the following share of methane emissions to national emissions caused by reciprocating compressors:
  - USA: 4.5% (to be placed in context of entire USA methane emissons of 0.2% of global)
  - Mexico: 10-20%
  - Europe: 0.16-0.48%
- Climate impact of recips: 0.03-0.1% of total GHG emissions since 1750
- Relative figures looks small, but absolute figures are still considerable
- Super emitters (sources which emits more than one would normally expect), skews the emission data and contributes in general to a Pareto distribution:
  - 80% of emissions are caused by 20% of the sources

# HOW TO ESTIMATE AND MEASURE EMISSONS: TOP-DOWN



- Quantification of emissions knows two approaches: **top-down** and **bottom-up**
- Both use a combination of *measurement* and *estimation.*
- **Top-down approach** (aircraft, satellite, drone, road vehicles):
  - *measure atmospheric,* or *ambient concentrations*, either at a surface level or higher altitudes, and can use that data to *estimate* emissions




Examples of top-down measurement

# HOW TO ESTIMATE AND MEASURE EMISSONS: TOP-DOWN

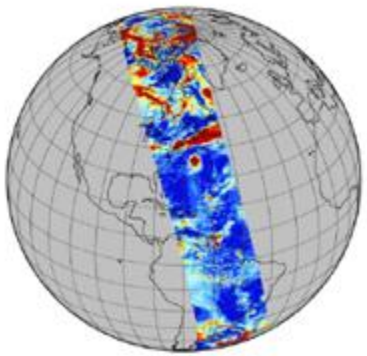
EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

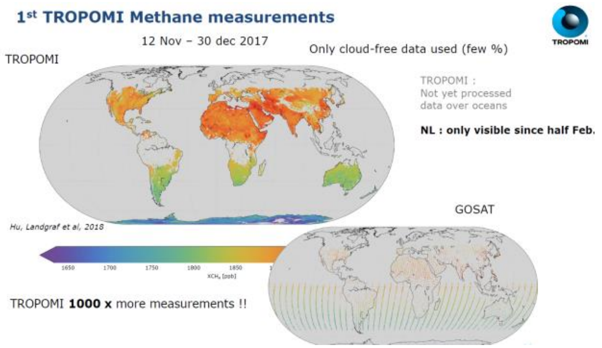
- Advantages top-down method:
  - Provides an aggregate of all emissions, which can be compared to total bottom-up measurements
  - Often highlight emissions that may be from the gas sector which are not accounted for in bottom-up approaches (e.g. supper emitters): it is not possible to determine the emissions sources
- Disadvantages top-down method:
  - Factors such as atmospheric variability, sampling biases, and choice of upwind background can make these estimates *unreliable*
  - Does not reveal which sources might be incorrectly estimated in inventories

# HOW TO ESTIMATE AND MEASURE EMISSONS: TOP-DOWN

- Huge improvements of top-down method with ESA's TROPOMI (**TROPO**spheric **M**onitoring **I**nstrument), launched end 2017


| | SCIAMACHY | GOSAT | TROPOMI |
|---|---|---|---|
| Resolution | 60 x 30 km$^2$ | 10 x 10 km$^2$ | 7 x 7 km$^2$ |
| Measurements/day | 50.000 | 4.000 | 10.000.000 |






TROPOMI and GOSAT measurements

- TROPOMI measures much more than older satellites
- Can cover the complete earth within one day
- From a global perspective on CH4 emissions
  - TROPOMI is a huge step forward

# HOW TO ESTIMATE AND MEASURE EMISSONS: BOTTOM-UP

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- **Bottom-up approach** (also named direct method):
  - *measures* individual emissions (flow and mass) at particular points and may use that to *estimate* emissions from similar sources
  - *extrapolates* the measured data using sampling techniques to achieve total emissions
- The *estimation* relies on the creation and application of Emission Factors (EF's)
- EF's are generalised emission properties of a certain source, expressed in such forms as:
  - units of pollutant per unit of weight, volume, distance, duration, etc.
  - piston pack packing emission: $m^3$/day
  - compressor: $m^3$/day/compressor per km pipe line
- Total estimated emission of all reciprocating compressors of a plant:
  - EF (measured or from literature)/$_{recip}$ x number of recips (activity data)
- Bottom-up approach can also be based entirely on measurements of all equipment: increasing accuracy greatly but at larger costs

Example of bottom-up leak measurement using a high volume sampler

# HOW TO ESTIMATE AND MEASURE EMISSONS: BOTTOM-UP

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- EF’s are published by the EPA in the EF **A**ir **P**ollutant (AP) 42 series for ≈200 sources Literature provides conflicting EF’s for components e.g. piston rod packing, pneumatic devices and blowdown valves
- EF’s of e.g. reciprocating compressors do not include:
  - pressure, power, number of cylinders, new of worn piston rod packings, etc.
- EF’s of recips are in general lower than than for centrifs, however a centrif has in general a much higher flow
- If EF’s are normalised to power: centrif emissions > recips
- Probably it is better to have normalised EF’s to e.g. power ($m^3$/day/**kW**)

| | Activity Data | | Emission Factor | | Mg $CH_4$/year |
|---|---|---|---|---|---|
| **Pipelines** | | | | | |
| Leaks | 489,900 | km | 0.027 | $m^3$/ day/ km | 3,310 |
| **Compressor Stations** | | | | | |
| Station | 1,807 | Stations | 248 | $m^3$/ day/ station | 111,200 |
| Reciprocating Compressor | 7,265 | Compressors | 430 | $m^3$/ day/ compressor | 774,800 |
| Centrifugal Compressor (wet seals) | 672 | Compressors | 1,422 | $m^3$/ day/ compressor | 236,700 |
| Centrifugal Compressor (dry seals) | 57 | Compressors | 912 | $m^3$/ day/ compressor | 12,880 |
| **Compressor Exhausts** | | | | | |
| Engines | 3.59E+13 | MWhr | 5.066 | $m^3$/ MWhr | 222,200 |
| Turbines | 8.57E+12 | MWhr | 0.211 | $m^3$/ MWhr | 2,209 |
| **Venting** | | | | | |
| Pneumatic Devices | 114,500 | km | 4,591 | $m^3$/ year/ device | 221,700 |
| Pipeline Venting | 489,900 | km | 895,880 | $m^3$/ year/ mile | 185,200 |
| Station Venting | 1,807 | Stations | 1.E+08 | $m^3$/ year/ station | 151,400 |
| **Total** | | | | | **1,922,000** |

Methane EF’s in 2012 for the US natural gas transmission sector, using data from the US GHGI (Balcombe et al., 2015, p. 30)

# HOW TO ESTIMATE AND MEASURE EMISSONS: BOTTOM-UP

- There will always be a wide spread in EF's due to:
  - EF's are averages
  - Generalisation of complex situations
  - Each process condition can be different
  - No piston rod packing is the same (aged, worn)
- One shall realise that published EF's can deviate for the system of interest:
  - direct measurements will give better results
- Using is EF's is promising and EF's are improving
- Literature also provides conflicting EF's of compressor components e.g. piston rod packing, blowdown valves, pneumatic transmitters, etc.

| Emission Source | Subramanian et al. 2015 (m³/min) | Harrison et al. 2011 (m³/min) | EPA/GRI 1996 (m³/min) |
|---|---|---|---|
| **Centrifugal compressors** | | | |
| Blowdown vent operating | 0.153 | 0.004 | 0.504 |
| Blowdown vent operating + idle | – | 0.085 | |
| Wet seal (operating) | 0.747 | 0.438 | 0.009 |
| **Reciprocating compressors** | | | |
| Blowdown vent (pressurised + idle) | 0.008 | 0.105 | 0.198 |
| Blowdown vent + Pressure relief valve (operating) | 0.192 | 0.458 | |
| Blowdown vent + Pressure relief valve (idle and depressurised) | – | 0.850 | |
| Rod packing (pressurised + idle) | 0.088 | 0.659 | 0.021 |
| Rod packing (operating) | 0.125 | 1.594 | |

Comparison of compressor emission factors from Subramanian et al., Harrison et al. and the EPA/GRI. (Balcombe et al., 2016, p. 51)

# HOW TO ESTIMATE AND MEASURE EMISSONS: BOTTOM-UP

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Emissions *estimates* are generally underestimated due to:
  - Miscounted number of facilities
  - Missing “super-emitters”
  - Out of date Emission Factors
- Difficult to obtain a truly representative sample from a large diverse population in the supply chain
- Improvements are made, however there is a concern of the quality and consistency of data

Source: Oil & Gas Journal, May 21, 2001.

Measurements with high volume sampler

# HOW TO ESTIMATE AND MEASURE EMISSONS: BOTTOM-UP

- API 2019 Compendium is a guidance document on:
  - Emission quantification, covering all topics like reporting, detection, estimation, etc.
  - Easy to use document for mandatory reporting
  - Is applicable to many sectors
  - Is applicable for CO2, CH4, N2O (nitrous oxide), HFC's, PFC's (Perfluorinated Chemicals) and SF6 (Sulfur hexafluoride)
- Special guidance document is developed to adress uncertainty and accuracy issues
- Software tools that make consistent and reporting easier
  - SANGEA, owned by API (URL: http://www.api-sangea.org)
  - EPA Emission estimation tools (URL: https://www.epa.gov/air-emissions-factors-and-quantification/emissions-estimation-tools

## EPA Emission estimation tools

| | |
|---|---|
| WebFIRE | The WebFIRE database includes EPA's recommended emissions estimation factors for criteria and hazardous air pollutants. |

| Emissions Estimation Tools- Documents |
|---|
| April 2015: Emission Estimation Protocol for Petroleum Refineries Version 3 |
| Nov 2010: Refinery wastewater emissions tool spreadsheet |
| Dec 2010: Greenhouse Gas Emissions Estimation Methodologies for Biogenic Emissions from Selected Source Categories: Solid Waste Disposal Wastewater Treatment Ethanol Fermentation - DRAFT |

| Emissions Estimation Tools- Software | |
|---|---|
| TANKS | TANKS estimates volatile organic compound (VOC) and hazardous air pollutant (HAP) emissions from fixed- and floating-roof storage tanks. |
| SPECIATE | SPECIATE is EPA's repository of Total Organic Compound (TOC) and Particulate Matter (PM) speciated profiles for a variety of sources for use in source apportionment studies. |
| LandGEM | The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emissions rates for total landfill gas, methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from municipal solid waste landfills. It is available from the EPA's Clean Air Technology Center. |
| WATER9 | WATER9, a wastewater treatment model, consists of analytical expressions for estimating air emissions of individual waste constituents in wastewater collection, storage, treatment, and disposal facilities; a database listing many of the organic compounds; and procedures for obtaining reports of constituent fates, including air emissions and treatment effectiveness. |
| PM Augmentation | May 2016. The PM Augmentation Tool helps to ensure completeness of PM inventories by correcting inconsistencies in submitted data and filling gaps where possible. PM Augmentation. The file is available on the Emissions Inventories page under **Emissions Inventory Tools**. |

# HOW TO ESTIMATE AND MEASURE EMISSONS

EUROPEAN FORUM for RECIPROCATING COMPRESSORS

**Two types of measurements:**

1. *Detection* (does not give an absolute value). Used in the Leak Detection and Repair (LDAR)
2. *Measurement* of concentration, flow and mass. Used in the Direct Inspection & Maintenance (DIM) method

**Leak *detection* measurement methods:**

1. Soap bubble screening
2. Electronic screening devices (sniffer)
3. Organic Vapor Analysers (OVA's) and Toxic Vapor Analysers (TVA's)
4. Infrared cameras
5. Acoustic leak detection

Example of a electronic sniffer screening

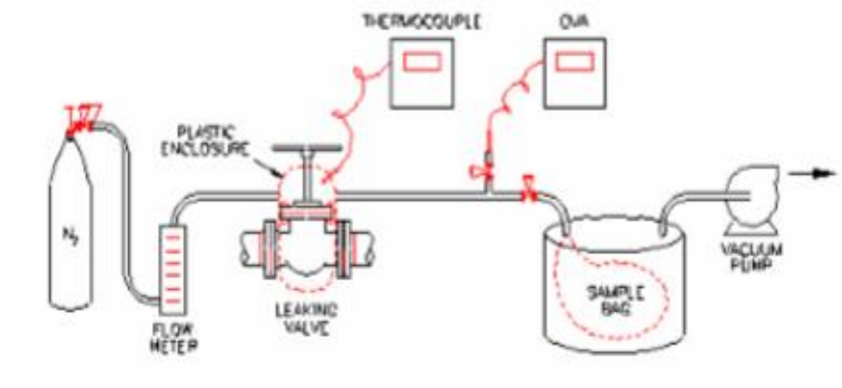


Examples of optical gas imaging camera's

# HOW TO ESTIMATE AND MEASURE EMISSONS

**Leak *measurement* methods:**

1. Calibrated bagging techniques:
   - fairly accurate (within ± 10 to 15%), but slow
   - not suitable for components that are very large, inaccessible, and unusually shaped.




Examples of a bagging technique

2. High volume samplers:
   - measures mass leak rates
   - very fast
   - complete emissions are captured and prevent interference from other nearby emissions sources

High volume sampler

3. Toxic Vapor Analysers (TVA's):
   - Is a flame ionization detector; can measure concentrations > 10.000 ppm
   - Can deviate from actual leak rates by as much as 3 to 4 orders of magnitude
4. Rotameters:
   - used to measure extremely large leaks that would overwhelm other instruments
   - can supplement measurements made using bagging or high volume samplers

# EMISSION REDUCTION METHODS

**Leading sources in emission reducing methods:**

•EPA's five white papers for the Oil and Natural Gas Sector, aiming emission reduction for VOC's including methane:

1. Compressors
   https://www.regulations.gov/document?D=EPA-HQ-OAR-2010-0505-5109
2. Hydraulically Fractured Oil Well Completions and Associated Gas during Ongoing Production
   https://www.regulations.gov/document?D=EPA-HQ-OAR-2010-0505-5108
3. Liquids Unloading Processes
   https://www.regulations.gov/document?D=EPA-HQ-OAR-2010-0505-5110
4. Pneumatic Devices
   https://www.regulations.gov/document?D=EPA-HQ-OAR-2010-0505-5032
5. Sector Leaks
   https://www.regulations.gov/document?D=EPA-HQ-OAR-2010-0505-5030

•EPA's white papers are complementary to the **N**ew **S**ource **P**erformance **S**tandards (NSPS):

– Compressor relevant standards are gathered in 40 CFR 60, Subpart OOOOa (2016)

# EMISSION REDUCTION METHODS

EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Lesson's learned by EPA's Natural Gas Star Program: https://www.epa.gov/natural-gas-star-program/recommended-technologies-reduce-methane-emissions
  - The website provides a reduction-method-matrix for different equipment in the NG system such as compressors & engines, dehydrators, pipelines, pneumatic controls, tanks, valves, wells, etc.

- Technical Guidance Documents (TGD) from Climate & Clean Air Coalition (CCAC) http://ccacoalition.org/en/content/oil-and-gas-methane-partnership-technical-guidance-documents
  - Natural Gas-Driven Pneumatic Controllers and Pumps
  - Fugitive Component and Equipment Leaks
  - Centrifugal Compressors with "Wet" (Oil) Seals
  - Reciprocating Compressors Rod Seal/Packing Vents

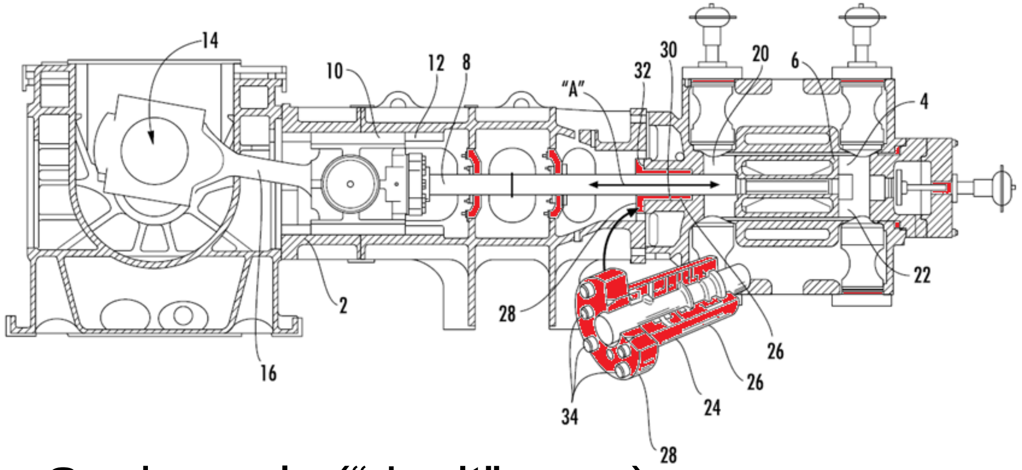
# EMISSION REDUCTION METHODS

EUROPEAN FORUM for RECIPROCATING COMPRESSORS

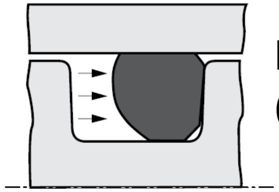
- Based on the EPA White Papers, NG Star and the CCAC, and *several supporting studies*, the following reduction topics relevant for compressors systems will be discussed :
  - Reciprocating compressor piston rod packing
  - Reciprocating compressor cylinder unloaders
  - Centrifugal compressor wet seals
  - Compressor engine driver
  - Vent and Flare Systems
  - Taking compressors off-line for maintenance (**U**nderground **G**as storage (UGS) **S**ystems)
  - Pneumatic control devices
  - **L**eak **D**etection **A**nd **R**epair (LDAR)
  - **D**irect **I**nspection & **M**aintenance at Compressor Stations (DI&M)

# EMISSION REDUCTION METHODS: PISTON ROD PACKING

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

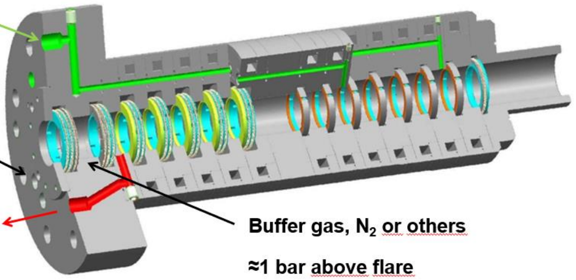



Red locations indicate gas leackage locations (source: HTC)



Example of a static seal (source: Parker Hannifin O-ring Handbook)

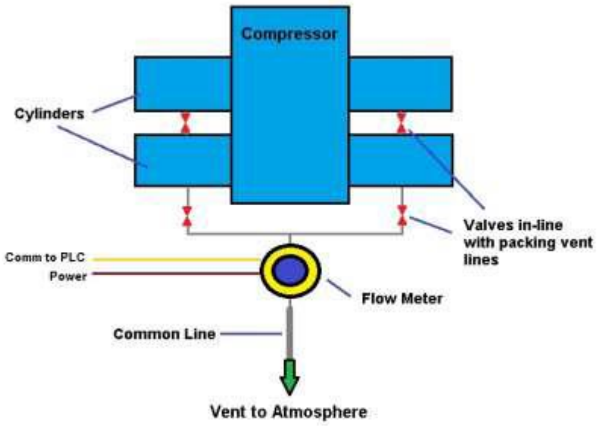
- Static seals ("don't" wear):
  - O-rings, Gaskets
- Dynamic seals:
  - Piston rod packing, Tail rod packing, Actuator rod seals
- Typical leak rates of a piston rod packing:
  - Lubricated piston rod: 0.1-10 Nm$^3$/hr
  - Non-lubricated piston rod: 50% more
  - Worn packing: 10 times of unworn




Example of a worn piston rod packing (source: HTC)

# EMISSION REDUCTION METHODS: PISTON ROD PACKING

- Replace piston rod packing according to EPA's 40 CFR Part 60:
  - On or before 26,000 operating hours, *or*
  - Prior to 36 months from last rod packing replacement or 36 months from the date of start-up of a new compressor, *or*
  - Collect the gas from the rod packing and route it to a process through a closed vent system
- Others recommend replacing the packing based on vent monitoring

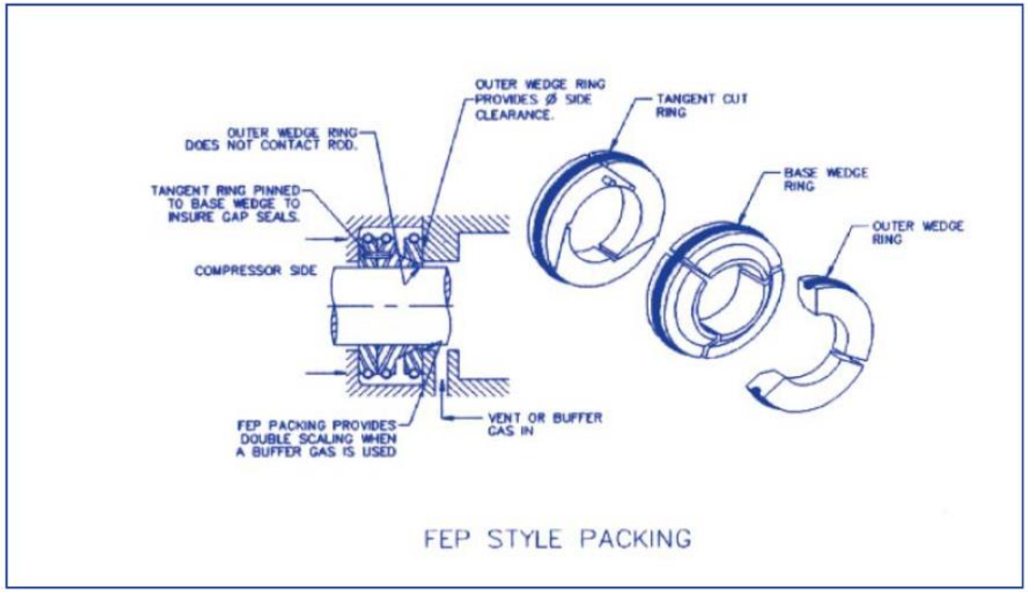


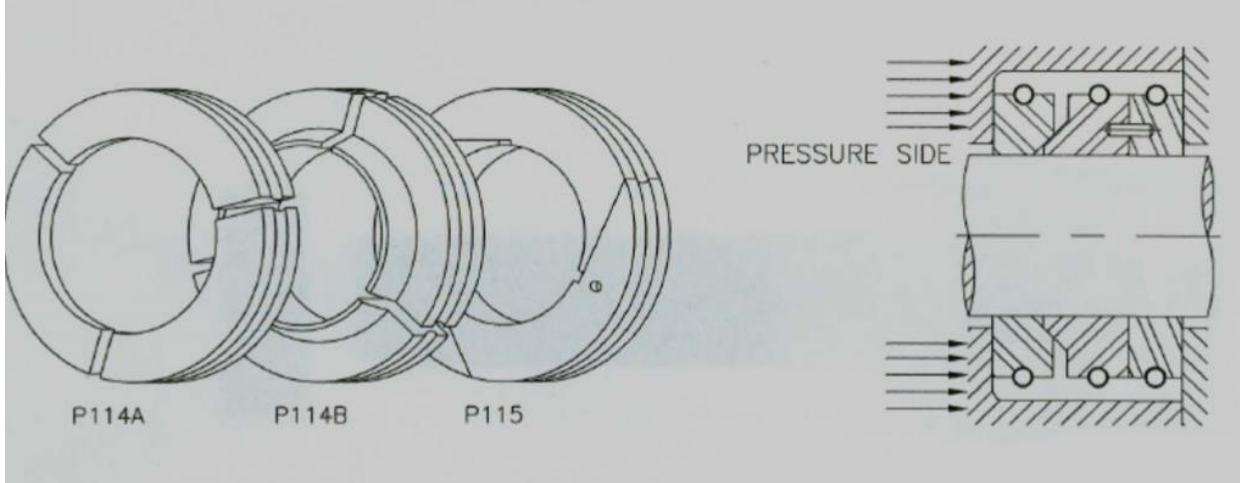

Measuring scheme  with one flow meter (GMRC 2016)

Field installation of individual vent flow lines for each cylinder (GMRC 2016 Atmos Energy)

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Additional options:
  - Rod packing rings (carbon-impregnated Teflon, one year longer lifetime than bronze)
  - Upgraded piston rod (reduce wear by tungsten carbide coating or chrome coating)
  - Three ring rod packing (packing cup replacement not necessary)
  - Etc.



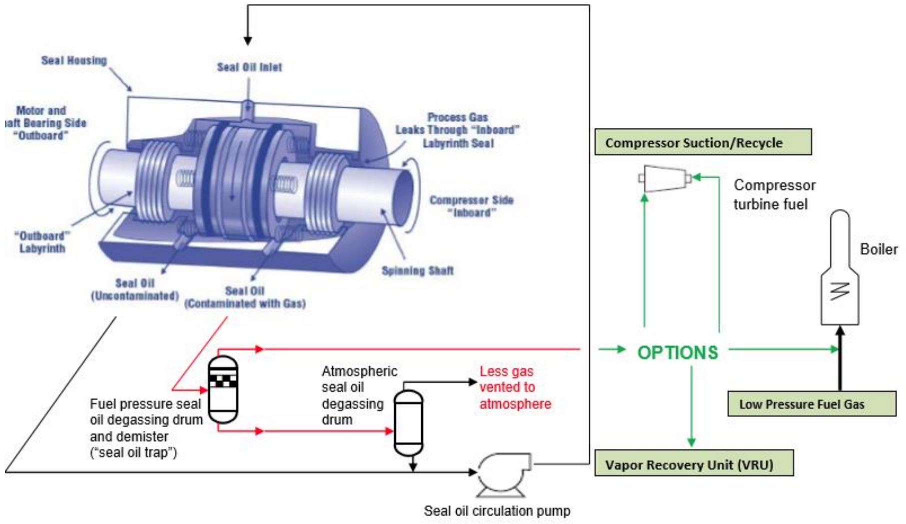




Three-Ring Fugitive Emission Rod Packing Assembly (source EPA)

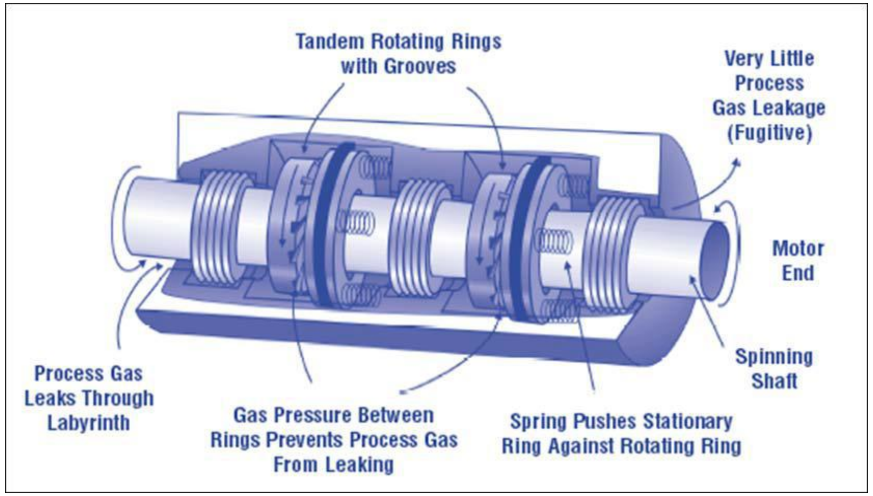
EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

**Centrifugal compressors (EPA 40 CFR Part 60)**

- EPA: you must reduce methane and VOC emissions from each centrifugal wet seal fluid degassing system by 95%
- Instead of fluid degassing it is also possible to use dry gas seals



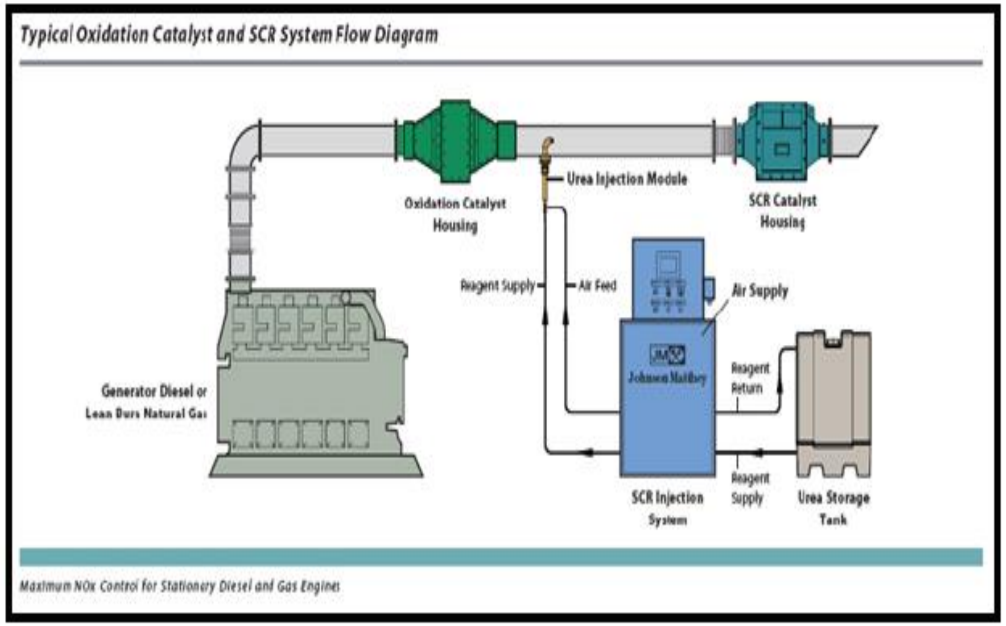

Fluid degassing scheme (source EPA)




Dry gas seals: 95% emission reduction (source EPA)

**Gas engines ($CH_4$ supply chain and off-shore applications)**
**(EPA's fact sheet number 103 and 105)**

- $CH_4$ reduction measures:
  - Replace gas starters with air or nitrogen
  - Reduce natural gas venting with fewer compressor engine start-ups & improved engine ignition (EPA: methane slip is ≈0.02 N/$m^3$ per kW engine power)
  - Install electric drivers and electric starters (called indirect emission)
- NOx,$SO_2$, CO and $CO_2$ (VOC's) reduction measures:
  - Catalytic reduction
  - After burner
  - Solar or battery power supply
  - Diesel engines: ultra-low sulphur diesel, particulate filter (PM2.5)

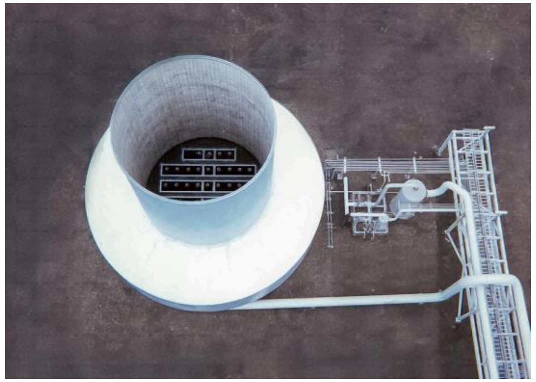



NOx control (source: US Forest Service 2011)

# EMISSION REDUCTION METHODS: FLARING AND VENTING

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- **Advantages of Flaring versus Venting**
  - Can destroy **H**azardous **A**ir **P**ollutants (HAP's are pollutants that are known or suspected to cause cancer or other serious health effects: acetaldehyde, benzene, formaldehyde, methylene chloride, naphthalene, toluene, and xylenebenzene)
  - Burning methane will give lower GWP ($GWP_{100}$ of CH4 is 28 times that of CO2!)
  - Can achieve 98% destruction efficiencies
- **Disadvantage:**
  - Needs a continuous supply of burning gas (≈0.6 $Nm^3$/hr per flare)

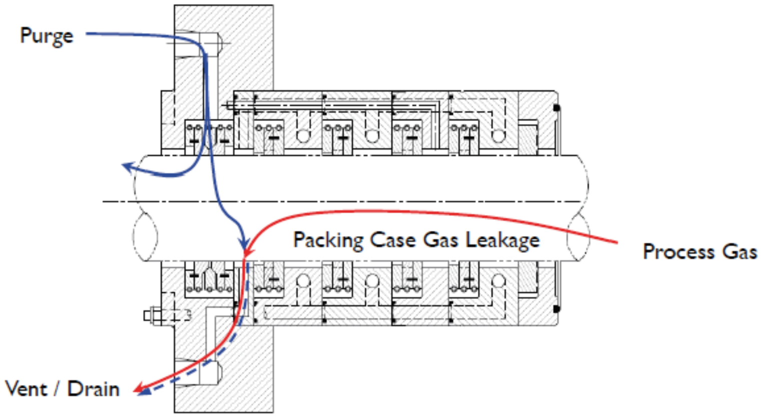


Example of an enclosed flare
(source: Zeeco Products & Industries)

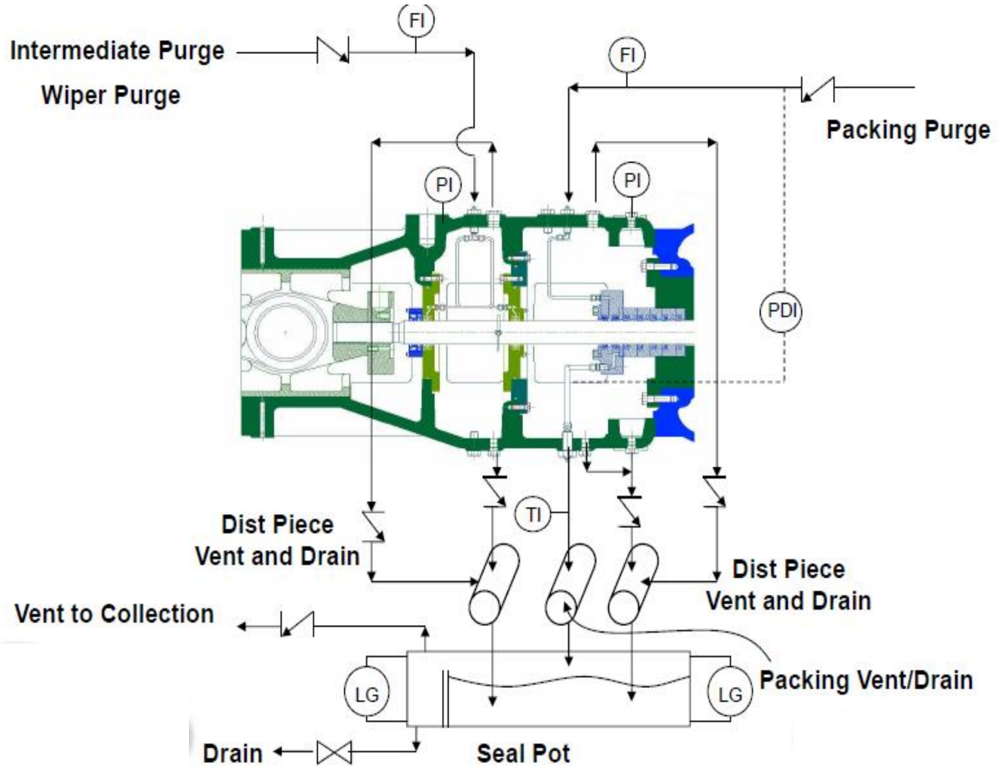
Example of an open flare system

EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Reciprocating Compressor Vent Gas Systems (API 618)




Flow path of the purge (vent) gas and process gas through a piston rod packing (source GEP, Ariel)




Example of the vent and drain line PI&D of a double distance compartment (source: GEP, Ariel)

- What to do with the vent gas?
  - send it to the atmosphere, vent or flare?
  - use it in other processes of the plant?
  - send it to a vapor recovery unit (VRU)?
  - etc.

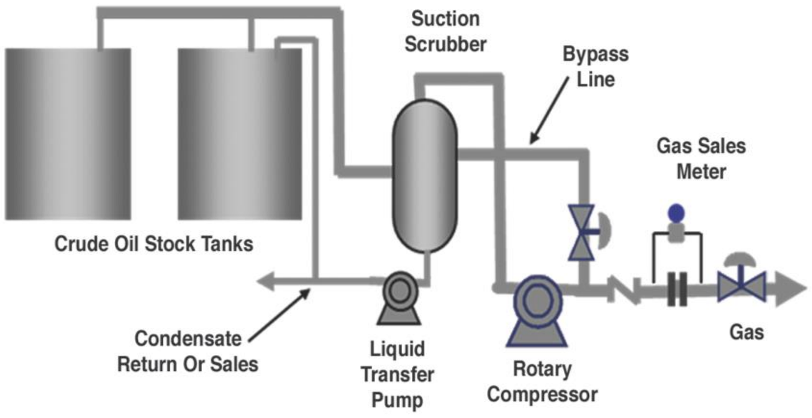
# EMISSION REDUCTION METHODS: VENTING RECIPROCATING COMPRESSORS

- **Design Considerations Vent and Drain Lines (**Source: GMRC Guideline for high-speed reciprocating compressor packages for natural gas transmission & storage applications)
  - Vent all distance pieces
  - Vent line size shall be large enough: minimum 2”
  - Vent lines shall be configered so that gas cannot be transfer to another compartment
  - Vent and drain lines shall be designed to avoid liquid build-up
  - Drain and vent lines shall be connected to a common separator
  - Drain manifolds need to be sloped towards drain pots and oil tank
  - Check valves can be used but keep in mind that fouling can occur
  - Pressure drop of vent and drain line shall be minimised
  - Packing vent/drain line shall not be tied to the distance piece prior to entering the separator (this is to avoid packing flow which can go back through drain connection)
  - Lube oil needs to be separated from the packing vent gas
  - Check valve shall be installed on the final vent line, whether to flare or open atmosphere

# EMISSION REDUCTION METHODS: VAPOR RECOVERY UNIT (VRU)

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- A Vapor Recovery Unit (VRU), is a compression system used to collect and compress low volume gas streams for injection into:
  - Suction side of a larger compressor
  - Local site fuel gas system
  - Directly into a gas gathering line
- Advantages of a VRU:
  - Send the natural gas recovered to the sales pipeline increasing the facility's total volume of gas sold (can make money for a facility)
  - Reduces emissions (recover vent gas rather than sending to atmosphere or flare)
  - Can reduce current and future risks and liability associated with greenhouse gas emissions




Typical flow scheme of a VRU

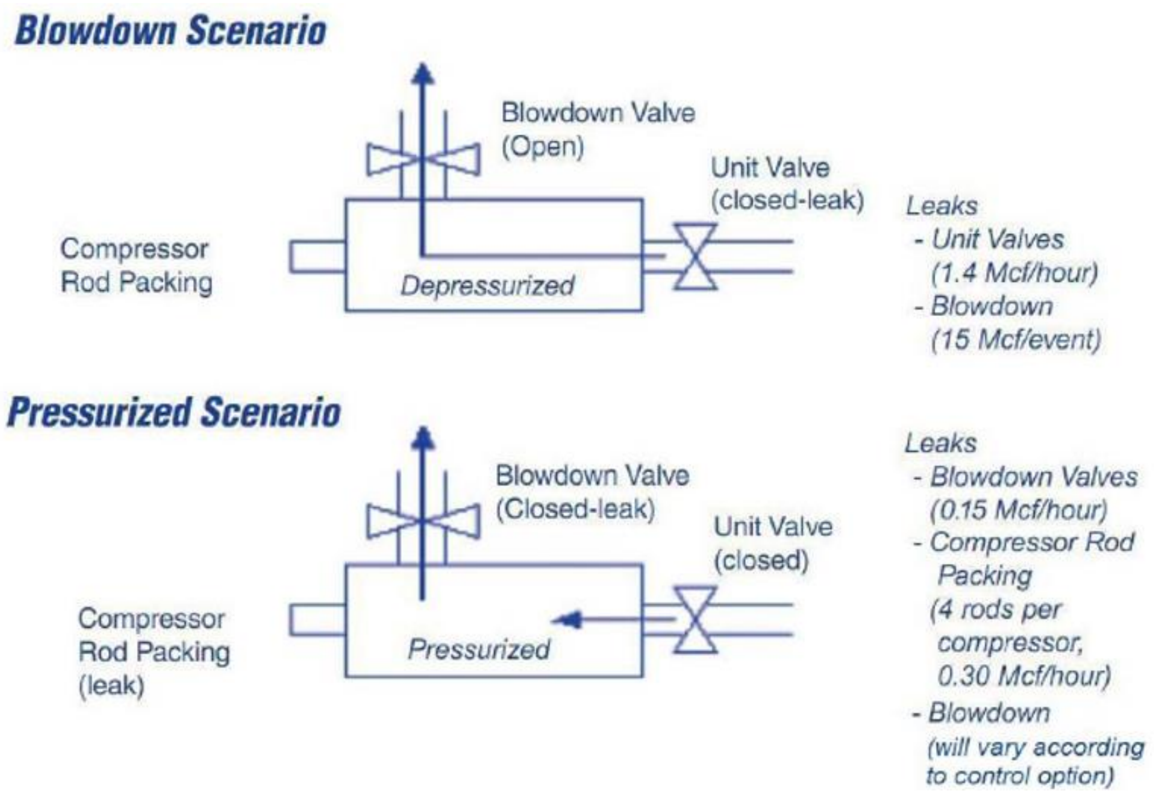
# EMISSION REDUCTION METHODS: VAPOR RECOVERY UNIT (VRU)

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Design parameters VRU's:
  - Variable flow
  - Variable pressure
  - Variable molecular weight
  - "Dirty gas"
  - Often corrosive service
- Used compressors:
  - Liquid ring compressors
  - Rotary sliding vane
  - Screw compressors
  - Reciprocating compressors

Photo of a typical VRU (source: HY-BON/EDI)

# EMISSION REDUCTION METHODS: COMPRESSORS PRESSURIZED WHEN OFF-LINE

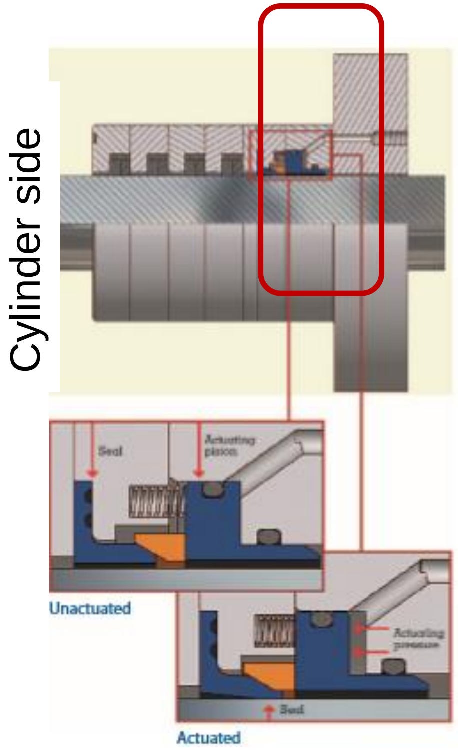


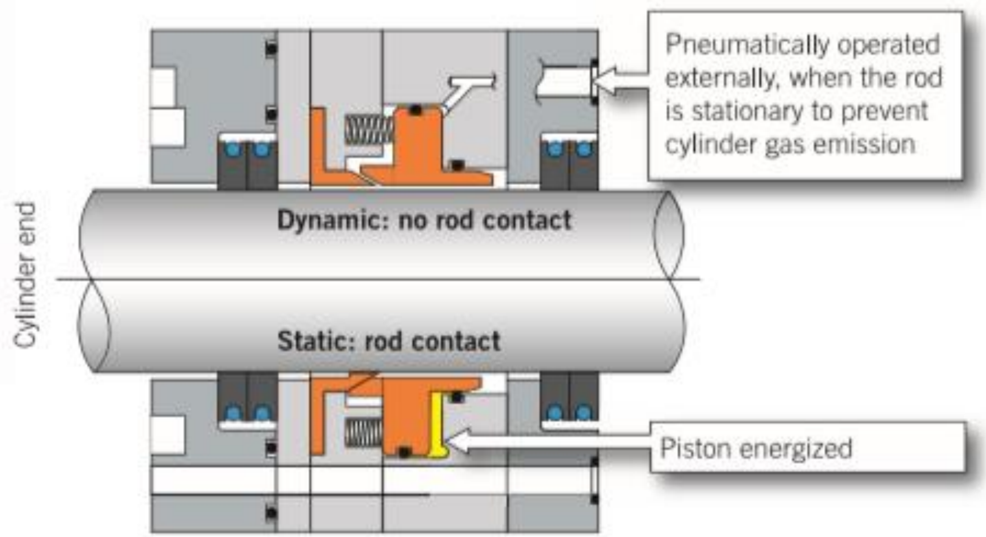

Blowdown versus Pressurized Scenario (source: EPA)

- Emissions of pressurized scenario can be ≈3 times lower than with the "blowdown" scenario
- Especially applicable for compressors of UGS systems which have high venting rates (more shut downs than other systems)

# **EMISSION REDUCTION METHODS:** COMPRESSORS PRESSURIZED WHEN OFF-LINE

- Piston rod leakage of a compressor kept under pressure when off-line is ≈50% larger than when depressurised, solution: install a static seal (≈90% reduction)

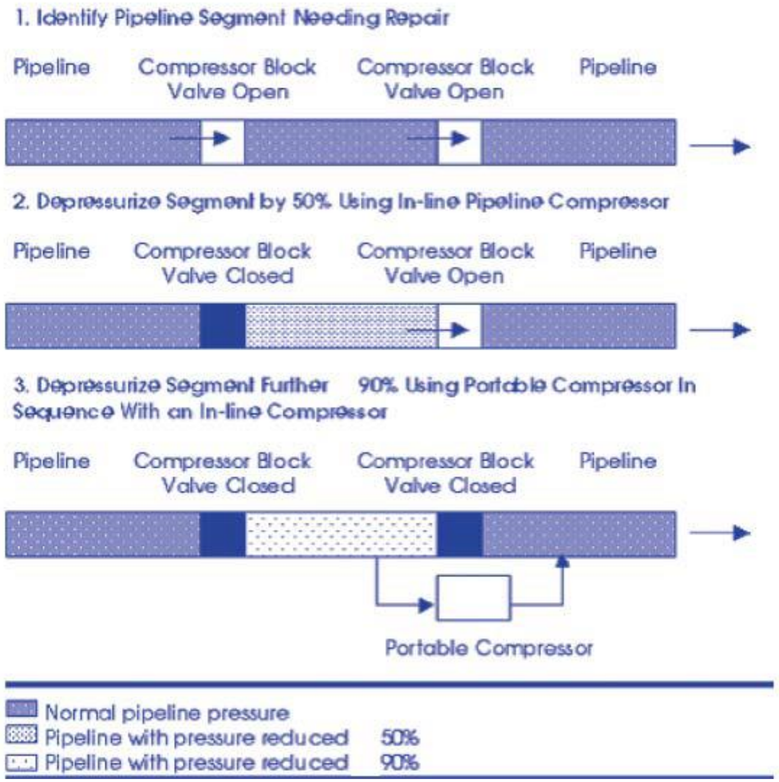



Examples of a static seal (left: Cook; right: Hoerbiger)

# EMISSION REDUCTION METHODS: VENTING BEFORE MAINTENANCE

- Pipe line venting can be reduced ≈50% by:
  - decreasing the line pressure beforehand e.g. by shutting the valve upstream of the pipeline segment and continuing to operate the downstream compressor
- Pipe line venting can be reduced further to ≈90% by:
  - depressurising before it is vented by using portable pull-down compressors

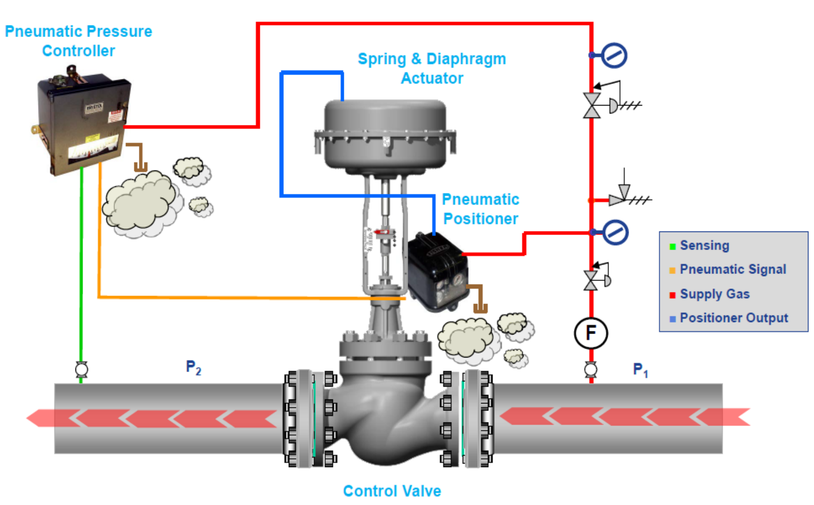



Scheme of reducing pipeline blowdown emissions by using a portable compressor

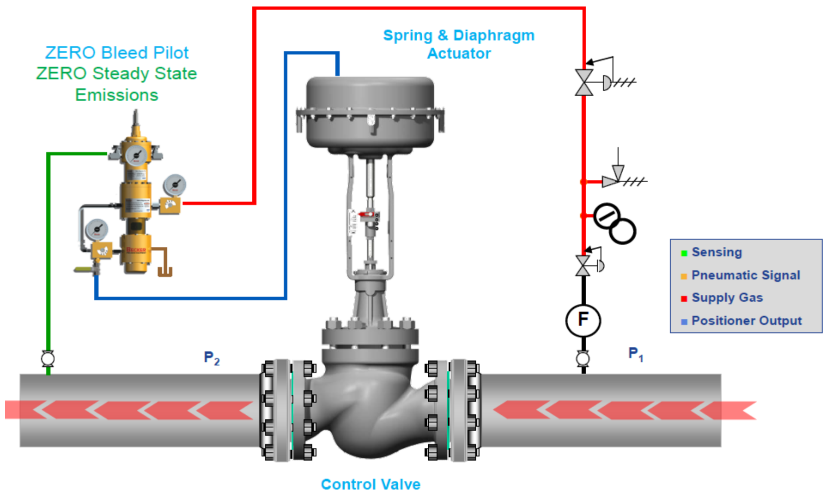
# EMISSION REDUCTION METHODS: PNEUMATIC CONTROLLERS

EUROPEAN FORUM for RECIPROCATING COMPRESSORS

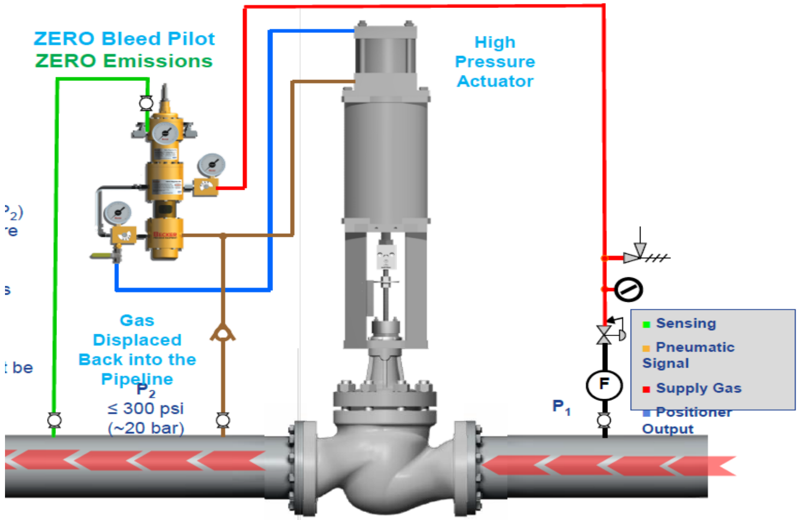
- Many pneumatic controllers (control of P, T, Level) are in general gas powered in the $CH_4$ supply chain
- Emission of a single pneumatic controller: ≈1500 $N/m^3$ /year
- Emissions can be reduced e.g. by non-gas powered equipment:
  - e.g. solar, electric, or instrument air (or $N_2$)
- Powered gas: emission reduction can be achieved by replacing a high bleed with a low bleed or even with a zero bleed controller




High bleed controller



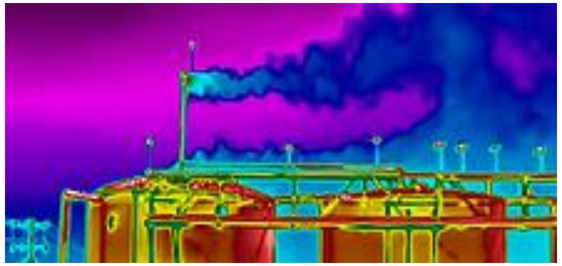

Low bleed controller (85% reduction)




Zero bleed controller

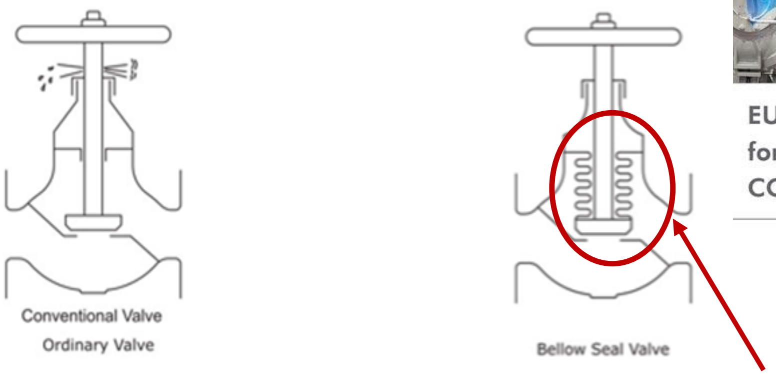
# EMISSION REDUCTION METHODS: LEAK DETECTION AND REPAIR (LDAR)

- LDAR is a work practice to identify leaking equipment so that emissions can be reduced through repairs (EPA's Method 21)
- LDAR is focussing on VOC's and Hazardous Air Pollutants
- Applied for valves, pumps, connectors, compressors, etc.
- A leak is detected when the measured concentration exceeds the threshold standard for the applicable regulation (EPA's NSPS: 10.000 ppm)
- Any leaking component must be repaired or replaced within a certain time frame.
- EPA: estimated VOC emission reduction of ≈%60, depending on the industry with a short payback time.

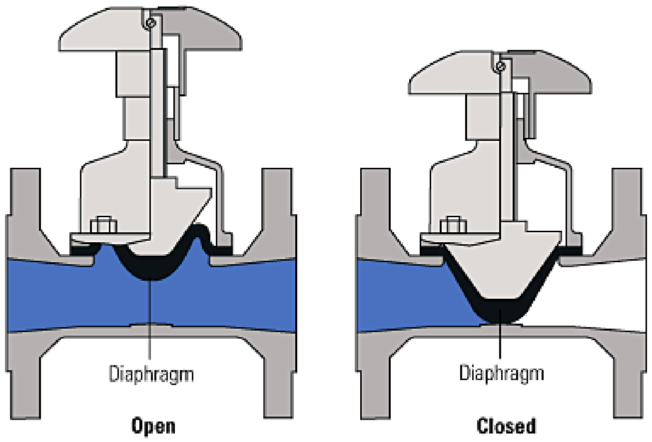


# EMISSION REDUCTION METHODS: LEAK DETECTION AND REPAIR (LDAR)

- Elements of an LDAR program:
  - Identifying components
  - Leak detection
  - Monitoring
  - Repairing
  - Record keeping
- The benefits of an LDAR program are:
  - Increasing safety for facility workers and operators
  - Decreasing exposure for the surrounding community
  - Reducing product losses
  - Potentially reducing emission fees
  - Avoiding enforcement actions
  - Short payback time




Example of a normal valve (left) and bellow type valve (right) (source: BellowSeal)




Example of a diaphragm type valve (source: IEEE)

# EMISSION REDUCTION METHODS: DIRECT INSPECTION & MAITENANCE (DI&M)

EUROPEAN FORUM for RECIPROCATING COMPRESSORS

- Majority of $CH_4$ emissions are from a relatively small number of leaking components (≈95% of CH4 emissions are from 10-20% leaky components at compressor stations)
- DI&M is a cost-effective way to:
  - *detect* leaks by a baseline survey
  - *measure* (mass/flow rate) (high volume sampler is cost-effective, fast and accurate)
  - *prioritize* on the largest emitters, and
  - *repair* equipment with the largest leaks
- Main differences with LDAR:
  - DI&M is applied mainly for methane (LDAR is used mainly for VOC's)
  - LDAR used only leak *detection,* DI&M identifies firts a leak and after that it *measures* also the emissions rate

# EMISSION LEGISLATION

**Europe**:

- One single clear legislative instrument: **I**ndustrial **E**mission **D**irective (IED)
- The permit regulations are gathered under the **I**ntegrated **P**ollution **P**revention **C**ontrol (IPPC) program:
  - a license directive based on the usage of **B**est **A**vailable **T**echnologies (BAT's) for compressors, flares, fugitive emissions, air emissions, etc.
- Implementation of the IED and its IPPC permits, is the individual responsibility of each EU member state
- The member states will implement the IED through operating licenses, the company's operations are approved by the government, the provinces, states, or municipality:
  - E.g. NL, "Richtlijn Industriële Emissies", GER: "BImSchG", AUS: Umweltbundesamt, etc.

# EMISSION LEGISLATION

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

**USA**:

- The Clean Air Act (CAA) is the extensive federal law that regulates air emissions from stationary and mobile sources.
- This law authorizes the EPA (regulatory authority) to establish National Ambient Air Quality Standards (NAAQS)
- Compressor relevant standards are gathered under the **N**ew **S**ource **P**erformance **S**tandard (NSPS) Subpart OOOOa.

EFRC
EUROPEAN FORUM for RECIPROCATING COMPRESSORS

# Thank you for your attention

# Questions?