Energy Efficiency in Refining: *Picking the low hanging fruit*

AIChE (Netherlands / Belgium Section)
22 November 2022

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Agenda

- Fluor at a glance
- Introduction- Why focus on energy efficiency?
- Illustrating tangible benefits of energy efficiency Improvement Ideas
- Impacts of fuel substitution / fuel price
- Key takeaways

Fluor at a glance

Executive Overview

12,000+ EMPLOYEES IN EAME

60 SPECIALISED INDUSTRIES SERVED

93 OFFICES IN **34** COUNTRIES ON **6** CONTINENTS

76 YEARS' EXPERIENCE IN THE REGION

109-year LEGACY

44,000+ EMPLOYEES EXECUTING PROJECTS GLOBALLY IN **60** DIFFERENT COUNTRIES

PROVIDING PROFESSIONAL AND TECHNICAL SOLUTIONS

#196 ON THE 2020 FORTUNE® 500 LIST

1,000+ PROJECTS IN ANY GIVEN YEAR

US$23.1 billion backlog

US$14.2 billion revenue

2 FABRICATION YARDS
Mexico | China

TRS staffing solutions
AGENCY ACCESS TRS - TO ANSWER MARKET DEMANDS

STORK A Fluor Company
STORK - **ASSET INTEGRITY PARTNER**

OUR AVERAGE ANNUAL SUPPLY CHAIN SPEND **$11.4B**

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Fluor Corporate Headquarters | Dallas, Texas

OUR PURPOSE
WE BUILD A BETTER WORLD

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Professional and Technical Solutions

DESIGN

Advanced Process Modeling | Conceptual Design | Estimating | Feasibility Studies | Permitting | Process Simulation | Project Financing | Routing | Scope Definition | Siting | Technology/ License Evaluation

ENGINEERING

Advanced Work Packaging | Cost Control | Detailed Engineering | Fabrication | Front-end Engineering | Modular Construction | Planning & Scheduling | Process Simulation | Safety Planning | Systems Integration

PROCUREMENT

Contracts Management | Expediting | Fabrication | Logistics | Low-Cost Country Sourcing | Materials Management | Purchasing | Requirements Planning | Supplier Quality | Staffing Resources | Warehousing

FABRICATION

Contractor Management | Material Control | Modular Construction | Purchasing | Quality Control | Safety Programs | Self-Perform Fabrication | Sourcing

CONSTRUCTION

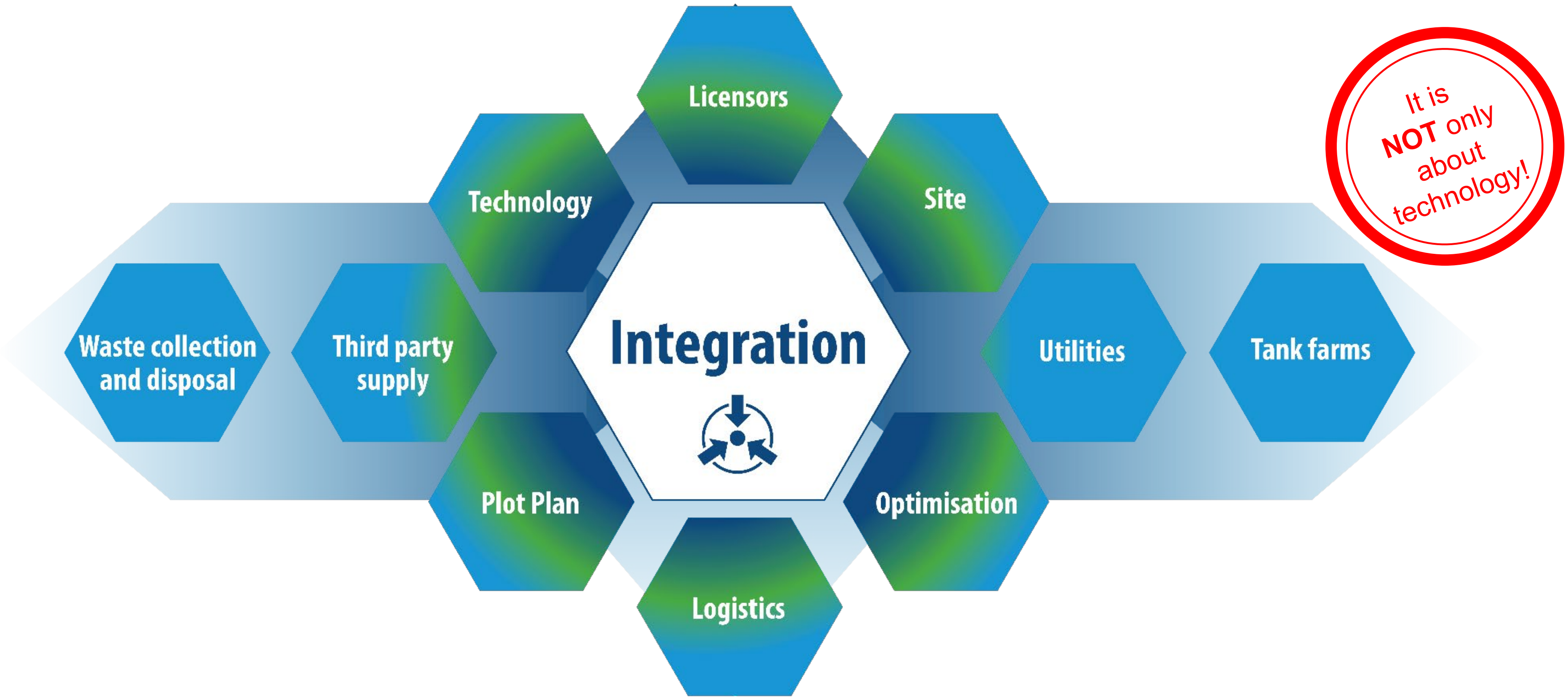
Construction Management | Contractor Management | Craft Staffing & Training | Equipment, Tools & Fleet Services | Field Mobilization | Modular Construction | Project & Program Management | Quality Control | Rigging | Safety Programs | Scaffolding | Self-Perform Construction | WorkFace Planning

START-UP

Commissioning | Engineering Support | Initial Production | Plant Readiness | Precommissioning | Systems Checkout | Turnover | Validation

SGMK003

Fluor as an Integrator



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Introduction

Why focus on energy efficiency?

Introduction

- **Why push for energy efficiency in refineries?**
  - Low hanging fruit: readily available solutions
  - Climate change forecasts, rising fuel prices, emission taxes driving the energy transition
  - COP26/27 – governments around the world are pledging net zero emissions by 2050/70
  - Refineries and chemical plants consume large amounts of energy- e.g., natural gas, steam, hydrogen, electricity
  - While there is a lot of talk and action on renewable / alternative feedstocks for refineries, the bulk of the world's refineries still process and will continue to process fossil fuels for the foreseeable future
  - While looking ahead at what's to come should not come at the expense of what can be done TODAY!
  - Great incentive to undertake energy efficiency programmes on a large scale; *cheapest energy is that which is not consumed*
  - Shorter payback times with rising emission taxes

Illustrating Tangible Benefits of Energy Efficiency Improvement Ideas

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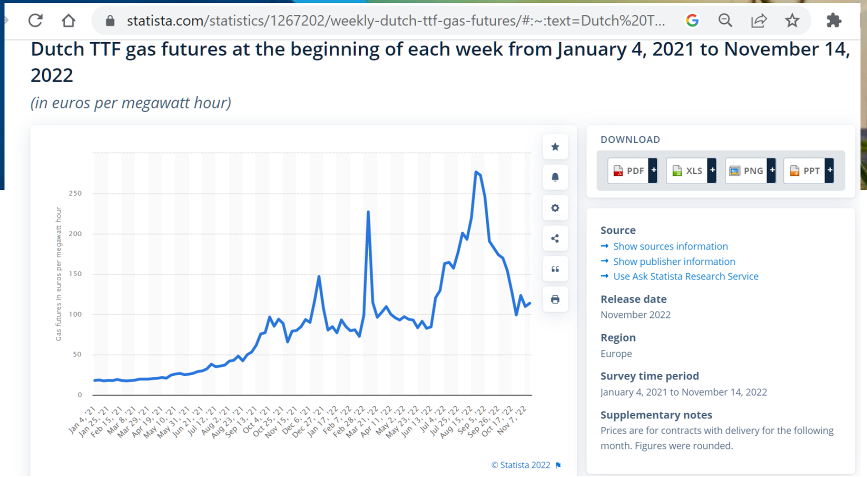
Illustrating the Benefits of Improving Energy Efficiency

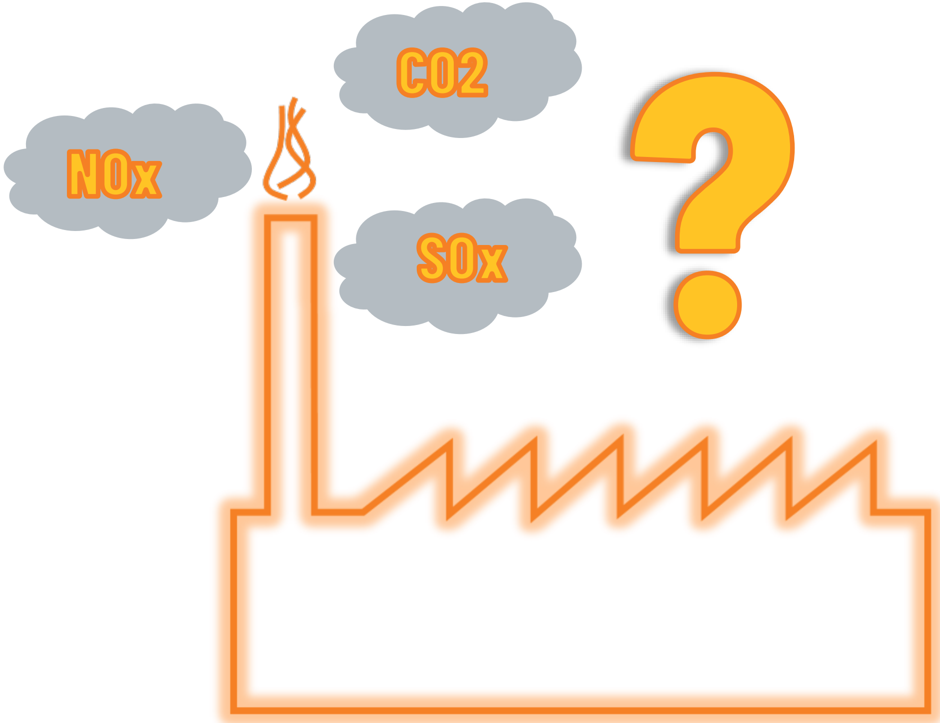
- Examples
  - High efficiency fired heater design
  - Reduction in specific energy consumption while increasing throughput in CDU/VDU
  - Hot inter-unit stream transfer v/s intermediate storage
  - VSD v/s control valves for Hydrotreater feed pumps
  - Highly integrated design in aromatics Plant
- Fuel substitution
  - Electrification
  - Green/Blue hydrogen vs. natural gas for furnace firing
- Good house-keeping for operations

Price Set/Assumptions

- Simple payback time approach
- On-stream factor = 8400 hours/year
- Prices considered for pay-back time calculations (2022 western Europe)
  - CO_2 tax = 100 €/ton
  - Natural gas = 110 €/MWh = 1.45 €/kg = 32 US $/MMBTU
  - Grey electricity = 300 €/MWh
  - Blue hydrogen = 2.5 €/kg (impact of increased utility prices not considered)
  - Green hydrogen = 4.5 €/kg



High efficiency fired heater revamp / design



Why focus on energy efficiency in fired heaters?

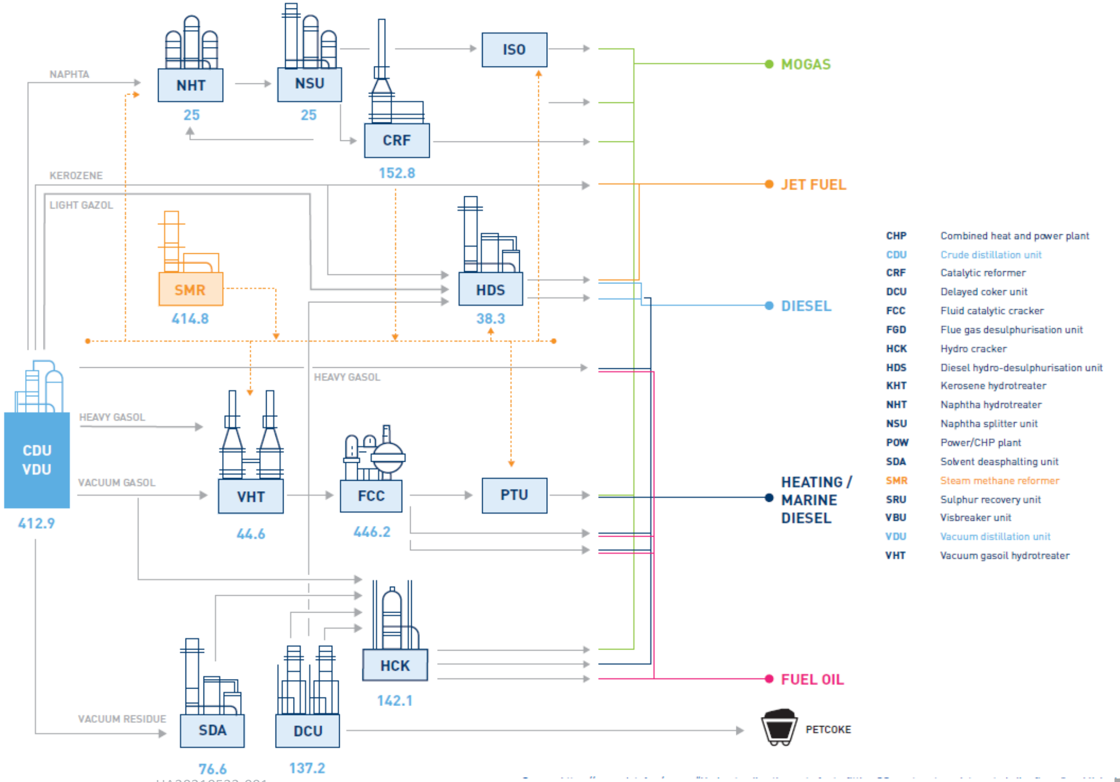
Revamp of existing heaters: case studies

Revamp of existing heaters: fuel substitution

Designing new heaters: key aspects to consider

The Role of Fired Heaters in Refineries

- Almost every major process unit has a fired heater
- Image shows CO_2 emissions in KTA for a typical complex refinery
- SMR, CDU/VDU, FCC largest emitters → all resulting from fuel firing (typically natural gas)
- Huge potential and incentive for refineries to optimise heater designs and reduce the cost of emissions



Source: *https://www.sintef.no/recap/, "Understanding the cost of retrofitting CO_2 capture to an integrated oil refinery", published in June 2017*

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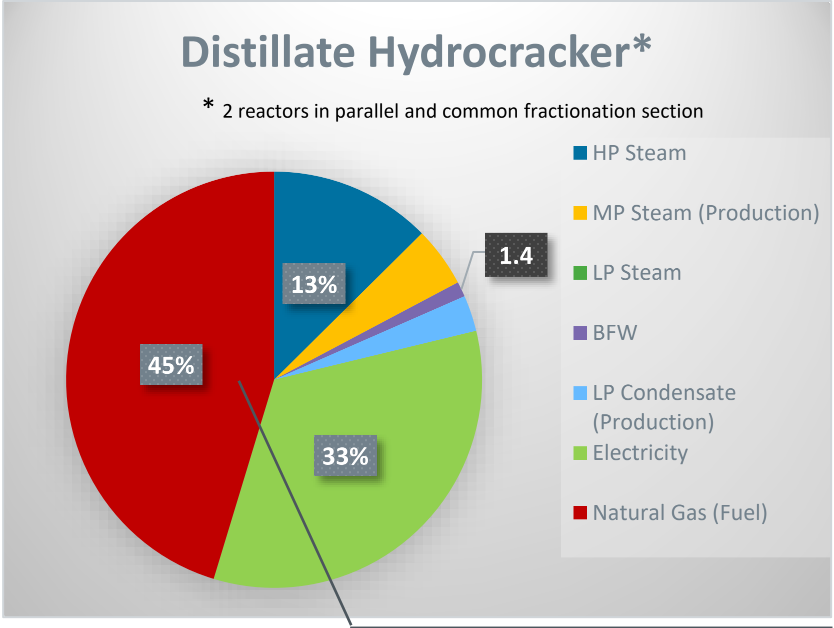
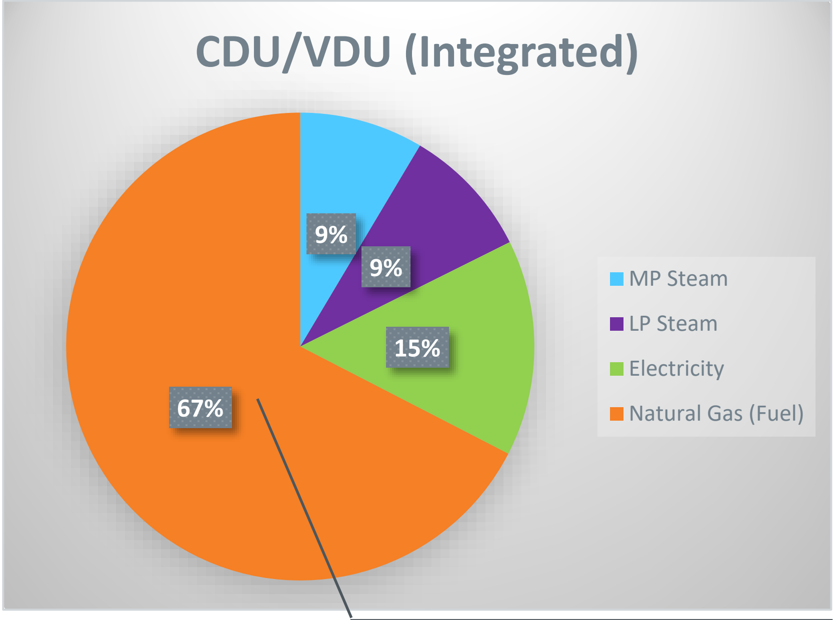
Energy Consumption in Common Refining Units



Consumptions from
- **Feed Heaters**
- **Fractionation Heater**



Consumptions from
- **Atmospheric Heater**
- **Vacuum Heater**

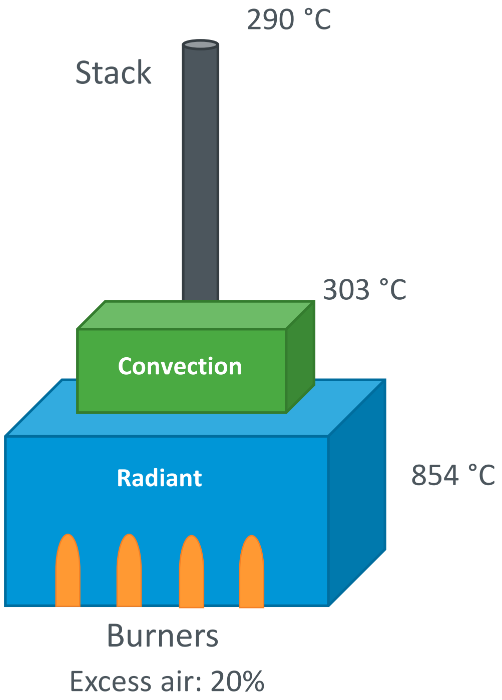
Source: In-house OTC project

Why focus on energy efficiency in fired heaters?

- New fired heater thermal efficiency of up to 95% with integrated designs
- Several existing heaters are designed without convection sections or air preheat (70-85% thermal efficiency)
- Revamp or replacement of inefficient designs can significantly impact refinery emissions and CO_2 taxes
- Improvement in operation philosophies and regular maintenance also contributes to reduction in fired heater fuel consumption
- Measures include:
  - Reduction of tramp air
  - Optimised excess air
  - Combustion air preheating
  - Condensing air preheater

Case Study: Base Case

- Crude heater, process duty in both convection and radiant section, **no air preheat**
- **Basis for all cases**
  - Fuel: natural gas/methane
  - Heater thermal calculation results obtained with FRNC5 heater simulation software
  - Cost of fuel: 1.45 Euro/kg
  - CO_2 tax: 100 Euro/ton



- Absorbed process duty: 118 MW
- Firing duty: 141 MW
- Thermal efficiency: 84%
- Fuel gas consumption: 89 MM kg/year
- CO_2 emission: 266.8 kTon/year
- Fuel gas cost: 129 MM Euro/year
- CO_2 tax: 27 MM Euro/year

Case Study: Excess Air Impact

To ensure complete combustion of the fuel used, the heater firebox is supplied with excess air.

Excess air heats up and leaves the stack with the flue gas.

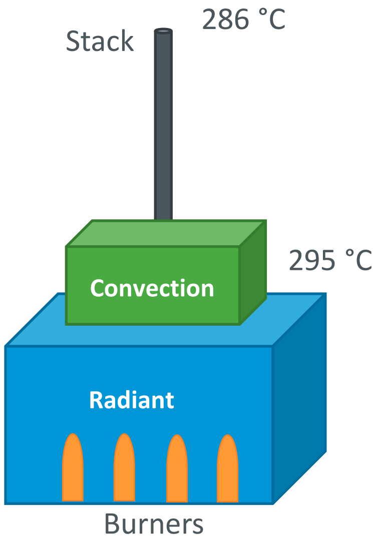
Normally heaters are designed for optimum

excess air = highest efficiency.

Good heater design:

- Burner design/selection
- Firebox dimensions
- Adequate combustion air supply
- Fuel air ratio control

During operation, fuel/air ratio might change (load change, fuel gas composition variation)



Excess air: 10%

- Absorbed process duty: 118 MW
- Firing duty: 139 MW
- Fuel gas consumption: 87 MM kg/year
- CO_2 emission: 262.4 kTon/year
- Fuel gas cost: 127 MM Euro/year (-1.3% base case)
- CO_2 tax: 26.2 MM Euro/year (-1.3% base case)

Case Study: Tramp Air Impact

Tramp air:

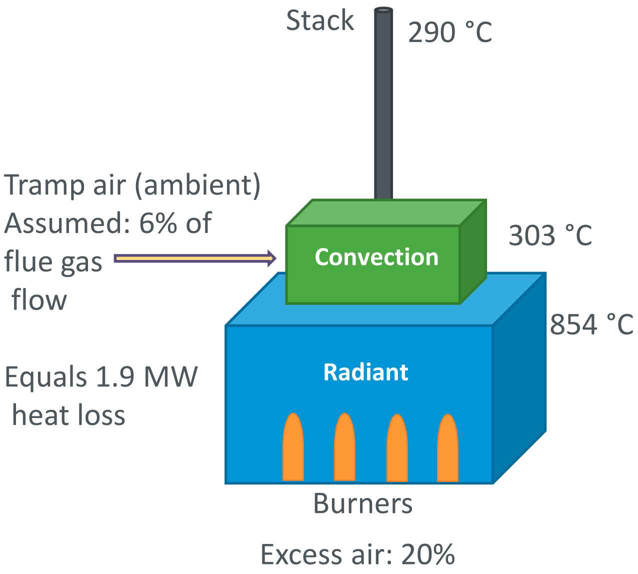
Air that is entering the heater and not taking part in combustion

Air entering the heater from:

- Peep doors
- Tube penetrations
- Header boxes
- Heater joints
- Unlit burners

"Shows up" in the oxygen analyser at the arch and in the stack

Not only economic reasons to avoid, also safety!



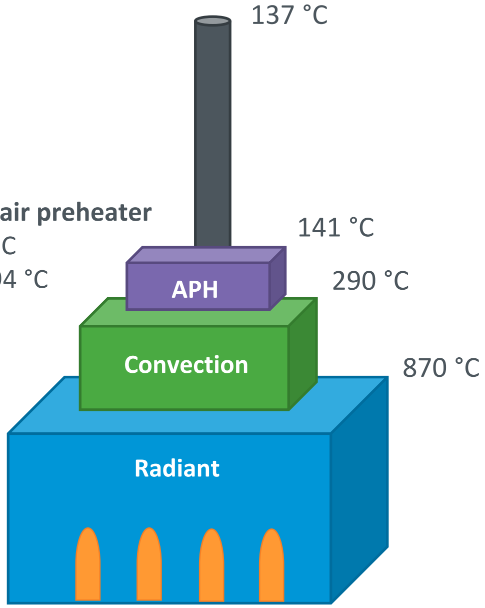
- Absorbed process duty: 118 MW
- Firing duty: 143 MW
- Fuel gas consumption: 89 MM kg/year
- CO_2 emission: 270.4 kTon/year
- Fuel gas cost: 131 MM Euro/year (+1.3% base case)
- CO_2 tax: 27 MM Euro/year (+1.3% base case)

Case Study: Combustion Air Preheater Impact

- Heat exchanger which warms up the combustion air from ambient to an elevated temperature, before it enters the heater. Heat source is the hot flue gas.
- More waste heat can be recovered from the flue gas, less FUEL gas required
- Economic balance between APH equipment cost and benefit of heat recovery
- Stack temperature of approx. 140-150 °C can be achieved

Avoid corrosion issues (acid water condensation) in the air preheater, flue gas duct and stack

Combustion air preheater
Tair, in = 15 °C
Tair, out = 194 °C



Excess air: 10%

- Absorbed process duty: 118 MW
- Firing duty: 128 MW
- Thermal efficiency; 92%
- Fuel gas consumption: 81 MM kg/year
- CO_2 emission: 242 kTon/year
- Fuel gas cost: 117 MM Euro/year (-9.3% base case)
- CO_2 tax: 24 MM Euro/year (-9.3% base case)

Case Study: APH + Condensing Heat Exchanger Impact

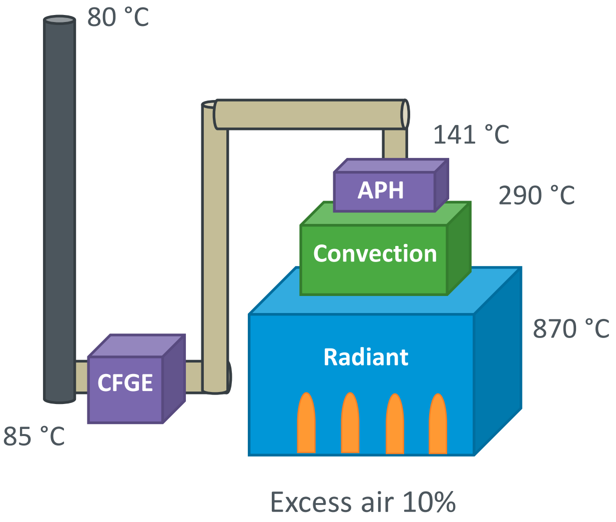
Heat exchanger which heats up a medium (e.g., water), using remaining heat from the flue gas. Heat exchanger is designed for condensing service and corrosive environment.

Even more waste heat can be recovered from the flue gas.

Condensation will take place in the heat exchanger on the flue gas side (acid water)

Heat exchanger material

- Polymer heat exchanger
- Glass lined/enameled heat exchanger



Heater

- Absorbed process duty: 118 MW
- Firing duty: 128 MW
- Fuel gas consumption: 81 MM kg/year
- CO_2 emission: 242 kTon/year
- Fuel gas cost: 117 MM Euro/year (-9.3% base case)
- CO_2 tax: 24 MM Euro/year (-9.3% base case)

Condensing HX: Water pre-heat (20 → 85 ^oC)

- Duty: 3.5 MW
- Fuel Equivalent saving: 2 MM kg/year
- CO_2 Equivalent saving: 7.2 kTon/year
- CO_2 Equivalent cost saving : 0.7 MM Euro year (assuming 92% thermal efficiency)
- Payback time APH + CHE + optimised excess air < 1 year!

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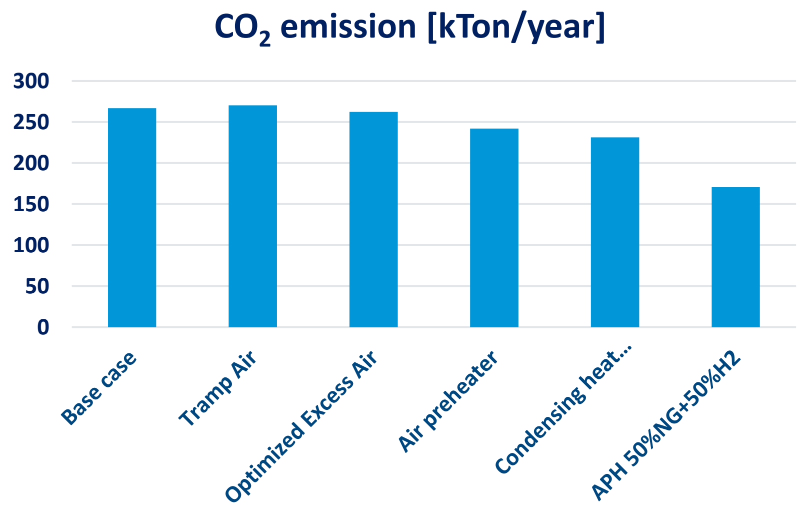
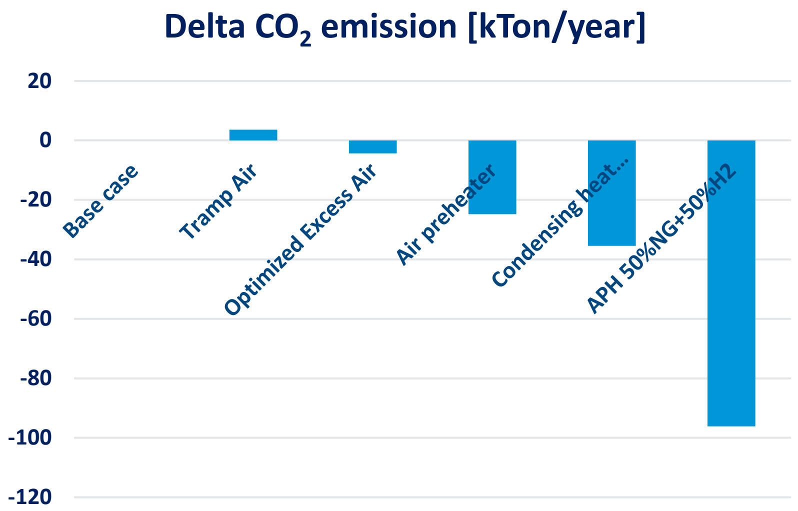
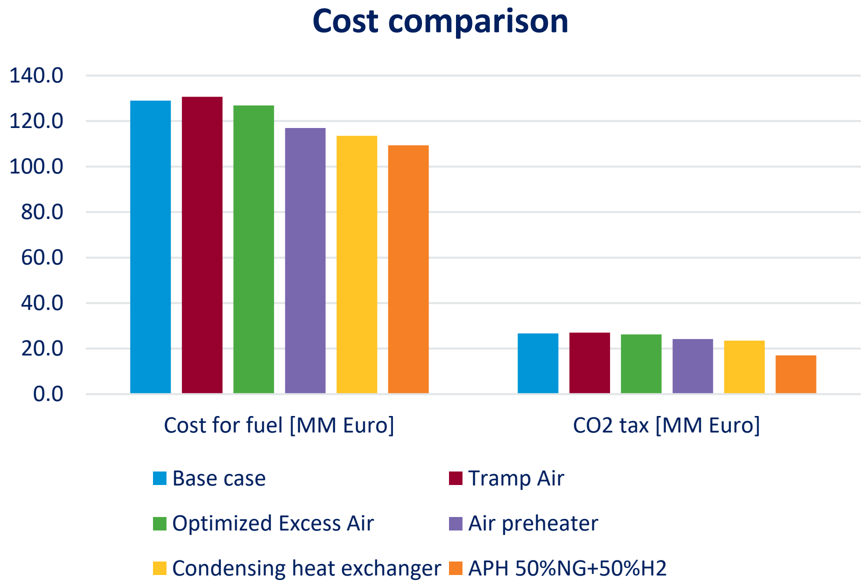
Comparison of all Cases: CO_2 Emissions

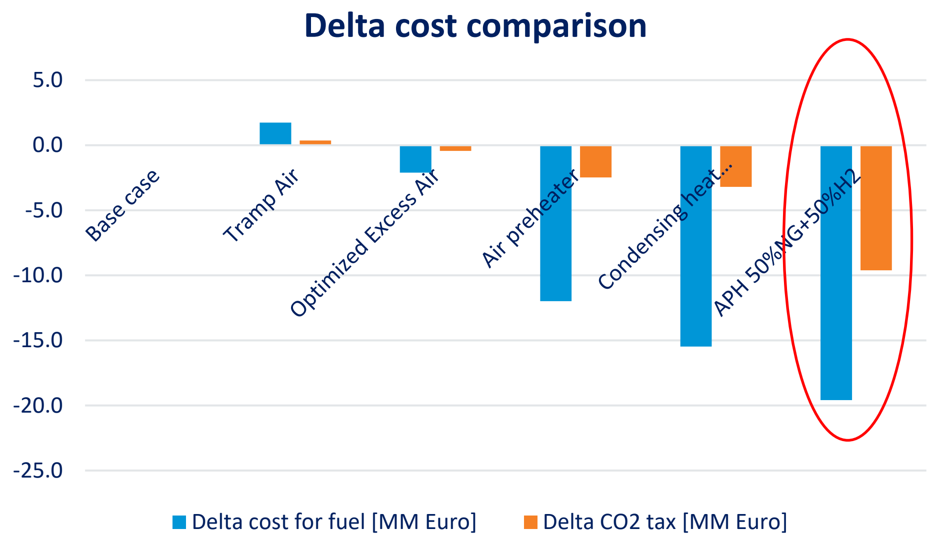




-Tramp air has a negative impact on heater operation, increased NG consumption and CO_2 emissions
-Air preheat and Condensing HEx are good solutions to reduce CO_2 emissions
-Even more CO_2 reduction possible with adding hydrogen to the fuel gas

Comparison of all Cases: Operating Costs





-Less fuel/MW firing is required with H_2 in the mix (higher heating value), cost and colour of hydrogen used determines the final delta

-Blue hydrogen @2.5 €/kg considered in this example

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Designing new Heaters: Key Considerations

- Optimised excess air
- State of the art burners → reduced NO_x
- APH → high thermal efficiency
- Fuel consideration → low carbon content in fuel, blend with H_2 , 100% H_2
- Electrification

Burner test: 85% hydrogen firing

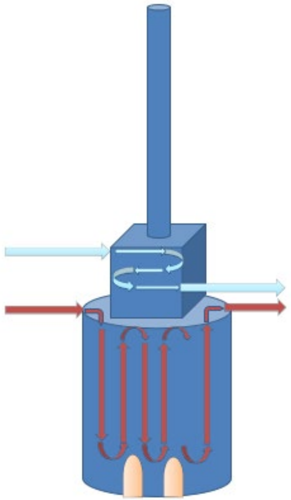
Example: Conceptual study for replacement and upgrade of a crude heater

Modern heater design approach:

- High thermal efficiency including combustion APH
- Firing refinery gas but suitable for future 100% hydrogen firing
- Turbine exhaust gas used as combustion air

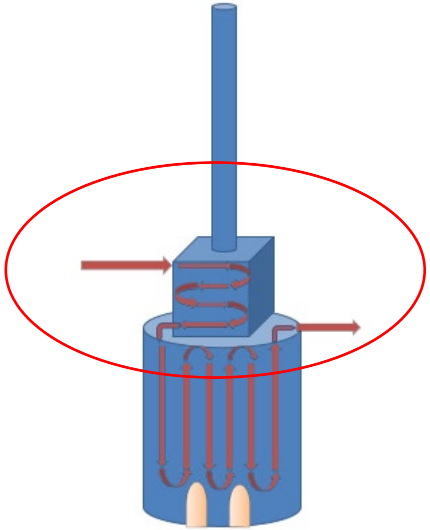
Designing new Heaters: Convection Section Consideration

Licensor design: no process duty in convection section



- Required process duty: 18.5 MW
- Firing duty: 34 MW
- Fuel gas consumption: 22 MM kg/year
- CO_2 emission: 65 kTon/year
- Fuel gas cost: 31 MM Euro/year
- CO_2 tax: 6 MM Euro/year

Fluor proposed design: process duty in convection section



- Required process duty: 18.5 MW
- Firing duty: 21.5 MW
- Fuel gas consumption: 14 MM kg/year
- CO_2 emission: 41 kTon/year
- Fuel gas cost: 20 MM Euro/year
- CO_2 tax: 4 MM Euro/year

Larger heater, higher firing duty, higher cost (operation and equipment)
HIGHER EMISSIONS

Case Study: Reduction in specific energy consumption while increasing throughput in a CDU/VDU

- **Revamp objectives:**
  - CDU (approx. 60% higher volumetric throughput), VDU (approx. 40% higher volumetric throughput)
  - improve VGO (vacuum gasoil) recovery at the expense of VR (vacuum residue)
  - no replacement of key equipment such as main column, fired heater, desalter
- **Objectives achieved by:**
  - plotting detailed heat exchanger composite curves to identify gaps in heat integration
  - adding new, efficient (low fouling, temperature cross) heat exchangers to fill in those gaps, CDU pre-flash drum + pumps, single to two-stage desalter, column tray modifications, improving vacuum on the VDU column (trays to packing), increase in VDU transfer line / VR rundown line size
- Higher VGO output implied increased feed to downstream cracker → increased operating profit/export
- Payback time of revamp project approx. 2 years
- Specific energy consumption (MW/ Sm^3/h) of the CDU and VDU went down by 11%

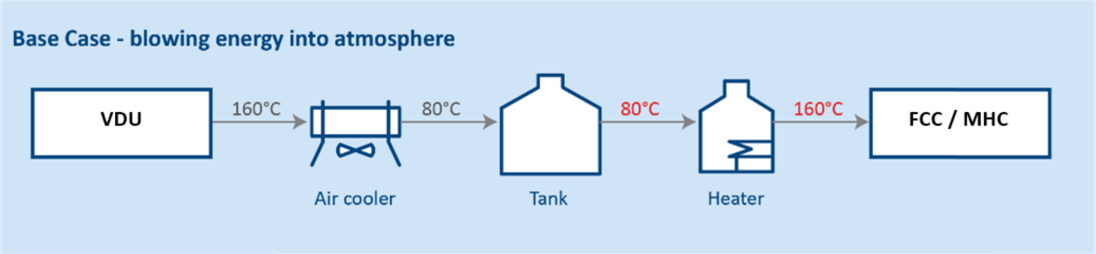
Savings in specific energy consumption = 11%!

	Units	Base Case	Future Case
Crude rate	Sm^3/h	X	1.6X
Crude heater inlet temperature	°C	222	259
Crude heater outlet temperature	°C	340	365
Crude heater duty	MW	25.2	35.4
Vacuum heater inlet temperature	°C	337	357
Vacuum heater outlet temperature	°C	398	418
Vacuum heater duty	MW	9.0	13.3
Total heater duty	MW	34.2	48.7
Specific energy consumption	MW / Sm^3/h	34.2 / X	48.7 / 1.6X = 30.4 / X

11% savings in refinery natural gas import is equivalent to heating an average of 4000 homes everyday in Western Europe!

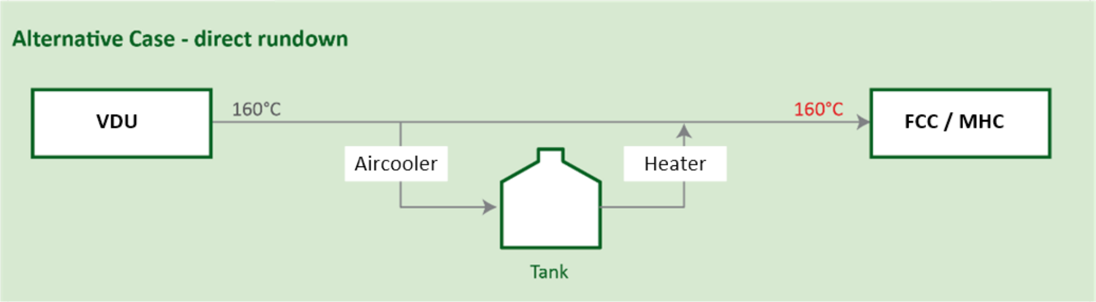
Case Study: Hot inter-unit stream transfer vs. intermediate storage

- Direct transfer of streams from unit A to B (VGO in this example)
  - Heater and cooler is assumed to be built for max. capacity (no reduction in CAPEX)
  - Benefit of having intermediate storage when the downstream unit is not in operation
  - No energy wastage in normal operation i.e. reduced OPEX



Typical 10 MM KTA crude oil refinery (25 wt% VGO)

Fuel gas cost savings = 12.6 MM Euro/year
Power cost savings = 0.08 MM Euro/year
CO_2 emission savings = 24 KTA
CO_2 cost savings = 2.4 MM Euro/year
Total OPEX savings = 15.1 MM Euro/year



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Case Study: VSD vs. Control valves for Hydrotreater feed pumps

- Consider a typical 200 ton/h or 235 m3/h diesel hydrotreater
  - One feed pump operating, one spare (both e-motor driven)
  - Total power per feed pump = 725 kW
  - Typical dP across feed pump control valve is 10 bar; corresponding pump power is approx. 90 kW
  - Approx. installed cost of VSD = 350 €/kW
  - Payback time for two VSDs is 2.2 years

- Alternative scenario: CO_2 tax payable by power plant is added to the power price paid by the refiner
  - 280 ton/year CO_2 emission to provide 90 kW power to the refinery, CO_2 tax 28 k€/year
  - Power cost for refiner is 337 €/MWh (base price was 300 €/MWh)
  - Payback time for VSDs is 2 years

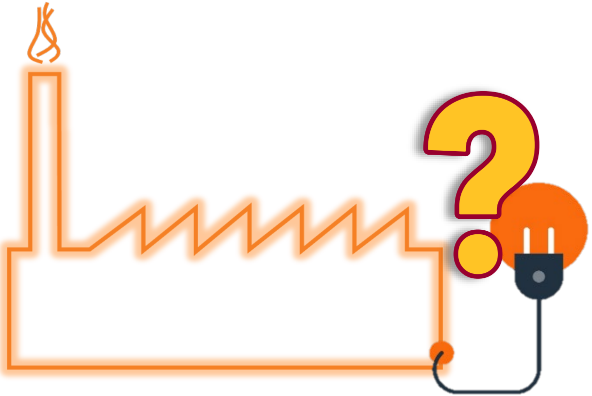
Example: Highly integrated design in aromatics plant

- Naphtha conversion to BTX consists of a combination of several units
- Complexes already include energy efficient design concepts: heat pumps, plate & frame heat exchangers, dividing wall columns
- OPEX reduction requests has led licensors to provide even more integrated designs
- Pros
  - Reduced utility consumption (heating / cooling)
  - Reduced emissions
- Cons
  - Process operability challenges (fewer degrees of freedom)
  - Turndown requirements (smaller operating window)
  - Start-up / shut-down (difficult and time consuming)
  - Plant layout challenges (long vapour and two-phase lines)
  - Safety (interaction between overpressure scenarios; sophisticated analysis required)

Fuel Substitution Considerations

Fuel Substitution: Electrification

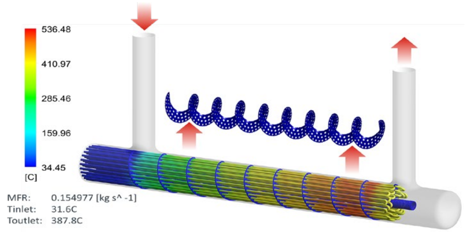
- Electrification (‘green’ electricity)
  - Electric heat exchangers
  - Steam boilers (for processes requiring live steam injection)
  - Change from turbine drivers to e-motors
  - Heat pumps instead of reboilers / condensers for distillation columns



Consequences:

- Fuel consumption ↓
- Emissions ↓
- Electricity demand ↑
- Possibility for excessive heat input ↑

Stork Electric Steam Boiler

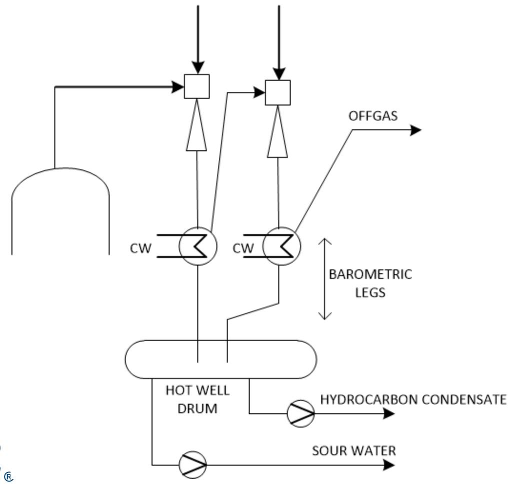


WATLOW
Helical Flow Electrically Heated Exchanger

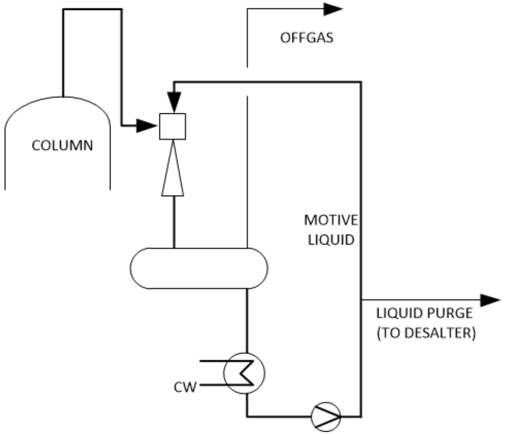
Fuel Substitution: Electrification

- Steam driven ejector to liquid driven ejector
  - reduced steam consumption, sour water generation
  - increased electricity consumption
  - possibly increased CAPEX

Steam driven ejector



Liquid driven ejector



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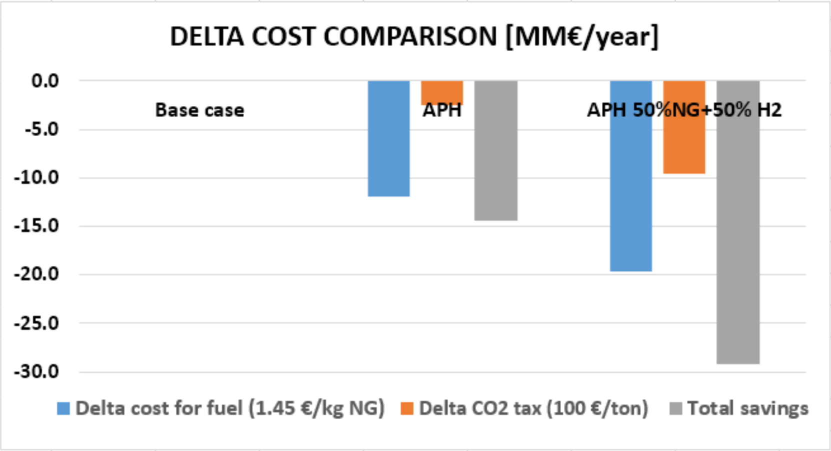
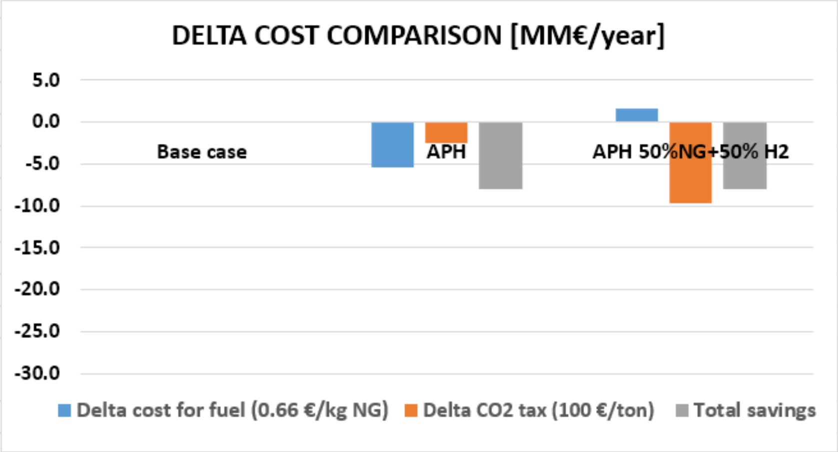
Fuel Substitution:
Blue hydrogen vs. natural gas for furnace firing

- Referring to APH example on slide 19,
  - Base case- 100% natural gas fuel, 20% excess air, no air preheater (APH)
  - APH- 100% natural gas fuel, APH, 10% excess air
  - Alternative case- APH, 50vol % **blue** H_2, 50 vol% natural gas fuel
  - At CO_2 tax of 100 €/ton, NG price of 1.45 €/kg, 2.5 €/kg **blue** H_2, total savings with using 50 vol% **blue** H_2 in fuel gas go up
  - At CO_2 tax of 100 €/ton, NG price of 0.66 €/kg, 2.5 €/kg **blue** H_2, total savings with using 50 vol% **blue** H_2 in fuel gas is offset by the increased cost of fuel





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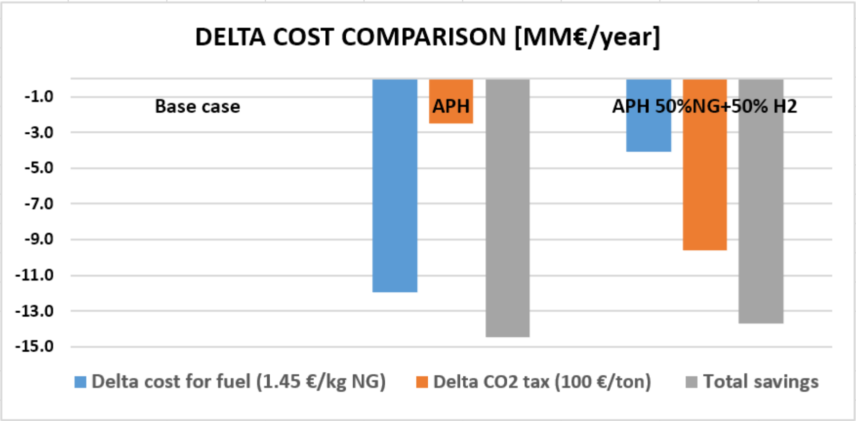
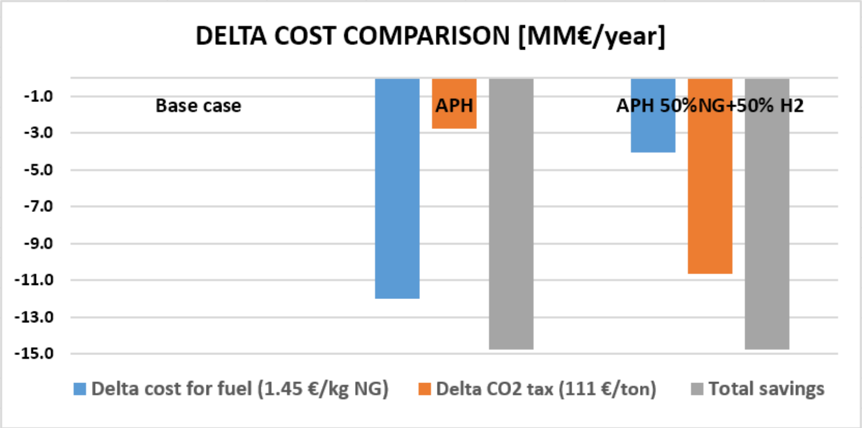
Fuel Substitution:
Green hydrogen vs. natural gas for furnace firing

- Referring to APH example on slide 19,
  - Base case- 100% natural gas fuel, 20% excess air, no air preheater (APH)
  - APH- 100% natural gas fuel, APH, 10% excess air
  - Alternative case- APH, 50 vol % **green** H_2, 50 vol% natural gas fuel
  - At CO_2 tax of 100 €/ton, NG price of 1.45 €/kg, 4.5 €/kg **green** H_2, total savings with using 50 vol% **green** are offset by the increased cost of fuel
  - A CO_2 tax of **111** €/ton, NG price of 1.45 €/kg, 4.5 €/kg **green** H_2, is required for to nullify the impact of increased cost of fuel on total savings





Fuel Substitution: Considerations

- Fuel type considerations
  - Use fuels with low carbon content

		LFO	HFO	Methane	Butane	Heptane	Hydrogen
H/C ratio (wt based)	[-]	0.1345	0.1281	0.3333	0.2077	0.1905	N.A.
Fuel / MW firing	[kg/hr]	88.7	90.5	72.0	79.5	80.1	30.0
CO2 emission / MW firing	[kg/hr]	303.3	307.9	216.0	263.2	269.3	0

  - In case of using increased quantities of Hydrogen in fuel gas, watch out for:
    - Cost of fuel
    - Burner suitability => check for Wobbe Index, flame speed
    - Increased NOx emissions due to increased flame temperature
    - Burner, burner tile and tube materials of construction due to increased temperatures
    - Changed heat/mass balance (flue gas side)

Good House-Keeping for Operations

- Monitoring and maintenance programs for energy efficient facilities
  - Transmitters
  - Analysers (e.g., excess O_2 in fired heater flue gas)
  - Combat / prevent fouling
- Heat loss prevention strategies
  - Insulation
  - Tracing
  - Steam trap maintenance

Key Takeaways

Key Takeaways

- Picking the low hanging fruit
  - Reduce energy consumption and corresponding emissions
    - High-efficiency furnace revamp / design
    - Latest heat exchanger technology combined with a high degree of heat integration
    - Fuel substitution when it makes sense (cost / emissions / availability)
    - Operational / maintenance improvements
- New designs
  - Robust for the future (lowest/zero CO_2 footprint)
    - Electrical heaters
    - Hydrogen firing
- Be critical of graphs / reports and be careful of drawing conclusions at face value. There is no single right answer; every result is simply a reflection of the input variables!
- How can Fluor help you?
  - Facility, location and scenario specific technoeconomic feasibility studies
  - Vast cost database and access to technology / equipment supplier networks
  - Economic modeling to calculate profit margins, payback times etc.

QUESTIONS?

COMMENTS?

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