



# Optimization of Compressed Natural Gas transportation Vessel: GASVESSEL project

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# Summary

- Gasvessel Project (CNG) – Description and Target
- Logistic optimization
- Structural optimization
- Risk analysis

ESTECO is an independent software provider,  
highly specialized in **numerical optimization**  
and **simulation data management**



# Our products

***modeFRONTIER***

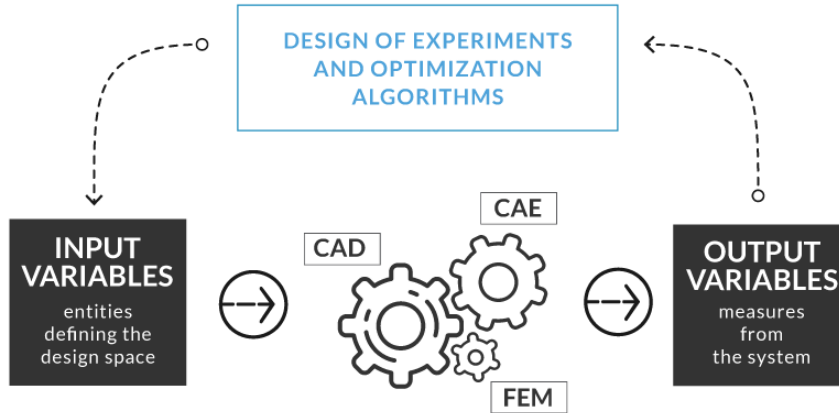
The comprehensive solution for  
process automation and optimization  
in the engineering design process

**VOLTA**

The collaborative web platform for  
Simulation Process and Data Management  
(SPDM) and design optimization



# Optimization-Driven Design



Enabling the optimization-driven approach allows for dramatic reduction of both development costs and time-to-market.



## THINK OUTSIDE THE BOX

Take advantage of automated design space exploration and discover innovative solutions that might otherwise have been dismissed.



## INNOVATE FASTER

Simulation is automated. Engineer focuses on the idea.

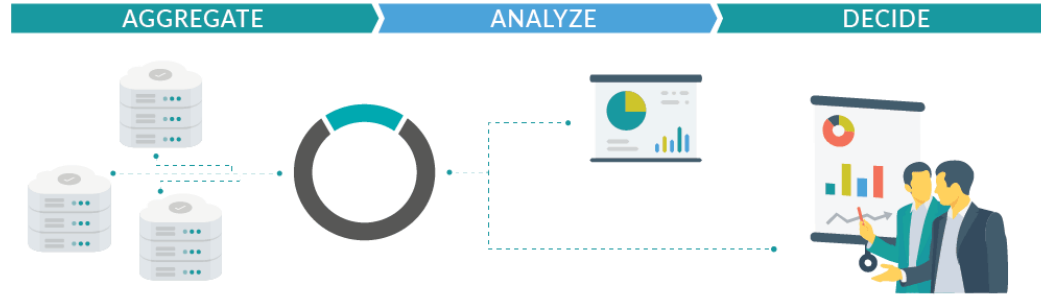


## EXPLORE EFFICIENTLY

Balance conflicting objectives by taking into account multiple concerns and requirements.



# Engineering Data Intelligence



Transform large amounts of data into valuable company assets and accelerate innovation



## UNDERSTAND

Turn data into valuable insights and propel your innovation process using a comprehensive environment for data analysis and visualization.



## FOCUS

Quickly identify relevant performance metrics so that you can focus on what is important and make better decisions, faster.



## DEMOCRATIZE

Tools for synchronized data visualization are not just for data analysts: they empower experts from other departments to access and use data with confidence.



# Our Customers & Industries

Embraer

Leonardo

Lockheed Martin

Bombardier

FCA

Ford

Honda

PSA Group

Toyota

Volvo Cars Corporation

Mahindra

TAFE

Volvo Trucks

ABB

Bajaj

BASF

Cummins

FAW

Whirlpool

Sony



**Automotive**



**Aerospace**



**Industrial  
Equipment**



**Construction**



**Energy &  
Environment**



**Consumer  
Goods**



**Marine &  
Offshore**



**Electronics**



**Biotechnology**

# Navalprogetti

NAVALPROGETTI is a ship design company of Naval Architects, Marine and Industrial Engineers and Ship Surveyors that has been operating since 1975





# Navalprogetti – Services and Skills

New building basic and detail design

Ship conversion, Ballast water treatment system and Scrubber retrofit design

Marine transportation of offshore structures studies

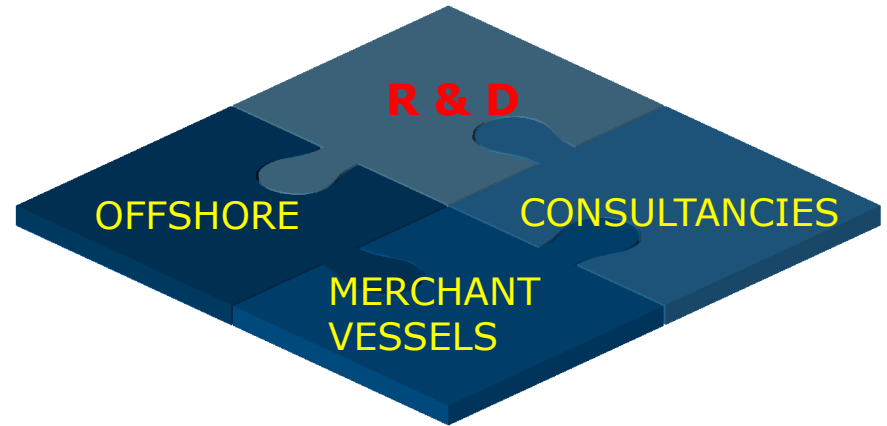
Alternative fuels (LNG, CNG, H2) studies

**CNG Transportation – GASVESSEL (EU Project)**

Model test assistance

Yard assistance

Inclining experiments and sea trials



# Navalprogetti – Clients



agip kco



saipem

Sonsub



Saipem



Ray Car Carriers Ltd.



MICOPERI



ERSAI



Enel



HYUNDAI - VINASHIN SHIPYARD CO., LTD.



D'ALESIO Group



Caspian Ocean LLP  
KAZAKHSTAN, AKTAU



RODRIQUEZ



OCEANTEAM



EDISON



GORIZIANE GROUP  
PIPELINE • SERVICE • OIL & GAS



Desde 1857



# Gasvessel Project



- CONSORTIUM formed by 13 Partner Companies
- 8 Countries represented:  
Belgium, Cyprus , Germany, Greece, Italy, Norway, Slovenia, Ukraine
- Project duration: 48 months (started June 1<sup>st</sup> 2017)
- EU contribution = Project's financial value = 12 M€

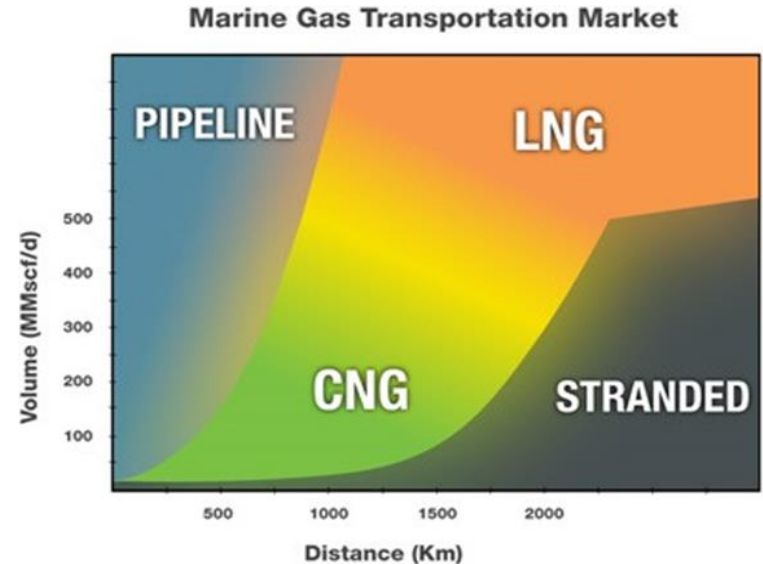


The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723030.

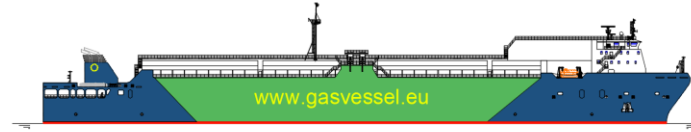


# EU Energy: Why Compressed Natural Gas (CNG)?

- 67% of gas in Europe is imported (of which 37% from a single supplier)
- 5 times the amount of consumed gas is currently stranded in **unexploitable gas reserves**
- **Expensive alternatives:**
  - Pipelines
    - Construction costs
    - Environmental and political difficulties
    - Point-to-point
  - LNG
    - Expensive liquefying and re-gasifying plants



# GASVESSEL solution



Innovative, cost-efficient CNG transport system

## 1. Novel lightweight Pressure Cylinders

- 70% lighter than state-of-the-art
- Large volume cylinders up to 175 m<sup>3</sup> (liquid volume)



## 2. New ship design

- Much higher payloads
- Safe (un)loading at 300 bar
- Gas Capacity up to 15 MNm<sup>3</sup>



# GASVESSEL Project

Built facilities and machineries for cylinder construction:



Hydroforming  
mould



Hydroformed  
cylinder



Winding  
machine



Curing  
station

# GASVESSEL Project

Built facilities and machineries for cylinder tests:



Autofrattage and fatigue test  
pumping unit  
for 10000 cycles



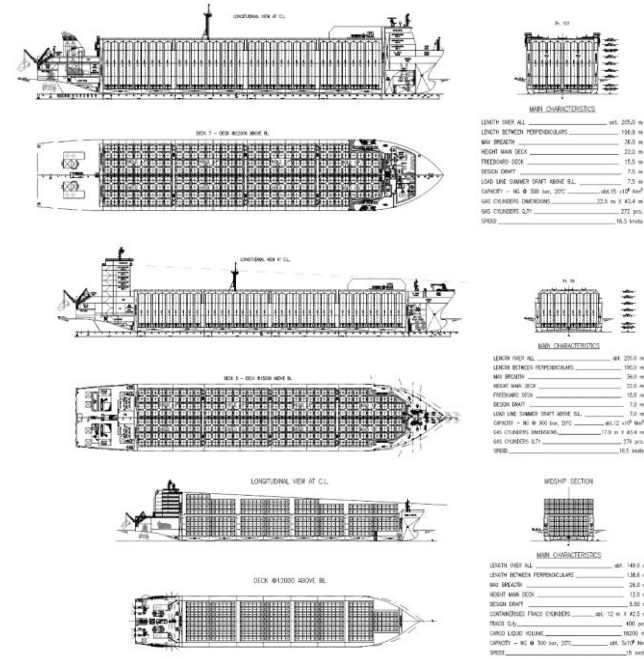
Burst test  
pumping unit  
up to 1000 bar

# GASVESSEL Project

## Ship Design

3 different capacity ships were designed:

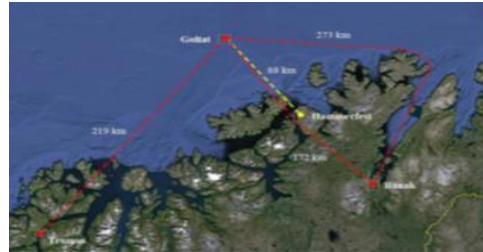
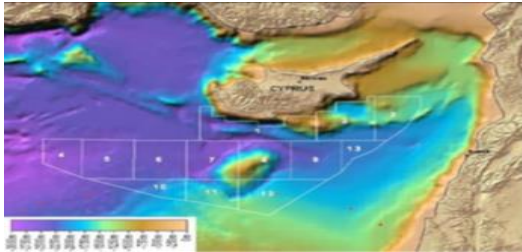
- Up to **15 Millions Nm<sup>3</sup>** with vertical large capacity cylinders
  - Cylinders length = 22.5 m
  - Cylinders diameter = 3.4 m
- Up to **12 Millions Nm<sup>3</sup>** with vertical large capacity cylinders
  - Cylinders length = 17.5 m
  - Cylinders diameter = 3.4 m
- Up to **5 Millions Nm<sup>3</sup>** with containerised cylinders
  - Cylinders length = 11.5 m
  - Cylinders diameter = 2.4 m



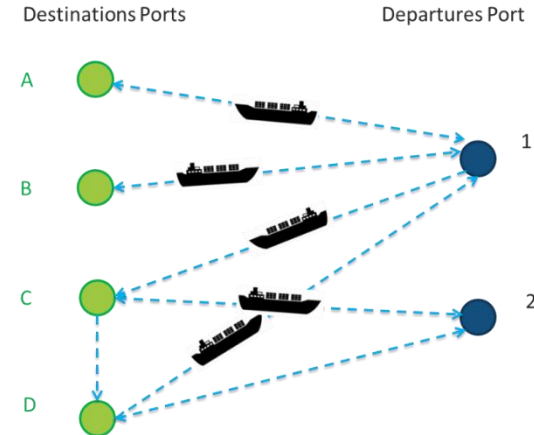


# Transportation scenarios

- **Analysis of 3 real-life geo-economical gas exploitation scenarios**  
(East Mediterranean, Barents Sea, Black Sea)



- **ESTECO software to optimize logistic**
  - Ship carrying capacity
  - No. of ship
  - Ship main design parameters
  - Transportation tariff



# Web-based collaboration platform (VOLTA)



Shared project and distributed execution

Report analysis and Post Processing

The screenshot shows the VOLTA PROJECT interface for a project named "Gasvessel\_tariff\_estimation\_LL". It features a 3D model of an engine component. On the right, session statistics are displayed: Total 2, Completed 1, Running 0. Below this, a "Recent Sessions" table shows a session named "CPT\_2018-09-27\_11-49" with a status of "Completed". A "PROJECT TEAM" section shows four user icons connected to a central server icon, with a hierarchical structure of folders and files below.



The screenshot shows the VOLTA SESSION interface for a session named "First Test Run is completed". It displays a table with columns: id, shipCapacity\_knot3, shipVelocity\_knots, workingDaysPerYear\_days, Report, ship\_mtu\_usage, and transportationTariff\_mwPerKnot3. The table contains 17 rows of data. Below the table, there is a graph showing the relationship between shipCapacity\_knot3 and shipVelocity\_knots. A callout box highlights specific data points from the table:

```
*****
Number of fleet ships: 2
Ship number 1
requested size: 12000000.0
used at 97.0193009259% of the time
works from source port 1 to delivery port 2
Ship number 2
requested size: 12000000.0
used at 96.3151342593% of the time
works from source port 1 to delivery port 1
works from source port 1 to delivery port 3
```



# VOLTA Platform: define optimization problem

[Export Plan](#)

**Constraints** -

+ - Import Constraints

No constraints inserted

---

**Inputs** -

▼ Scalar Inputs Import Inputs

| Name                    | Constant                            | Value                               | Lower Bound                         | Upper Bound                        | Step                                  | Base                           | Arrangement                          |
|-------------------------|-------------------------------------|-------------------------------------|-------------------------------------|------------------------------------|---------------------------------------|--------------------------------|--------------------------------------|
| Requirements_Nm3        | <input checked="" type="checkbox"/> | <input type="text" value="5.07E8"/> | <input type="text"/>                | <input type="text"/>               | <input type="text" value="0"/>        | <input type="text" value="0"/> | <input type="text" value="Ordered"/> |
| activityYears_years     | <input checked="" type="checkbox"/> | <input type="text" value="20.0"/>   | <input type="text"/>                | <input type="text"/>               | <input type="text" value="0"/>        | <input type="text" value="0"/> | <input type="text" value="Ordered"/> |
| interest_rate           | <input checked="" type="checkbox"/> | <input type="text" value="0.02"/>   | <input type="text"/>                | <input type="text"/>               | <input type="text" value="0"/>        | <input type="text" value="0"/> | <input type="text" value="Ordered"/> |
| mortgagePeriod_years    | <input checked="" type="checkbox"/> | <input type="text" value="20.0"/>   | <input type="text"/>                | <input type="text"/>               | <input type="text" value="0"/>        | <input type="text" value="0"/> | <input type="text" value="Ordered"/> |
| shipCapacity_Nm3        | <input type="checkbox"/>            | <input type="text" value="1.2E7"/>  | <input type="text" value="900000"/> | <input type="text" value="1.2E7"/> | <input type="text" value="11100000"/> | <input type="text" value="2"/> | <input type="text" value="Ordered"/> |
| shipVelocity_knots      | <input type="checkbox"/>            | <input type="text" value="11.0"/>   | <input type="text" value="8"/>      | <input type="text" value="16"/>    | <input type="text" value="1"/>        | <input type="text" value="9"/> | <input type="text" value="Ordered"/> |
| workingDaysPerYear_days | <input checked="" type="checkbox"/> | <input type="text" value="300.0"/>  | <input type="text"/>                | <input type="text"/>               | <input type="text" value="0"/>        | <input type="text" value="0"/> | <input type="text" value="Ordered"/> |

▼ String Inputs

| Name            | Description   | Value                             |
|-----------------|---|-----------------------------------|
| considerIntPort | Consider or not triangular option for the ship path | <input type="text" value="true"/> |

▼ File Inputs

| Name             | Description   | Value   |
|------------------|---|---|
| GeographicalData | File containing geographic characteristics (ports, routes, etc) | <input type="button" value="+ Choose"/> <input type="text" value="data.txt (1.02 KB)"/> <input checked="" type="checkbox"/> |

**Project**

---

**ID** 42  
**Name** GasvesselNP  
**Version** 1

**Model**

---

**Name** GasvesselNP

**Inputs**

---

0 variables and 7 constants

**Constraints**

---

0 constraints

From the Project interface select range of variation of design variables and select objectives type

# VOLTA Platform: define optimization problem

**VOLTA** DOE PLAN

Select Plan *Select DOE Plan*      Domain *Define DOE Domain*      Algorithm *Select Algorithm*      Designs *DOE Table*      Summary *Set Parameters*

◆ CONFIGURATION SUMMARY

Select Queue

**Gasvessel Queue** [4]      0 MESSAGES

Details

Session Name\*

Description

Concurrent Designs [1, 1024]

System Tags

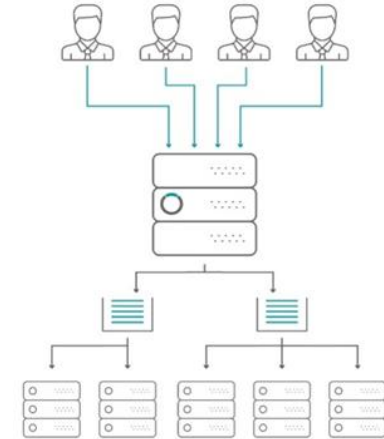
Custom Tags

WOBO Encrypted User Credentials

Run Options  
 DISTRIBUTED       ALL IN ONE

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From the Plan interface select Computational queue where the simulations will be run

# VOLTA Advisor: analyze results

VOLTA SESSION

First Test Run is completed  
GasesseH®

OVERVIEW EVENTS RESULTS

Post Process

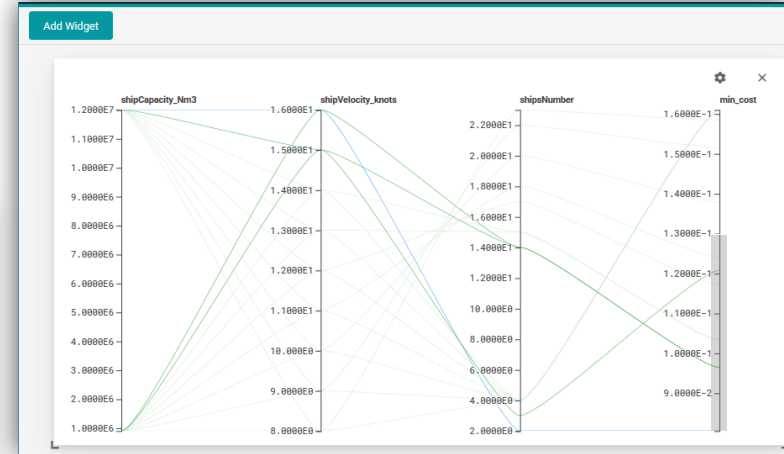
Filter:  Best  Feasible  Unfeasible  Error

| ID | shipCapacity_Nm3 | shipVelocity_knots | workingDaysPerYear_days | Report     | min_ship_usage   | shipsNumber | transportationTariff_EuroPerNm3 |
|----|------------------|--------------------|-------------------------|------------|--|-------------|---------------------------------|
| 3  | 9.0000E5         | 1.1000E1           | 300                     | Report.txt | [0.6663571843434343, 0.6663571843434343, 0.93992248625899]   | 1.3000E1    | 1.1418E8                        |
| 4  | 9.0000E5         | 1.2000E1           | 300                     | Report.txt | [0.6132483179812346, 0.6132483179812346, 0.954162263888891]  | 1.2000E1    | 9.7387E-1                       |
| 5  | 9.0000E5         | 1.3000E1           | 300                     | Report.txt | [0.5683188462962962, 0.5683188462962962, 0.985199583333336]  | 1.1000E1    | 8.1783E-1                       |
| 6  | 9.0000E5         | 1.4000E1           | 300                     | Report.txt | [0.5297915277777778, 0.5297915277777778, 0.9209384034391537] | 1.1000E1    | 8.1783E-1                       |
| 7  | 9.0000E5         | 1.5000E1           | 300                     | Report.txt | [0.9733842534722225, 0.9733842534722225, 0.9928176234567981] | 9.0000E0    | 5.4779E-1                       |
| 8  | 9.0000E5         | 1.6000E1           | 300                     | Report.txt | [0.9185546893750083, 0.9185546893750083, 0.9343978783783783] | 9.0000E0    | 5.4779E-1                       |

ADD A WIDGET

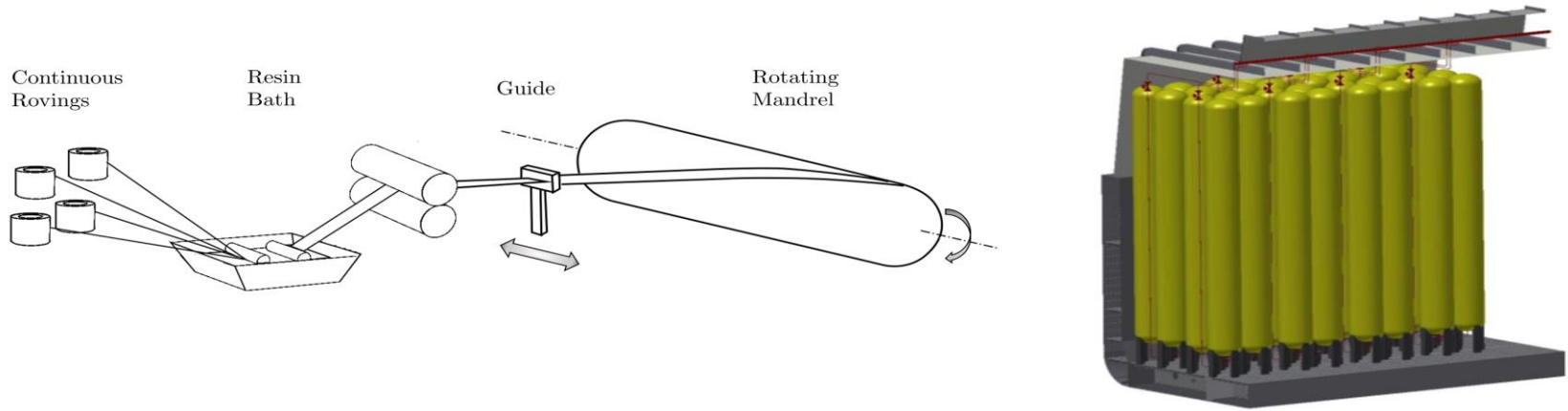
Choose a widget for your dashboard

- Parallel Coordinates**  
Spot patterns in variable behaviour and correlations between variables.
- Data Table**  
View and sort raw data and identify feasible, unfeasible and error designs.
- Comparison Table**  
Compare designs side-by-side and easily spot the differences between them.
- Scatter Bubble**  
Plot up to 4 dimensions to see the relationship between variables.
- 3D Scatter Bubble**  
Plot up to 5 dimensions to see the relationship between variables.
- 3D Surface**  
View the relationship between variables and expose trends.
- History**  
See how the values of variables change across designs.
- Performance History**  
See how the values of a variable improve across designs.
- Correlation Matrix**  
See correlation coefficients between multiple variables.
- Scatter Matrix**  
See variable distribution and linear correlations and relationships between multiple variables.
- Probability Function**  
See how variable values are distributed across the variable domain.
- Carpet Plot**  
See how two independent variables and one or two dependent variables interact.



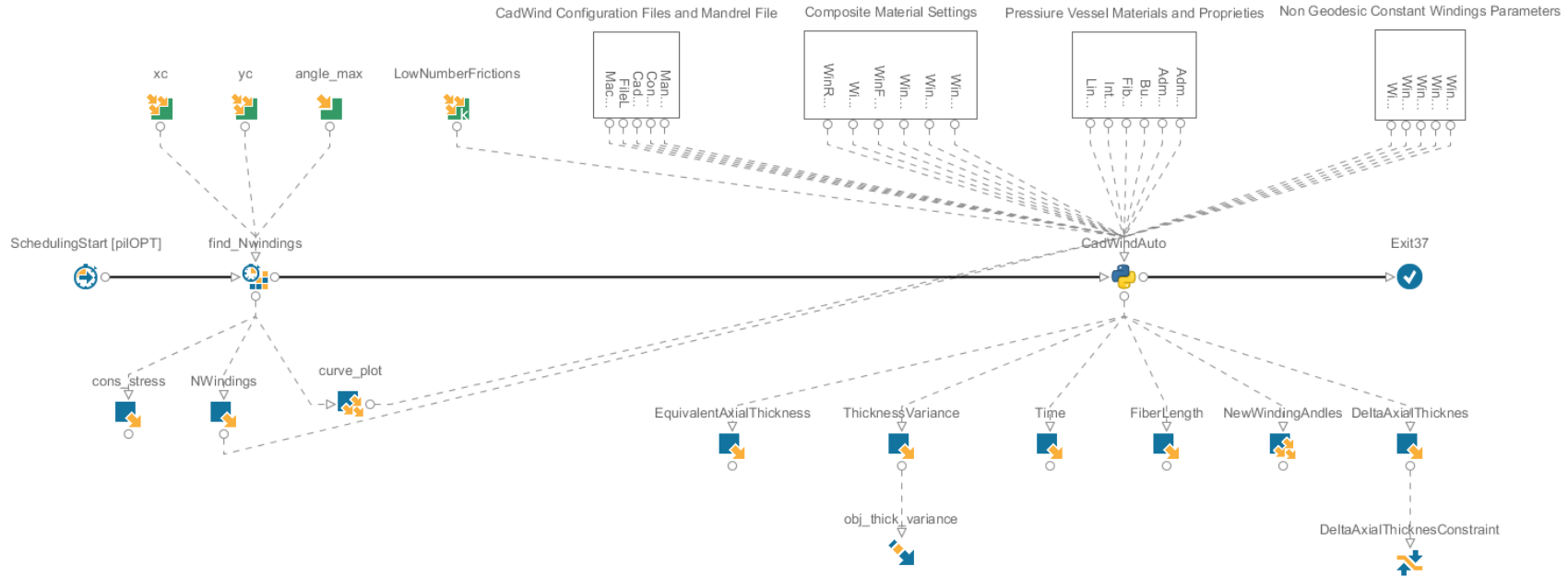
Use available charts to analyze solution and help decision making

# Structural Optimization of pressure vessels



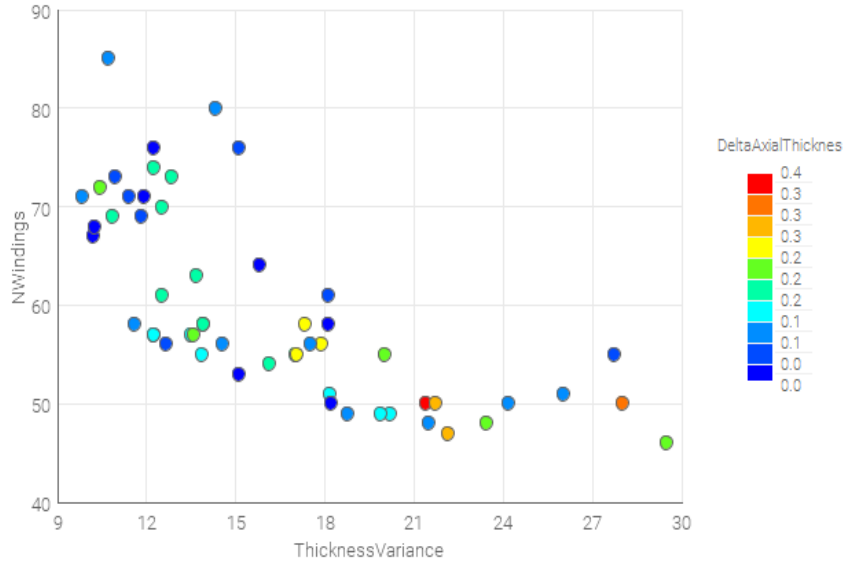
- Pressure vessels are defined by a **steel liner and an overwrap of composite material**
- **Autofrettage** pressure (150% of exercise pressure = 300 bar) applied during production to obtain pre-stress that reduces operative stress
- **Geometry and material are optimized** (mass and safety factors)

# Optimization workflow with modeFRONTIER

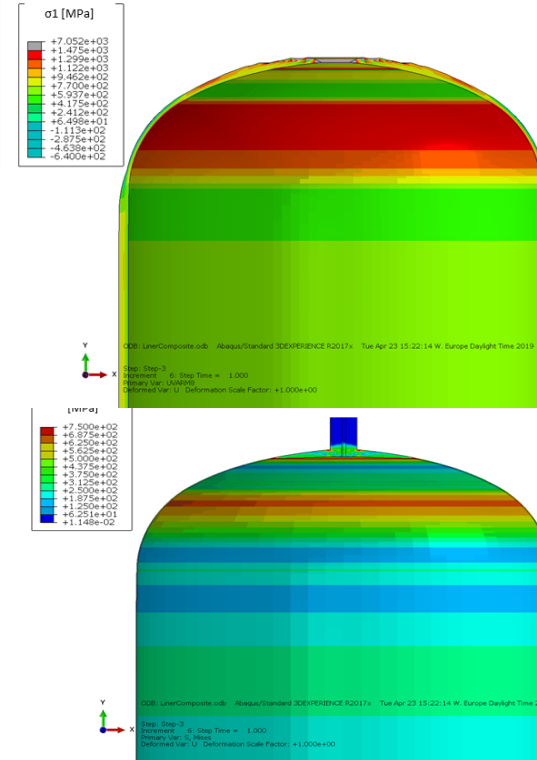


- **Inputs:** steel thickness and composite material, fibers %, angle of winding layers
- **Simulation:** structural analysis (Python code) and CADWIND to simulate winding manufacturing process
- **Optimization:**
  - minimum number of winding layers to respect admissible stress (burst pressure at 750 bar)
  - minimize thickness variance (for an uniform coverage)

# Optimization results: Pareto frontier



Pareto front (optimal solutions)



Overwrap Max stress:  
2470 MPa

Liner Yield stress:  
750 MPa

Chosen design validated by FEM analysis

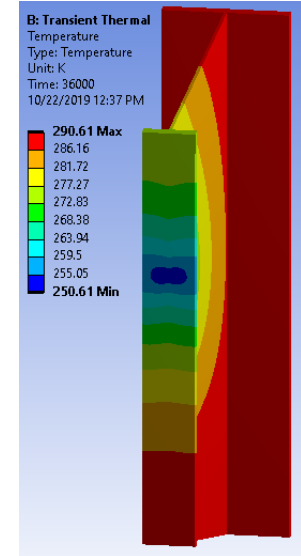
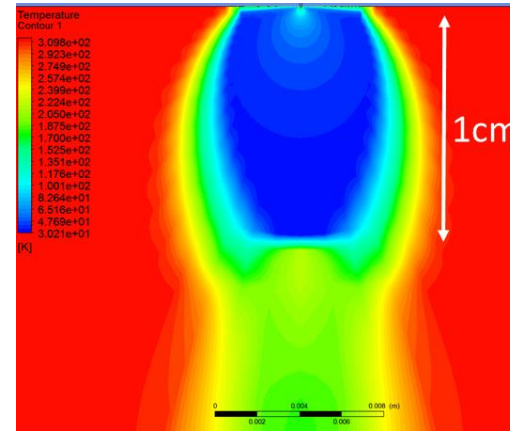
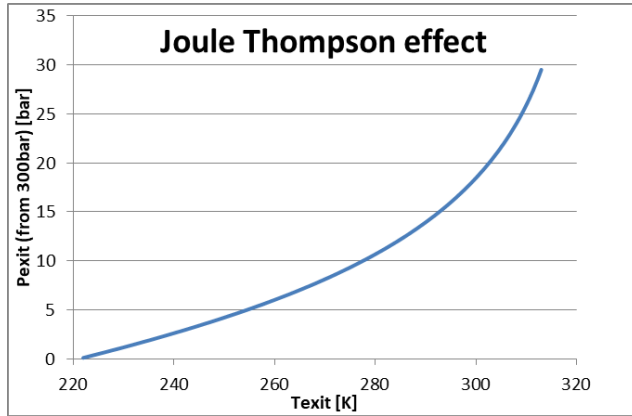


# Experimental validation



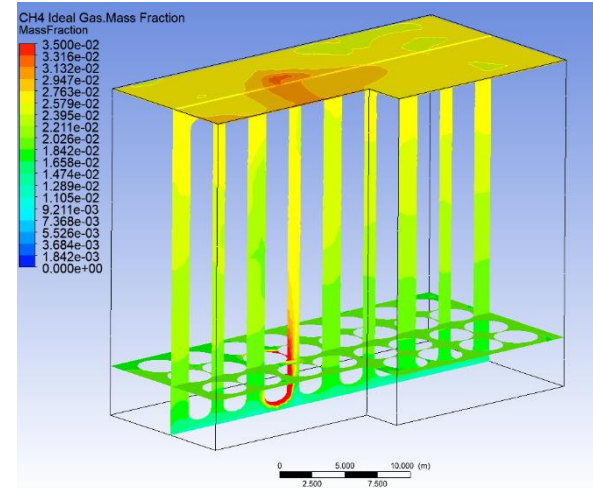
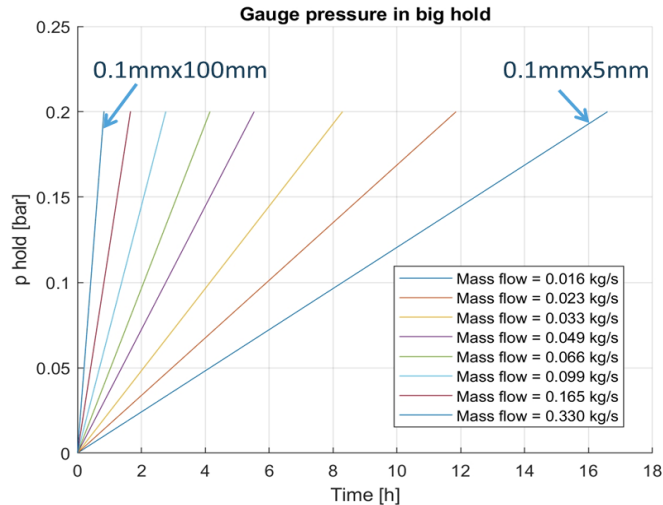
First prototypes of the vessels have been built by BMPlus at Buttrio (Italy)  
Burst and fatigue tests are in progress

# Risk Analysis – Analytical model for leakage



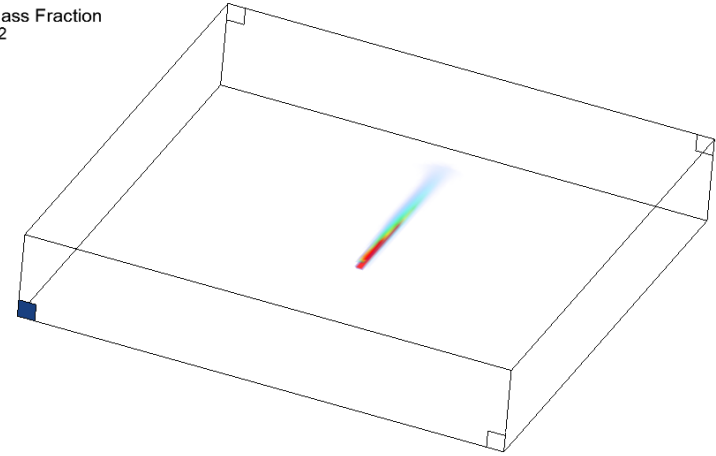
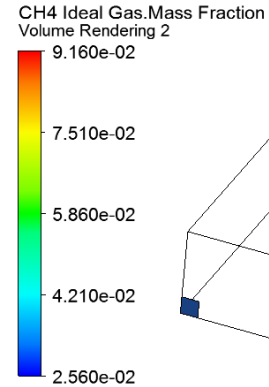
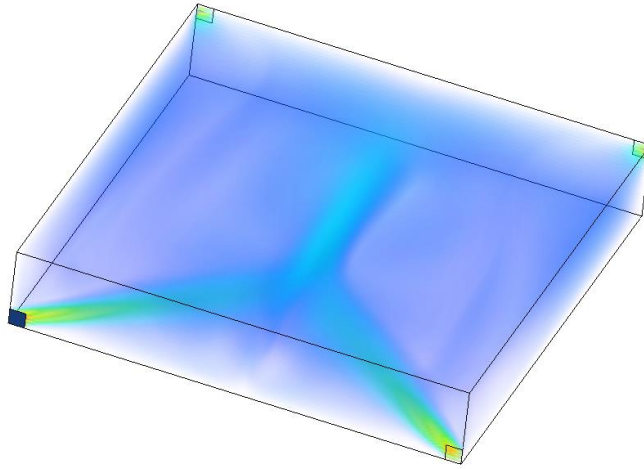
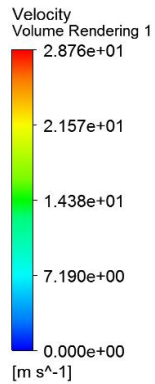
- Due to J-T effect, **gas dispersion** from cylinders (300 bar) occurs at low T (220K)
- By enthalpy balance we can predict how **gas mixture T and P** in the hold varies
- Local supersonic expansion ( $T < 100K$ ) from orifice recovered within **1cm**
- At 1m of distance **support receives a gas jet** at 80m/s and 220K (thermal analysis confirms its resistance)

# Risk Analysis – Analytical model for leakage



The model (Matlab, validated by CFD) can be automated by modeFRONTIER to analyze **Pressure and Temperature** variation in the hold for different mass flows

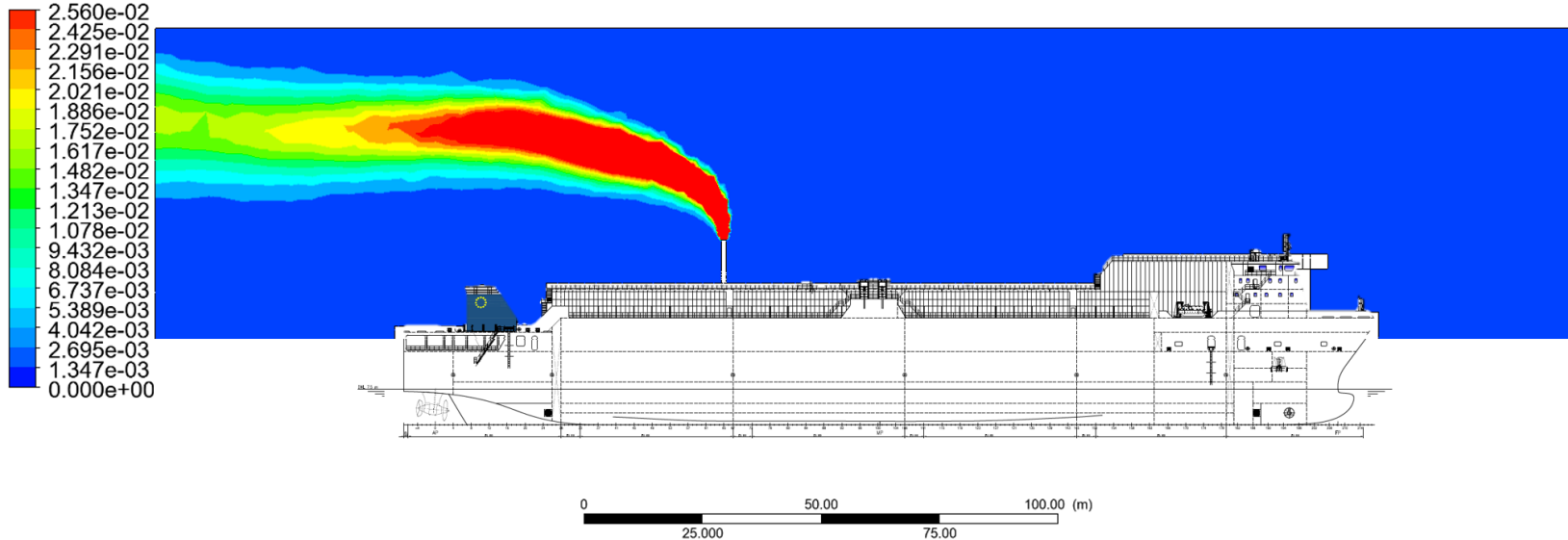
# Risk Analysis – Compressor room



Optimized **ventilation system** reduces **critical concentration** of methane (2.56% of mass) and risks of explosion in compressor room

# Risk Analysis – vent mast analysis

CH4 Ideal Gas High Density.Mass Fraction  
Contour 1



Vent mast system is designed (to evacuate gas when overpressure in hold is reached)  
Critical mass concentration (red color > 2.56%) is dissipated immediately

# Conclusion

- **Gas Transportation scenarios:** Minimize costs to fulfill requests
- **Gas cylinders:** Minimize costs and optimize layers uniformity, guaranteeing the respect of safety factors
- **Explosion risks:** analyze gas leakages to minimize risks

# Thank you for your attention!



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[www.navalprogetti.net](http://www.navalprogetti.net)



[www.gasvessel.eu](http://www.gasvessel.eu)