REGASIFICATION PLANTS: CRYOGENIC ORC TO ENHANCE THE EFFICIENCY OF LNG TERMINALS

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SUMMARY

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- LNG REGASSIFICATION ENERGY REQUIREMENTS
- TECHNOLOGY OVERVIEW
- CRYOGENIC ORGANIC RANKINE CYCLES
- ENERGY EFFICIENT LNG REGASIFICATION TECHNOLOGIES
- CONCLUSIONS

INTRODUCTION

LNG Value Chain

Energy Loss: 1-3% → 7-10% → 0.1-1% → 0.2-2%

Upstream	Liquefaction Plant	LNG Transport	LNG Import Terminal
• On- & Off- Shore Field Development • On- & Off- Shore Pipelines	• Gas/Liquid Treatment • Liquefaction Units • LNG Export Terminal • Marine Facilities • Floating Alternative: FLNG	• Membrane Storage • MOSS Technology	• Storage Tanks • Regasification Units • Jetty • Marine Infrastructure • Floating Alternative: FSRU

245 MTPA TRADED LNG

(REF 2015 – Source IGU World LNG Report 2015)

INTRODUCTION
LNG Regasification

IGU World LNG Report 2016

- Global Regasification capacity: 757 MTPA
- Increase from 2014: 33 MTPA, +5%
- Floating Regasification: 77 MTPA, +35% yoy

- LNG Regasification is an excellent chance to diversify energy sources
- Global Regasification market continues to expand at a steady pace
- LNG supply is steadly increasing

SAIPEM REFERENCES
Designed and built:
12 LNG terminals
1 FSRU
40 LNG tanks

SAIPEM

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INTRODUCTION

Recover Energy - Reduce Emissions

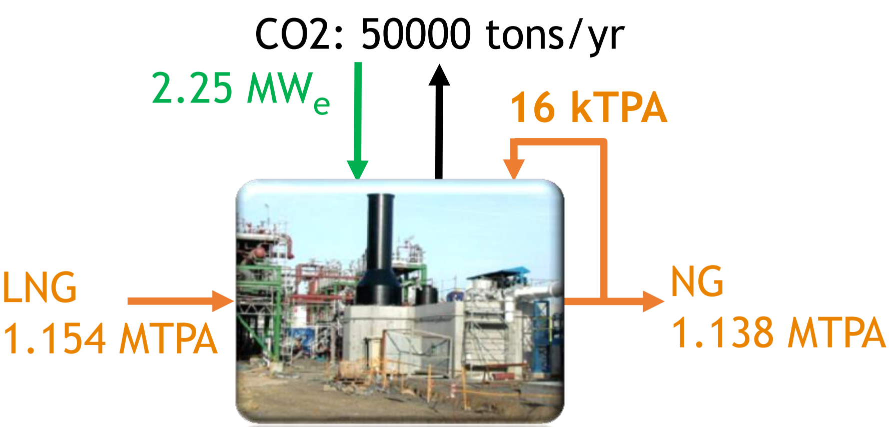
- Import Terminals pay considerable expenses for electrical power import
- Low usage, recurring seasonally, increases power cost weight on income
- Possible Carbon Tax would further increase the costs for power consumption

Saipem in cooperation with **Politecnico di Milano** has:

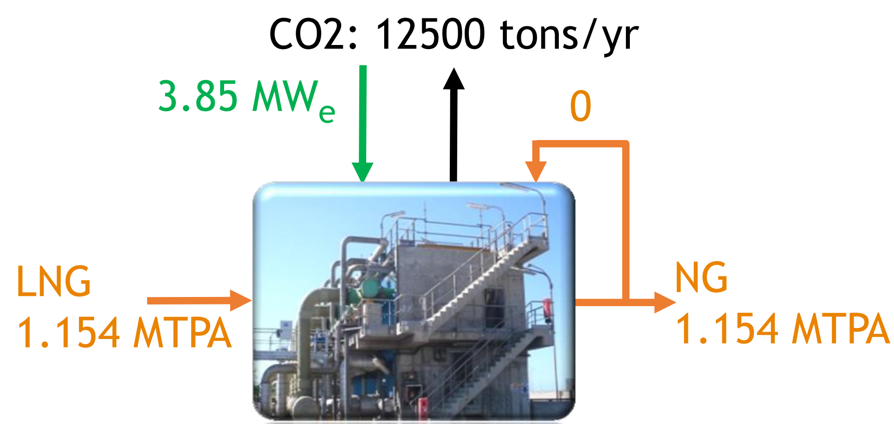
- studied possible schemes for **meeting the electrical load of only a single regasification line while reducing (or eliminating) the primary energy use**
- investigated the market for equipment technical feasibility and economics

LNG REGASSIFICATION ENERGY REQUIREMENTS

Thermal and Electric Power



Submerged Combustion Vaporizer
Heat Source: NG



Open Rack Vaporizer
Heat Source: Sea Water

TECHNOLOGY OVERVIEW

Energy Recovery Performances

Performance indexes

Target

$$\text{Specific Fuel Consumption (SCF)} = \frac{Equivalent\ NG\ consumption}{regasified\ LNG}\ [kg_{NG}/tons_{LNG}]$$

→ 0

$$\text{Fuel Consumption Saving (FCS)} = \frac{Consumption - SCV\ or\ ORV\ consumption}{SCV\ or\ ORV\ consumption}\ [\%]$$

→ -100

$$Reference\ Conversion\ Factor\ (Thermal\ to\ Electric) = \mathbf{50\%}$$

TECHNOLOGY OVERVIEW

Energy Efficient Technologies

Direct expansion, pumping the cryogenic LNG to high pressures and expanding the regasified LNG to delivery pressures

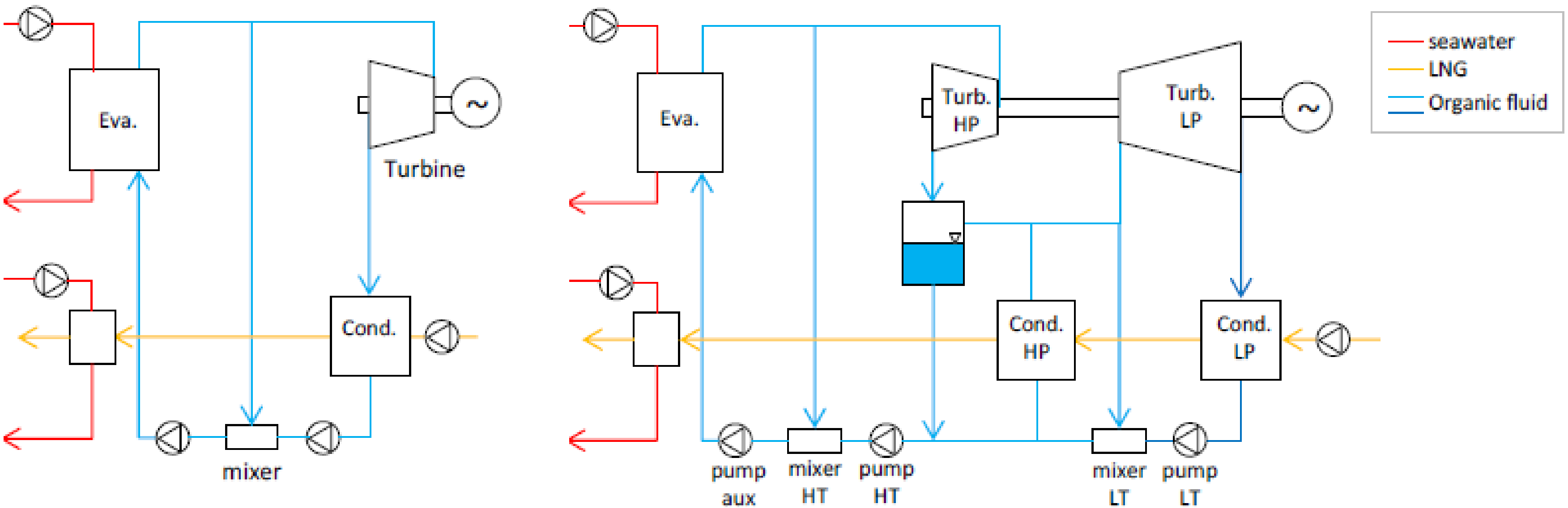
Cogeneration, producing simultaneously electric and thermal power from burning a fraction of the regasified LNG

Gas Cycle, producing electric power from a fraction of the regasified LNG rejecting heat (thermal power) to regasify LNG

Organic Rankine Cycle (ORC), producing electric power using seawater as an energy source and rejecting heat to regasify LNG

CRYOGENIC ORGANIC RANKINE CYCLES

ORC: Plant configurations



- **Plant schemes**, employing direct contact heat exchanger prior to evaporation:
  - single condensation level cycle (left)
  - double condensation level cycle (right)

- **Single condensation level cycle** is the simplest, but allows for a considerably lower power production than the other solution, yielding a lower reduction of the SFC

- **Double condensation level cycle** operates with a pure fluid and allows the achievement of a higher efficiency, mainly thanks to a lower irreversibility in the heat exchange occurring in the LNG regasification process

CRYOGENIC ORGANIC RANKINE CYCLES

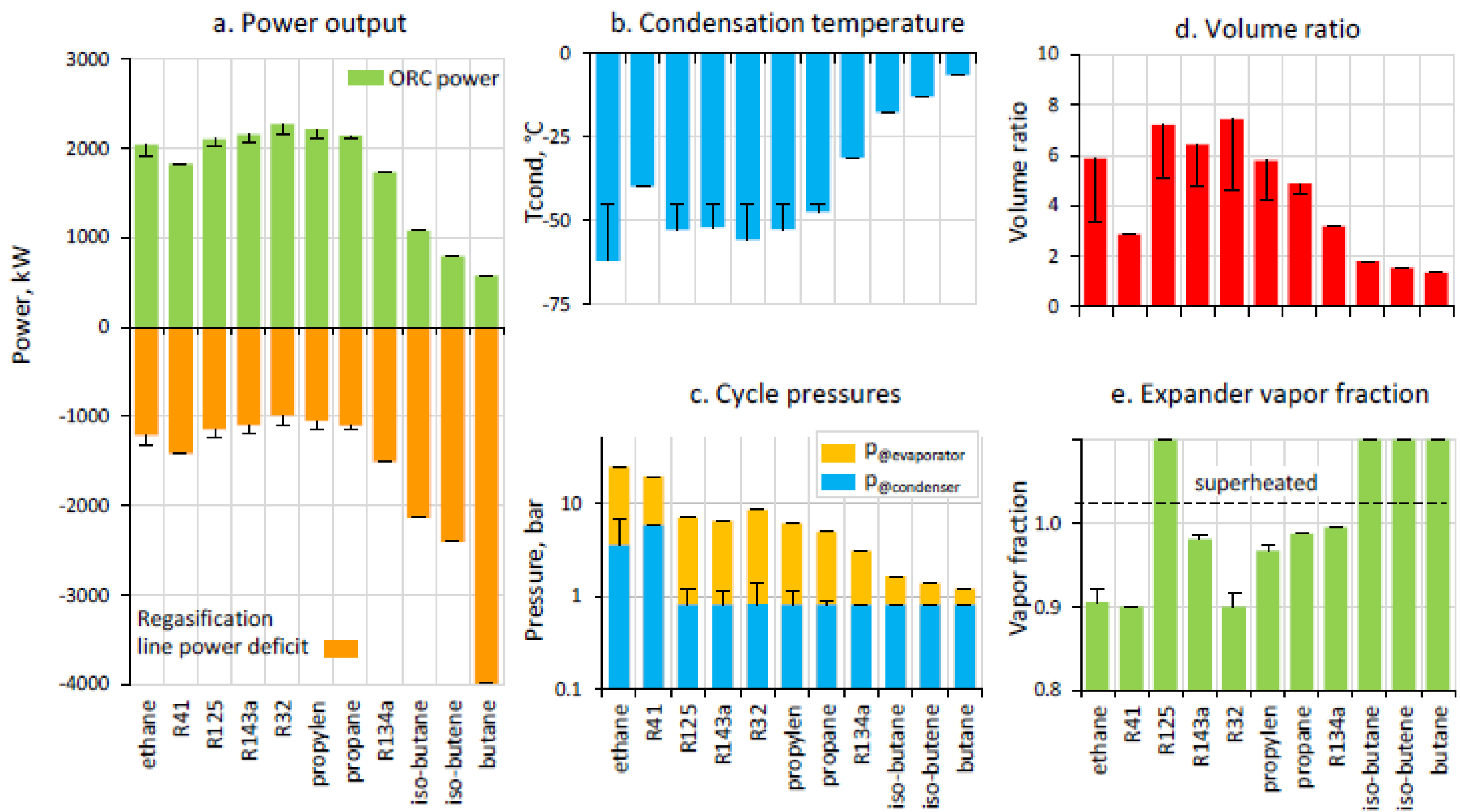
ORC: Organic working fluid selection

Fluid	Formula	Tcrit	GWP	NFPA codes		
				H	F	I
Ethane	CH_3-CH_3	32.2	<10	1	4	
R41	CH_3F	44.1	150	1	4	0
R125	CF_3-CHF_2	66	3500	1	0	0
R143a	CF_3-CH_3	72.7	4470	1	4	0
R32	CH_2F_2	78.1	675	1	4	0
Propylene	CH_2=CH-CH_3	91.1	<10	1	4	0
Propane	CH_3-CH_2-CH_3	96.7	<10	1	4	0
R134a	CF_3-CH_2F	101.1	1430	1	0	1
Iso-butane	$(CH_3)_2$-CH-CH_3	134.7	<10	1	4	0
Iso-butene	CH_2=C-CH_3	145	<10	1	4	0
Butane	CH_3-$(CH_2)_2$-CH_3	152	<10	1	4	0

- Organic working fluids are selected among **hydrocarbons and refrigerants** having:
  - an Ozone Depletion Potential (ODP) equal to zero
  - critical temperatures adequate for fluid evaporation near ambient temperature
- Global Warming Potential (GWP) and National Fire Protection Agency (NFPA) safety codes for the considered fluids have been considered too

CRYOGENIC ORGANIC RANKINE CYCLES

ORC: Fluid results for single condensation level cycles

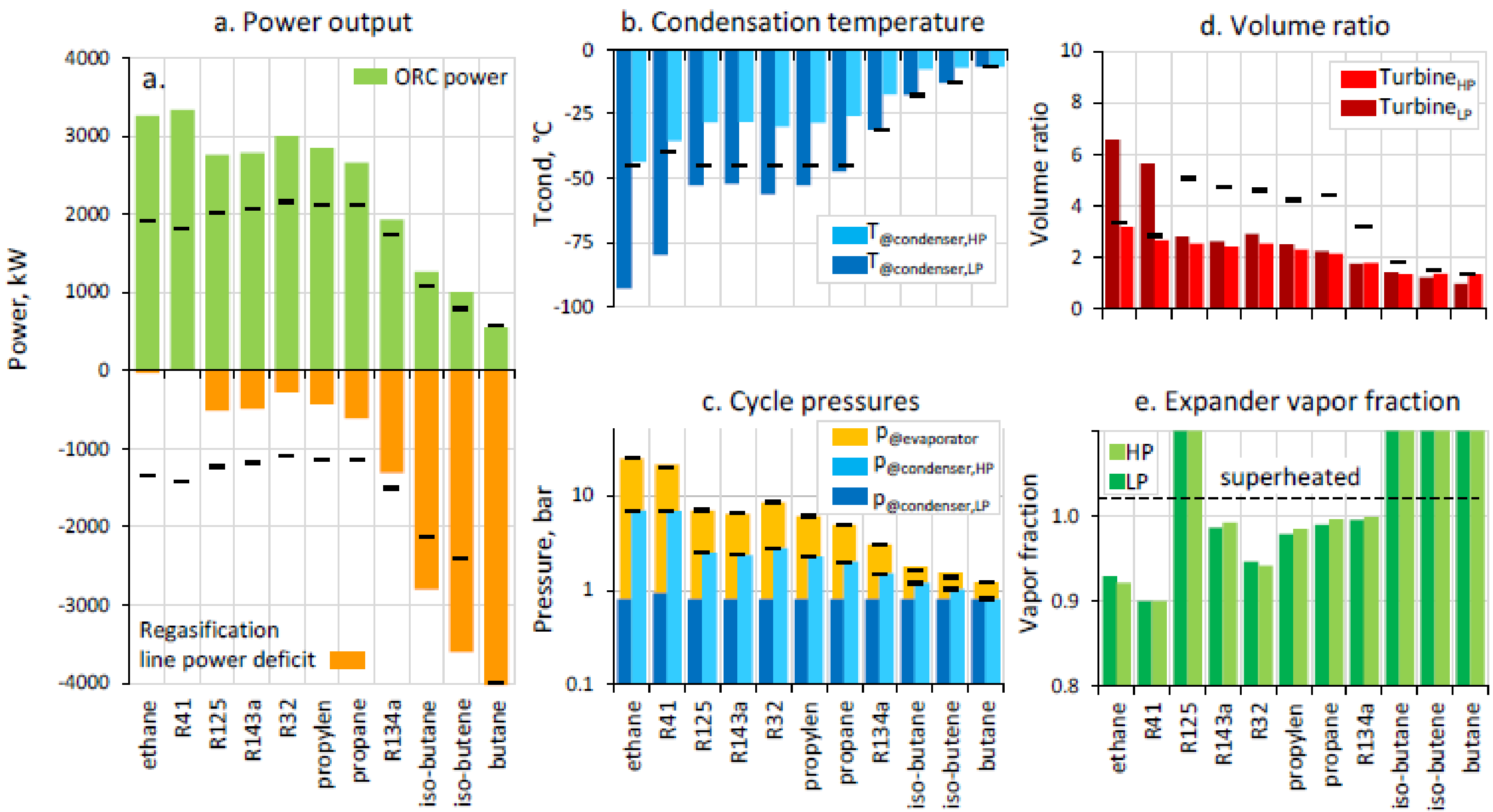


Limiting phenomena are:

- low condensation pressure for fluids with high critical temperature
- high vapor fraction at turbine exit for fluids with low critical temperature

CRYOGENIC ORGANIC RANKINE CYCLES

ORC: Fluid results for double condensation level cycles



Positive outcomes with respect to single condensation level:

- much higher net power outputs
- much lower volume ratios for each turbine

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CRYOGENIC ORGANIC RANKINE CYCLES

ORC: Plant configuration comparison selected fluids

Parameter	Unit	R32 Single level	R41 double level	
ORC power output	kW	2152.7	3318.8	
Single line electric deficit	kW	-1101.6	20.6	
% of regasification heat provided by ORC		63.74%	73.83%	
			HP	LP
Volume ratio in expansion		4.6	2.67	5.65
Condensation temperature	°C	-45	-35.3	-79.8
Condensation pressure	bar	1.41	6.8	0.9
Turbine discharge steam quality		0.917	0.9	0.9
Specific Fuel Consumption (single line)	kg/t	1.16	-0.022	
Specific Fuel Consumption (plant)	kg/t	3.52	2.34	

- The **double condensation level cycle** allows increasing the ORC power output that is sufficient to cover the line electrical consumption with a **small power surplus**
- The double condensation cycle require **more expensive equipment**:
  - the low temperature condenser needs suitable materials for cryogenic conditions
  - installation of two turbines, having an overall volume ratio larger than the one of the single condensation level cycle with R32

CONCLUSIONS

- LNG Regasification Terminals play a strategic role in the energy sources diversification, with a particular emphasis in Europe

- Saipem and PoliMI have analyzed various solutions to improve the energy efficiency of Regasification Terminals: Organic Rankine Cycle (ORC) has the highest potential in terms of energy savings even in the case of cold seawater

- Several schemes, assessed with information from executed EPC projects and referenced equipment manufacturers, confirm the feasibility

Thank you