Testing of a new supercritical ORC technology for efficient power generation from geothermal low temperature resources

ASME ORC 2013 Conference

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Rotterdam, 6-8 October 2013

Enel today

An international, integrated energy operator

Presence in:
40 countries

Installed capacity:
97.839 MW

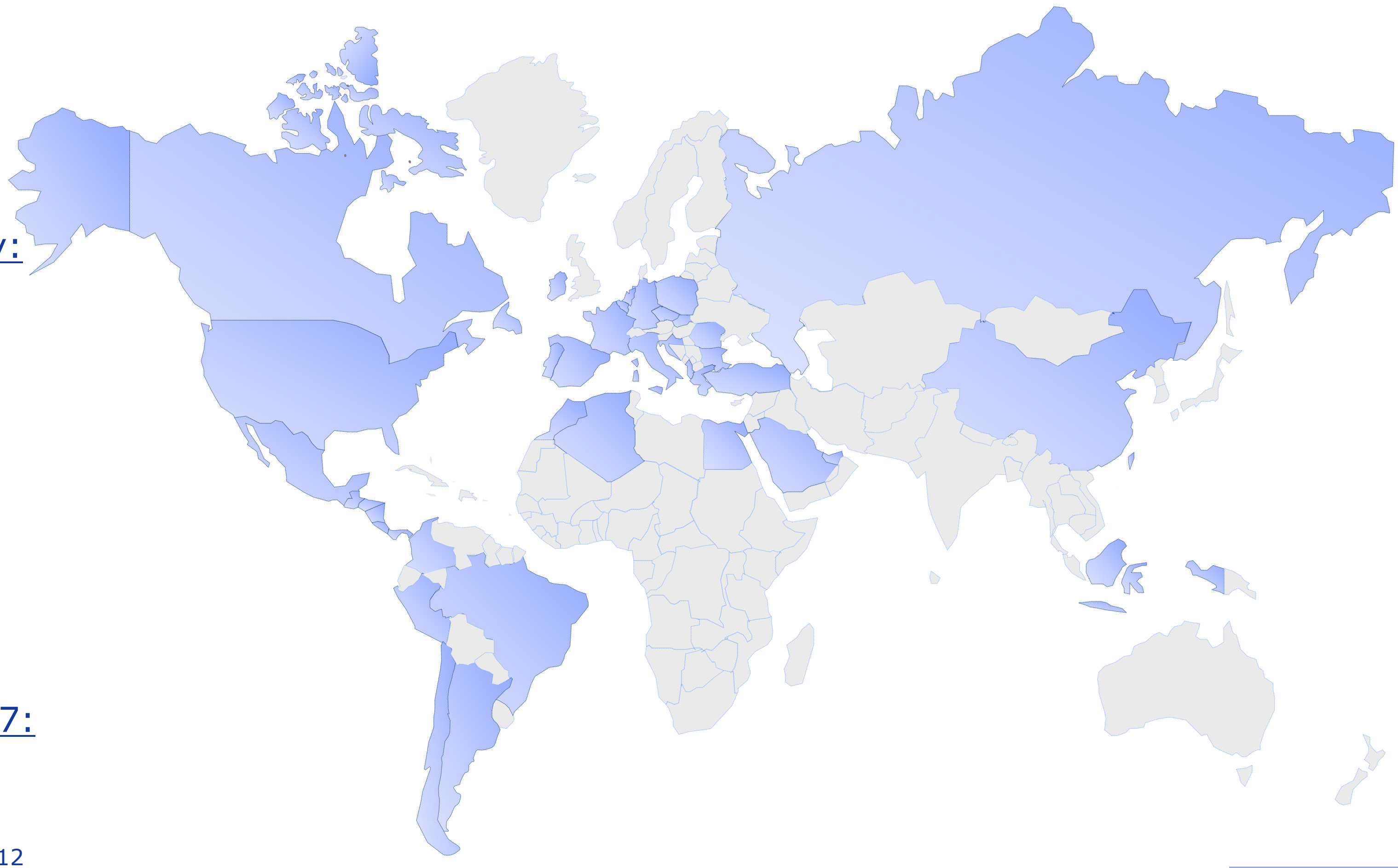
Annual output:
295,7 TWh

EBITDA:
16,7 bln €

Customers:
60,5 million

Employees:
73.702

CAPEX 2013-2017:
€27 billion



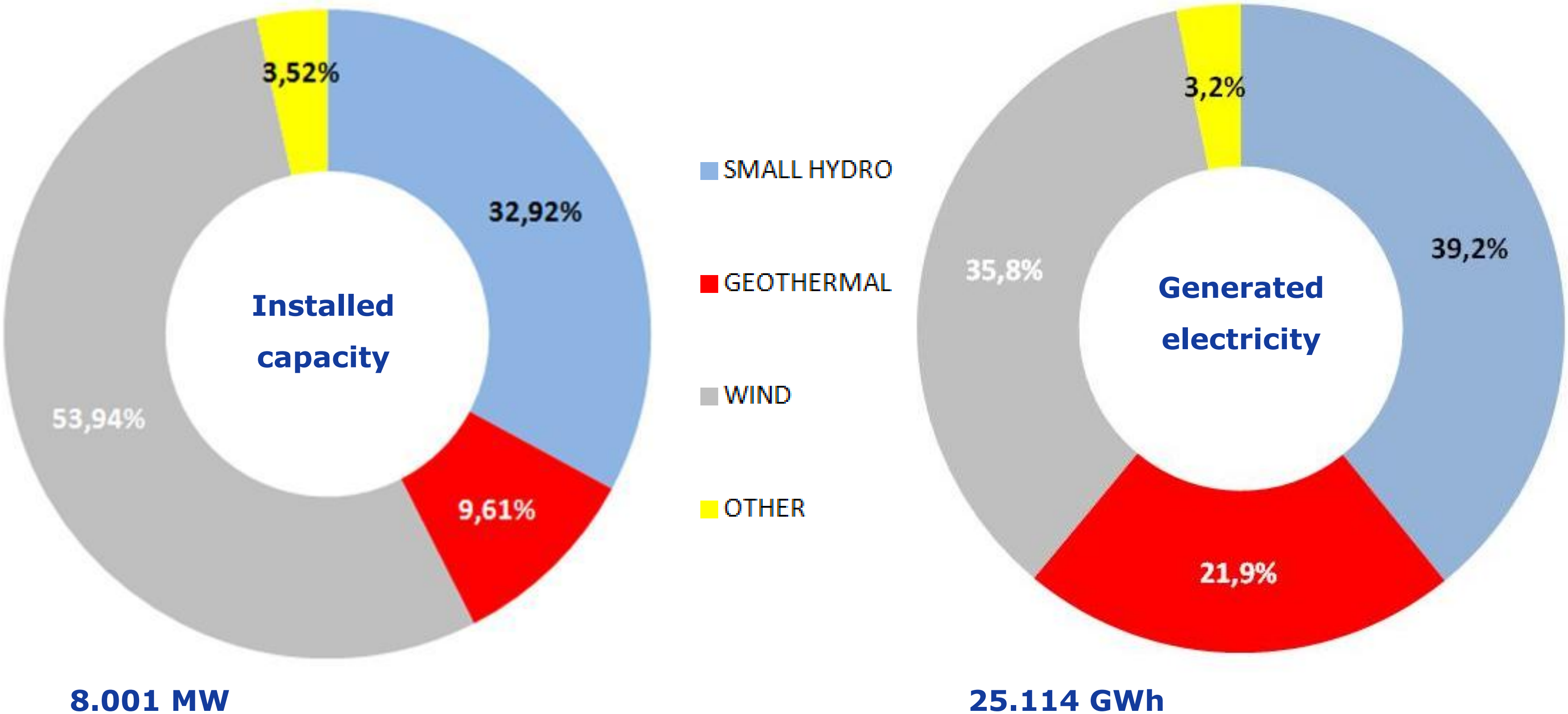
Data updated @ 31/12/2012

1st utility in Italy, 2nd largest in Europe by installed capacity
Present throughout the entire electricity and natural gas value chain

Enel today

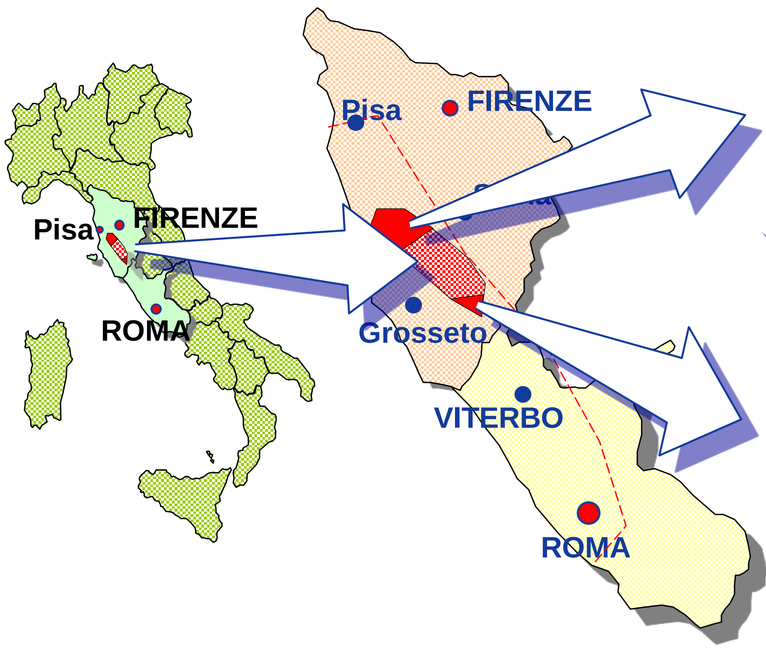
An international, integrated energy operator

RENEWABLES - ENEL GROUP - YEAR 2012



Geothermal energy represents 30% of the total renewable energy generated by the ENEL group, excluding big hydro installations

Enel geothermal experience: a long history of success



Larderello/Lago (250 km²)

- Since 1913 – superheated steam
- Installed capacity: 478 MW

Travale-Radicondoli (30 km²)

- Since 1950 – saturated steam
- Installed capacity: 175 MW

Piancastagnaio/Bagnore (Mt. Amiata – 50 km²)

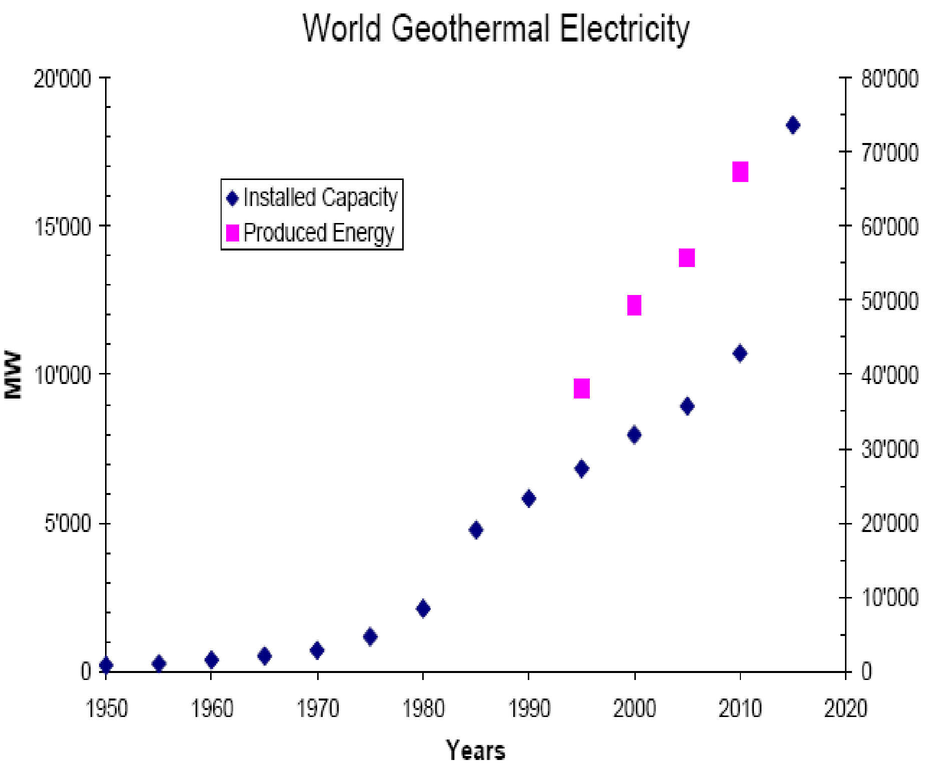
- Since 1955 – water dominated
- Installed capacity: 69 MW

Data updated @ 31/12/2011

34 units, 722 MW gross generating capacity

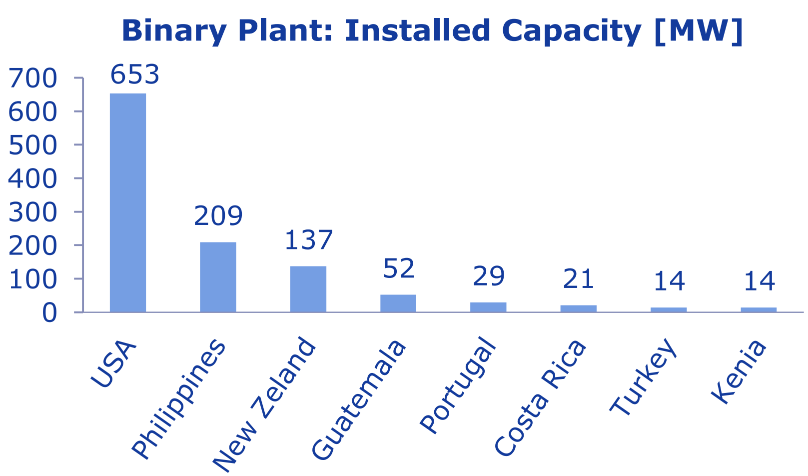
The big potential of low-medium enthalpy resources

GEO - Total

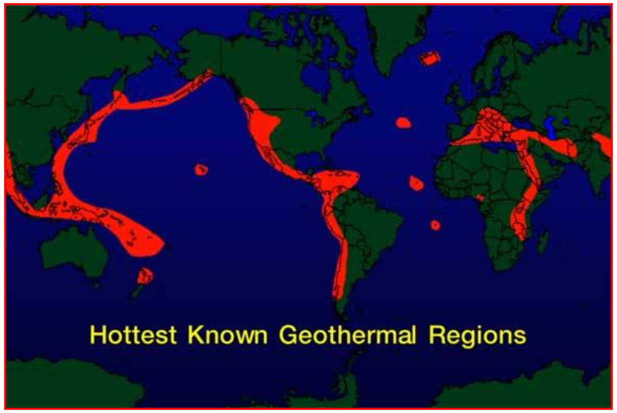


GEO – Low/medium enthalpy

Installed Capacity [MW]			
	2005	**2010**	**Δ%**
TOT_GEO	8.912	10.715	**20,2%**
GEO_LH	685	1.178	**72,0%**



ENEL international projects



USA

- ORC (Organic Rankine Cycles)
- 2 plants in operation (Salt Wells, Stillwater)
- 1 under construction (Cove Fort I)
- Other investments under evaluation (Cove Fort II, Surprise Valley)
- Future developments: coupling with CSP technology

Salvador

- Participation in LaGeo S.A. (~1/3 of shares)
- 2 fields under exploitation (Ahuachapan, Berlin) – 200MW, 1,4 TWh/yr
- 2 fields under exploration (San Vicente, Chinameca)

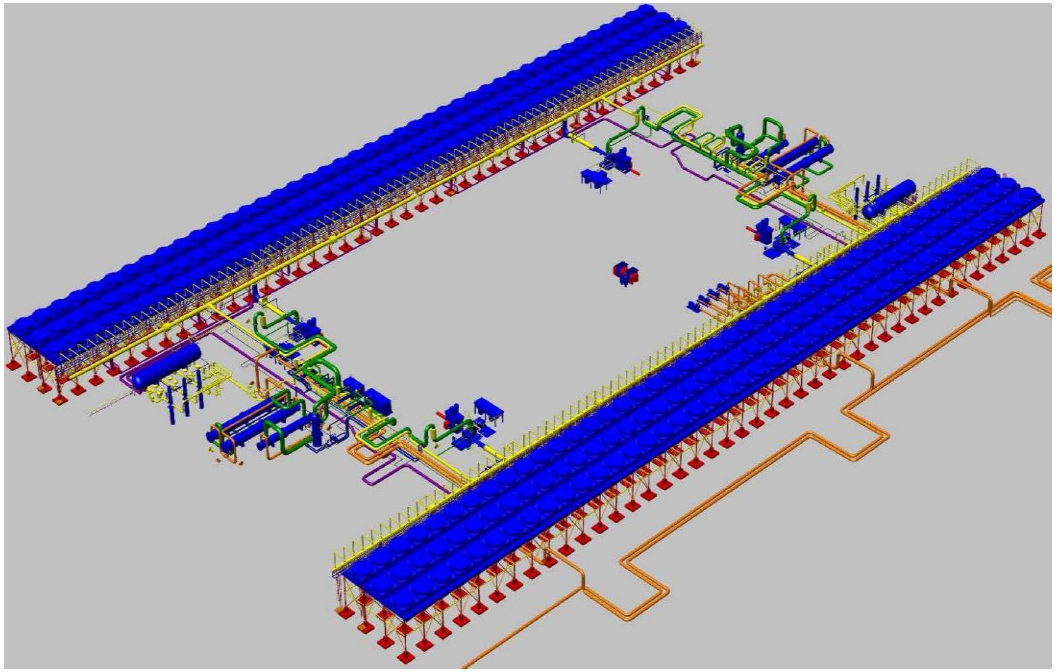
Chile

- Cerro Pabellon 40 MW Single Flash plant (Apacheta area)
- Construction to be started

Other Countries

- Exploration in the Mediterranean Area (Greece, Turkey) and in Central America (Nicaragua)

Stillwater Plant – Pictures & Layout



Innovation in binary cycle technology

STATE OF THE ART

ORC EFFECTIVENESS

7% ÷ 10%

↓

ORC power production from low temperature resources has a **low thermal efficiency**

ORC PLANT CAPITAL COST

1,4 ÷1,6 M€/MW [(1)]

↓

Low efficiency requires increased power plant equipment size that can become **cost prohibitive**

INNOVATION MAINSTAYS

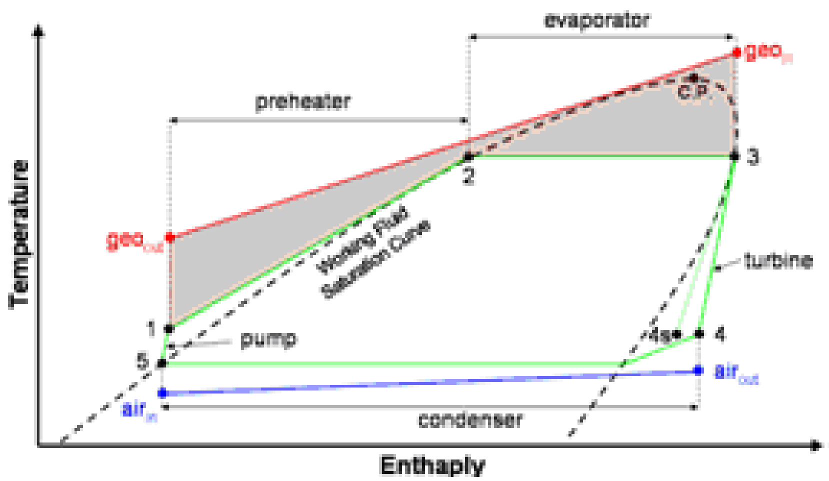
ENHANCED PERFORMANCES & OPERATIONAL FLEXIBILITY

- To upgrade geothermal resources exploitation and reduce risks (electric generation more profitable)
- To better match the characteristics of geothermal reservoirs (more flexibility)
- To avoid performance decline due to the natural resource depletion and temperature drop

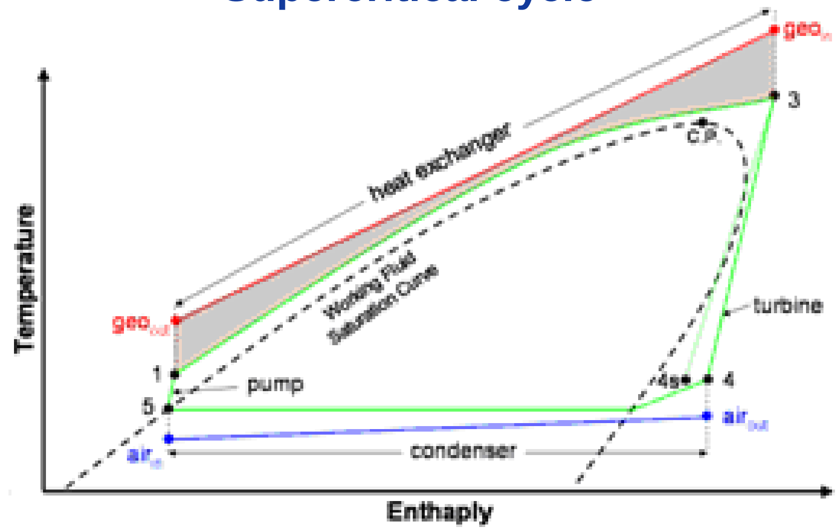
[(1)] 5 ÷ 10 MWe units, only supplies excluding extraction/injection wells

Subcritical vs. Supercritical Cycles

Subcritical cycle



Supercritical cycle



Supercritical cycles allow a better exploitation of the geothermal resource (no pinch point limitation), an higher generation efficiency and simpler plant configuration

Advanced ORC technologies – Development program

2009-2011

Cycle conceptual design and pilot plant EPC

→ **2012** →

Basic data for Feasibility & Costing analysis of a **FULL SCALE** power plant, with respect to conventional technologies

↑

Experimental activities

- ✓ Optimization and demonstration of performance and control strategy
- ✓ Tuning of process and CFD models
- ✓ Validation of design criteria
- ✓ Evaluation of component reliability
- ✓ Fluid degradation and new fluids

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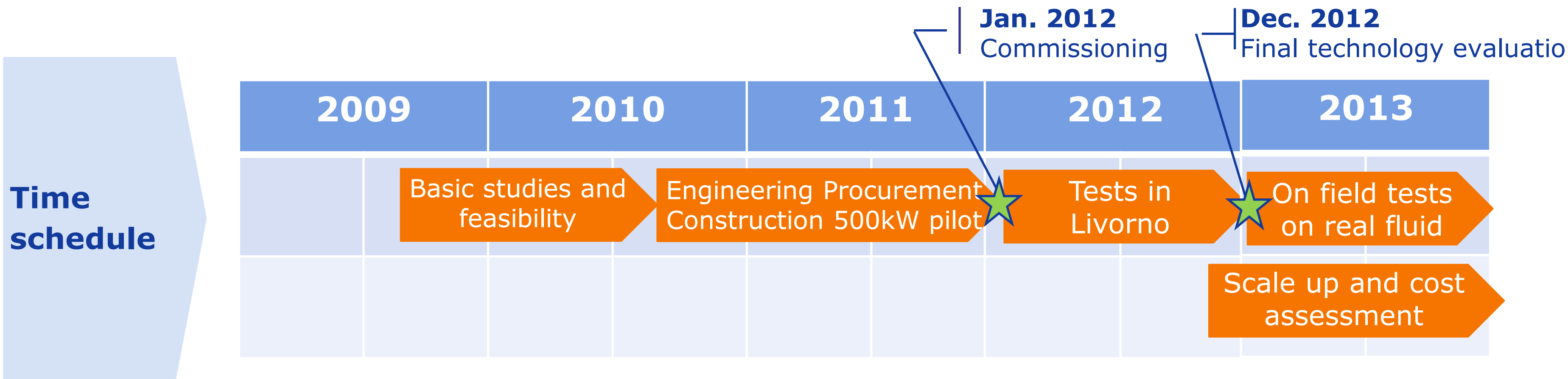
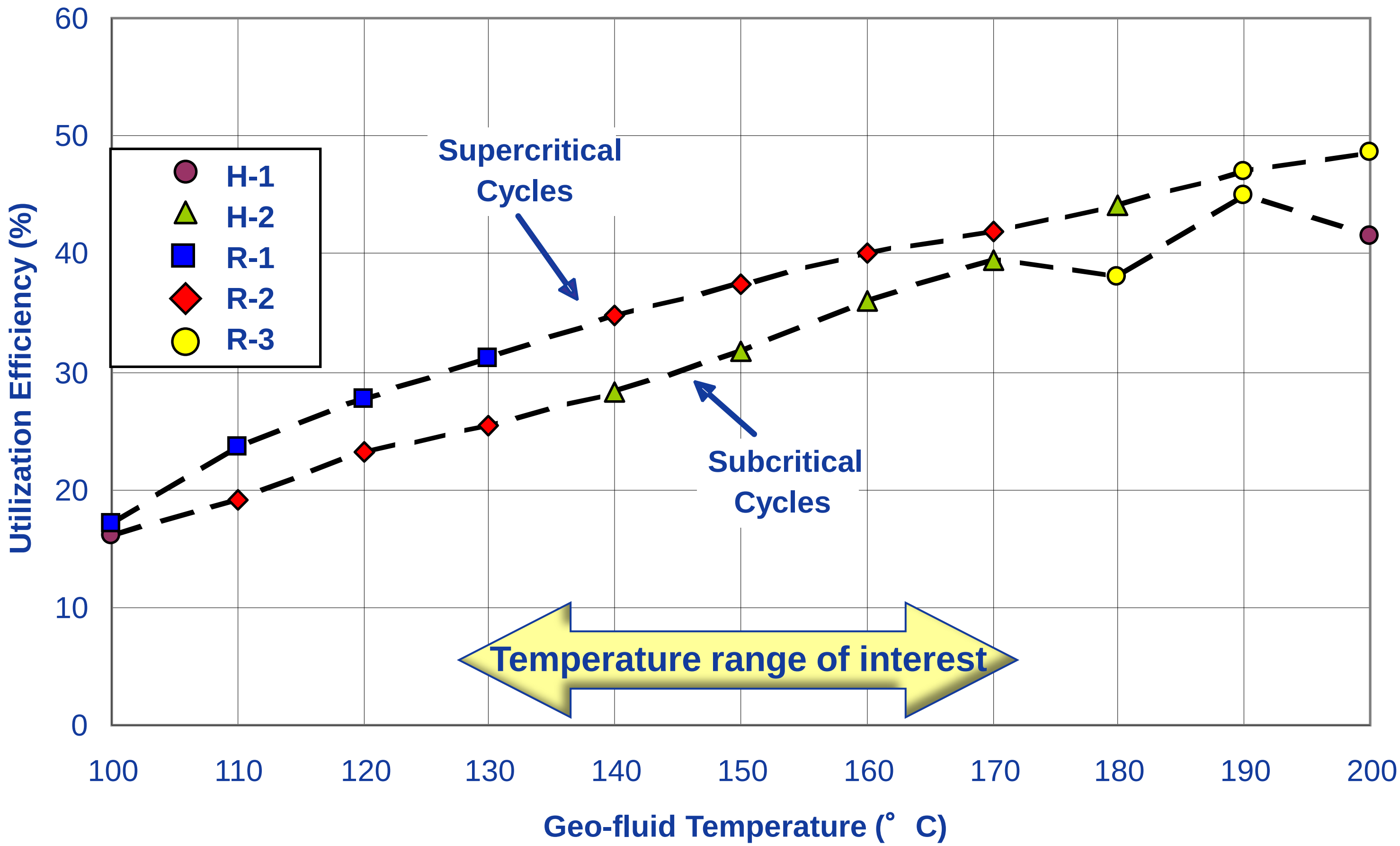
Project detailed program and partnership



Scientific Partners	Technology provider	End user
POLITECNICO DI MILANO; MIT Massachssets Institute of Technology	clean energy ahead TURBODEN	Enel

Fluid and cycle selection



Supercritical cycles provide higher utilization efficiency for all geo-fluid temperature range, resulting in max 23% increase in net power

Advanced 500 KW_e ORC pilot plant (Livorno)

Supercritical ORC cycle

- Working Fluid: refrigerant (not toxic, not flammable)
- Axial turbine
- N°3 shell & tube heat exchangers
- N°1 shell & tube regenerator
- Air cooled condenser "spray & dry"
- Multi-stadium centrifugal pump

Pilot plant in operation since January 2012

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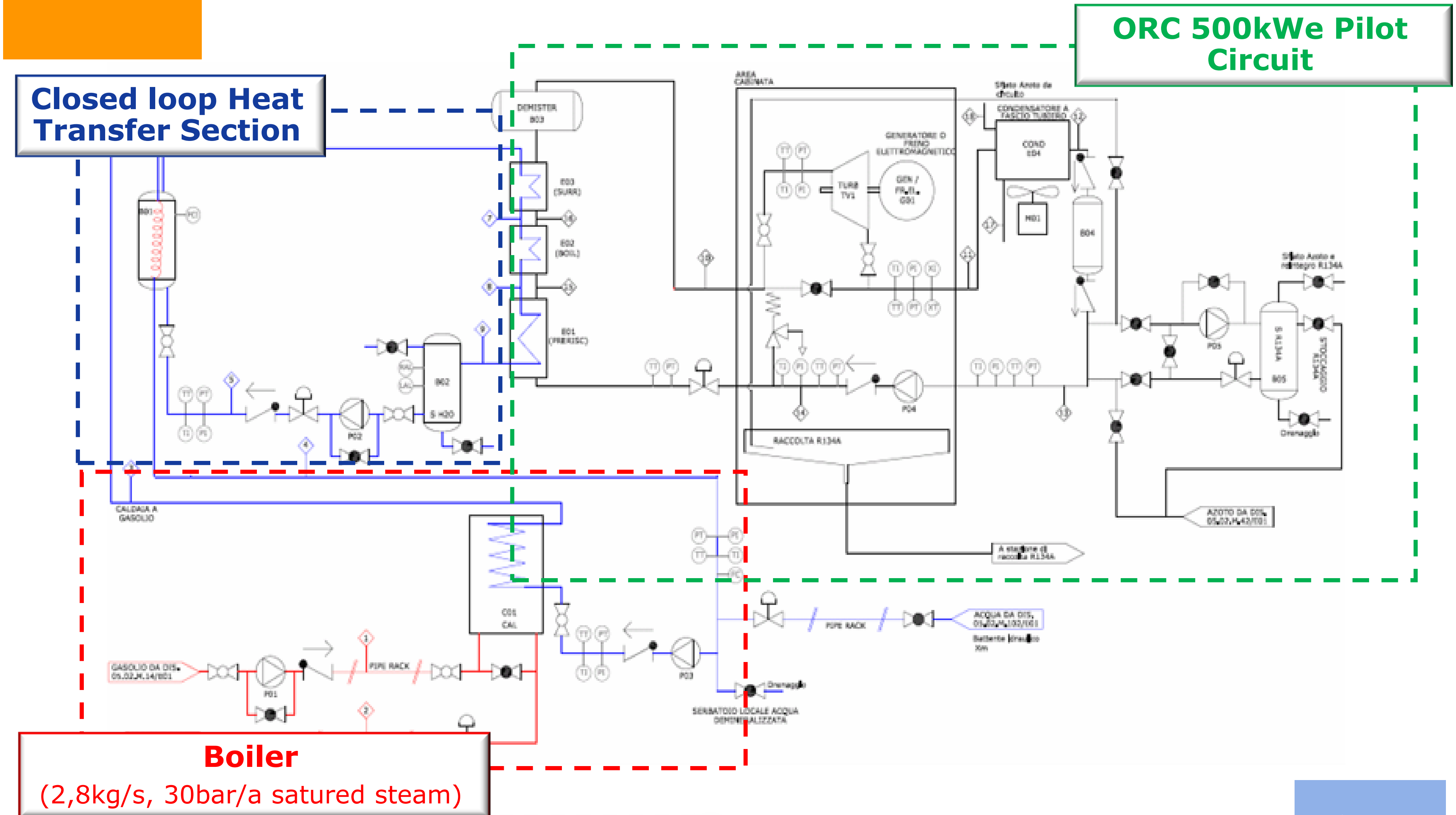
Pilot Plant circuit overall scheme



Possibility to operate in flexible and controlled conditions

Experimental program

Experimantal phases

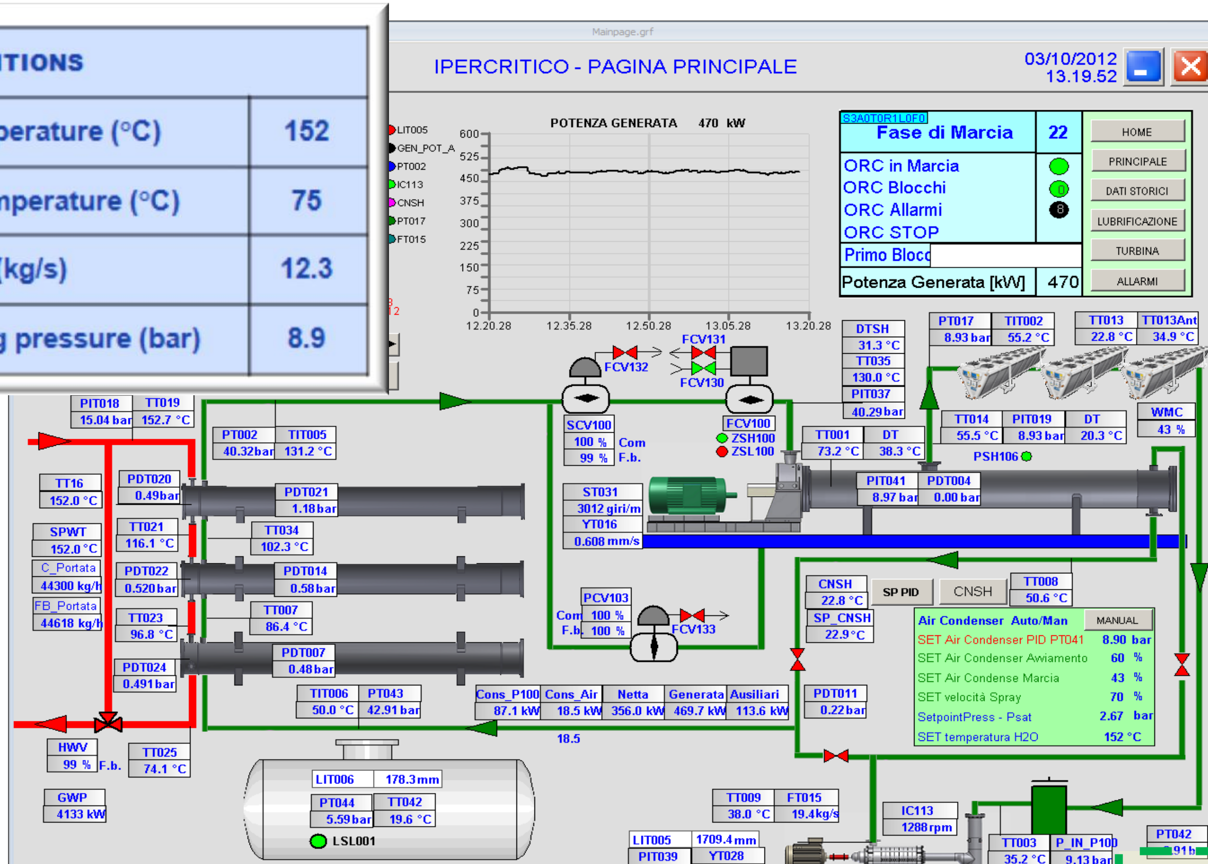
- **PHASE 1 →** Commissioning and performance tests
- **PHASE 2 →** Component characterization and operational optimal curve determination
- **PHASE 3 →** System control philosophy optimization
- **PHASE 4 →** Operating stability evaluation through long-run tests

Heat source experimental conditions		
	T [°C]	**M [kg/s]**
Mmax-Tmax	170	16,6
Mmax-Tnom	152	16,6
Mmax-Tmin	130	16,6
Mnom-Tmax	170	12,3
Mnom-Tnom	**152**	**12,3**
Mnom-Tmin	130	12,3
Mmin-Tmax	170	8,6
Mmin-Tnom	152	8,6
Mmin-Tmin	130	8,6

M = Flow rate, T=Temperature, nom=nominal, max=maximum, min=minimum

Performance tests at design conditions

Design conditions	
Brine inlet temperature (°C)	152
Brine outlet temperature (°C)	75
Brine flow rate(kg/s)	12.3
WF condensing pressure (bar)	8.9



	Design	Measured	Normalized @ 25°C amb. temp.	Delta kW
Gross power (kW)	462	471	471	+ 9
Partial net power [1] (kW)	362	383	383	+ 21
Net power[2] (kW)	319	364	350	+ 31
Ambient temperature (°C)	25	22,5	25	

1 Gross power minus circulating pump power consumption
2 Gross power minus circulating pump and ACC power consumption

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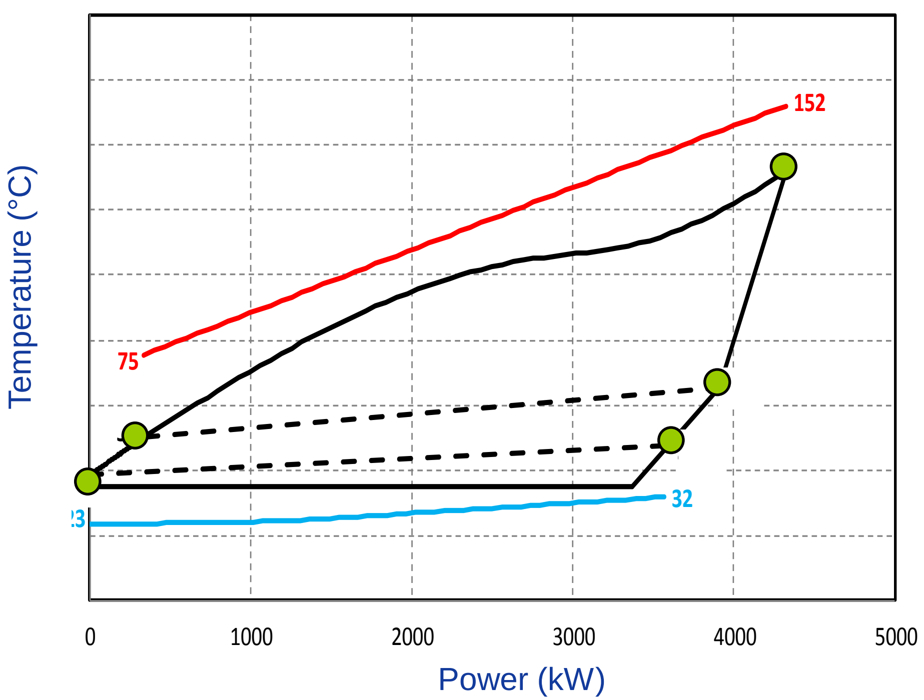
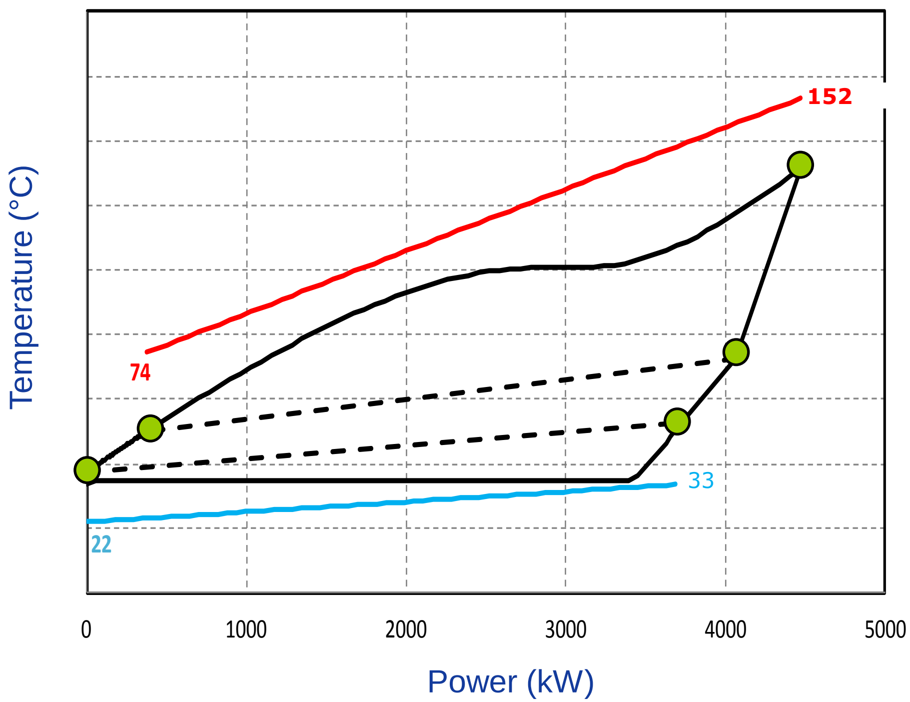
Thermodynamic cycle - Design vs. experimental

Design



Actual

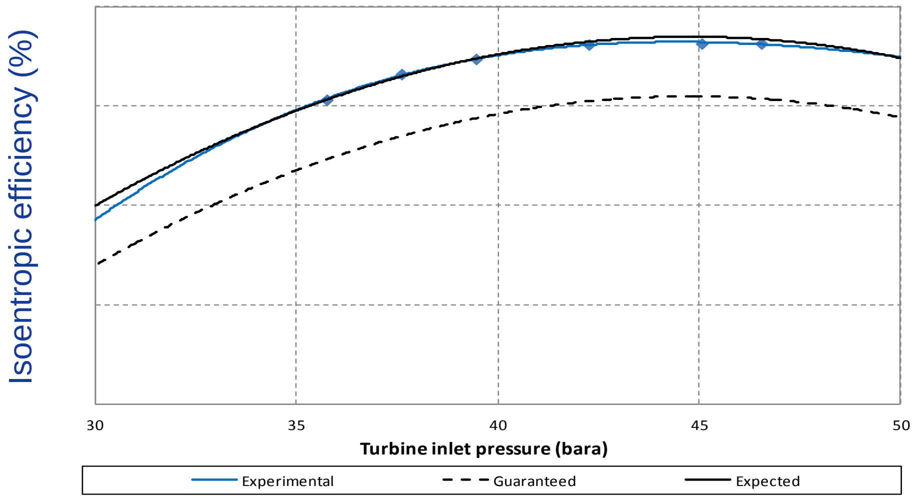


Theoretical thermodynamic cycle was reproduced with negligible deviations

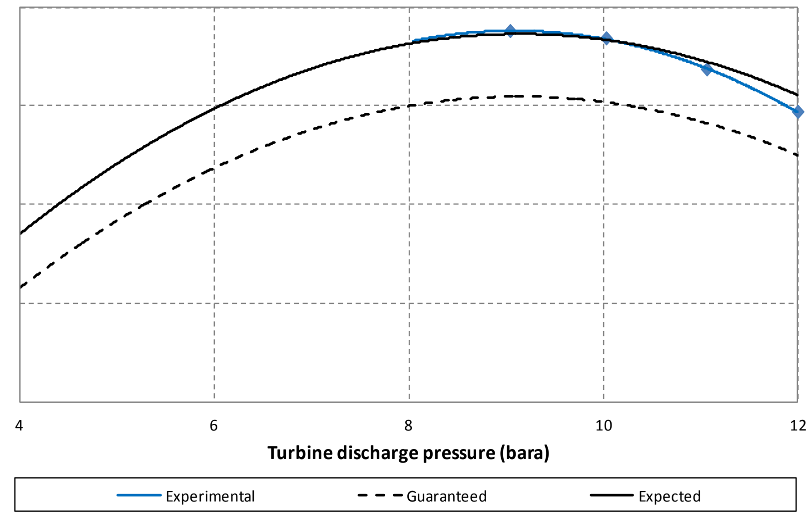
Performance tests on main componets

Turboexpander

@ Fixed WF discharge P and inlet T



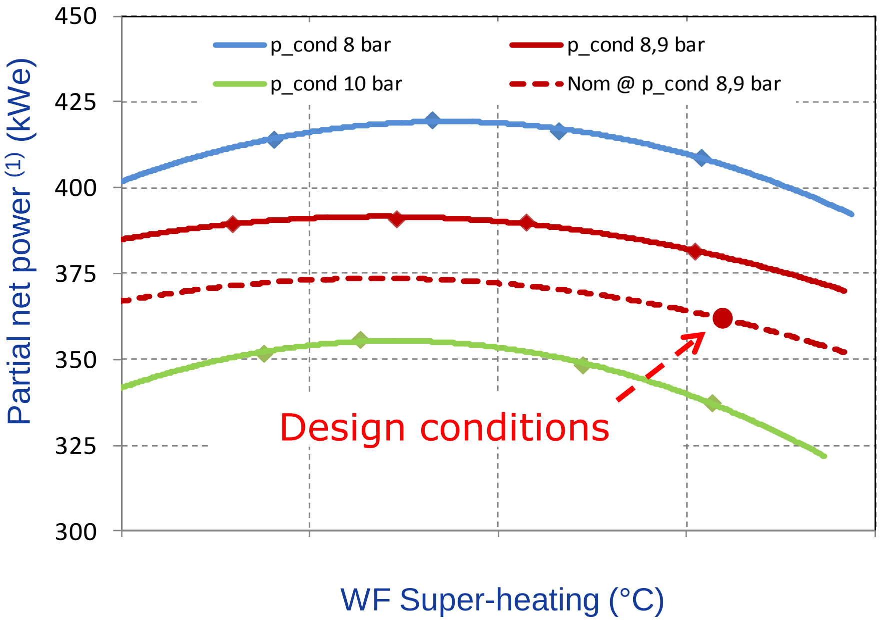
@ Fixed WF inlet P and T



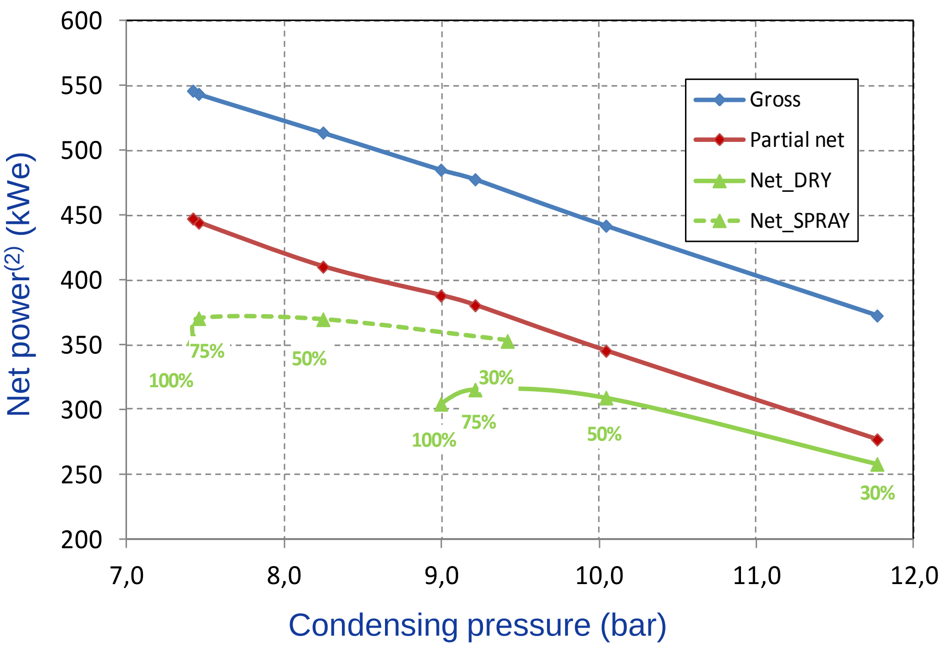
Performances higher than design for all main components (turbine, feed pump, heat exchangers)

Cycle optimization tests

Cycle optimization



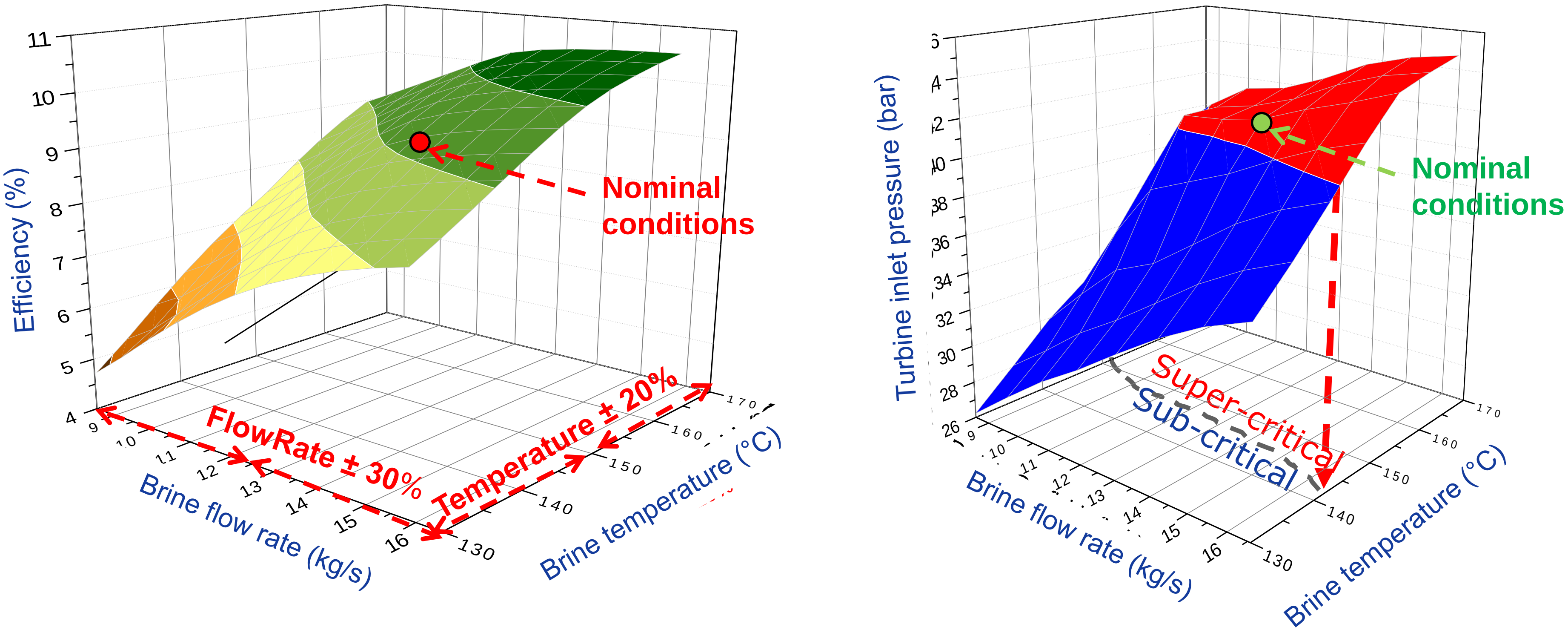
Optima operating curves



Optimized performance curves implemented in DCS

1 Gross power minus circulating pump power consumption
2 Gross power minus circulating pump and ACC power consumption

Operational limit evaluation



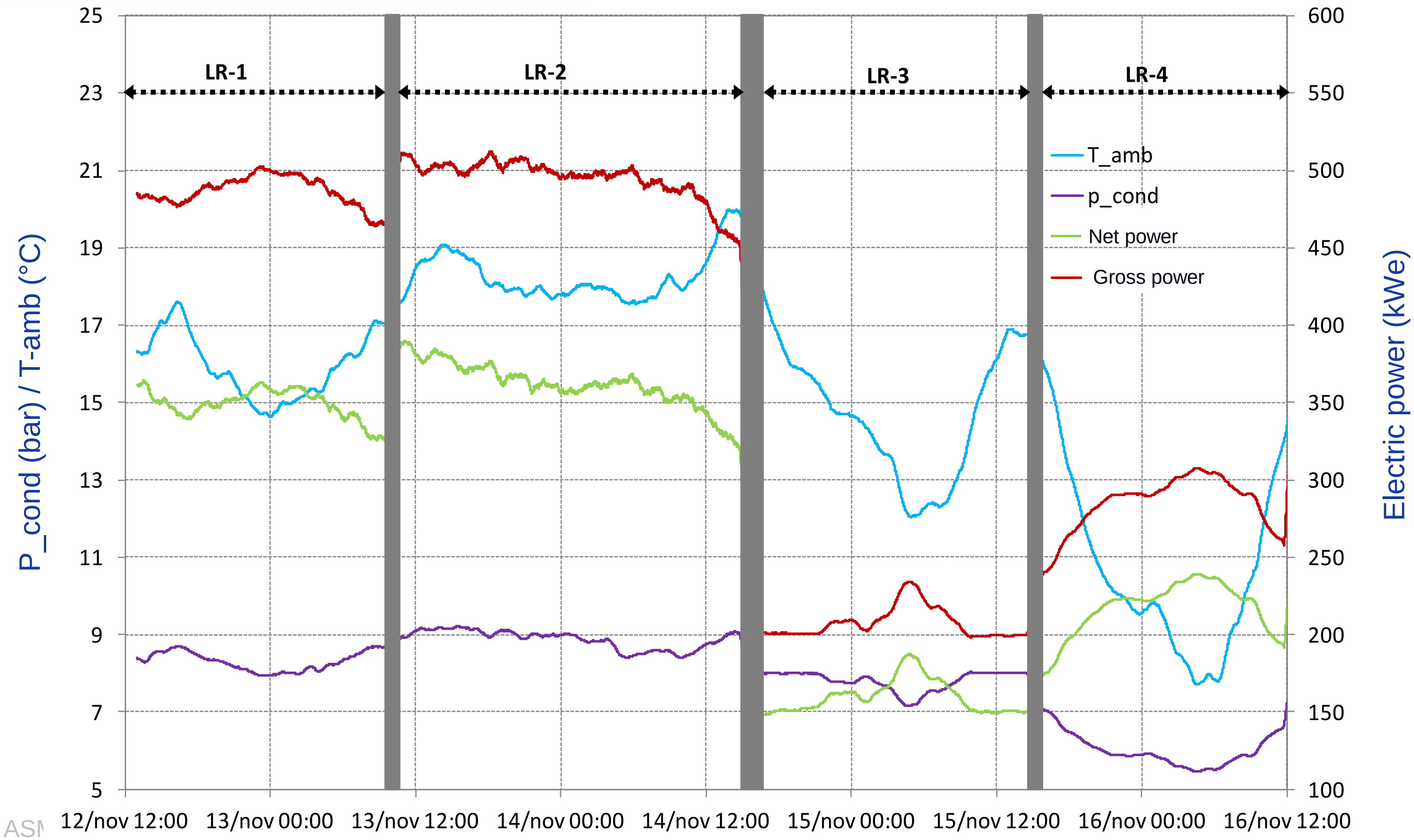
High operational flexibiliy, capability to operate in subcritical and supercritical conditions

Long run tests

No working fluid degradation observed after 1000h of operation

Experimental configurations		
	Heat source	**Cycle conditions**
LR-1	Mnom-Tnom	Super-critical
LR-2	Mnom-T=162°C	Super-critical
LR-3	Mnom-Tmin	Sub-critical
LR-4	Mnom-Tmin	Sub-critical

M = Flow rate, T=Temperature, nom=nominal, min=minimum



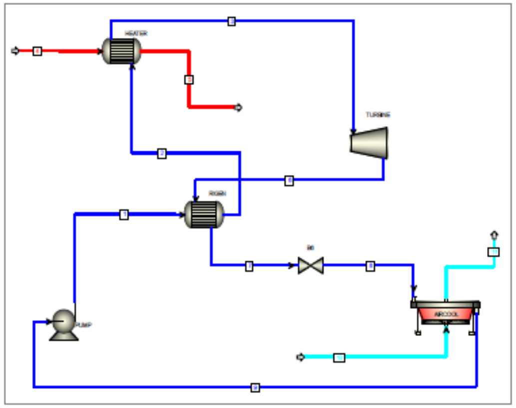
Scale up preliminary evaluation

Supercritical vs. Subcritical with iso-butane

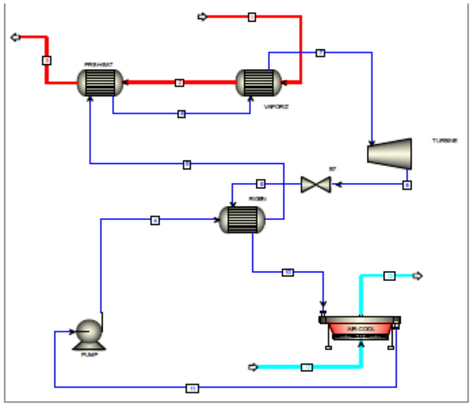
INPUT DATA

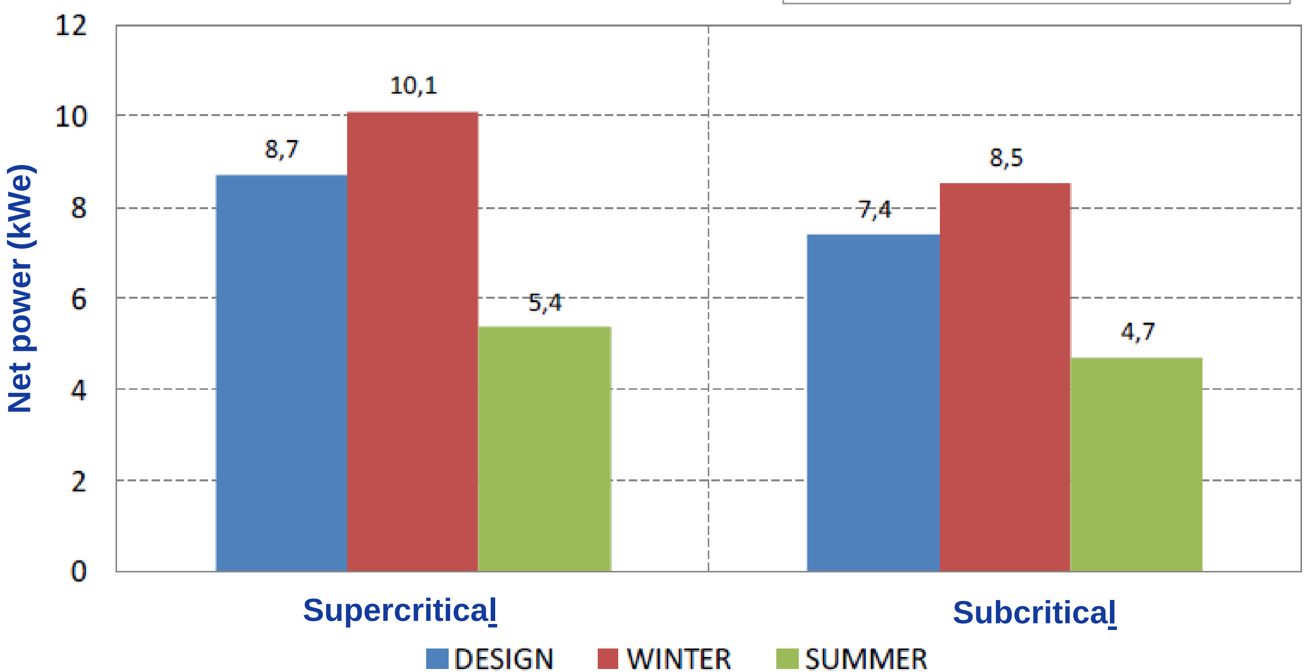
- Brine inlet temperature: 152°C
- Brine mass flow: 190 kg/s
- Design net power: 10 MWe
- Design ambient temperature: 10.7 °C
- Summer ambient temperature: 31.1 °C
- Winter ambient temperature: -1.1 °C

Super-critical



Sub-critical





Annual net energy production estimation ~ 15-20% higher for supercritical ORC with respect to subcritical

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Concluding remarks

- During the experimentation at the pilot scale, supercritical technology showed no criticalities in terms of components and control stability
- Design criteria were confirmed by experimental results and performances of main components and equipments were in line or higher than those expected
- The pilot plant was able to operate in a wide range of brine temperature and flow rates (± 30% vs. design), highlighting a high operational flexibility and the ability to operate even in subcritical conditions
- During the experimental activities significant degradation phenomena of the working fluid were not observed which, not being flammable, determines obvious simplifications in the authorization and design phases compared to conventional hydrocarbon fluids
- The extrapolation of results from pilot scale (500kWe) to full scale (10MWe) confirmed the findings of the feasibility phase: the supercritical technology results in an increase of net annual electricity production in the range of 15-20% compared to one-level pressure subcritical cycles available on the market

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Thank you for your attention