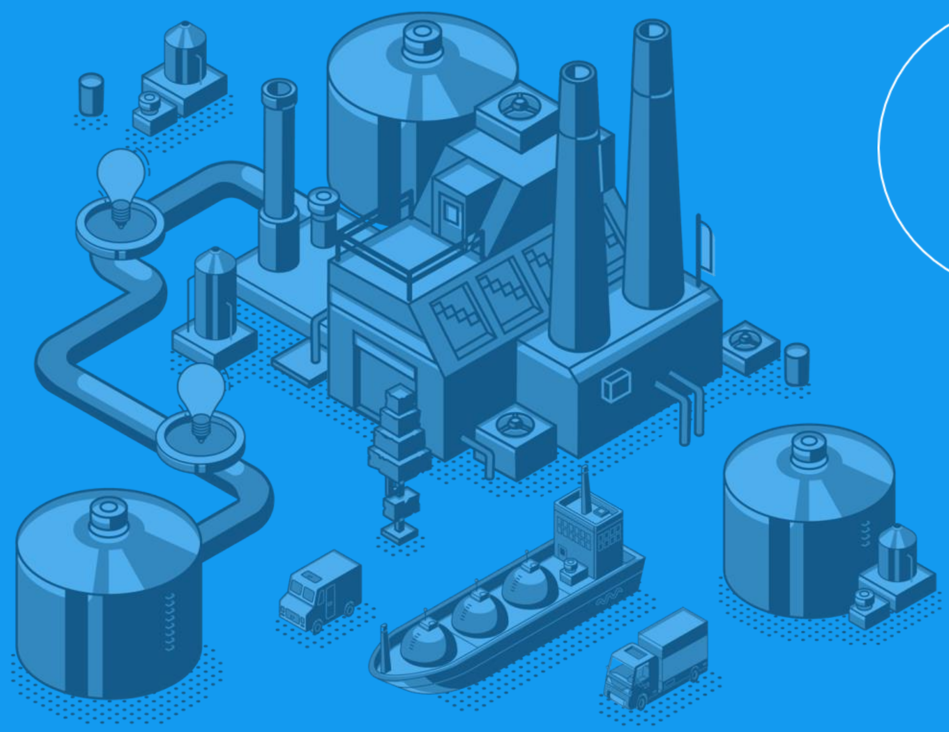
WEBINAR SERIES | LNG WASTE COLD

Session #2:
Ways to unlock the maximum potential value of LNG waste cold



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AN INNOVATION OF IFC International Finance Corporation WORLD BANK GROUP

March 24, 2021

Professor Toby Peters, University of Birmingham, Heriot Watt University

Professor Milind Atrey, IIT Mumbai

Associate Professor, Alessandro Romagnoli, Nanyang Technological University

Michael Ayres, Flexible Power Systems

The Packaging of LNG

LNG is gas packaged in cold at below -161°C

Alongside the gas, we also transport 84,000 GWh_{Coolth}

Less than 1% of this is harnessed

Use thermal energy vector to decouple supply and demand by time and location

- Opens up premium value cooling demands, including in transport (refrigeration / AC)
- Diversity revenue streams to de-risk capital investment
- Avoided new-build electricity generation capacity

[1] Prof. Toby Peters – University of Birmingham

To 2050, using a system approach

4,000 TWh_{coolth} emission-free high-grade cold

~2.2bn tonnes of CO2e

>$440 bn of economic value

Ways to unlock the maximum potential value of LNG waste cold

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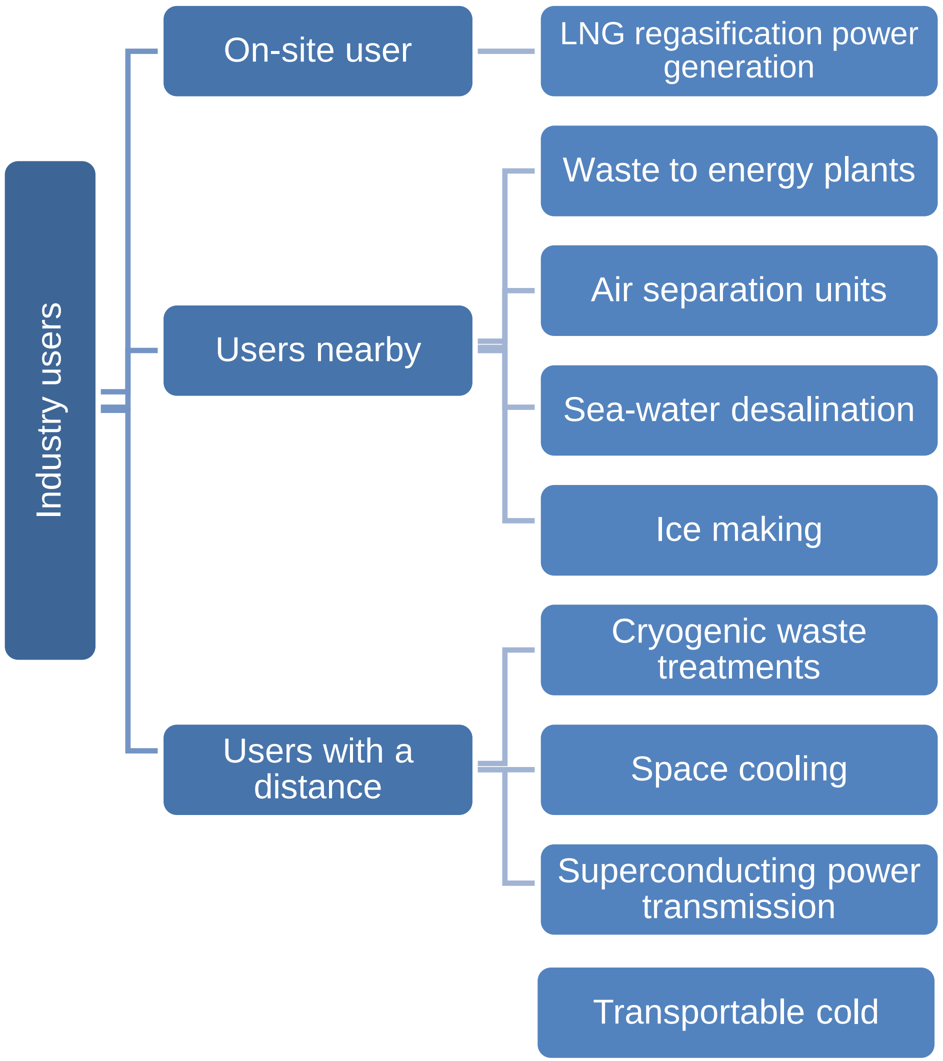
LNG Cold energy: Industry users

Assoc. Prof. Alessandro Romagnoli



Power generation

Using the LNG cold for power generation

- Various concepts available
- Proven technology

Cryogenic seawater desalination

Use the LNG cold energy for seawater desalination

Transportable cold energy storage

Use cold energy storage to transport cold energy from the terminal to end-users

- Using 1) containers or tanks to deliverer the cold energy, or 2) cold panels for passive cooling
- Can be profitable within limited ranges

Air Separation Units (ASU)

Use the LNG cold energy for air separation (O_2, N_2, Ar)

- Reduces electricity consumption by 30-50%

Waste-to-Energy (WtE) Plant

Use the oxygen generated from the ASU for oxygen rich combustion in the waste-to-energy plant

- 40% more waste incinerated for oxygen concentration of 28%
- 10% profit increase for both ASU and WtE

Indoor and outdoor space cooling

Use the cold energy directly for indoor / outdoor climate cooling:

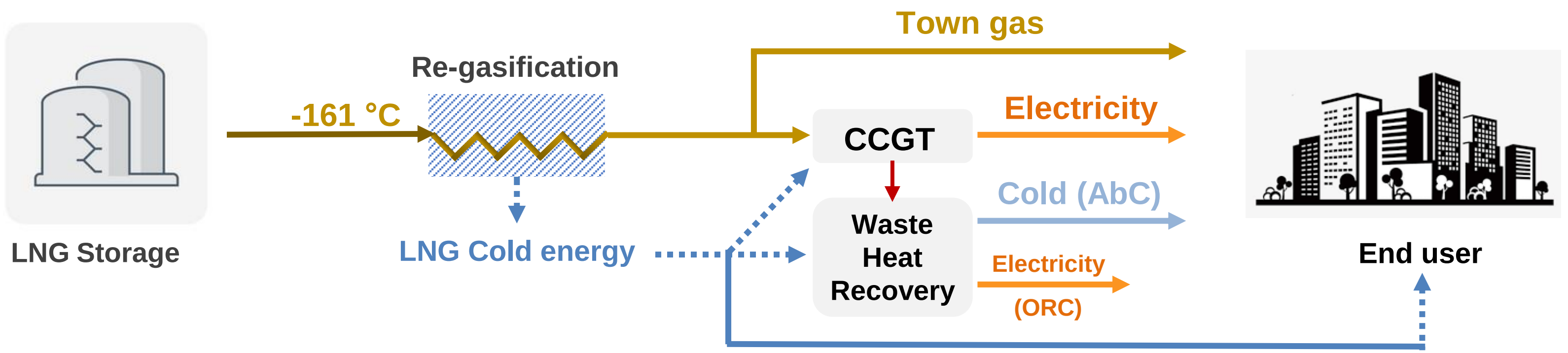
- Data Centre
- Household / Office (via District Cooling)

Superconducting Power Transmission

- 3-5 times power can be transmitted comparing to conventional cables
- Less space needed
- Can use LN_2 or LNG

LNG Cold energy: high TRL systems

Assoc. Prof. Alessandro Romagnoli



	LNG Chemical energy used for:	LNG Cold energy used for:		
Baseline:	CCGT	Wasted		1
Organic Rankine Cycle (ORC):	CCGT	ORC		2
CCGT + Inlet air precooling:	CCGT	CCGT air precooling		3
CCGT + AbC + Direct Cooling :	CCGT	Absorption chiller	Direct cooling	4
CCGT + AbC + Ice making:	CCGT	Absorption chiller	Ice making	5
CCGT + AbC + Deep freezing:	CCGT	Absorption chiller	Deep freezing	6
CCGT + AbC + Seawater desalination:	CCGT	Absorption chiller	Seawater desalination	7

Options 1–3: LNG cold energy utilized to generate more electricity

1

It assumes all the LNG cold is wasted and the Natural Gas is used to generate power in a conventional Combined Cycle Gas Turbine (CCGT)

2

The LNG cold and the waste heat from the CCGT are used to drive a closed power cycle - an organic Rankine cycle (ORC)

3

The LNG cold is used to precool the air before the CCGT → so to improve CCGT efficiency and power output

Air precooling is the most established and adopted option for LNG cold energy utilization

4 5 6 7

- The waste heat from the CCGT is recovered to generate chilled water via an absorption chiller
- The CCGT inlet air is precooled by using chilled water from the Absorption chiller
- The LNG cold is used for Direct Cooling (e.g. Data Centres/District Cooling), Ice making (-20°C), Deep freezing (-78°C) and Seawater desalination (-20°)

LNG Cold energy: high TRL systems

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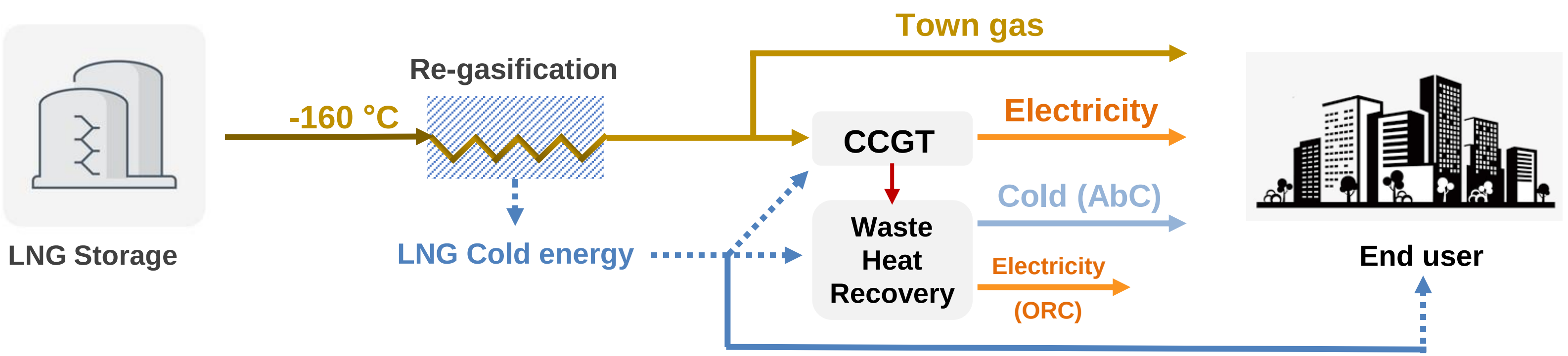
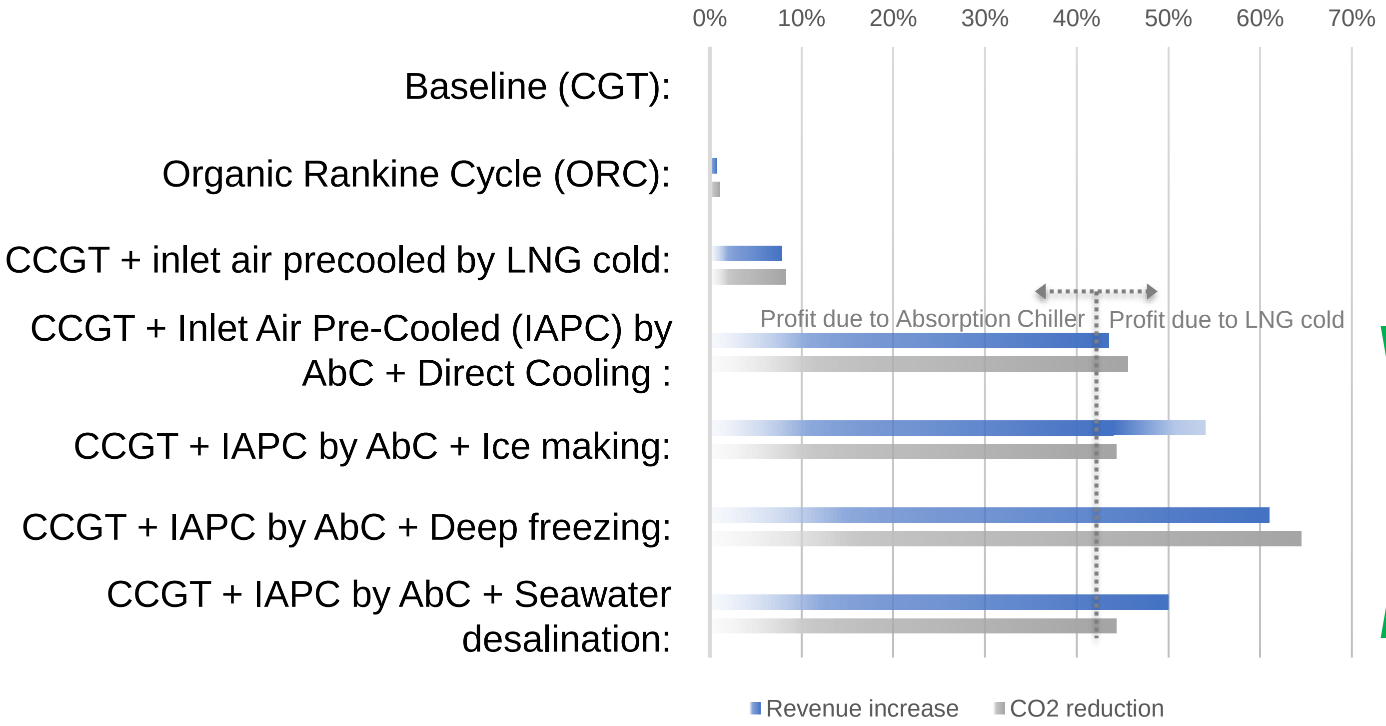


Overall revenue increase and CO2 emissions reduction for high TRL systems



- A fixed size for the CCGT under the Baseline case has been assumed and therefore any additional revenue and CO_2 emissions reduction is being calculated against the Baseline case.
- It is assumed that by utilizing the Waste heat from the CCGT and the Waste Cold from the LNG regasification, it is possible to generate either/both, more electricity or/and more cold that can bring extra revenue
- The reference scenario is Singapore (i.e. electricity price tariffs, etc.).

Absorption chiller contributes for more than 40% CO2 emissions reduction

The higher the heat and cold integration, the higher is the benefits in terms of CO_2 saving and revenue increase

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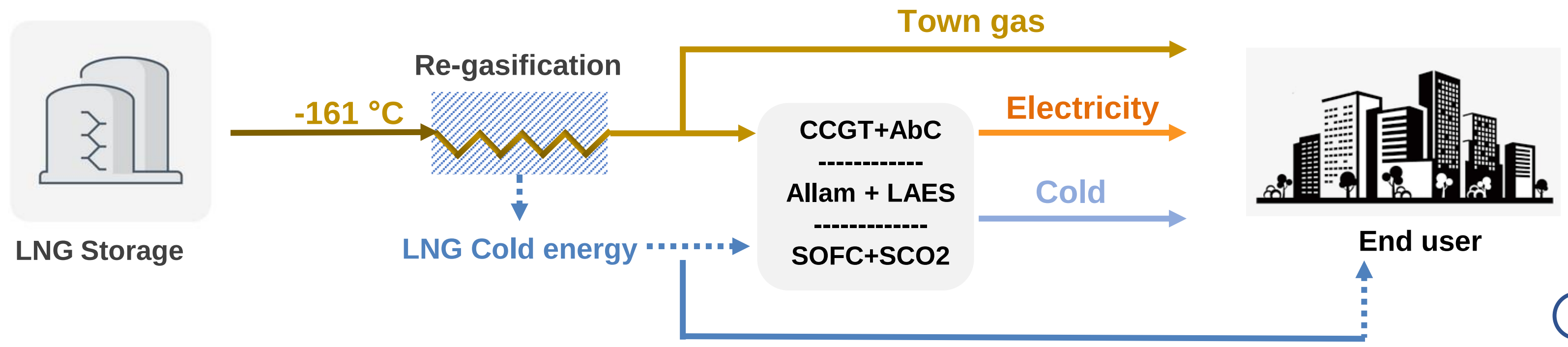
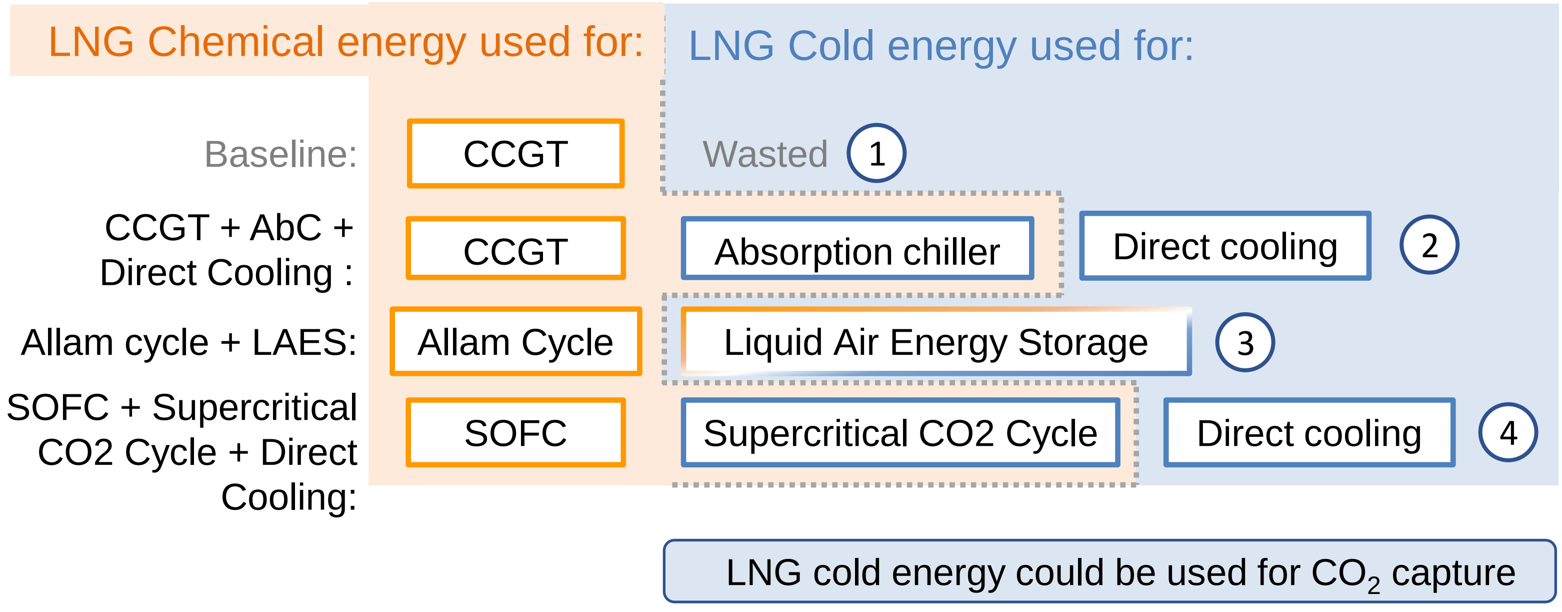
LNG Cold energy: new energy technologies

Assoc. Prof. Alessandro Romagnoli





1

It assumes all the LNG cold is wasted and Natural Gas is used to generate power in a Combined Cycle Gas Turbine (CCGT)

2

- The waste heat from the CCGT is recovered to generate chilled water via an Absorption chiller
- The CCGT inlet air is precooled by using chilled water from the Absorption chiller
- The LNG cold is used for Direct Cooling (e.g. Data Centres/District Cooling)

3

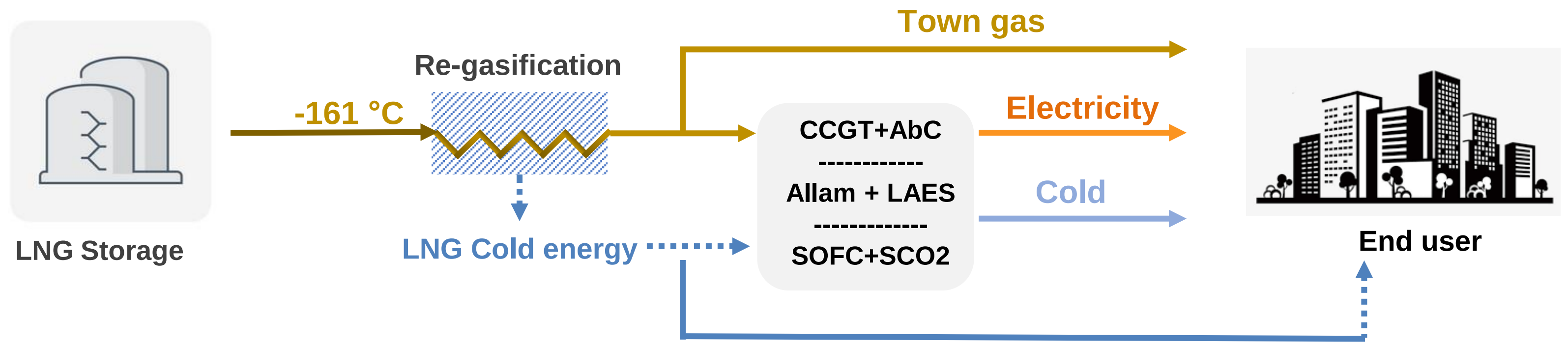
The LNG cold is used for an Air Separation Unit to produce O_2 and N_2. The O_2 is used in a novel oxy-fuel power cycle (i.e. the Allam Cycle) and the liquefied N_2 is used for Liquid Air Energy Storage

4

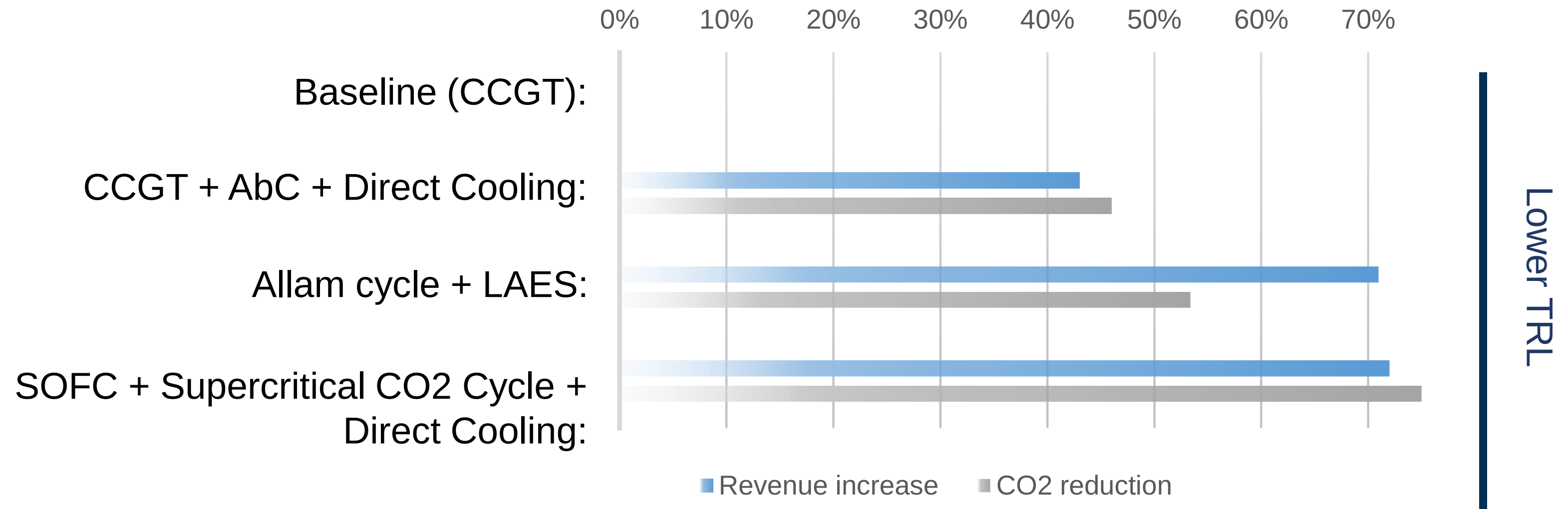
- The natural gas is used in a high temperature fuel cell (Solid Oxide Fuel Cell) and its high temperature byproduct used to drive a Brayton cycle and an Absorption chiller
- The LNG cold is used for Direct Cooling (e.g. Data Centres/District Cooling)

LNG Cold energy: new energy technologies

Assoc. Prof. Alessandro Romagnoli



Overall revenue increase and CO2 emissions reduction for advanced LNG systems integration



The efficient utilization of LNG for CO_2 capture could lead to up to 80% of energy savings compared to conventional CO_2 capture

- A fixed size for the CCGT (hence fixed amount of Natural Gas burnt) under the Baseline case has been assumed and therefore any additional revenue and CO2 emissions reduction is being calculated against the Baseline case.
- It is assumed that by utilizing the Waste heat from the CCGT and the Waste Cold from the LNG regasification, it is possible to generate either/both, more electricity or/and more cold that can bring extra revenue
- The reference scenario is Singapore (i.e. electricity price tariffs, etc.).

- In the Allam cycle and the SOFC case studies, it was assumed that the same amount of Natural Gas as the Baseline case is going to be used. Hence the revenue generated and the CO2 emissions reduction come as a direct consequence of higher conversion efficiencies and better waste heat and waste cold utilization.
- In the Allam Cycle + LAES, the LAES uses the LNG cold to separate the air, and stores the liquid nitrogen produced to generate electricity during the peak hours for extra profit (higher electricity tariff)

- LNG waste cold could be used to enhance CO_2 capture processes; this holds great potential, research on going and some cases at pilot scale.

LNG Cold energy: cold thermal energy storage

Assoc. Prof. Alessandro Romagnoli

LNG terminal

Generation of cold energy

Transportation

Delivery of cold energy

End users

Utilization of cold energy

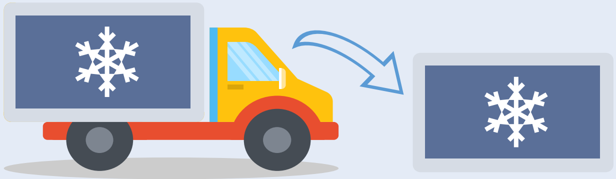
① **Passive cooling vehicle for the cold supply chain**

Charging cold thermal energy storage packs using the LNG cold, and use the cold energy to replace the refrigeration units of trucks

- Reduces up to ***40%*** of the environmental impacts of a diesel-driven food vehicle

② **Transportable cold thermal energy storage units for cold supply to end users**

Using containerized cold thermal energy storage units to harvest the LNG cold and transport to the end users to replace the refrigeration systems.



- Reduces the operation cost of conventional AC users as long as the journey is shorter than a breakeven delivery distance (around 10km in SG).
- Available low temperature storage materials (below -110°C) can significantly increase the breakeven distance.

Thank you

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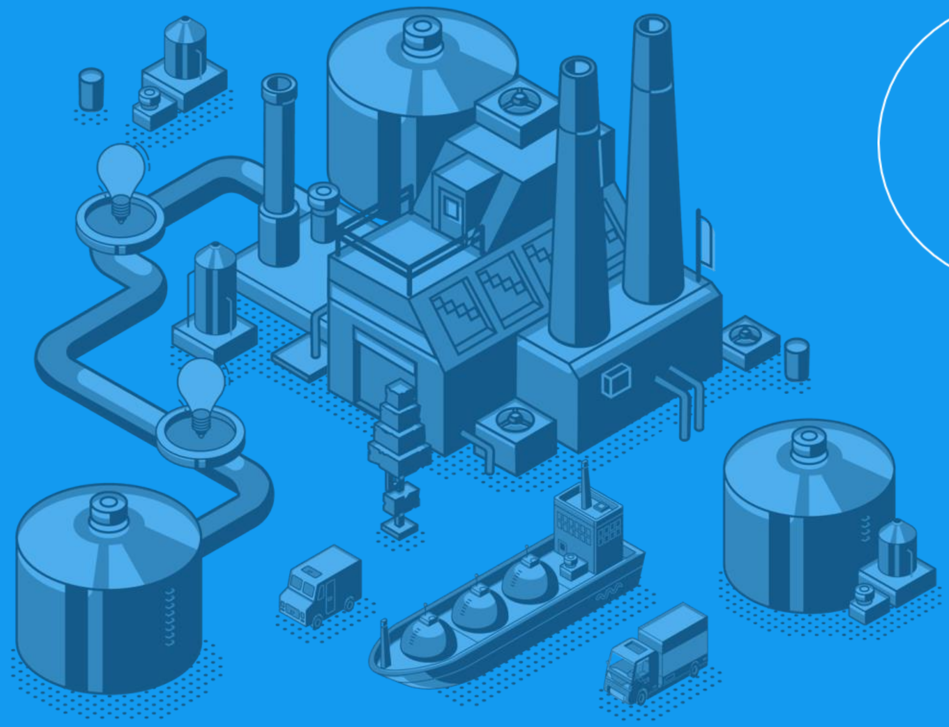

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FPS Flexible Power Systems

March 24, 2021

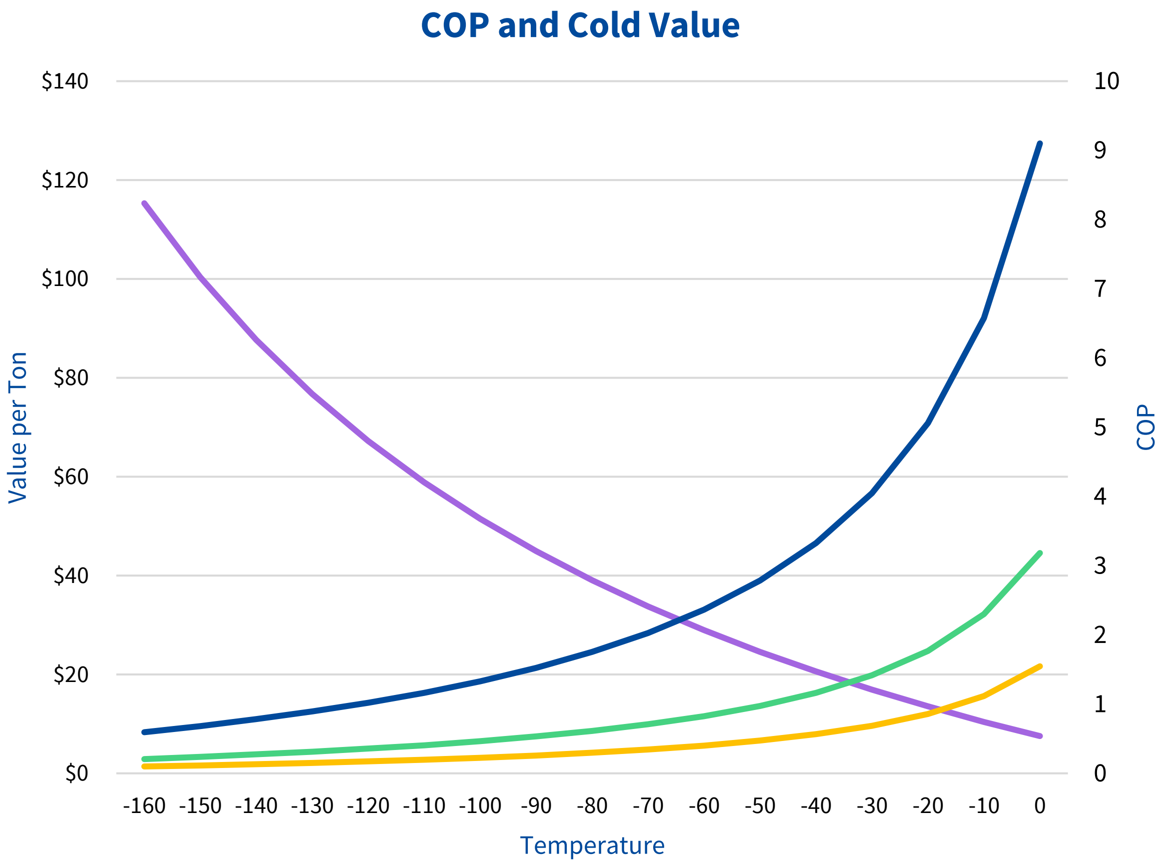
Michael Ayres, Managing Director

Example Combined Applications

Returns from cold recovery applications are a function of terminal throughput, local demand volumes (and its proximity to the terminal) and relative energy prices etc. As a result they are somewhat location specific.

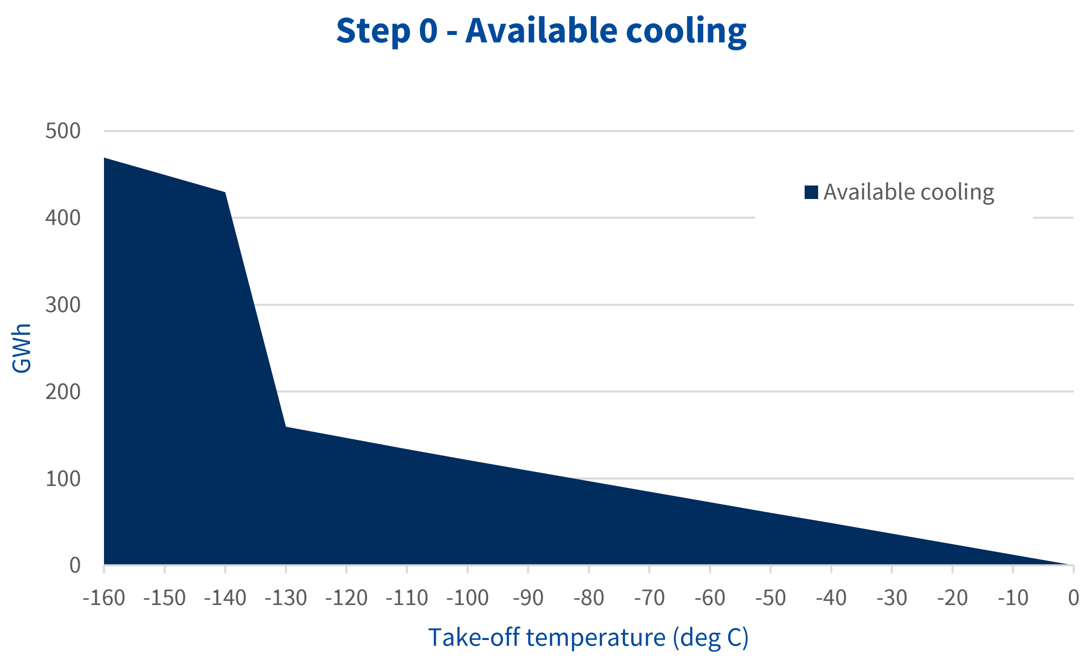
As an indication, we have constructed a hypothetical example terminal with the following metrics:

- 2MT/year LNG throughput
- Local Energy price of 10c/kWh
- Carbon intensity of electricity production 475gCO2/kWh (world avg 2018 IEA)
- Value of displaced energy determined by typical cooling equipment efficiencies at the required temperature level shown in the chart on the right



Cold Availability

Annual Cold Availability from the terminal is about 469GWh per year at a variety of grades

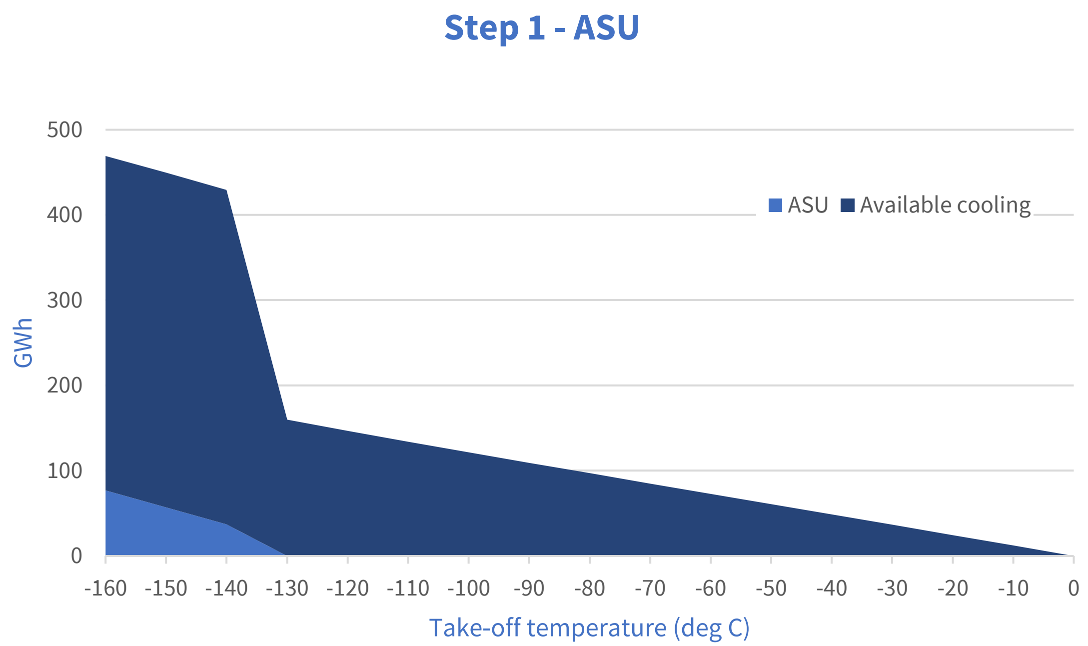


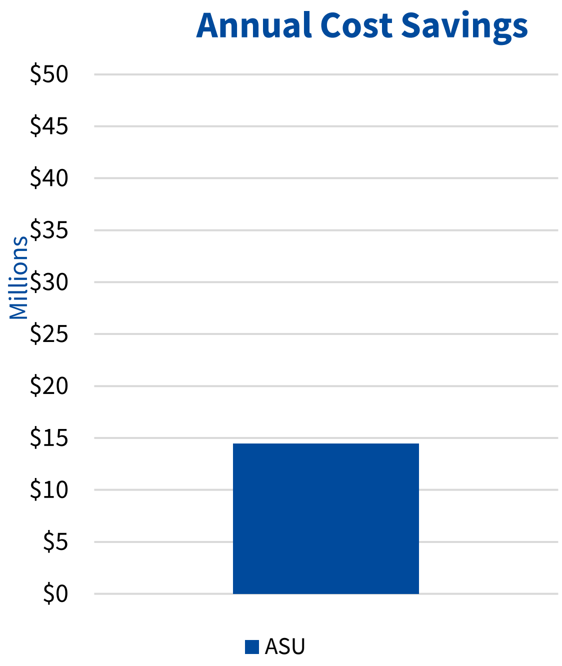
In this example we will add:

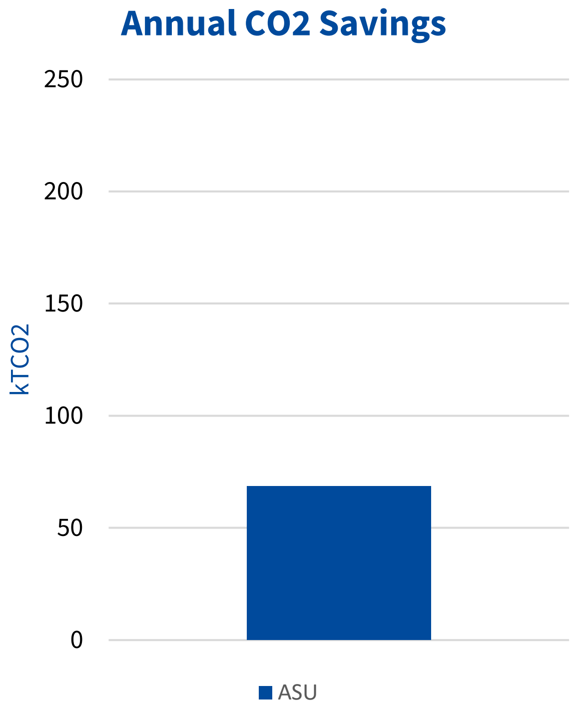
- An air separation unit
- An ethylene production plant
- A blast freezing/food processing cluster
- A temperature controlled warehouse
- A district cooling system and
- Some onsite cooling

Air Separation Unit

Co-locating a 1200T/day air separation unit makes use of a substantial proportion of the high-grade cold, with energy savings totalling ~$14m p.a.

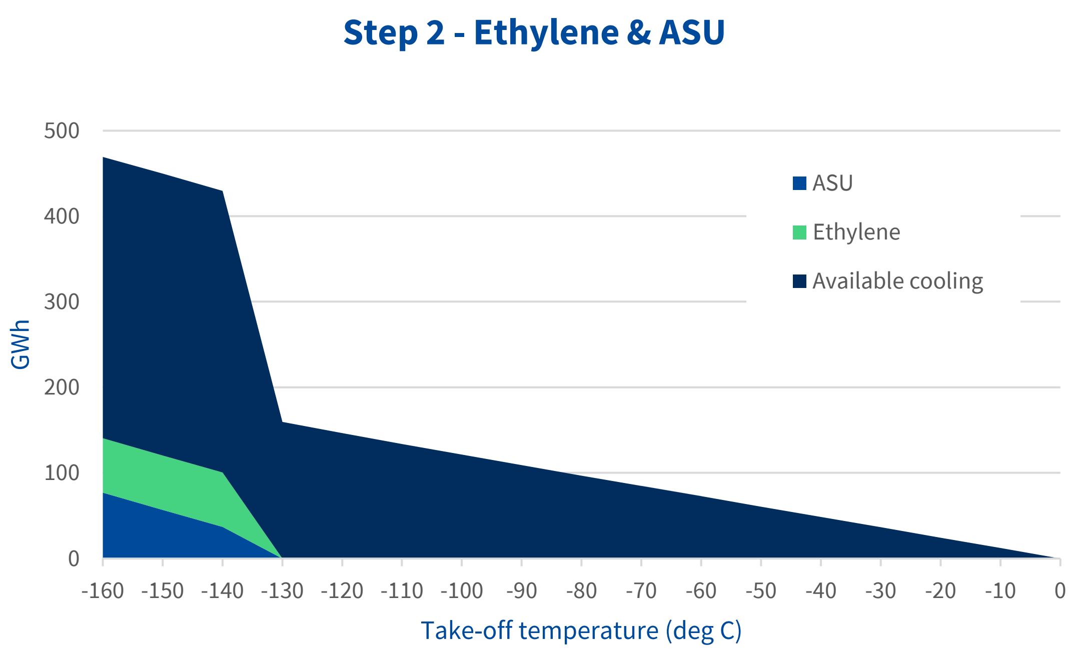


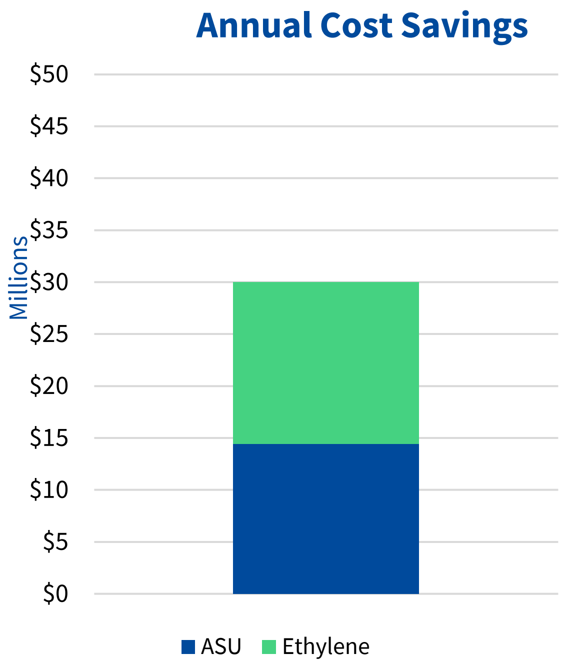


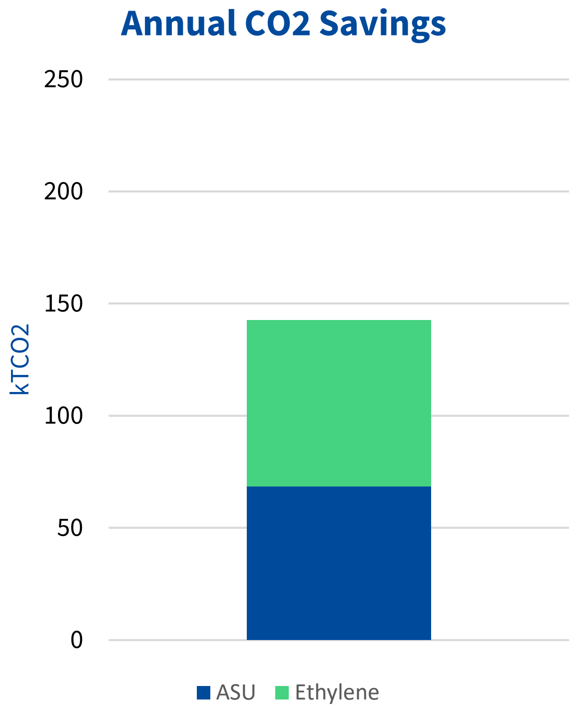


Ethylene Production

Applying remaining cooling in the -140 to -130C range to Ethylene production processes utilizes a further 64GWh of cooling p.a saving $15m p.a. in energy costs.

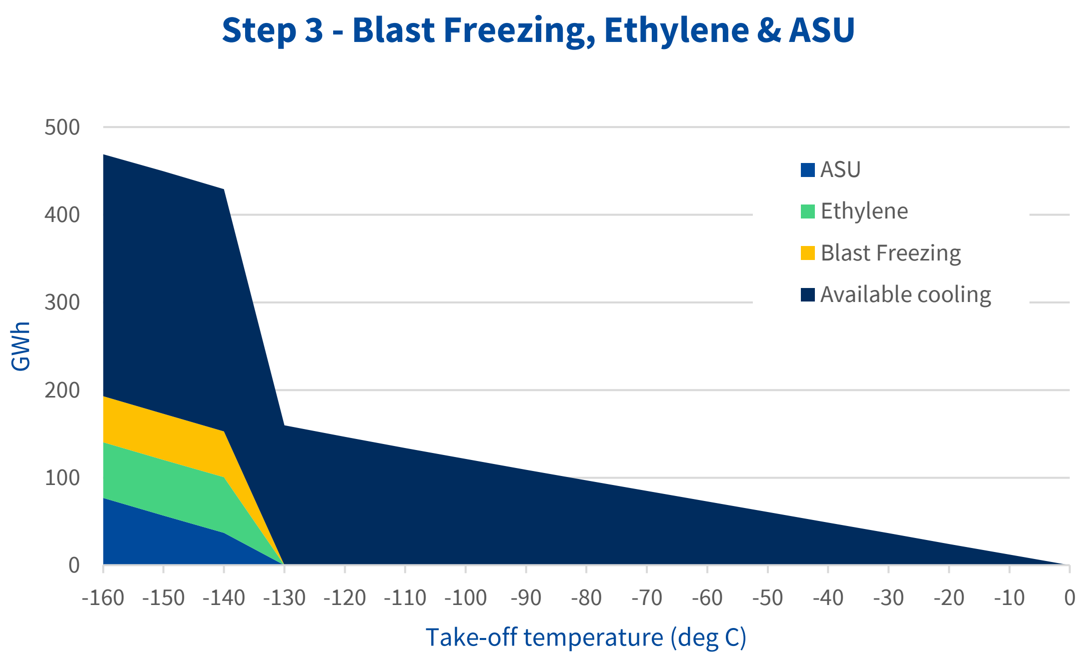


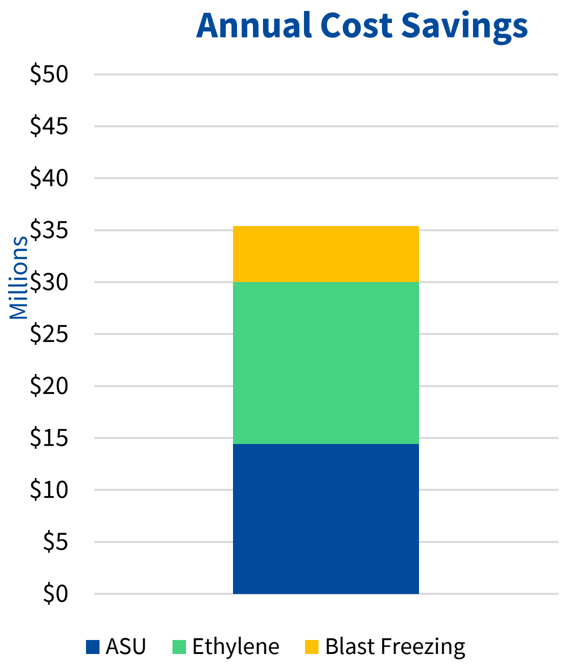


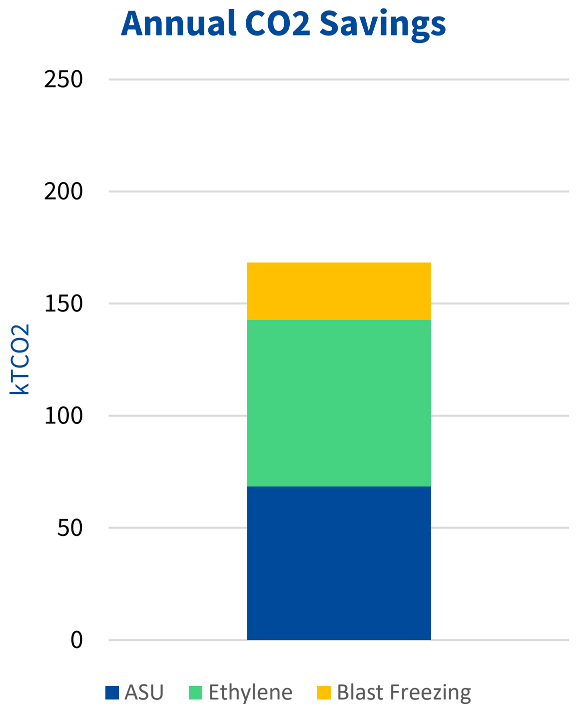


Blast Freezing

A small food processing cluster may consume about 52 GWh of cooling per year with a displaced electricity value of about $5.3m per year.







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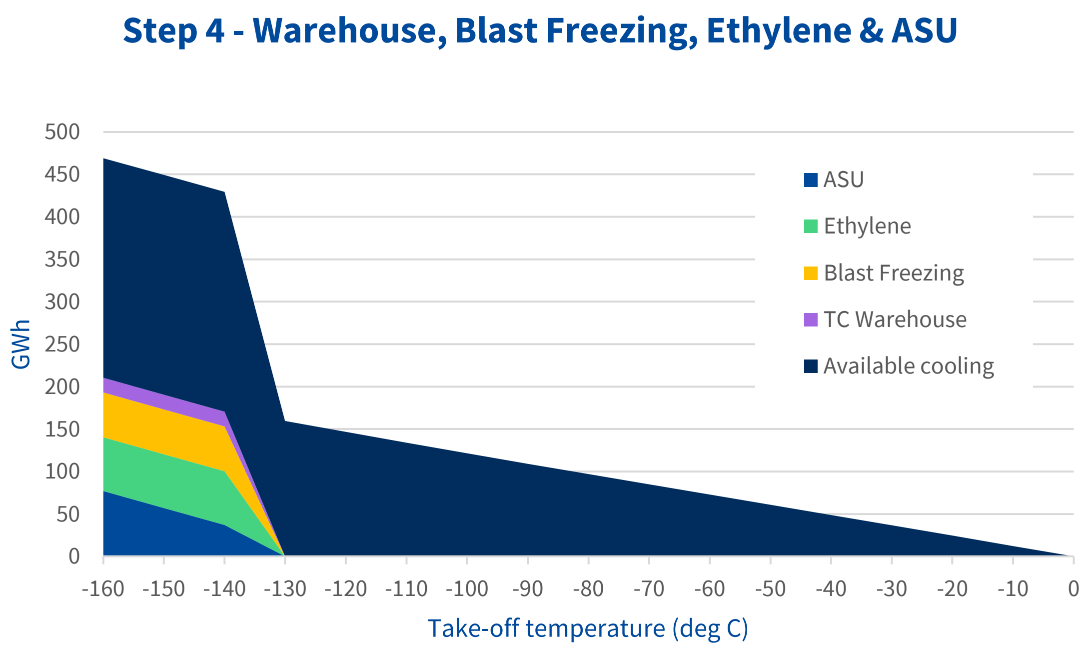
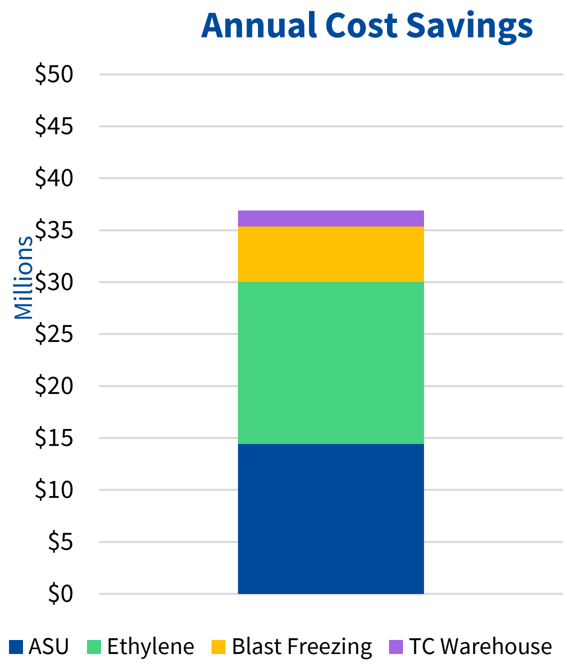
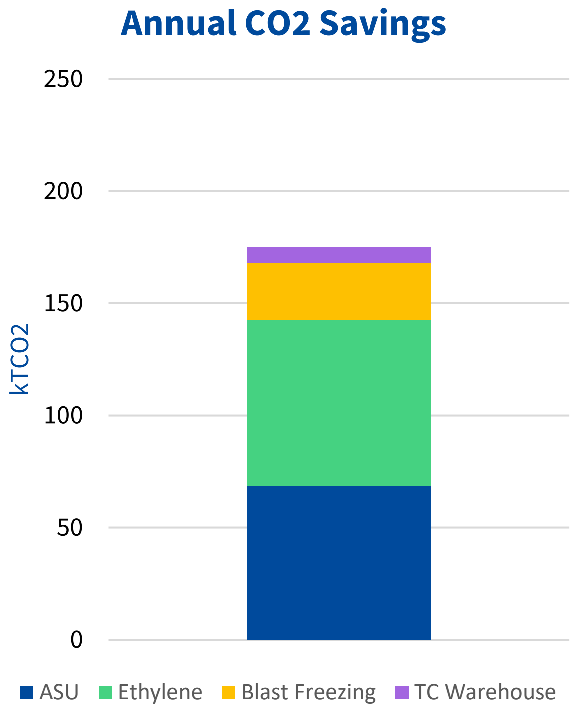
Temperature Controlled Warehouse

A 12,000 m2 warehouse may demand a further 17GWh of cooling per annum using about $1.5m p.a. to provide that cooling.







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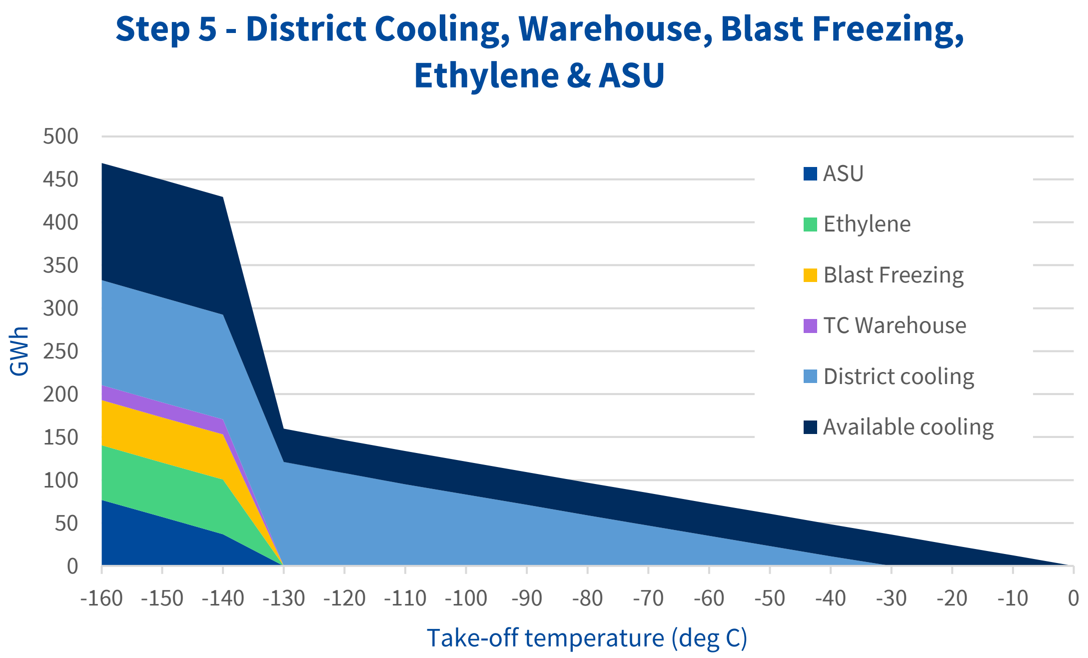
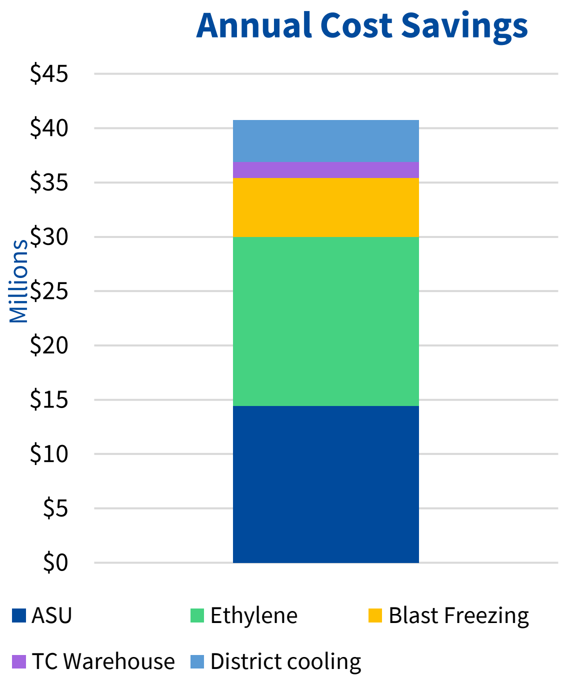
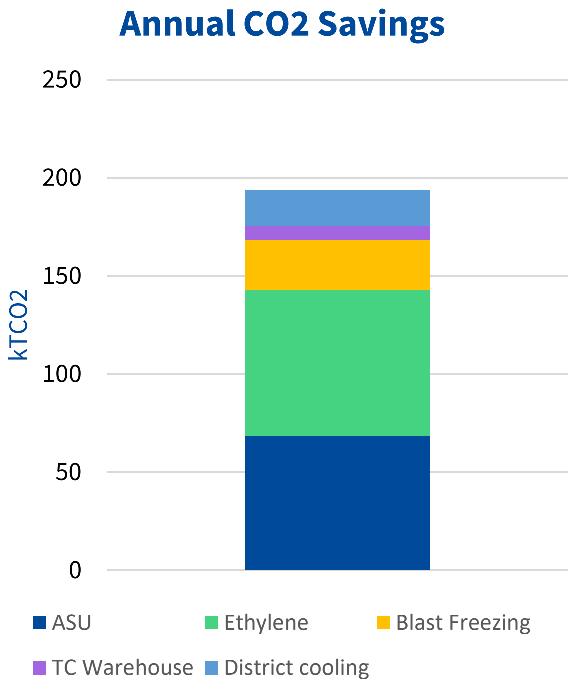
District Cooling

A district cooling system sized to provide 15,000RT of cooling would require about 122GWh of cooling per year costing about $3.8m p.a. to provide.







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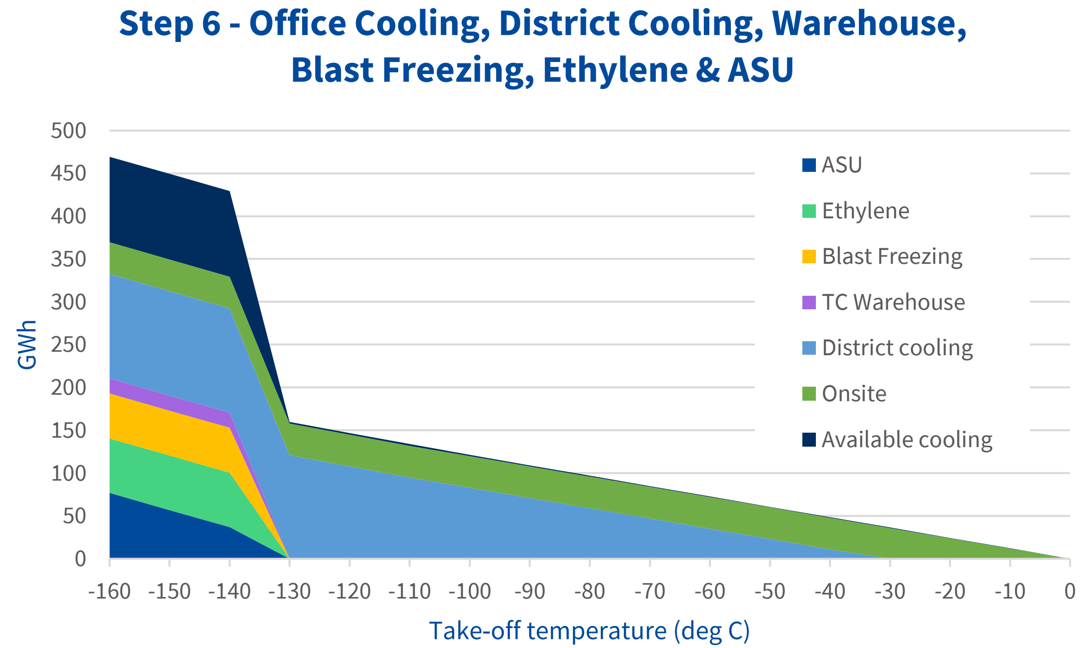
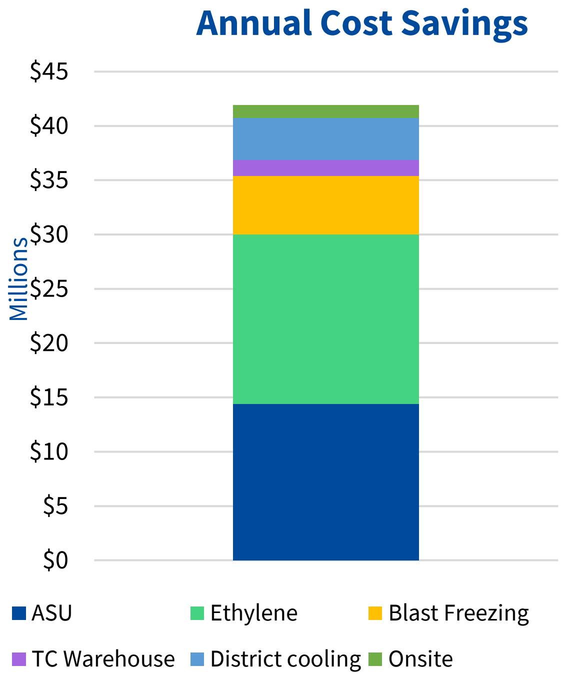
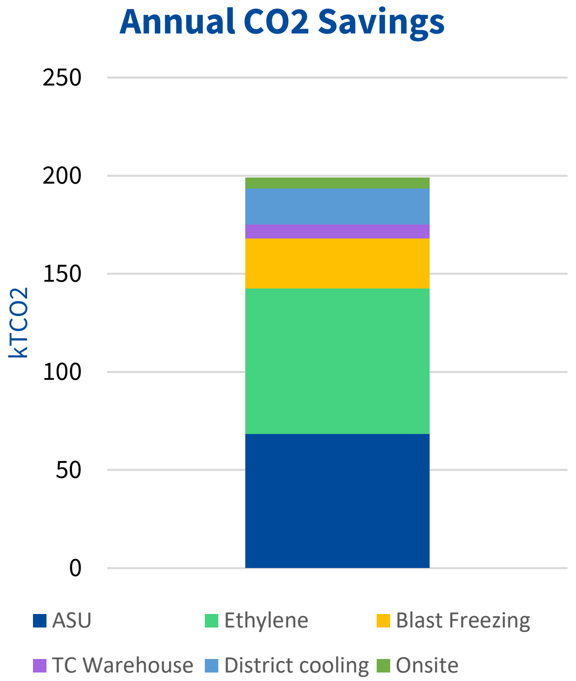
Onsite Office Cooling

Onsite cooling for offices and other processes related to the terminal could use as much as a further 36GWh of cooling avoiding about $1.1 m p.a. of electricity usage. This example accumulates to a value of $42m in energy cost savings per annum and 206kTCO2 p.a. and world average grid carbon intensity.







The combined value of this applications stack is about $21/Ton of LNG regassified.

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Packaged Gas Applications

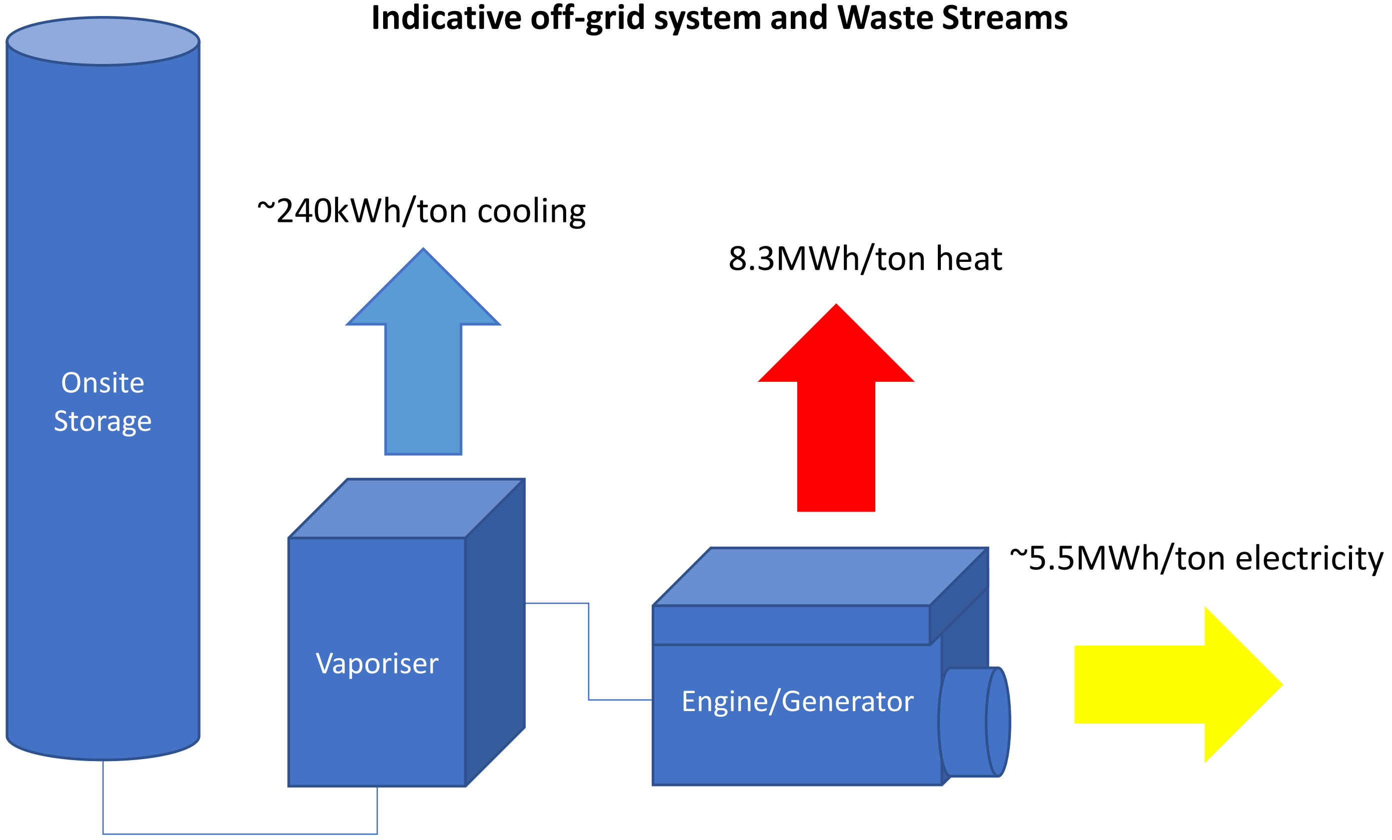
Natural gas is often distributed via pipelines at ambient temperature meaning that cold resources are available at the terminal.

However, it can be supplied to off-grid applications via tankers or iso containers as a liquid to applications like:

- CNG Truck filling stations
- Off-grid power generation
- Industrial boilers
- Drying systems

Cold recovery options will be much more location specific but could still offer benefits. Our current project will investigate the potential for this in Kochi.

Indicative off-grid system and Waste Streams



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