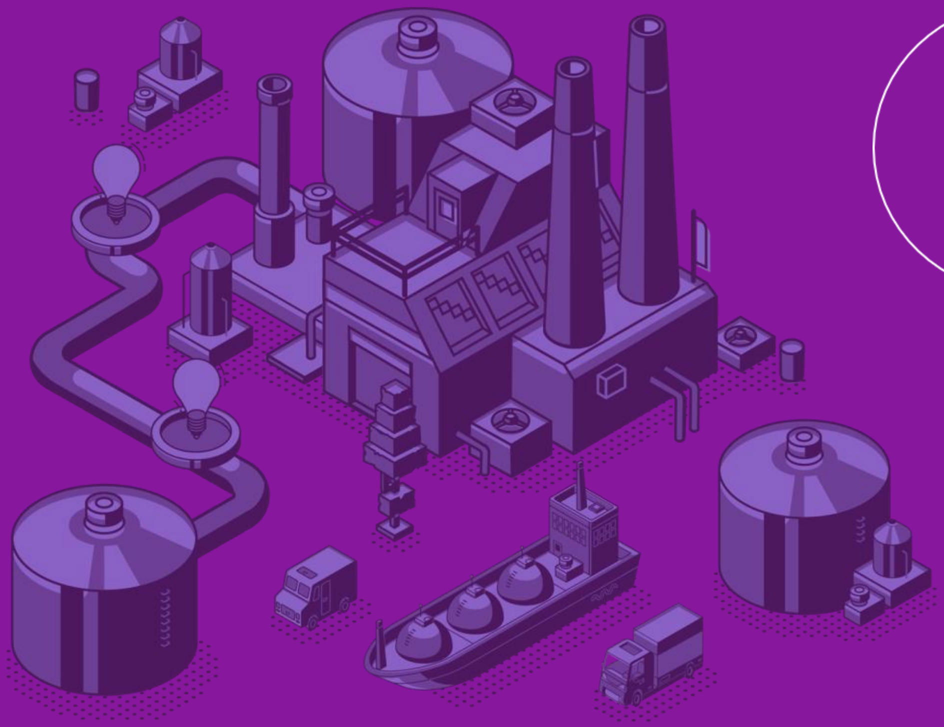
WEBINAR SERIES | LNG WASTE COLD

Session #3: Practical considerations, business models, and risks of LNG waste cold recovery



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FPS Flexible Power Systems

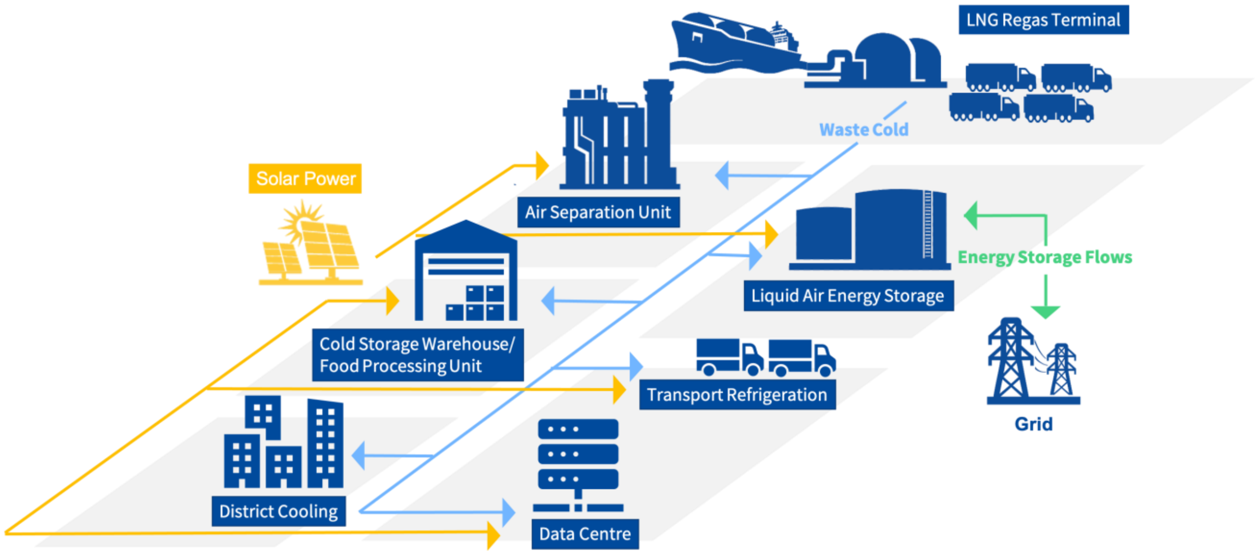
April 22, 2021

Michael Ayres, Managing Director

Practical Considerations

Effective consideration of business models requires investigation of a range of factors:

- **Technical** decisions made prior to and during your feasibility study will impact costs of off-take, vector systems and application integrations.
- **Geography** will impact what is feasible natural and human features influence the choice of applications and what is feasible.
- **Commercial** arrangements to remunerate the terminal for the cold and terms on which end users benefit from it impact deployment economics.
- **Regulatory** considerations may significantly impact how commercial arrangements can work or the cost of technical solutions.



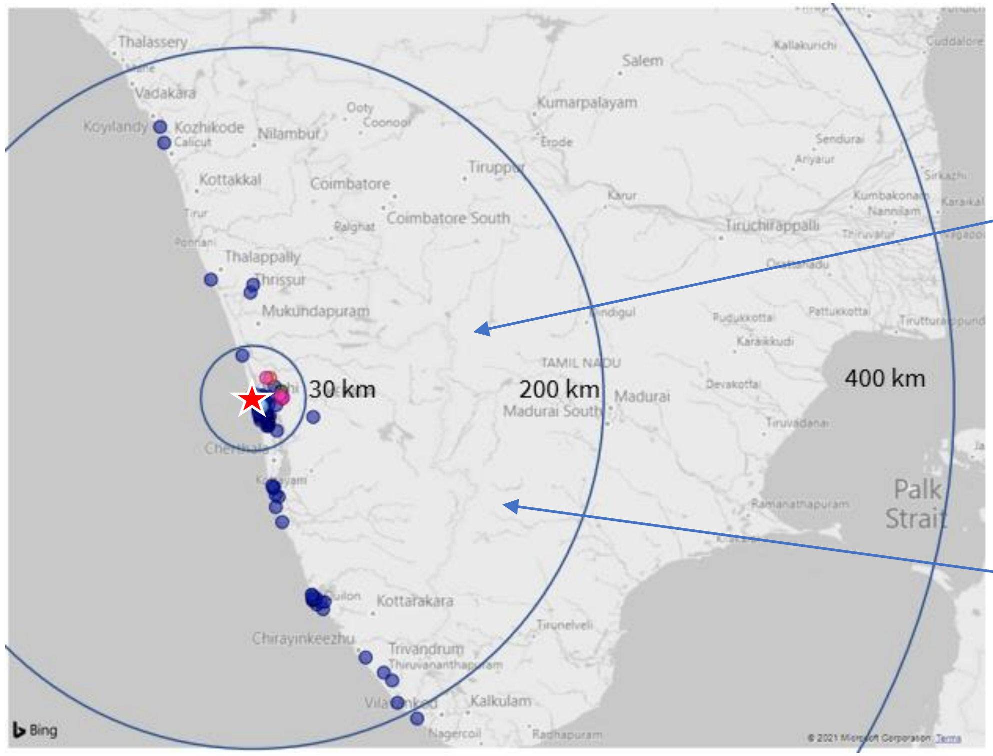
Technical

Factors can be site specific, but the table below offers a range of technical factors to consider:

Project Stage	Off-take	Vectors	Applications
Pre-Project	• Type of terminal floating vs. onshore. • Current regasification method. • LNG vs. pipeline supply • Redundancy built into vaporisers.	• Any off-take or coupling with external heat sources	• Minimum process temperatures. • Process design (e.g. refrigerant choice) • Equipment age and efficiency.
Planning	• Direct vs. indirect off-take • Co-located vs. remote processes • Interaction with existing regasification processes.	• Choice of vector • Transport type (e.g. trucks, rail or vessel vs. pipelines) • Transport conditions (e.g. temperature, flow rates or distance)	• Choice of application • Integration method (e.g. subcooling vs. direct use of cold)

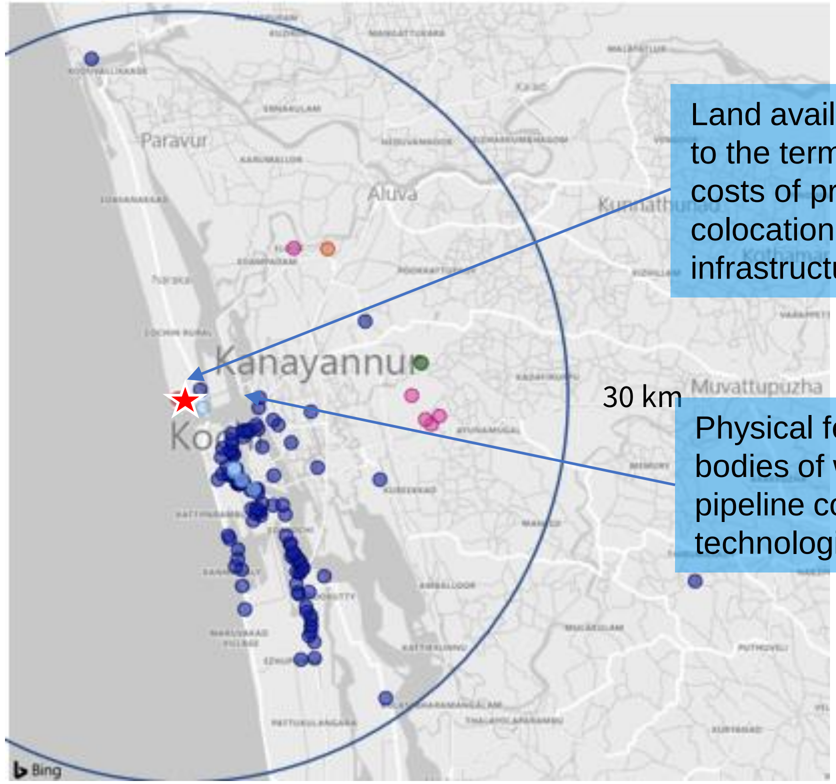
Geography

Where the terminal is and what surrounds it has a very substantial impact on the business case:



Distance to users of cold can have very substantial impacts on transport vector type

Distance to users of can also impact costs



Land availability close to the terminal impacts costs of process colocation and vector infrastructure

Physical features like bodies of water impact pipeline costs and technologies

Type ★ LNG Terminal ● TC Warehouse ● Seafood Processing ● Data Centre ● Power Station ● Industry Facilities

Commercial

Commercial arrangements at each step of the process can have substantial implications for the relative costs vs. a business as usual implementation.

Terminal Operations

- Send out rates and supply. arrangements
- Investment costs and structure for offtake.
- Payment arrangements for waste cold.
- Avoided regas costs.

Vectors

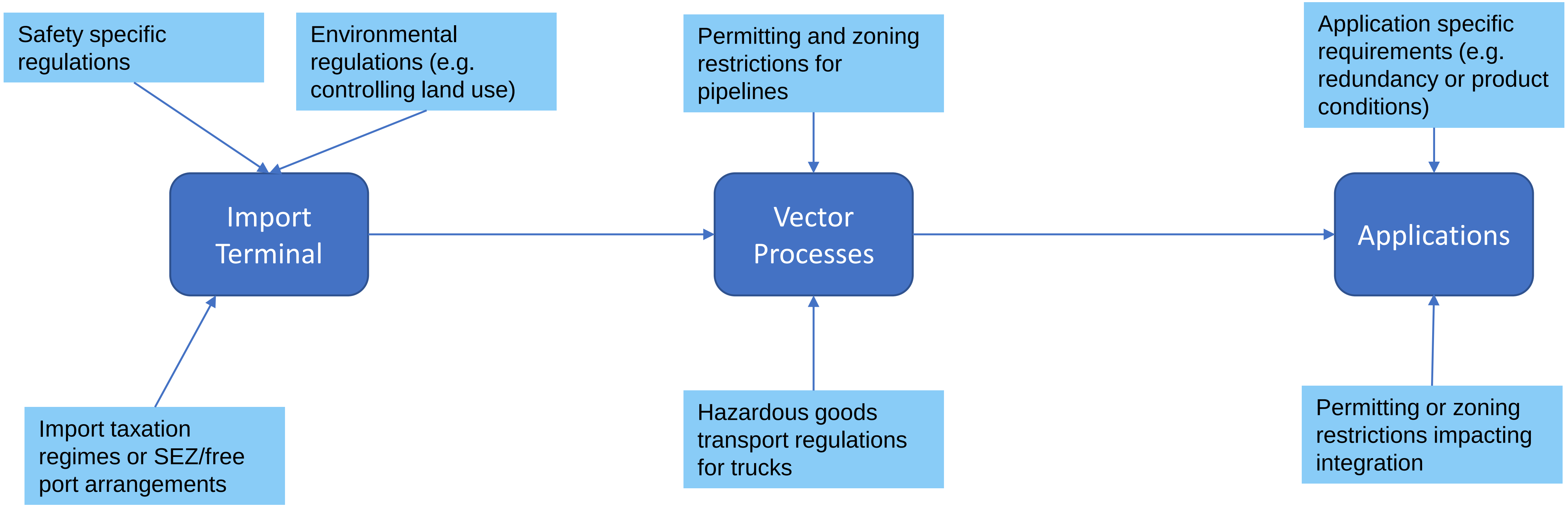
- Investment costs, structure and cost recovery.
- Recurring cost structure and recovery.
- Ownership model vs. other stakeholders.

Applications

- Current application cost base (especially energy costs).
- Integration investment costs, structure and recovery.
- New build vs. greenfield locations.

Regulatory considerations

LNG import terminals are strategic national assets importing $billions worth of energy products and so are often heavily regulated. Regulatory issues and permitting can have substantial impacts on project feasibility. Some examples are given below:



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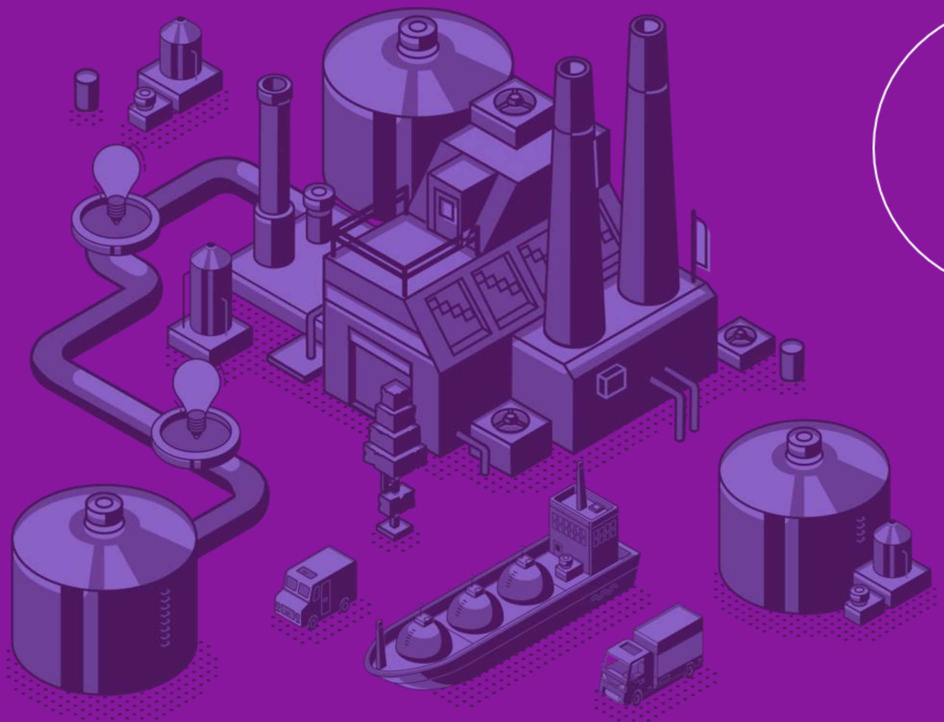

April 22, 2021

System-level approaches for recovering the waste cold from LNG

Dr John M Andresen & Prof M. Mercedes Maroto-Valer

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1 Technical and commercial requirements

1.1 Two LNG regasification terminals in Malaysia

1.2 System integration for cooling data centres

2 Realising the opportunity: Systems approach

1.1 Two LNG regasification terminals in Malaysia

Sungai Udang Melaka (RGTSU) and Pengerang Johor (RGTPJ)

Item	RGTSU	RGTPJ
Facilities		
Jetty	Offshore LNGC size:130,000–220,000 m^3 Maximum unloading rate = 10,000 m^3/h	Onshore LNGC size:5000–260,000 m^3 Maximum unloading rate = 14,000 m^3/h
Storage	2 units 130,000 m^3 (FSRU)	2 units 200,000 m^3 full containment and LNG tank
Vaporization Scheme	IFV with propane as an intermediate fluid and the heating medium is seawater	ORV with sea water as the heating medium
Capacity	3.8 MTPA (500 mmscfd)	3.5 MTPA (490 mmscfd)

Techno Economic Evaluation of Cold Energy from Liquefied Natural Gas Regasification Terminals

- Great sustainable and technical potential of using the available cold energy for space and industrial process cooling to replace fossil NG.
- For a 20-year project life, an internal rate of return (IRR) of up to 33% and 17% for RGTPJ and RGTSU, respectively.
- Cryogenic LNG containers proposed as low-risk pathway to introduce solution.

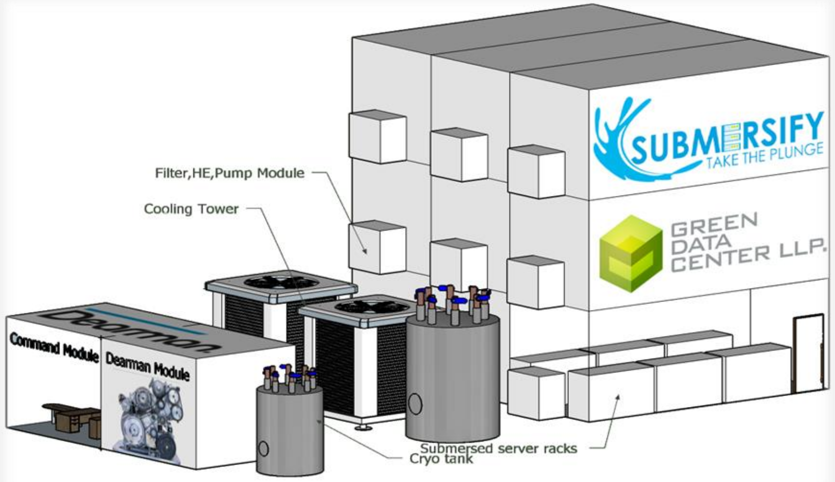
Energies 2019, 12, 4475; doi:10.3390/en12234475

It was recommended that the owners of RGTPJ and RGTSU should consider installing systems able to capture the waste cold energy during regasification of LNG at both terminals

1.2 System integration for cooling data centres

Reduction of energy consumption and greenhouse gas emissions

- Sustainable computing through innovative cooling and power generation.
- Successfully demonstrated the technology at a business park outside Kuala Lumpur: nine 20-foot containers, totalling 216m^3 and submerging 2,268 servers.
- 50% reduction in cooling energy consumption, saving 740 tonnes CO_2 annually and the potential for creating South East Asia's largest data centre.
- Great potential for using existing cooling systems.



"Next Generation Green Data Centres for Environmental and Business Sustainability"
Newton Malaysia-UK Research and Innovation Bridges

https://doi.org/10.1016/j.apenergy.2019.05.029

IET The Institution of Engineering and Technology Innovation Awards Finalist 2019

Global AWARDS 2017 Finalist IChemE

UTM UNIVERSITI TEKNOLOGI MALAYSIA

Dearman.

GREEN DATA CENTER LLP.

HERIOT WATT UNIVERSITY 200 Years

2 Realising the opportunity: Systems approach

Challenges	Opportunities
Temporal limitation: LNG regasification process and cold demand during peak / off peak	**Technological innovation** required for cold energy storage, e.g. phase change materials
Spatial limitation: consideration of proximity of cold energy users and the LNG terminal	**Development of intelligent control system** for cold energy distribution and utilisation
Exergy gap analysis: optimisation of source and sink must be optimised for efficient use	**Building sustainable cold chain** that demand cooling and generating waste heat

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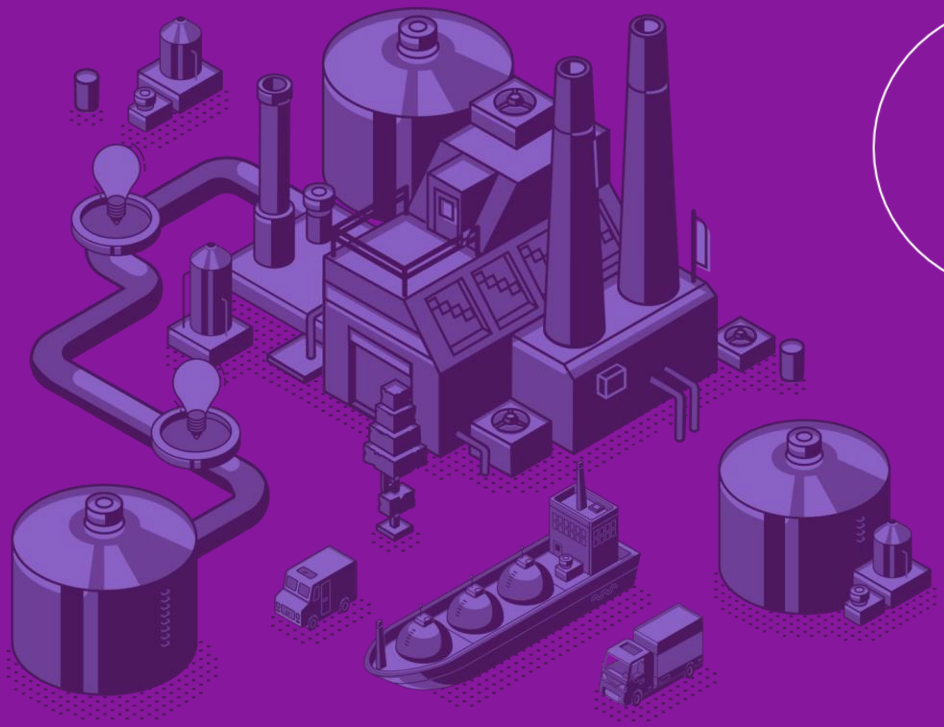
Session #3:
How to quantify social and environmental benefits from LNG waste cold recovery



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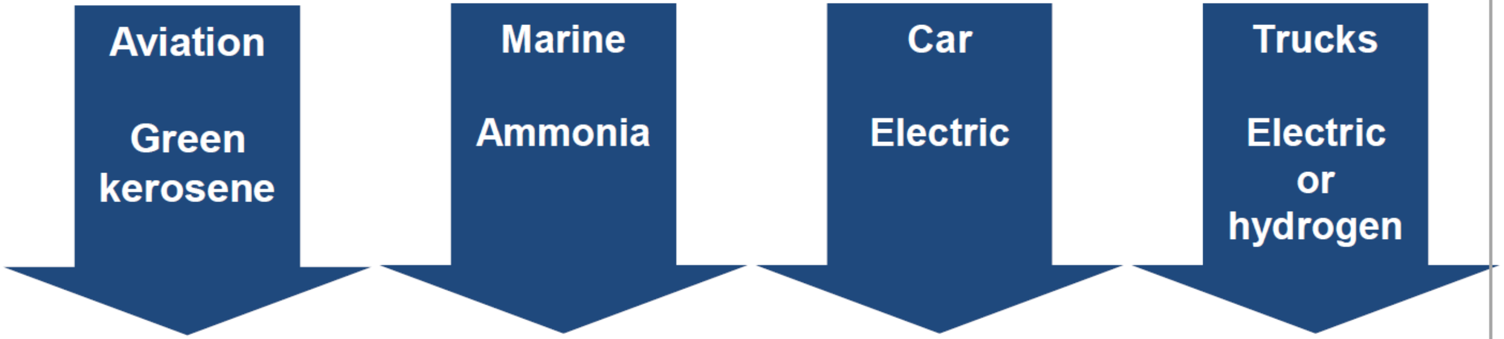
Professor Rob Morgan,
University of Brighton

Taking a system view is necessary but not easy!

Top down energy system led view – limited solutions per sector



Led by macro energy system constraints

(Over) simplification of market and technology fit

Very reliant on the fidelity of the system model (eg consideration of LCA effects)

Reconciliation of both approaches is needed to guide effective policy

Bottom up propulsion technology led view – multiple solutions per sector

Led by market needs and technology fit

Siloed, risk of double counting of available sustainable energy resources

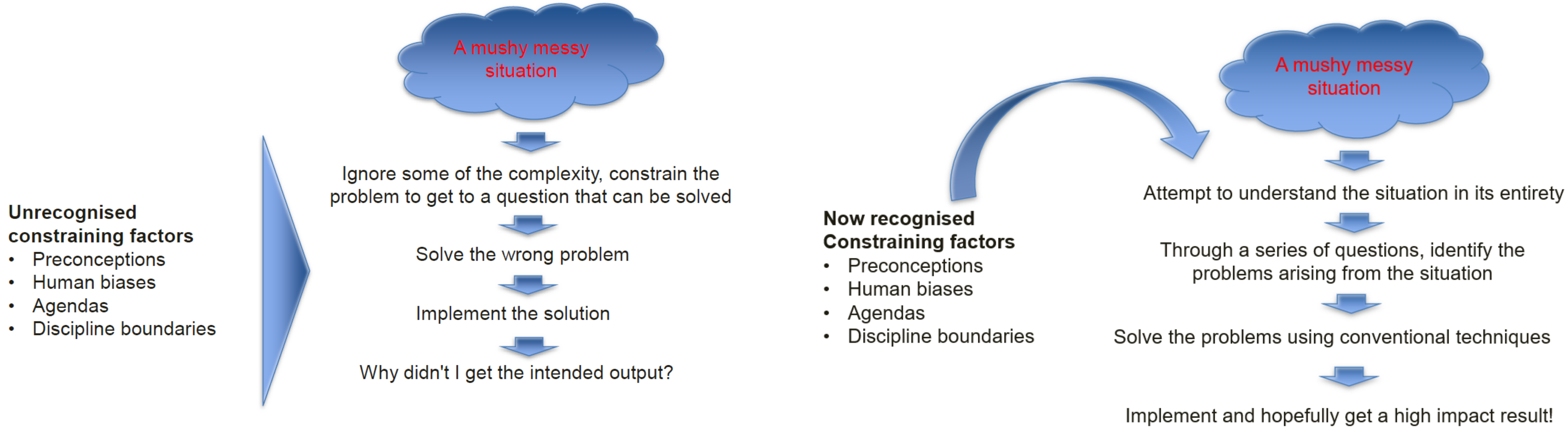
Does not consider system balancing effects

https://www.apcuk.co.uk/planning-future-automotive/spokes/transport-energy-network

The cold chain has features of a wicked problem

- Classic examples of wicked problems include economic, environmental, and political issues.
- A problem whose solution requires a great number of people to change their mindsets and behaviour is likely to be a wicked problem.
- These include global climate change, pandemic influenza, nuclear weapons, waste and social injustice.

https://en.wikipedia.org/wiki/Wicked_problem



The cold that turns NG to LNG is essentially packaging that can be upcycled

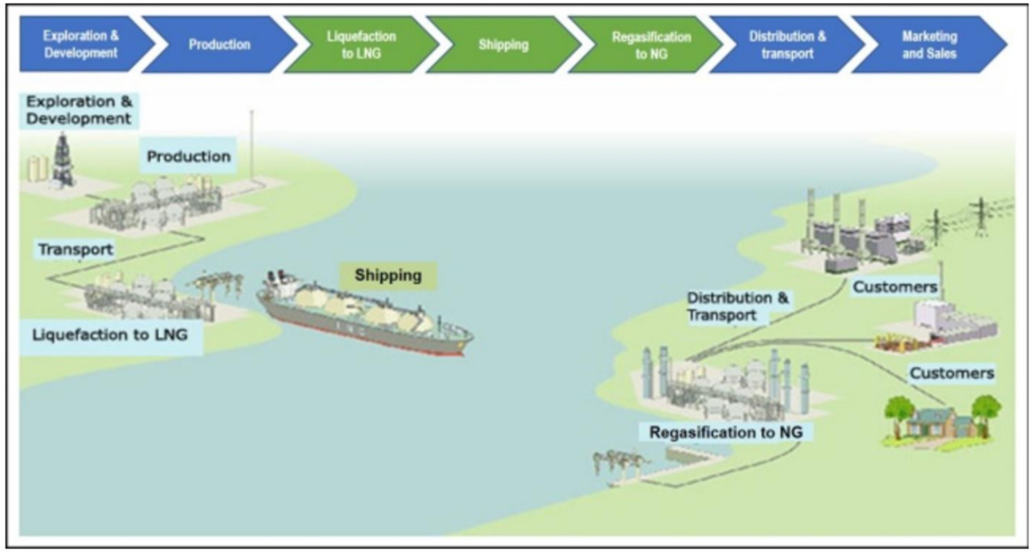
Make the investment
Supply the energy
Clean up the pollution

The cold is essentially packaging for the NG
Can the customer 'upcycle' the cold and unlock economic and environmental value?

https://www.ownerteamconsult.com/overview-of-the-lng-industry/
Adapted from Oman LNG, 2020

The environmental impact of the cold chain must be correctly accounted probably across national boundaries

Increase in the value of the LNG but not the cost



Danger of ‘off shoring’ pollution and carbon emissions

Grid balancing

Food distribution

Efficient clean propulsion for freight

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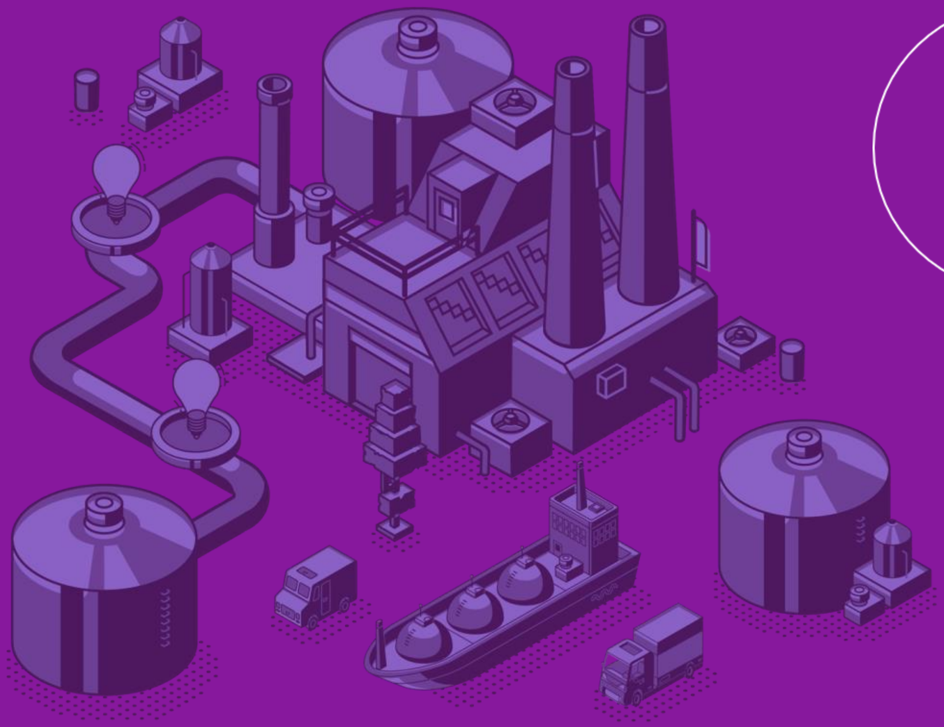

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April 22, 2021

Assoc. Prof. Alessandro Romagnoli

Welfare improvements of LNG cold utilization

Assoc. Prof. Alessandro Romagnoli

Recovering cold energy from LNG would:

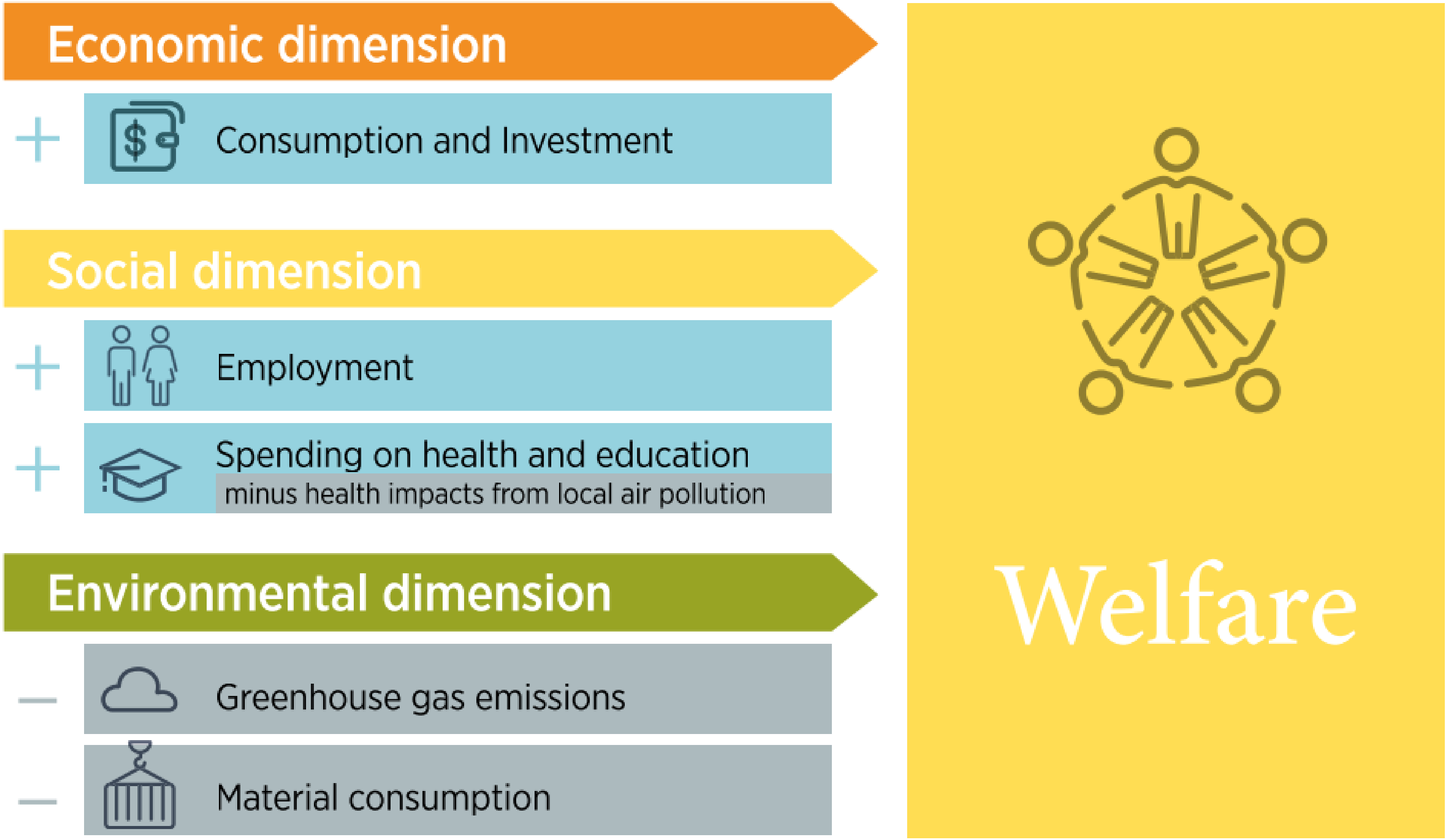
Create extra revenue through power generation and provide cold energy, reduce the cost of producing certain products, increase investments

Create jobs in the energy systems related to LNG cold recovery

Reduce the spending on health due to improved air quality

Significantly reduce the GHG emissions

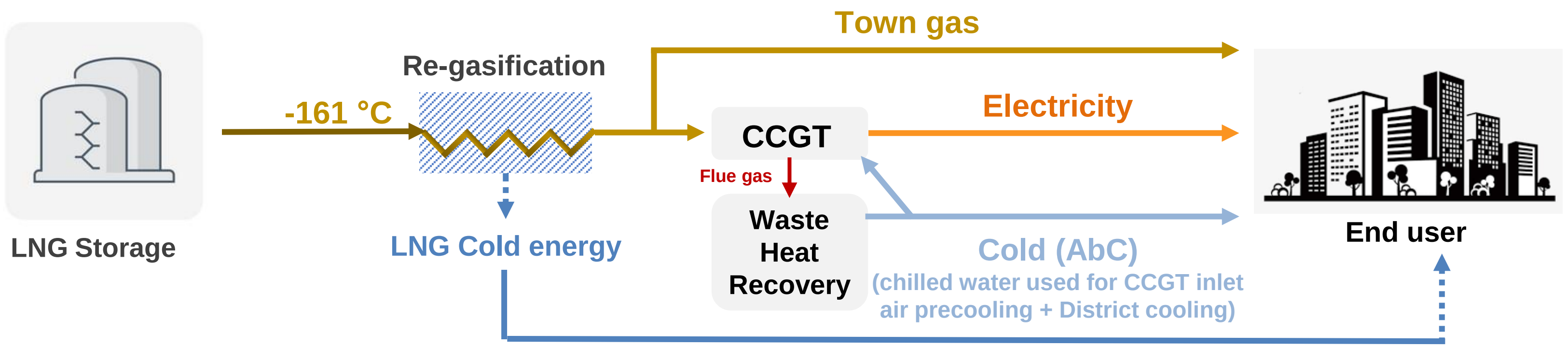
Reduce the consumption of fossil fuels



Welfare improvements – key dimensions Economic, IRENA (2017a), "Chapter 3: Global Energy Transition Prospects and the Role of Renewables", In International Energy Agency and IRENA (Eds.), Perspectives for the Energy Transition: Investment Needs for a Low-carbon Energy System, pp. 121-189, OECD/IEA and IRENA, Paris and Abu Dhabi.

Case study: LNG Cold energy for deep freezing

Assoc. Prof. Alessandro Romagnoli



Economic dimension

+ Consumption and Investment

LNG Chemical energy used for:		LNG Cold energy used for:
CCGT	Absorption chiller (AbC)	Deep freezing

Investment due to the construction

- Evaluate the **investment cost** of the system
- Evaluate the **savings of the investment cost** of the power generation / refrigeration system that can be replaced by this system

Profit from extra power generation

- Calculate the cold energy demand for inlet air precooling
- Evaluate the CCGT efficiency vs. inlet air temperature
- Calculate the **extra power generation and its value** from local electricity tariff

Profit from extra cooling energy production (7°C)

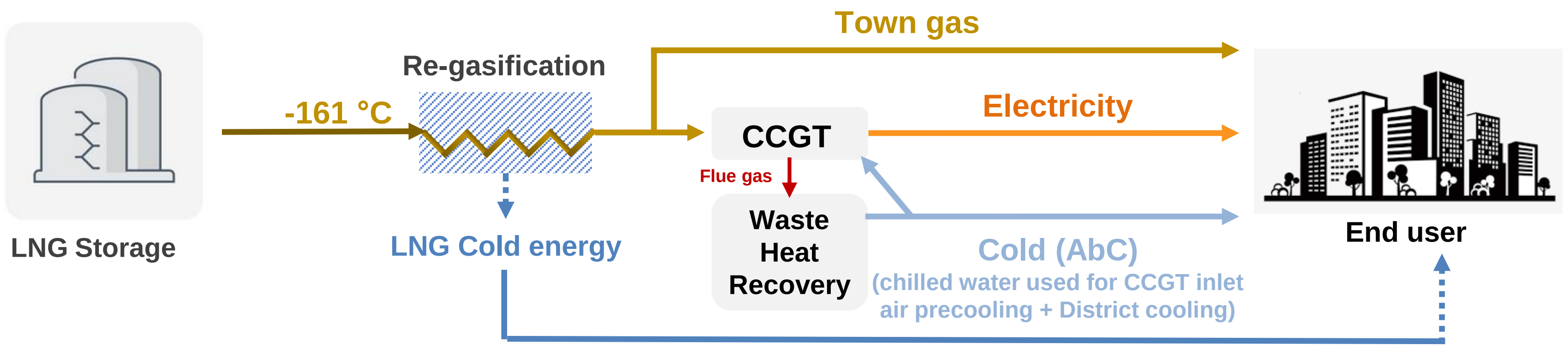
- Evaluate the waste heat from the CCGT
- Estimate the COP of the Absorption chiller to calculate the extra cold production
- Estimate the local COP_{ave} @ 7°C to calculate the **economic value of the cold produced**

Profit from extra deep cold production (-78°C)

- Evaluate available LNG cold energy
- Estimate the local COP_{ave} @ -78°C to calculate **economic value of the deep cold produced**

Case study: LNG Cold energy for deep freezing

Assoc. Prof. Alessandro Romagnoli



LNG Chemical energy used for: CCGT | Absorption chiller (AbC)

LNG Cold energy used for: Deep freezing

Employment increase for the construction of such a system

- Estimate the local employment level of energy project construction
- Evaluate the investment cost of the system to estimate the **employment increase** due to the **construction** of such an energy system

Employment increase for the operation/ maintenance of such a system

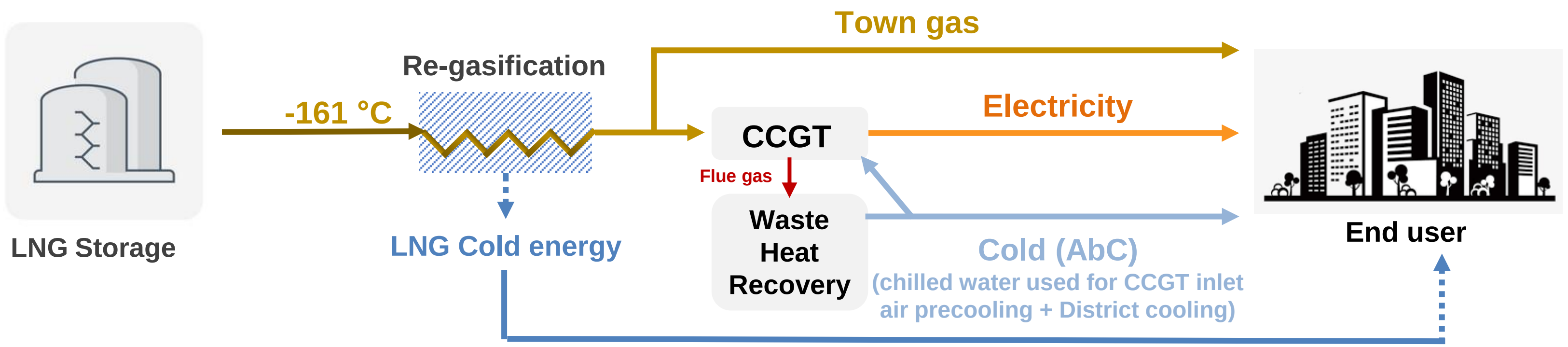
- Estimate the local employment level of energy project maintenance/operation
- Evaluate the investment cost of the system to estimate the **employment increase** due to the **operation/maintenance** of such an energy system

Minus health impacts from local air pollution

- Estimate the local health spending vs. air quality
- Evaluate the fossil fuel reduction from electricity saving and efficiency enhancement
- Evaluate the **air quality improvement** from the fuel consumption reduction

Case study: LNG Cold energy for deep freezing

Assoc. Prof. Alessandro Romagnoli



Environmental dimension

Greenhouse gas emissions

LNG Chemical energy used for:		LNG Cold energy used for:
CCGT	Absorption chiller (AbC)	Deep freezing

CO2 emission reduction from extra power generation

- Estimate the local emission factor for power generation
- Evaluate the **CO_2 emission reduction** by the **extra power generation** from CCGT inlet air pre-cooling

CO_2 emission reduction from extra cooling energy production (7°C)

- Estimate the local emission factor for power generation
- Evaluate the **CO_2 emission reduction** from **electricity saving** to produce cold energy @ 7°C

CO_2 emission reduction by the extra deep cold production (-78°C)

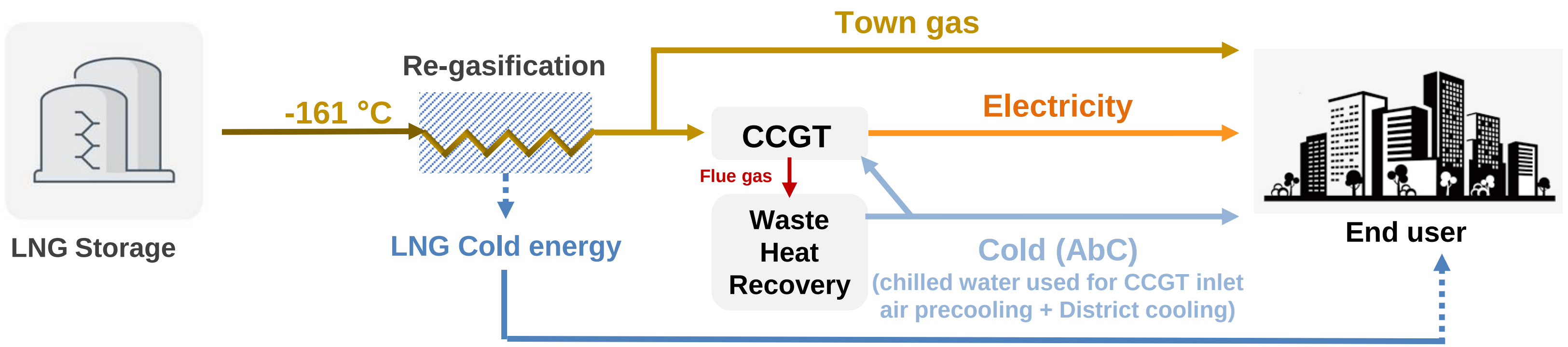
- Estimate the local emission factor for power generation
- Evaluate the **CO_2 emission reduction** from **electricity saving** to produce cold energy @ -78°C

HFC emission reduction from refrigeration system replacement

- Evaluate the amount of refrigeration system saved
- Estimate the average local HFC leakage rate
- Calculate the **HFC emission reduction**

Case study: LNG Cold energy for deep freezing

Assoc. Prof. Alessandro Romagnoli



Environmental dimension

– Material consumption

LNG Chemical energy used for: CCGT | Absorption chiller (AbC)

LNG Cold energy used for: Deep freezing

Fossil fuel reduction from extra power generation

- Estimate the local fuel consumption for power generation
- Evaluate the **fossil fuel reduction** by the **extra power generation** from CCGT inlet air pre-cooling

Fossil fuel reduction from extra cooling energy production (7°C)

- Estimate the local fuel consumption for power generation
- Evaluate the **fossil fuel reduction** from **electricity saving** to produce cold energy @ 7°C

Fossil fuel reduction by the extra deep cold production (-78°C)

- Estimate the local fuel consumption for power generation
- Evaluate the **fossil fuel reduction** from **electricity saving** to produce cold energy @ -78°C

Material reduction from refrigeration system replacement

- Evaluate the amount of refrigeration system saved
- Estimate the material needed for the chillers
- Calculate the chiller **material reduction** from **refrigeration system replacement**

Risks

We have developed a risk register.

The major risks are around forward security of LNG flows – demand or political.

Given the additional wins from harnessing waste cold, de-risk and project extension tool LNG projects

=> Alongside business model, need to fully understand and optimise <u>and evidence</u> the environmental and societal wins.

Technical	Oversizing capacity	Green
	Lack of inadequate infrastructure	
	Lack of flexibility	
Operational	LNG Import Terminal	Green
	Lack of skilled resource	
	Poor reliability and performance	
Commercial	Demand insufficiency	Amber
	Lack of customer interest	
	Not fit for market	
	Lack of business case for LNG cold recovery	
	Variations in Gas Throughput	
	Potential unfairness	
Technology, Geo-politics	Failure to quantify real level of emissions	Green
	Political unrest in some of the countries importing/exporting LNG	
Political & Regulatory	Lack of policy support	Amber
	New costs	
	Changes in energy policy / economics	
	Misalignment to the political and developmental goals and targets	
	Incompatibility between LNG and net-zero 2050	
	Impossibility of co-locating facilities/customers next to the LNG terminal (regulatory constraints/any possibility to be relaxed?)	

Green = Manageable / Mature solutions
Amber = Risks to be resolved

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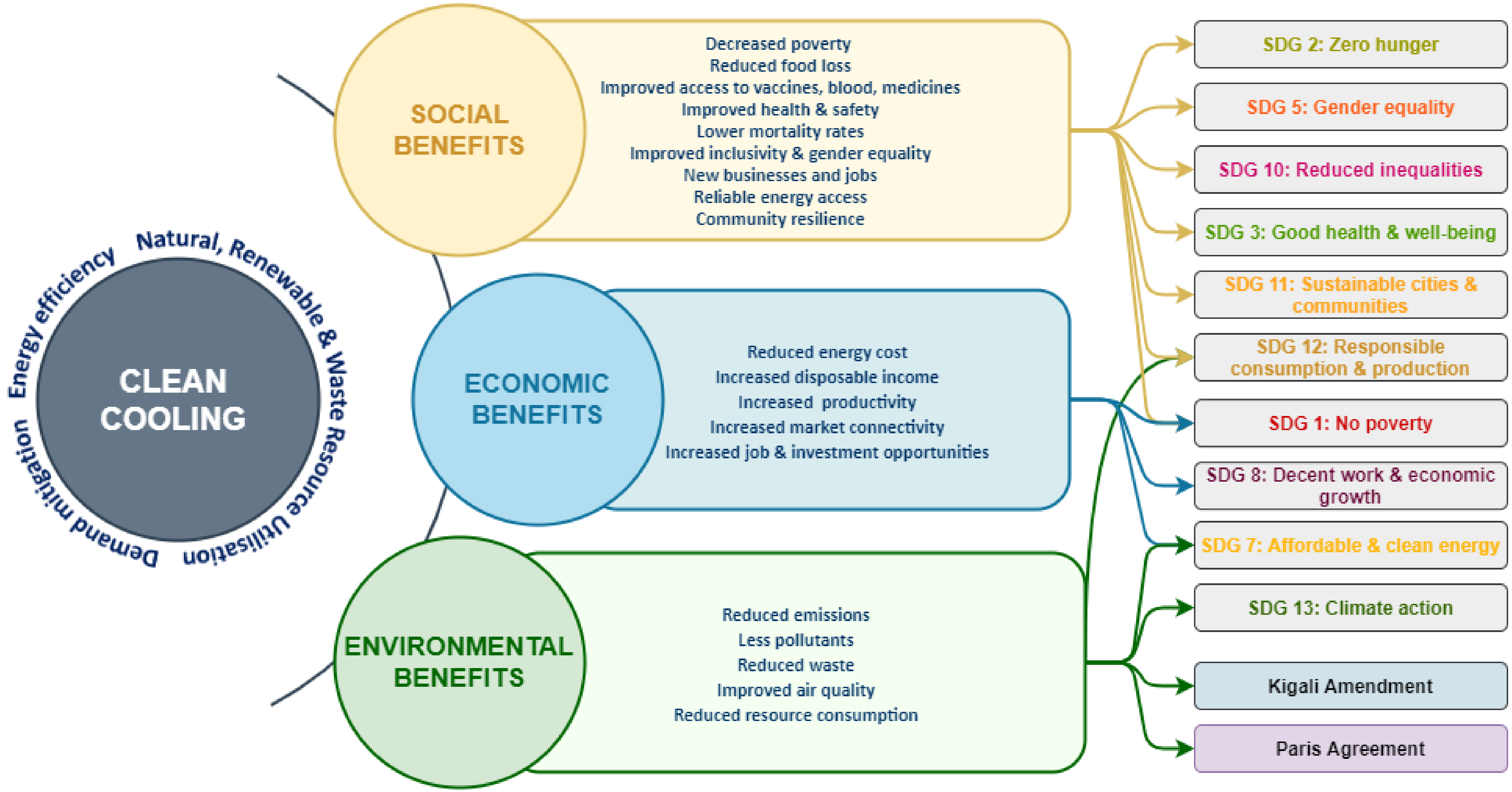
Clean Cooling - SDGs



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