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Integrated Solar Combined Cycle Power Plant using Organic Rankine Cycle for reliable, dispatchable, low carbon electricity

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Introduction

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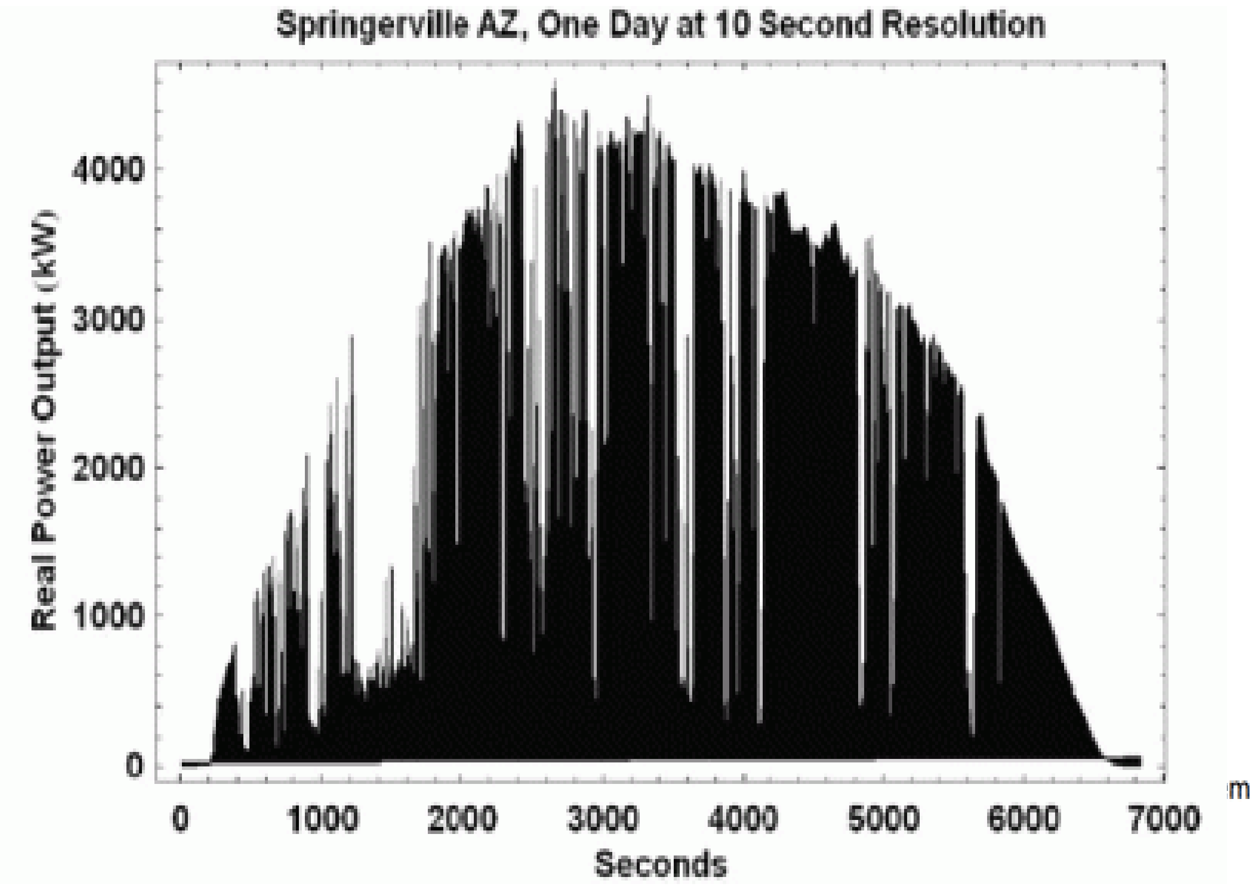
Decarbonization, Decentralization, Digitalization

- Increasing deployment of intermittent renewable energy, especially in power generation

- Intermittency creates integration issues:
  – Predictable variations
  – Less predictable variations
  – Not *'the'* solution, certainly without storage
  – Retirement or new operating regimes for fossil fuel assets
  – Fast response required from other generation sources
  – Reduced system inertia



Renewables have a major role to play in decarbonizing energy production in an economic manner

Introduction

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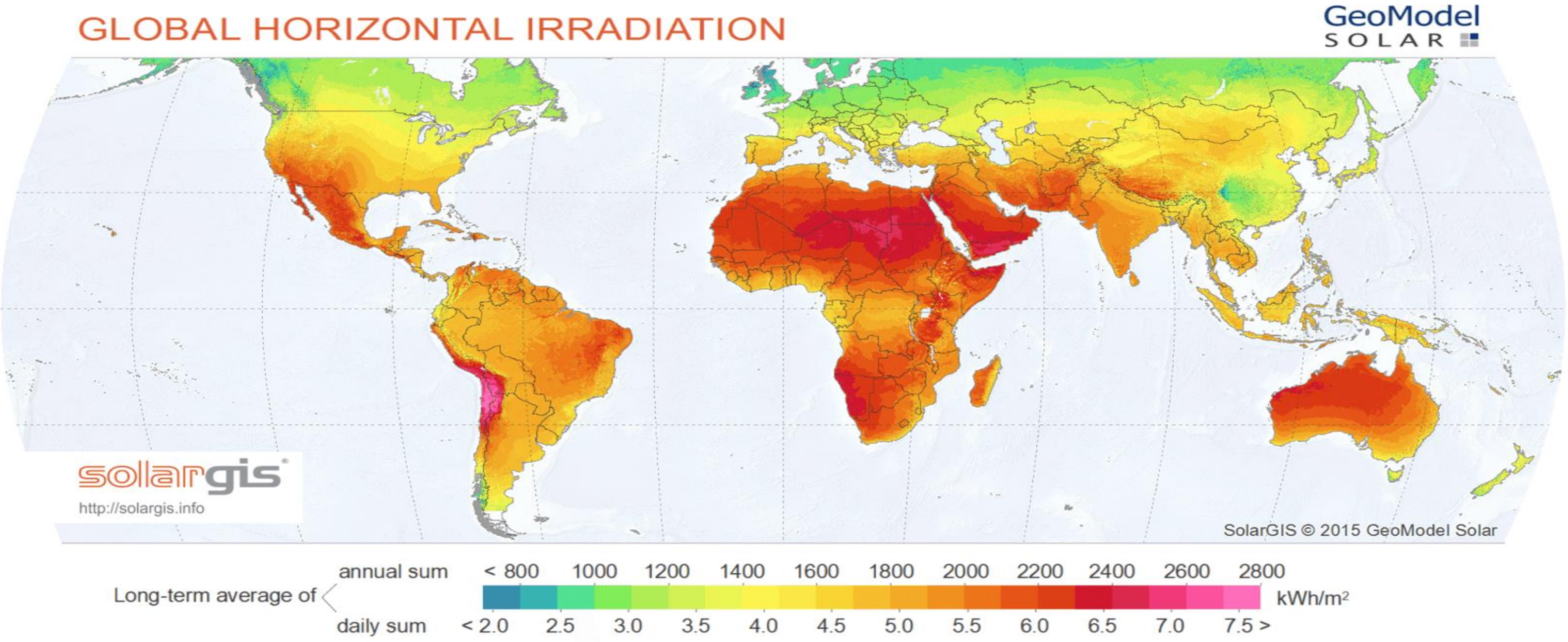
Solar energy is a plentiful, widespread resource

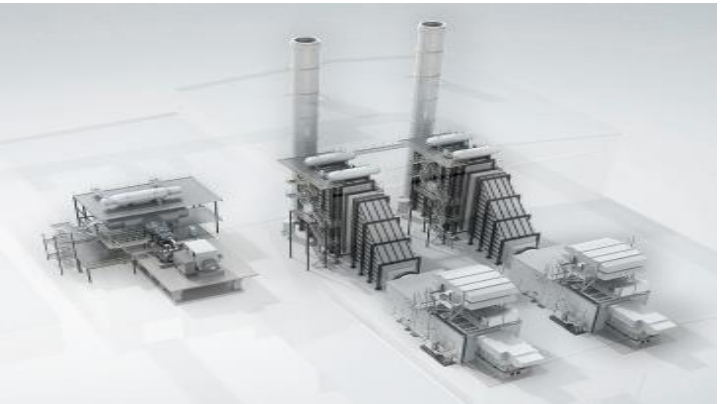


The Low Carbon Landscape

Renewable Generation

- Zero Emissions
- Economical

...but not dependable



Gas Fired Generation

- Dispatchable
- Reliable
- Economical

...but not instantaneous

Stored Energy

- Instantaneously Dispatchable or Fast Response
- Zero or low emissions

...but not continuous

No single technology can meet the requirements of efficiency, dispatchability, and reliability

Solar / Fossil Fuel Hybrids

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Combining Fossil Fuel and Solar Technologies can reduce costs and improve operability

- Enhanced integration and shared facilities
  - Common grid connection, common control room, supervisory system and operating staff etc.
  - Energy storage permits improved performance of fossil fuel generation
  - Enhanced power plant response and asset utilization
- Security of Supply
  - Fossil fuel provides electricity when renewables unavailable or at low level
  - Fossil fuel generation provides fast response to changes in renewable generation and system inertia
- Decarbonization
  - Renewable generation reduces fossil fuel consumption
- Decentralization
  - Local, secure, low carbon power generation with reduced footprint
  - Elimination or reduction in transmission system costs/upgrades

It's important that a hybrid solution is not just technically feasible but economically viable too

Solar / Fossil Fuel Hybrids

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Solar PV and Gas / Diesel Engine Hybrids Exist

- Solar PV displaces fossil fuel consumption
- During daylight hours engines start and stop as necessary, run at part-load or as spinning reserve
- Battery energy storage can be used to optimize operations
  - High cost, round-trip efficiency, high degradation

- **Can the system respond fast enough to changes in solar PV output without batteries?**
  - Average rate of change 3% per second*
  - Max. instantaneous 75% per second*

  Medium speed gas engines
  - Fast start = 2 mins
  - Load acceptance c. 30% max step change
  - Recip Ramp Rate c. 2% per second

- **Low system inertia**

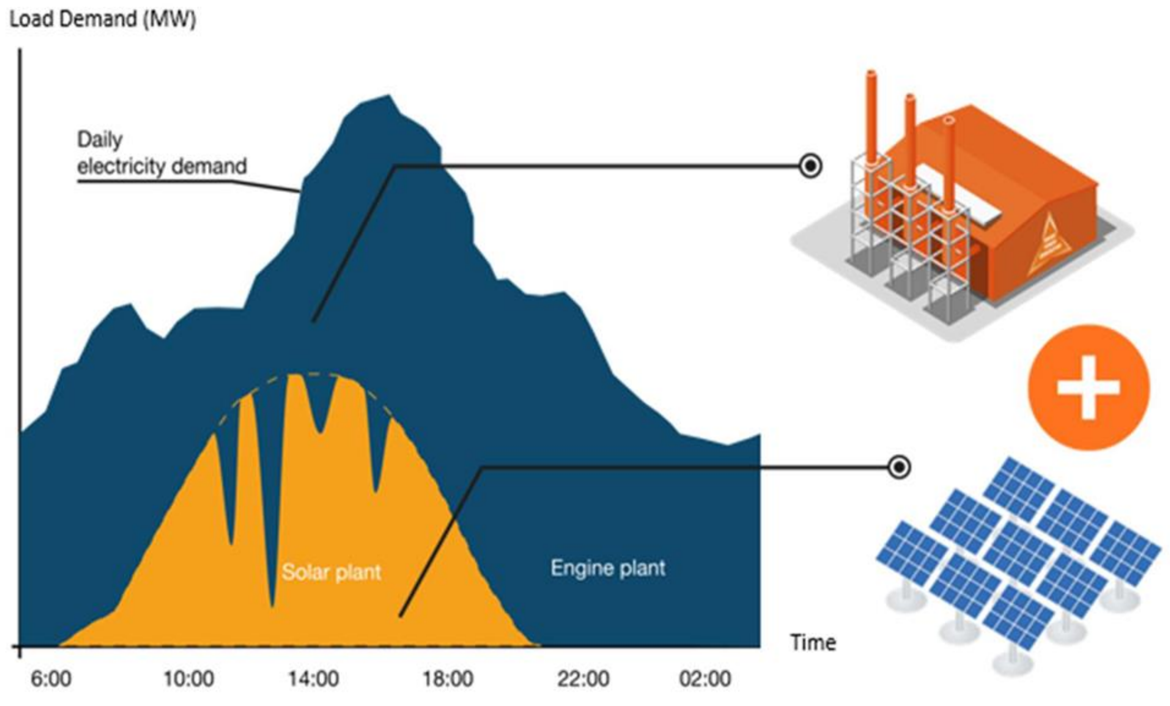

Chart showing typical generation profile from gas engines and solar PV, illustrating how the solar PV contribution displaces fossil fuel consumption

Mahlin Ostman, Wartsila: Solar PV-Engine Hybrid in the Philippines: A conceptual case study, PowerGen Asia, Seoul, September 2016

* Kari Lappalainen, Seppo Valkealahti, Tampere University of Technology

Solar / Fossil Fuel Hybrids

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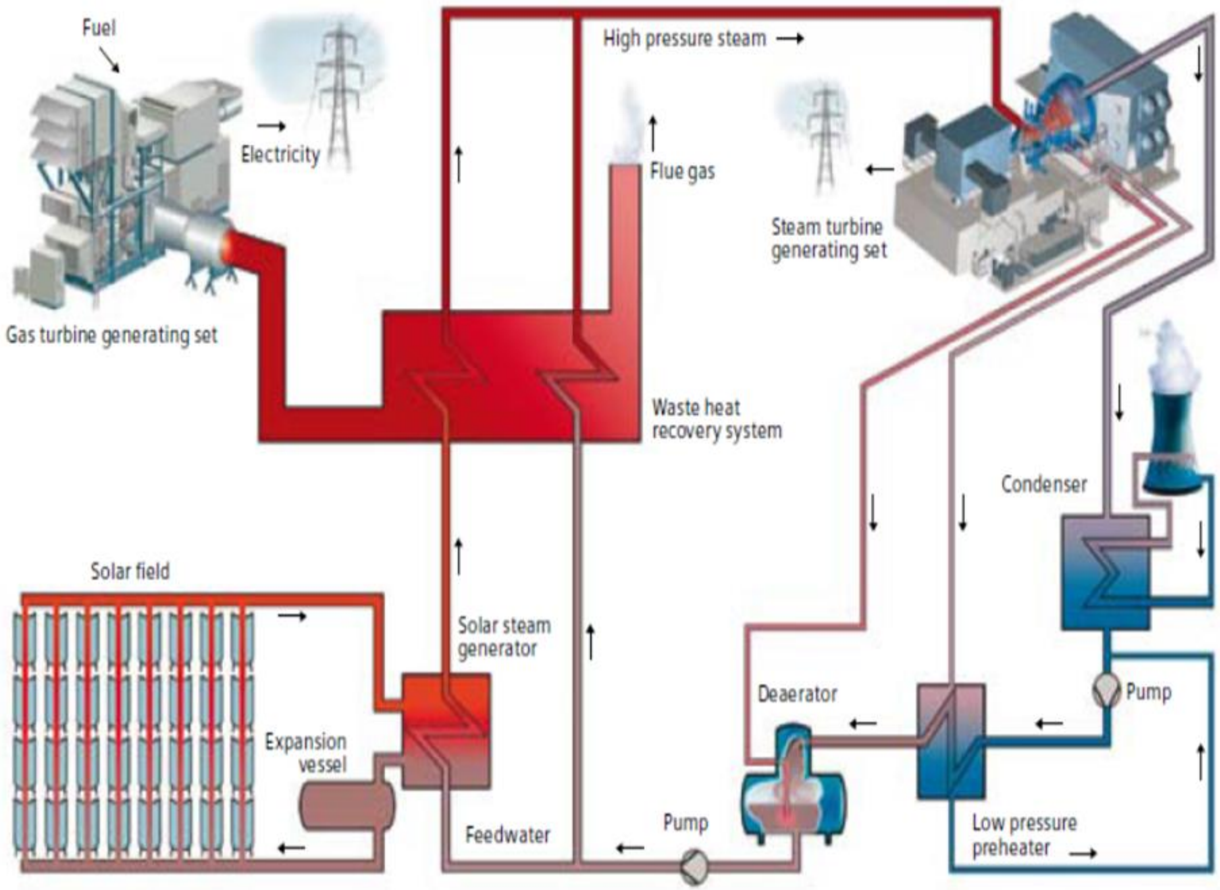
Gas Turbine Combined Cycle and Solar Thermal (CSP) hybrids exist too

- **Solar field feeds heat into the bottoming (steam) cycle of the power plant to boost efficiency**
  - Option 1: boost steam turbine output
  - Option 2: maintain steam turbine rating, reduce gas turbine load, reducing fossil fuel consumption
  - High inertia, fast response rate to variable solar output

- **Thermal storage of any surplus heat to change plant operating profile**

- **High equipment count**
- **Solar field requires gas turbines to be operating**
- **Currently only deployed at Utility scale**



Solar / Fossil Fuel Hybrids

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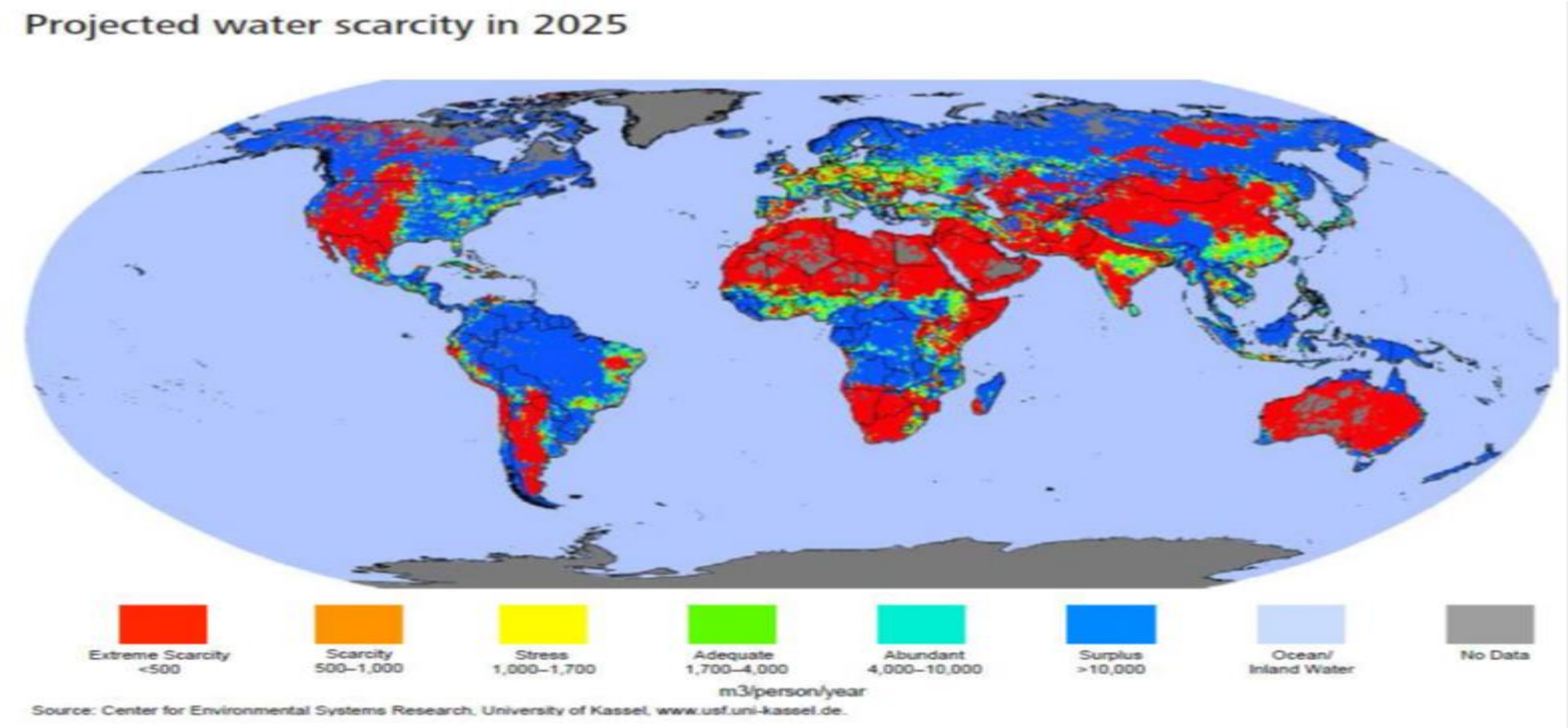

Water is a scarce resource in regions with high solar potential

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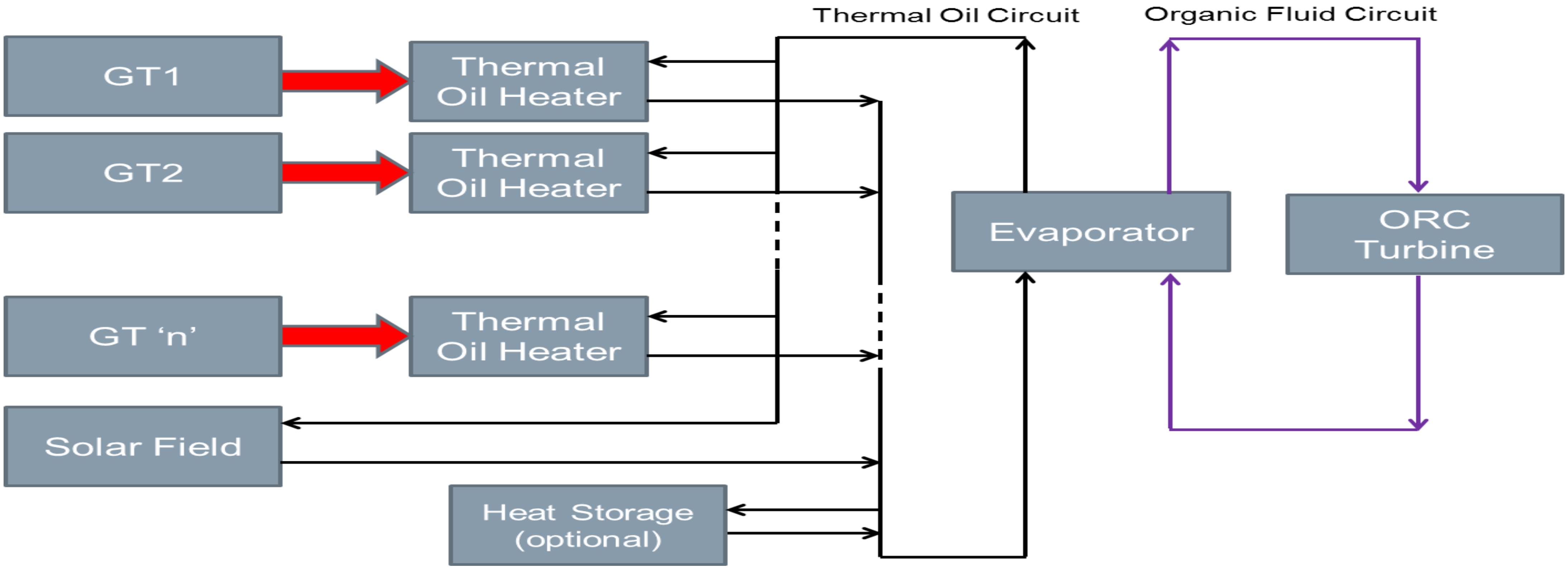
Use Organic Rankine Cycle (ORC) in the bottoming cycle



The ISORCC Concept

Integrated Solar Organic Rankine Cycle (ISORCC)

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Provides a water-free solution to address Decentralized Power Generation applications

- All technologies proven
  - Just connecting them together in a different way
- ORC well-suited to low exhaust gas temperatures of smaller gas turbines required for decentralized power plants
- Use of same working fluid simplifies concept and reduces equipment count (CAPEX)
- Solar field can operate independent of gas turbines if required
- Offers enhanced grid support features compared to RICE
  - High step load acceptance (up to 100%)
  - Higher system inertia
  - Combination with low cost thermal storage
    - Higher round trip efficiency, less degradation than batteries
- Potential to use ‘renewable’ fuels with minimal performance impact (Biogas, H_2) for ‘zero CO_2 electricity’

Hybrid CSP + Biomass Boiler + ORC for a District Heating scheme in Denmark (photo courtesy of Turboden S.p.A.)

Technically possible but is it economically viable at Distributed Power scale ?

The Simple ISORCC Study

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Ground Rules: Focus on real world applications

- LCOE chosen as a comparative measure

- Efficiency considered as ‘fossil fuel’ efficiency
  - Solar energy is free, conversion efficiency has no impact on fuel costs in LCOE calculations or CO_2 emissions
  - Does impact the CAPEX though

Aim was to be able to demonstrate potential for LCOE below US$150/MWh

The Simple ISORCC Study

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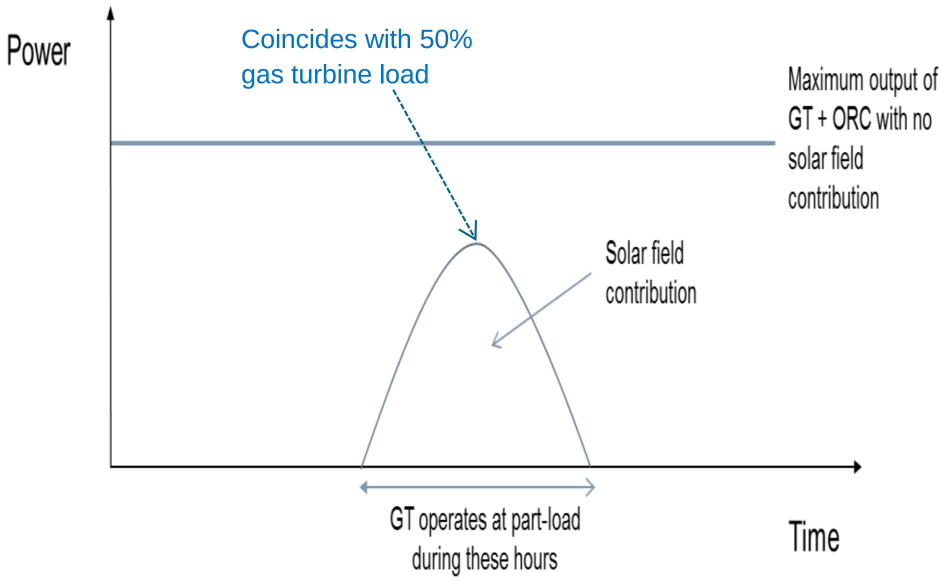
Considered a ‘challenging’ base case condition for economic evaluation before committing to further investigation

- 40°C constant ambient temperature
  - Sub-optimal gas turbine performance, adverse US$/kW calculation
- Indirectly heated ORC configuration using thermal oil
  - Least efficient combined cycle solution, highest US$/kW
- Fixed installation solar collectors with 50% solar-to-thermal efficiency
  - Anticipated to show lower solar contribution than a real case
- Selected SGT-750 as baseline model
  - Not normally considered for combined cycle due to low exhaust gas temperature
- Considered constant power output from combined cycle scheme only without thermal storage
  - Over-sizing and sub-optimal efficiency of ORC



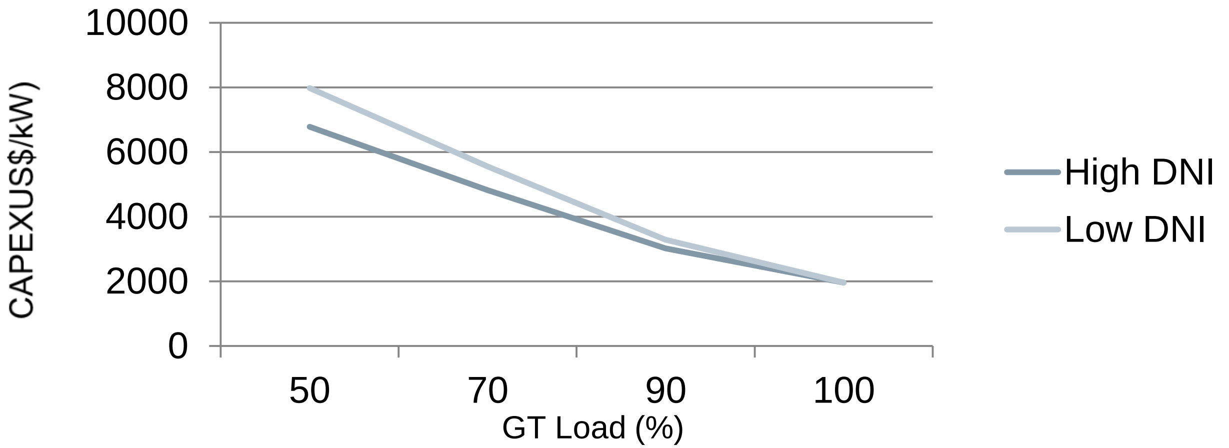
Baseline Plant Data for LCOE calculations (without Solar Contribution):
Power Output: 35.82MW
Gross Electrical Efficiency (LHV Basis): 46.5%
CAPEX: US$70 million (US$1955/kW)

Aim was to be able to demonstrate potential for LCOE below US$150/MWh

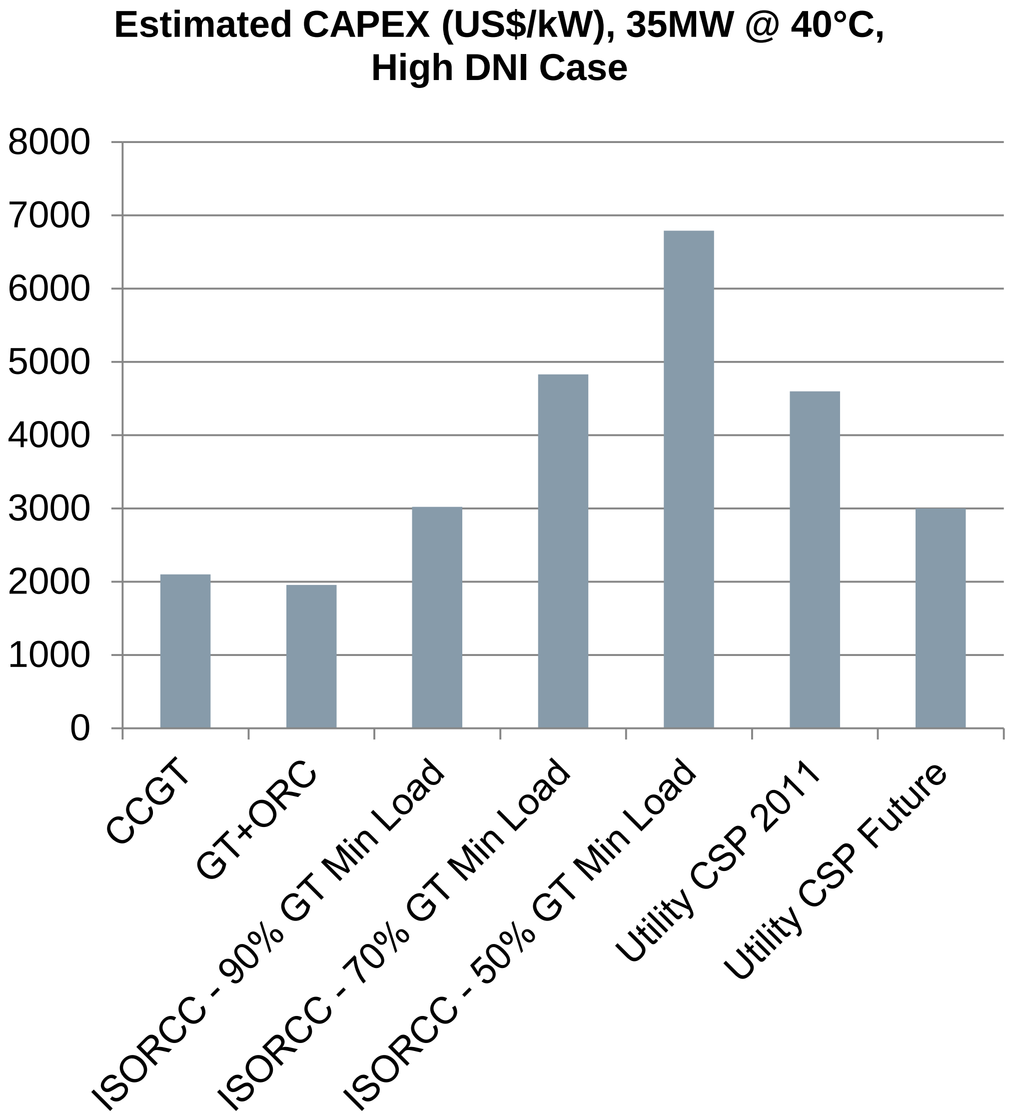
The Simple ISORCC Study

CAPEX Investigation and Results

- Looked at different solar field sizes permitting gas turbine to operate down to minimum 50% load
  - Considered DNI of 2700kWh/m^2 and 2100kWh/m^2
  - Assumed solar field cost of US$255/$m^2$
  - Assumed solar collector efficiency of 50%
  - Assumed additional 10% losses in heat transfer system



Indicates GT operation to 70% load for max solar field size



The Simple ISORCC Study

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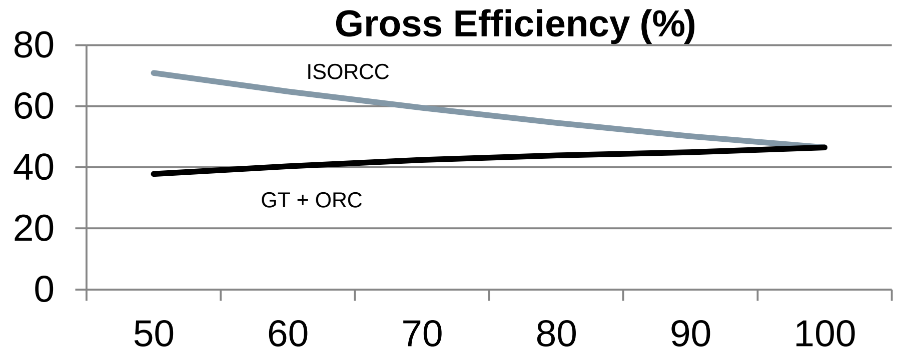
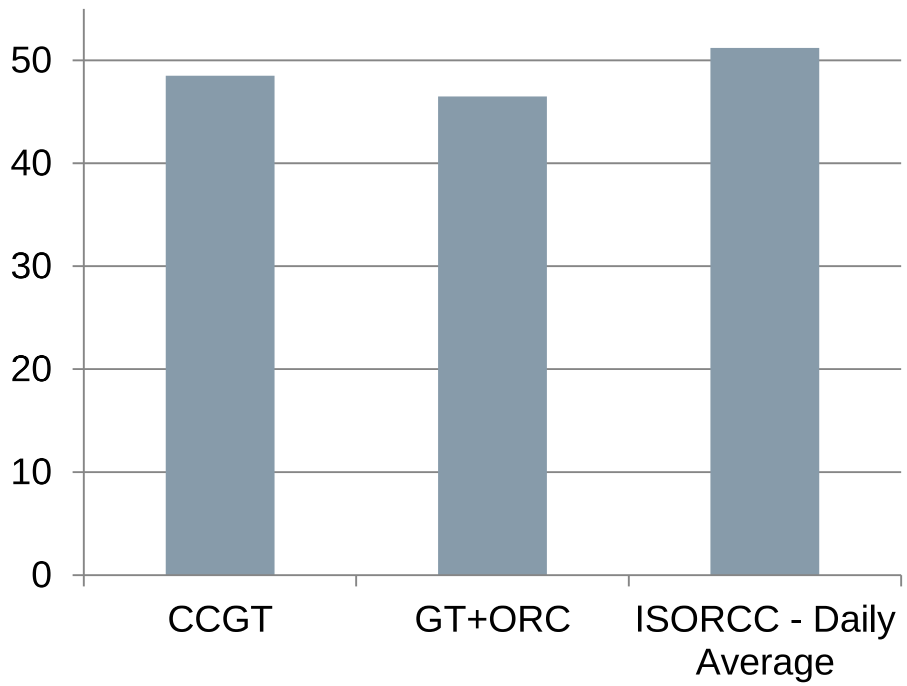
Efficiency Investigation and Results

- Considered instantaneous efficiency for different solar field contributions
- Calculated daily average operating gas turbine to 50% load = 51.7%
- c.10% fuel reduction for high DNI case
  - US$2.3 million/year fuel cost saving at US$10/mmBtu
  - 12,750 tonnes/year CO_2 savings





ISORCC boosts fossil fuel efficiency compared to conventional combined cycle configurations

The Simple ISORCC Study

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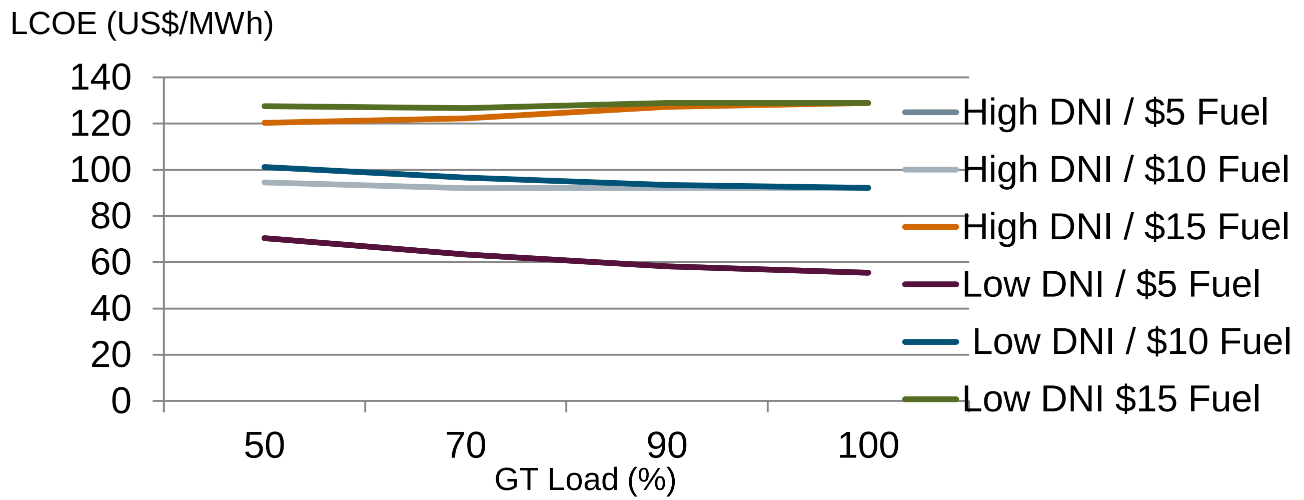
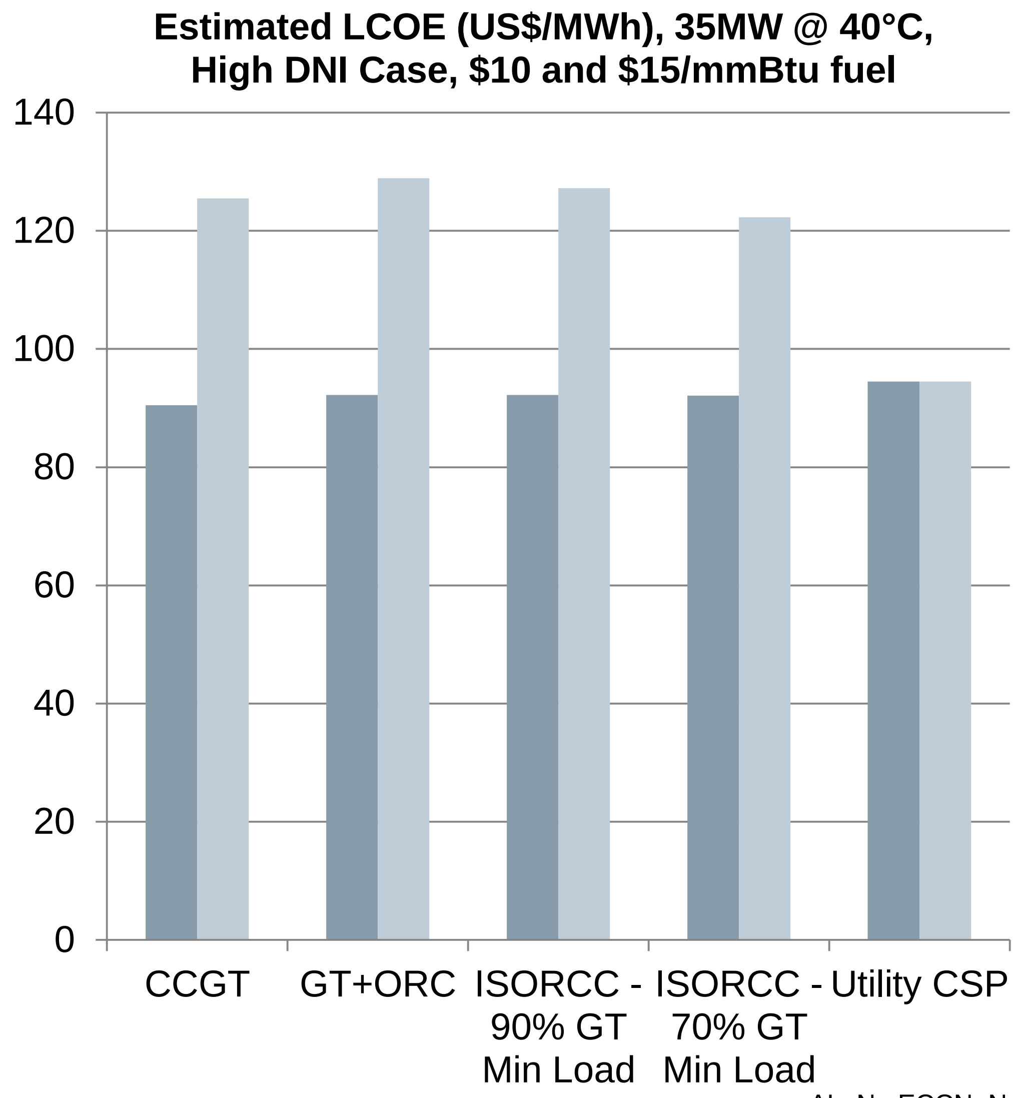
LCOE Investigation and Results

- Considered 3 fuel costs for both high and low DNI cases
  - US$5, 10 & 15/mmBtu
- Testing hypothesis of Alqahtani & Patino-Echeverri
  - ISCC should be competitive with CCGT when natural gas prices range from US$4 – 18/mmBtu



ISORCC can offer competitive LCOE to CCGT



Areas for Potential Future Investigation

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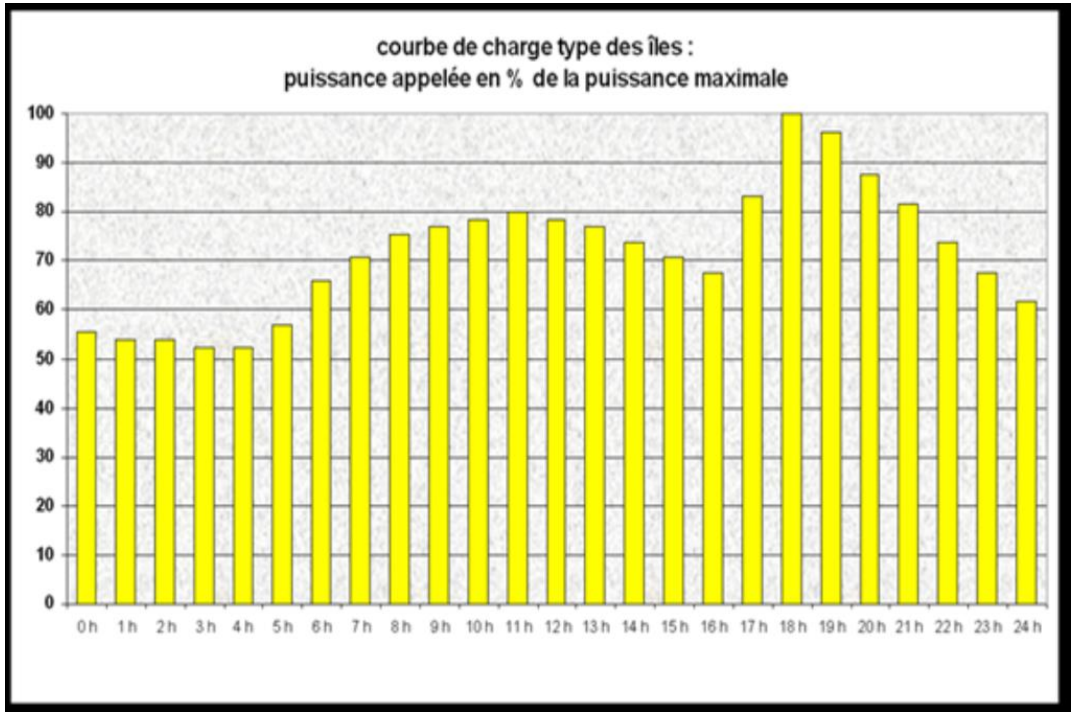
Simple Study indicated sufficient cause for optimism

- Indicated ISORCC could be economically viable as well as providing a good technical solution for integration of fossil fuels with renewables

- Next stage:
  - Investigate at a more normal ambient temperature
  - Optimize overall design
    - ORC Cycle and solar field sizing
  - More accurate costings
  - Look at different operating regimes
    - Fixed power, maximum power, load following
  - Impact of thermal storage



Typical load profile for an island nation (courtesy of EdF)

TU Delft have been engaged to undertake the next phase of study

Areas for Potential Future Investigation

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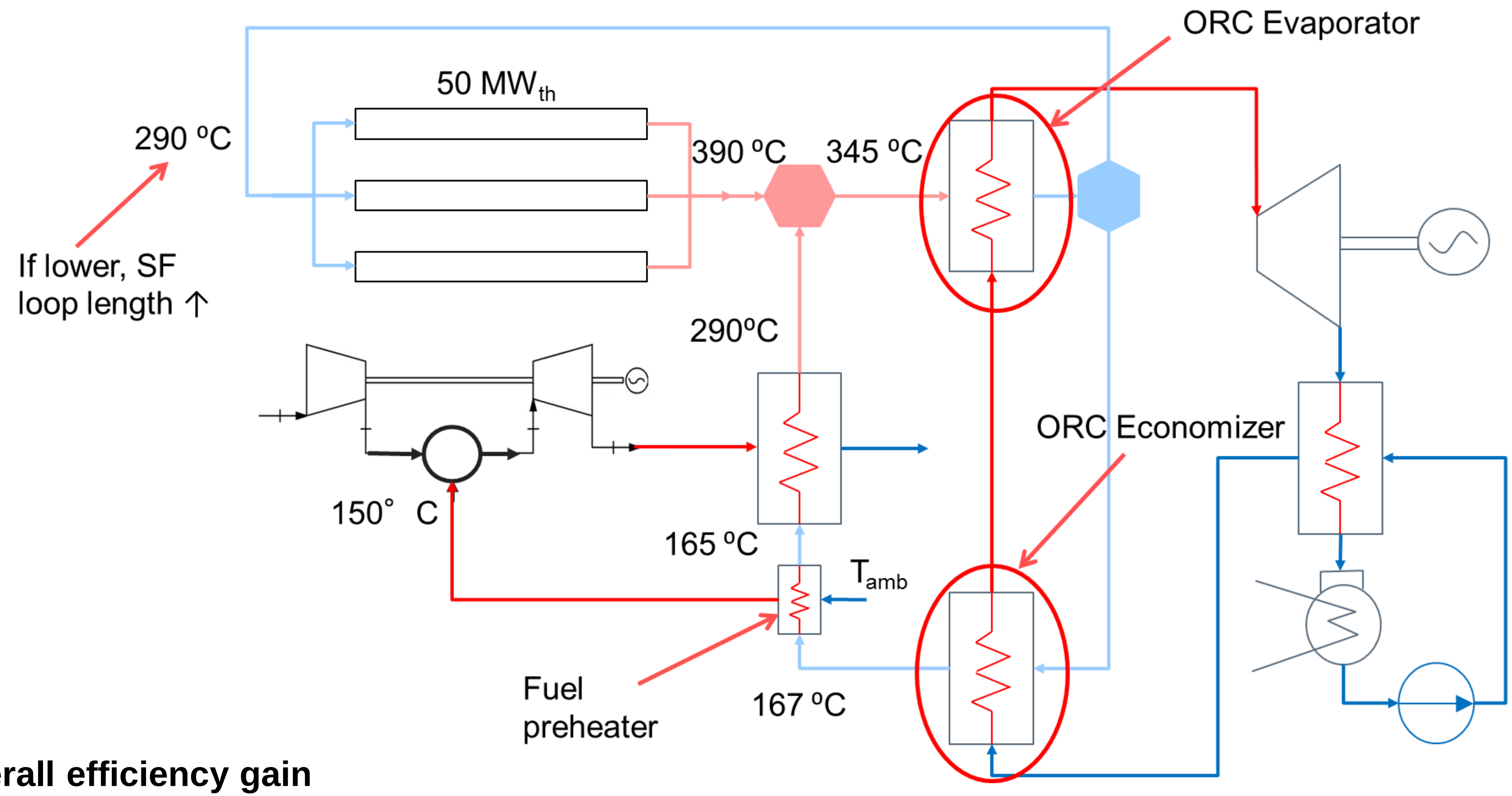
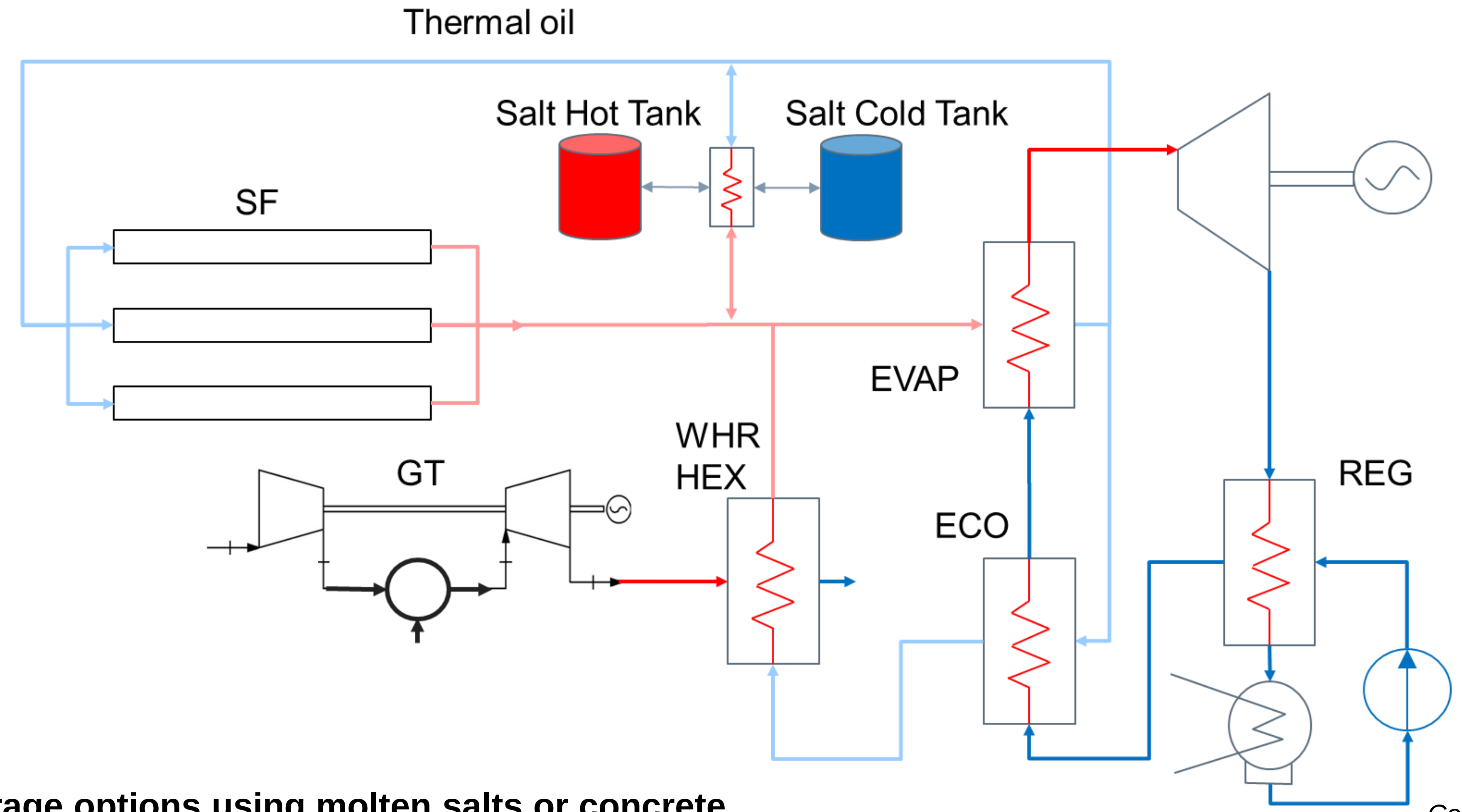


- Fuel Preheater for overall efficiency gain
- Optimizing solar field size against thermal oil return temperature

Courtesy of TU Delft

Areas for Potential Future Investigation



- Thermal storage options using molten salts or concrete

Courtesy of TU Delft

Areas for Potential Future Investigation

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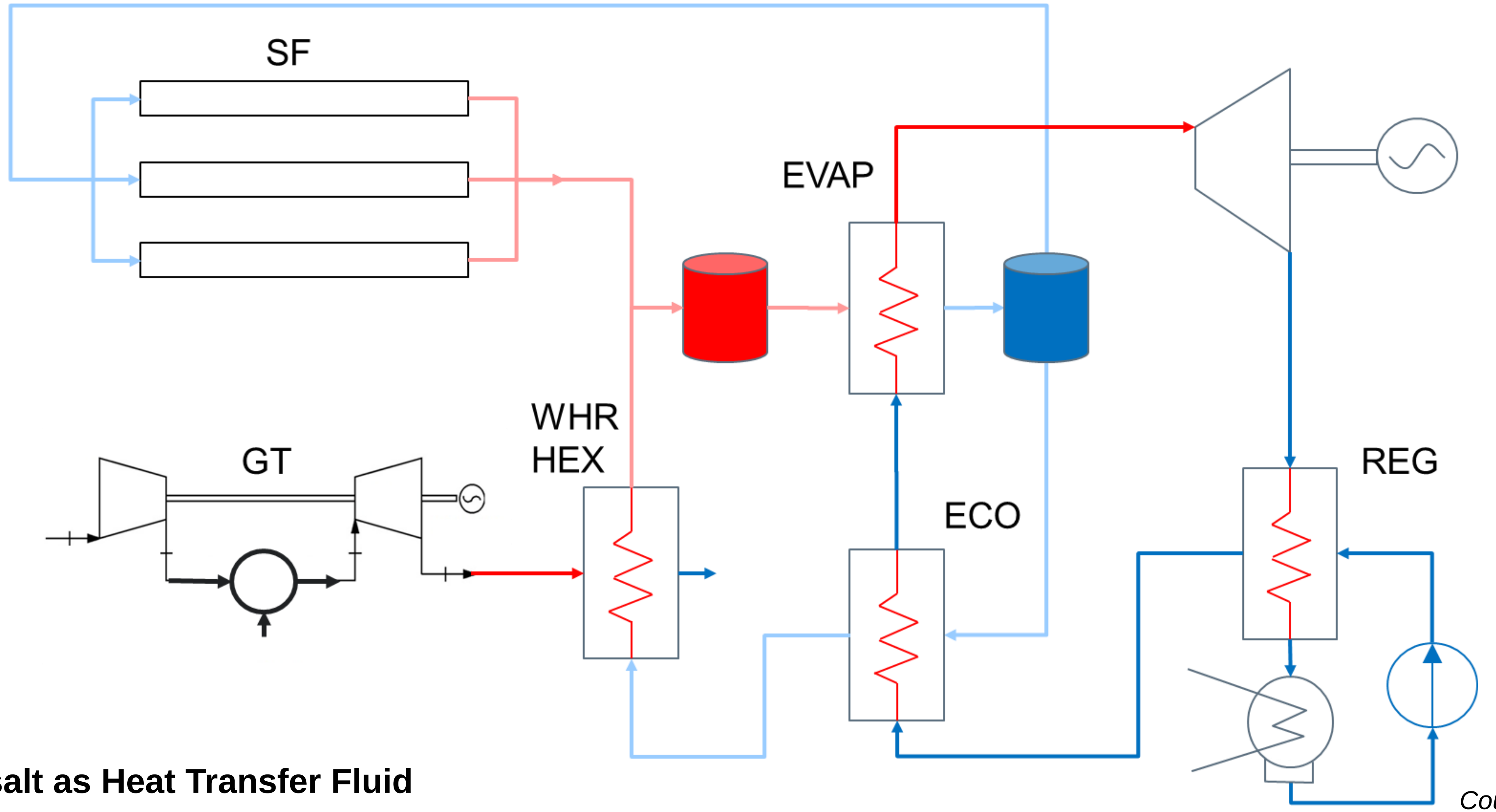

- **Molten salt as Heat Transfer Fluid**

Courtesy of TU Delft

Conclusions

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ISORCC could offer a possible fossil fuel/renewable hybrid solution in Distributed Power applications

- **Hybrid solution that:**
  - **Reduces fossil fuel consumption and CO_2 emissions**
    - Future potential for renewable fuels for zero CO_2 electricity
  - **Provides security of supply for small grids and micro grids**
    - Low maintenance, high availability, high reliability
    - Low OPEX and reduced CAPEX through shared infrastructure
  - **Provides fast response, inertia and flexibility for grid support**
    - Gas turbine can compensate rapidly for variations in solar output, solar field can operate alone if necessary
  - **Appears to be economically attractive compared to fossil fuel only or renewable only power plants**
  - **Compatible with low cost thermal storage solutions**
    - High round trip efficiencies and minimal degradation with time or cycling
  - **Requires minimal water**
    - Washing only

Potentially meets all the requirements of network operators for Distributed Power

Acknowledgements

The presenter would like to thank:

- My co-author, Heidi Anttila of Siemens Industrial Turbomachinery in Lincoln, UK
- Nicola Rossetti, Tommaso Ferrari and their colleagues at Turboden S.p.A., Italy
- Carlo de Servi, Federico Ghezzi and Prof. Piero Colonna from TU Delft, Netherlands
- Ludwig Bellehumeur of EnergyNest, Canada

Thank you for your attention

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