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Chemical
Process and
Energy
Resources
Institute

An IT solution for enhancing vessels performance by applying "big – data" / "AI" / "ML" approaches

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Abstract:

An IT solution has been developed and successfully applied for processing "big – data" sets of both global and shipboard, "neural" or other, data such as "quasi"-steady values of main engine and propeller RPM, fuel oil consumption rates, main engine – propeller shaft torque / power, vessel TTW (through the water / log) speed, and other as well directly or indirectly related to the above. The solution comprises fundamental principles as these are applied in ship propulsion, and "by ships in practice" in particular (being in this regard part of main engines manufacturers' recommended good practice), as well as, edge, multi – dimensional / non – linear, optimization technologies which have proved to be amazingly effective in achieving "fenced" local minimums of standard deviation between the above "big" data sets and the respective predictions of dynamically recalibrated, comprehensive / multi – disciplinary, numerical models. In this regard, this solution is offering a remarkably powerful insight in vessels hydro and thermal analyses, as can be exhibited in the results of the solution's application over the data of a small fleet of oil carriers.

Fundamental principle (law) of similarity and dimensional analysis:

"For *fixed hydrostatic conditions (displacement, draft / trim)*, fixed water temperature and salinity, fixed air barometric pressure and any *given steady vessel*, water and air *state and conditions*, the steady state power delivered by the propeller shaft to the *fixed pitch screw propeller (FPP)*, when *such a ship is making steady course way* along a fixed latitude circle, at fixed rudder angle and through *sufficiently deep and otherwise unconstrained waters*, depends only on the steady through the water (TTW) speed of it and the *steady rotational speed of the FPP propeller*."

Correlation step #1:

- *Between* actual seagoing, mean effective over time or instantaneous, conditions, *and*, perfectly still (calm) water and air conditions, otherwise same to the actual, mean effective or instantaneous, seagoing air and water conditions, for the same draft and trim.

Correlation step #2:

- *Between* perfectly still (calm) water and air conditions, otherwise same to the actual, mean effective or instantaneous, seagoing air and water conditions, *and*, ship and voyage specific “virtual” sea trials “ideal” conditions, for the same draft and trim.

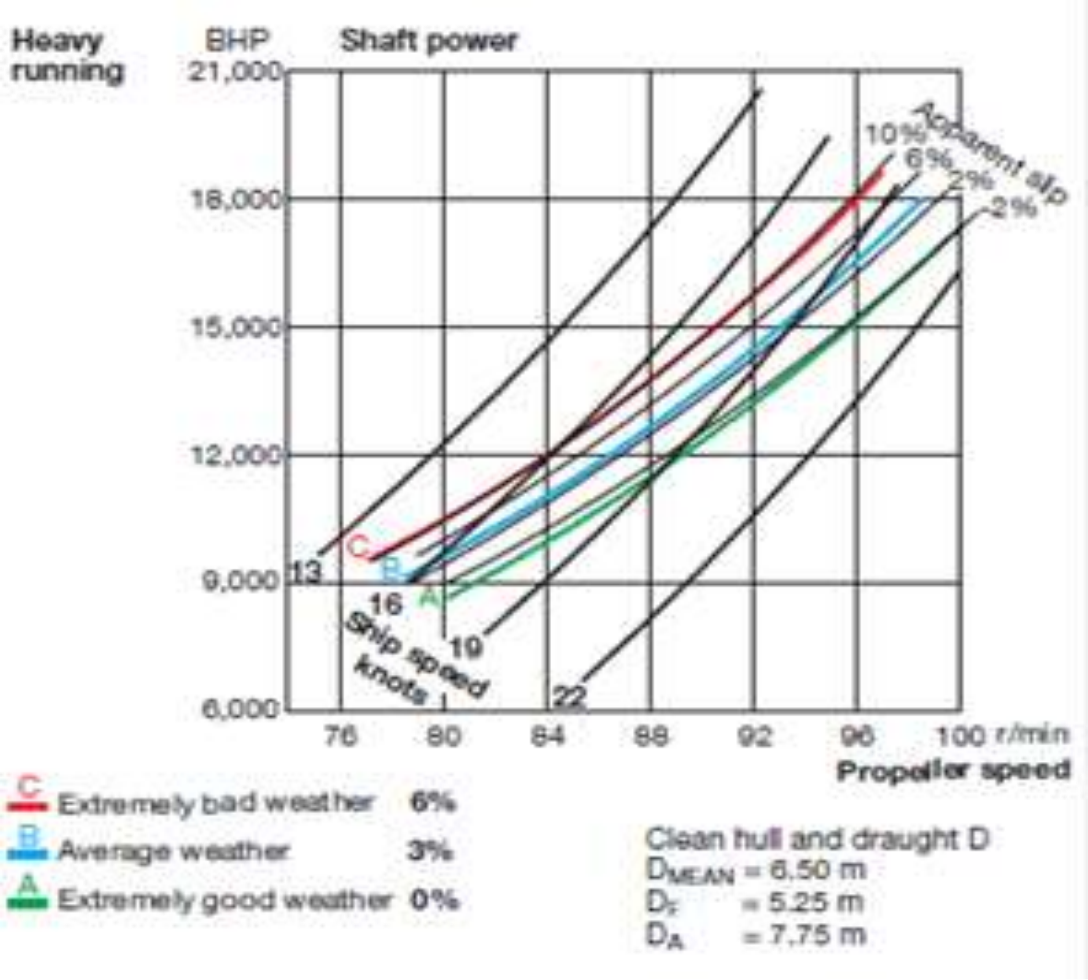
Correlation step #3:

- *Between* the ship / voyage specific "virtual" sea trials at "ideal" conditions, *and*, the same ship's "virtual" sea trials "ideal/new vessel" conditions upon the latest delivery of the vessel by a shipyard after a new building or major modification, and for the same draft and trim.

Correlation step #4:

- *Between* the same ship's "virtual" sea trials "ideal / new vessel" conditions upon the latest delivery of the vessel by a shipyard after a new building or major modification, for the same as above draft and trim, *and*, the same ship's official sea trials corrected results, in either laden or ballast conditions.

Correlation step #1:



Correlation step #2:

- *Water density changes*, which for voyages in sea waters with *salinity* ranging from ~ 33 to 37 gr/kgr (~ 0.3% of density change) and *temperature* ranging from ~ 5 to 35 deg. C (~ 0.7% of density change), and/or entering / leaving *inland fresh or low salinity waters* from/to *sea water* and/or combinations thereof (within a maximum range of ~ 2.8% of density change for same temperature), may be considered for representing the actual *density, salinity and temperature values*.

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Correlation step #2:

- *Water density change* has also a secondary effect as, for the same voyage, or leg of it, and/or *for effectively the same deadweight, water density changes* will consequently cause *draft changes*, and *draft* is also a factor related to the power delivered by the propeller shaft to the propeller.

Correlation step #2:

- *Water kinematic viscosity* also varies with *salinity* and *temperature* and relates to the *dimensionless Reynolds number* which in turn has an effect on the power delivered by the propeller shaft to the screw propeller when the ship is making way, and on the *frictional contributor* to the shaft power in particular. The *distribution* of the shaft power to a *frictional and dynamic contributor* is ship and voyage specific and mainly depends on the ship category and speed.

Correlation step #2:

- *Acceleration of gravity* as such varies with *latitude*, relates to the *dimensionless Froude number* which in turn has an effect on the power delivered by the propeller shaft to the screw propeller when the ship is making way, and on the *dynamic contributor* to the shaft power in particular, as such is discussed above.

Correlation step #2:

- *Air barometric pressure*, as well as *water density* and *water saturated vapor pressure*, as the last 2 vary with *water temperature* and *water salinity*, *acceleration of gravity* as such varies with *latitude*, and *draft* as well, relate to the *propeller cavitation dimensionless number σ* which also has an effect to the steady state power delivered by the propeller shaft to propeller, and on the *propeller performance* in particular, as such is related to the power delivered by the propeller shaft to the propeller.

Correlation step #2:

- Sufficiently deep, also otherwise unconstrained, non – icy, waters will not effect to the propulsion power calculation, however *shallow, or otherwise constrained, or icy waters*, will result to affecting the vessel's attainable speed.
- *Rate of Turn (ROT)* is a *direct indication of the rudder angle* as such may be dynamically controlled for turning the vessel, or for keeping a steady course against dynamically fluctuating current's, wind's and waves' direction and scale, and as such may have a significant *speed loss effect* on the vessel's attainable TTW speed in the forward direction.

Correlation step #2:

- *Ratio of the TTW speed in the athwart ship direction, to the TTW speed in the forward direction, is also a direct indication of the rudder angle* as such may be statically controlled for keeping a steady course against current, wind and waves of steady lateral direction and scale, and as such may have a significant *speed loss effect* on the vessel's attainable TTW speed in the forward direction.

Correlation step #2:

- The effect of the *TTW acceleration / deceleration*, including *TTW acceleration / deceleration in the forward and in the athwart-ship direction*, calculated on the basis of data availability, and analysis thereof, with regard to the *TTW speed in the forward and in the athwart-ship direction, Rate of Turn (ROT) and Ship's position*, on the power delivered by the shaft to the propeller, may also be considered, or neglected, as applicable.

The *AIS data* being part of the relevant "big data" set, include the following:

- *IMO Number* and *Type of ship*.
- *Ship's position (longitude and latitude in decimal degrees) with accuracy indication and integrity status*: Automatically updated from the position sensor connected to AIS. The accuracy indication is approximately 10 m.
- *Position Time stamp in UTC (date; hour; minute; second; 24 hours format YYYY/MM/DD HH:mm:ss:* Automatically updated from ship's main position sensor connected to AIS.

- *Course over ground (COG, ° -180 to 180 Northbound, 0 to 360 Southbound):* Automatically updated from ship's main position sensor connected to AIS, if that sensor calculates COG. This information might not be available.
- *Speed over ground (SOG, knots)*: Automatically updated from the position sensor connected to AIS. This information might not be available.
- *Heading (°-180 to 180 Northbound, °0 to 360 Southbound):* Automatically updated from the ship's heading sensor connected to AIS.

Navigational status: To be manually entered by the OOW and changed as necessary:

- underway by engines;
- at anchor;
- not under command (NUC);
- restricted in ability to maneuver (RIATM);
- moored;
- constrained by draught;
- aground;
- underway by sail.

- *Rate of turn, or (ROT, ° per minute)*: Automatically updated from the ship's ROT sensor or derived from the gyro. This information might not be available.
- *Draft (Ship's draught, m)*: To be manually entered at the start of the voyage using the maximum draft for the voyage and amended as required (e.g. – result of de-ballasting prior to port entry).
- *Destination*: To be manually entered at the start of the voyage and kept up to date as necessary.
- *ETA (date; hour; minute; second; UTC 24 hours format):* To be manually entered at the start of the voyage and kept up to date as necessary.

The *AIS data* included in the relevant "big data" set:

- Are transmitted by ships at predefined frequencies related to the navigational status, speed and rate of turn (ROT), thereof.
- Are received and made available at subsets of lesser, varying, frequencies depending on actual circumstances and capabilities, by other ships, satellite stations and terrestrial stations.
- Although it would be really "nice", apparently, there is not one, universal system receiving and storing all AIS data, of all ships, at all frequencies.

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Metocean (meteorological & oceanographic), “hindcast” or not, data (potentially included in the relevant “big data” set):

- *Barometric Air Pressure (mbar)*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.
- *Air Temperature (° C)*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.
- *Air Relative Humidity (%)*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.
- *Air Density (kgr/m3)*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.
- *Wind Speed (m/s)*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.

- *Wind Direction (°)*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.
- *Rain, Snow or Hail (as available)*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.
- *Water Depth (m)*: At AIS Ship’s position (sufficiently deep unconstrained waters needed not be reported / tracked in detail, while the non – availability of depth data would denote an erroneous position ashore).
- *Water Salinity (gr/kgr)*: Average value between surface (zero depth) and depth equal to AIS Ship's draught, at AIS Ship's position and AIS Position Time stamp in UTC.

- *Water Temperature (° C)*: Average value between surface (zero depth) and depth equal to AIS Ship's draught, at AIS Ship's position and AIS Position Time stamp in UTC.
- *Water Density (kgr/m3)*: Average value between surface (zero depth) and depth equal AIS Ship's draught, at AIS Ship's position and AIS Position Time stamp in UTC.
- *Water Kinematic Viscosity (m2/s)*: Average value between surface (zero depth) and depth equal to AIS Ship's draught, at AIS Ship's position and AIS Position Time stamp in UTC.

- *Water Saturated Vapor Pressure (mbar)*: Average value between surface (zero depth) and depth equal to AIS Ship's draught, at AIS Ship's position and AIS Position Time stamp in UTC.
- *Ice in Water*: Average value between surface (zero depth) and depth equal to AIS Ship's draught, at AIS Ship's position and AIS Position Time stamp in UTC.
- *Water Current Speed (m/s) and Direction (°)*: Average values between surface (zero depth) and depth equal to AIS Ship's draught, at AIS Ship's position and AIS Position Time stamp in UTC.
- *Wave data*: At AIS Ship's position, AIS Position Time stamp in UTC and sea surface level.

Correlation steps #1 and #2, combined :

- The ratio between the shaft power delivered to the FPP propeller under actual seagoing conditions, to the shaft power delivered to the FPP propeller in “ideal” conditions, when considered for sustaining the same “ideal” conditions TTW speed, decreased by one (or by 100% in case it is calculated as a percentage), is defined as the *sea margin*.
- The above shaft power ratio, when considered for sustaining the same “ideal” conditions shaft rotational speed, decreased by one (or by 100% in case it is calculated as a percentage), is defined as the *sea running margin*.

Correlation steps #1 and #2, combined :

- The *light running margin* is defined as the reduction percentage (%) of the “ideal” conditions shaft rotational speed necessary for delivering the same “ideal” shaft power to the FPP propeller.
- The *speed loss* is defined as the reduction (%) of the “ideal” conditions TTW speed necessary for delivering the same “ideal” shaft power to the FPP propeller under the above actual conditions.
- Both the above, are *common for, and representative of, steady (fixed) sea margin and/or sea running margin values, for any given value of the shaft power delivered to the FPP propeller.*

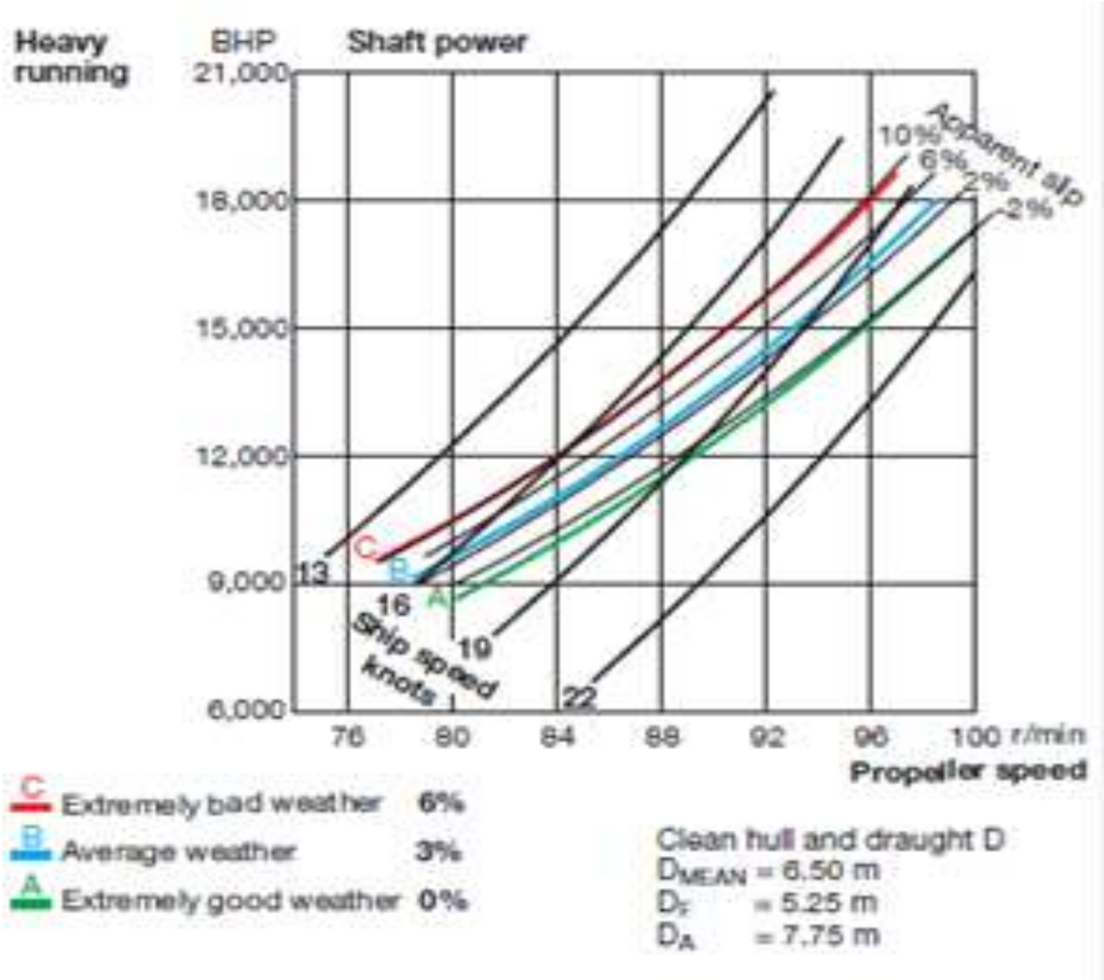
Correlation steps #1 and #2, combined :

- The above *dimensionless indexes (sea margin, sea running margin, light running margin and speed loss)* are all interrelated to each other, meaning that *when one of them is determined, then the other three are determined as well, while each one and all of them may be comprehensively defined on the basis of all the above actual, other than ideal, conditions available data*.

Correlation steps #1 and #2, combined :

- The *apparent TTW slip, when subtracted from unity*, stands as a *ship specific dimensionless ratio* of the *TTW speed in the forward direction* to the *FPP speed (RPM)*, and depends mainly to *any and all of the above indexes*, and slightly only, to the *FPP speed (RPM)*.

Correlation steps #1 and #2:



Correlation step #3:

- *Between* the ship / voyage specific "virtual" sea trials at "ideal" conditions, *and*, the same ship's "virtual" sea trials "ideal/new vessel" conditions upon the latest delivery of the vessel by a shipyard after a new building or major modification, and for the same draft and trim.

Correlation step #4:

- *Between* the same ship's "virtual" sea trials "ideal / new vessel" conditions upon the latest delivery of the vessel by a shipyard after a new building or major modification, for the same as above draft and trim , *and*, the same ship's official sea trials corrected results, in either laden or ballast conditions.

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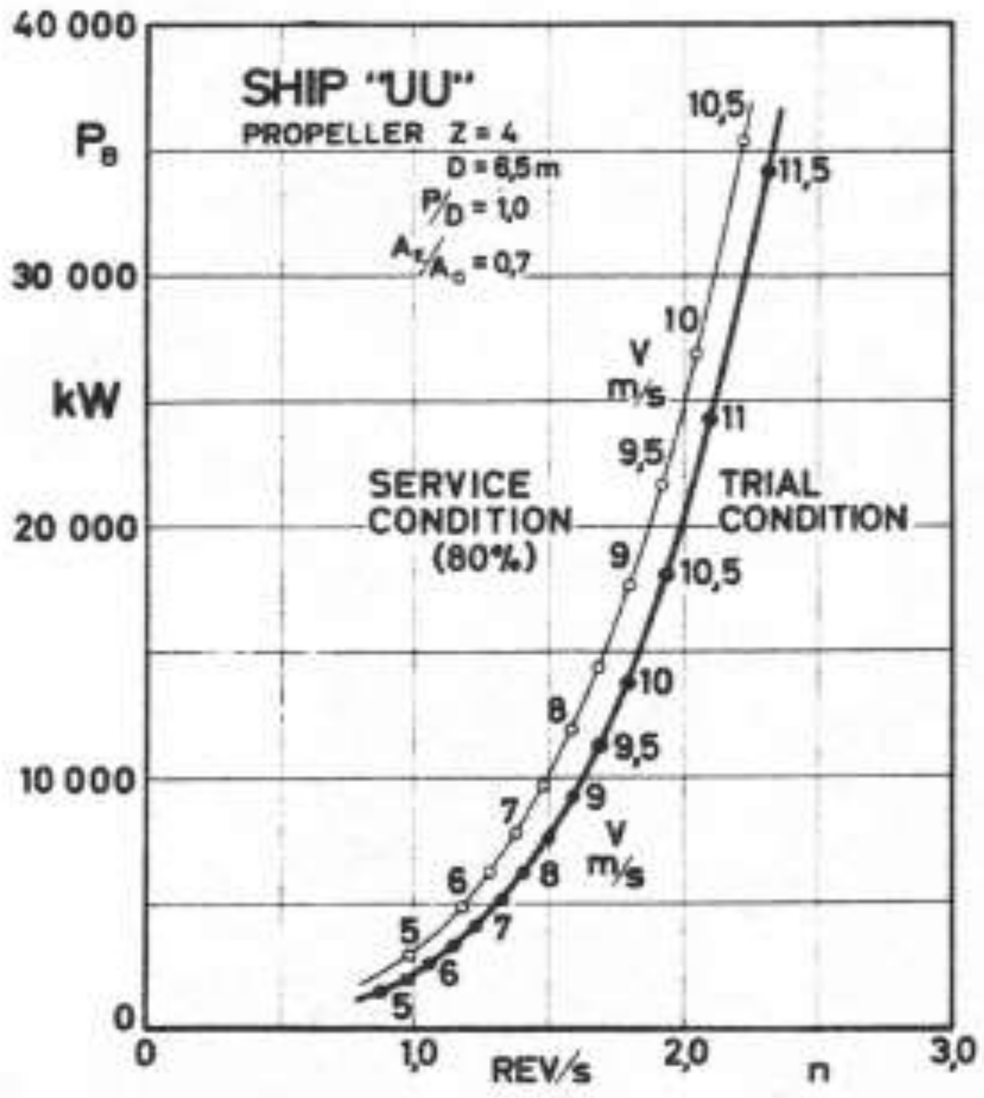
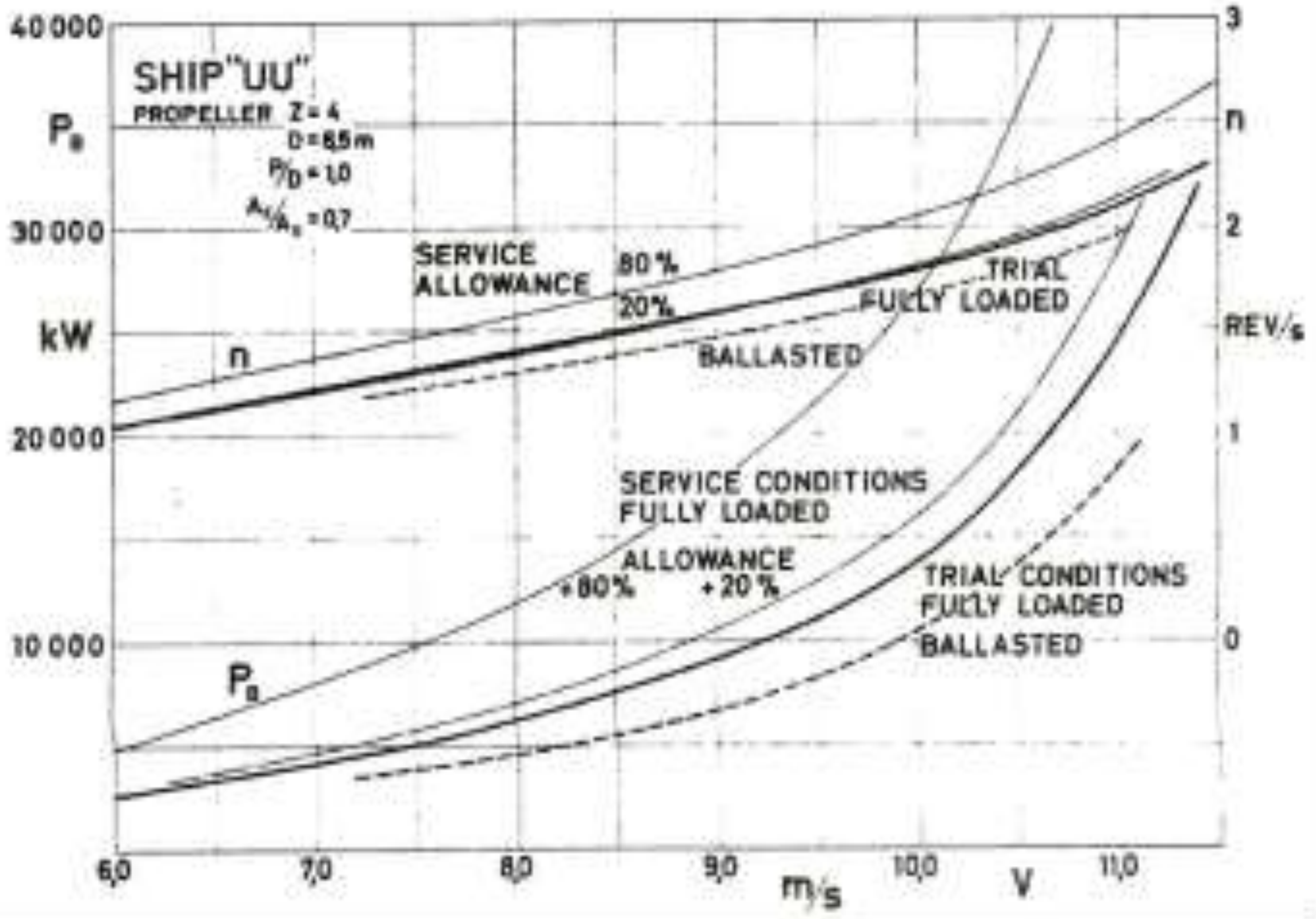


Correlation step #4:

The *ship specific "virtual" sea trials "ideal / new vessel" condition upon the latest delivery of the vessel by a shipyard after a new building or a major modification, and for the actual draft and trim, and the respective displacement as well*, may be compiled on the basis of the *same ship's official sea trials corrected results, in either laden or ballast*, and to this end, *all the in-between the above conditions, alternative power ratio forms / expressions (sea margin, speed loss, light running margin, sea running margin), and apparent TTW slip as well, are as per the above, properly balanced to each other*, on the basis mean effective values of characteristics of the above conditions, including *draft and displacement.*

Correlation step #4:



Fundamental principle (law) of similarity and dimensional analysis:

"For *fixed hydrostatic conditions (displacement, draft / trim)*, fixed water temperature and salinity, fixed air barometric pressure and any *given steady vessel*, water and air *state and conditions*, the steady state power delivered by the propeller shaft to the *fixed pitch screw propeller (FPP)*, when *such a ship is making steady course way* along a fixed latitude circle, at fixed rudder angle and through *sufficiently deep and otherwise unconstrained waters*, depends only on the steady through the water (TTW) speed of it and the *steady rotational speed of the FPP propeller*."

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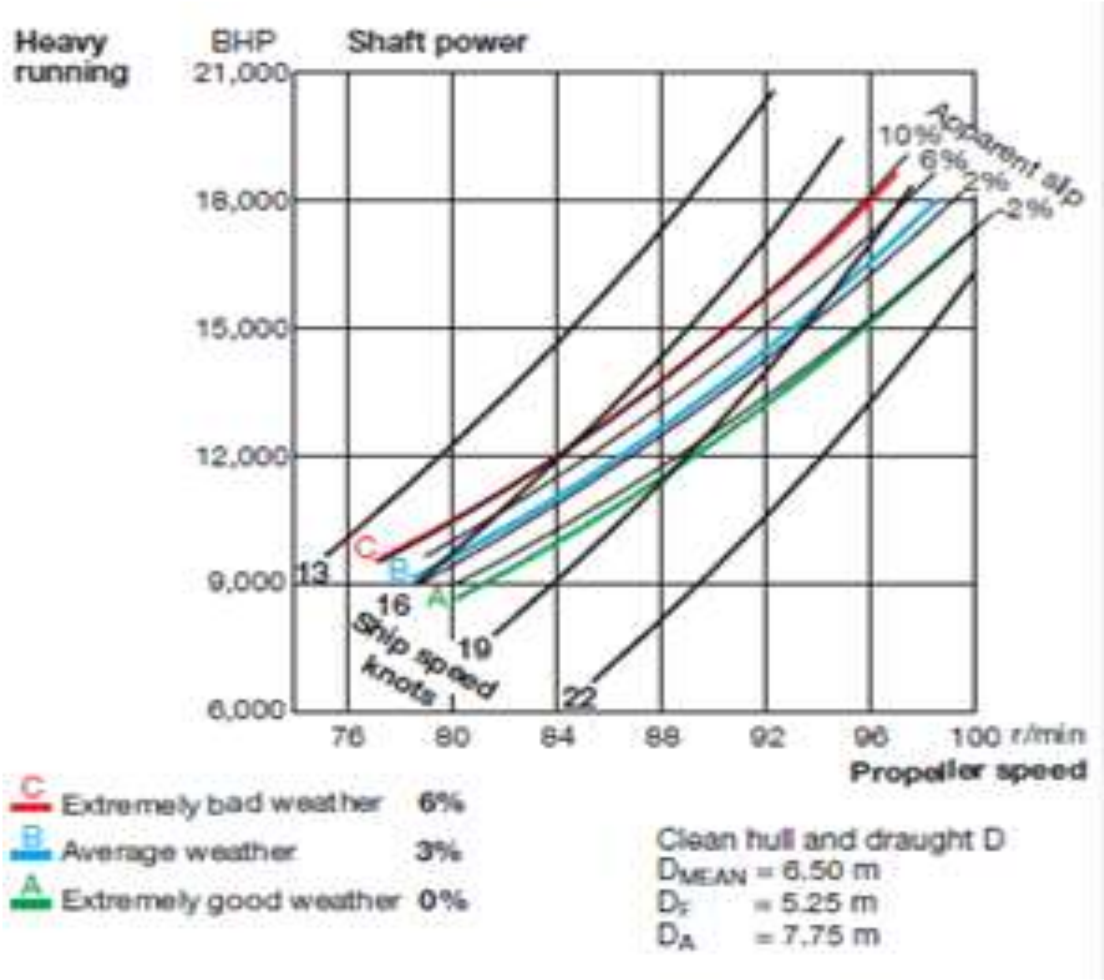


Uncertainty:

- A parameter, associated with the result of the determination of a quantity, that characterises the dispersion of the values that could reasonably be attributed to the particular quantity, including the effects of systematic as well as of random factors, expressed as a percentage, and describes a confidence interval around the mean value comprising 95 % of inferred values taking into account any asymmetry of the distribution of values.
- In the above context, an uncertainty default value in line with industry standards, is 10%.

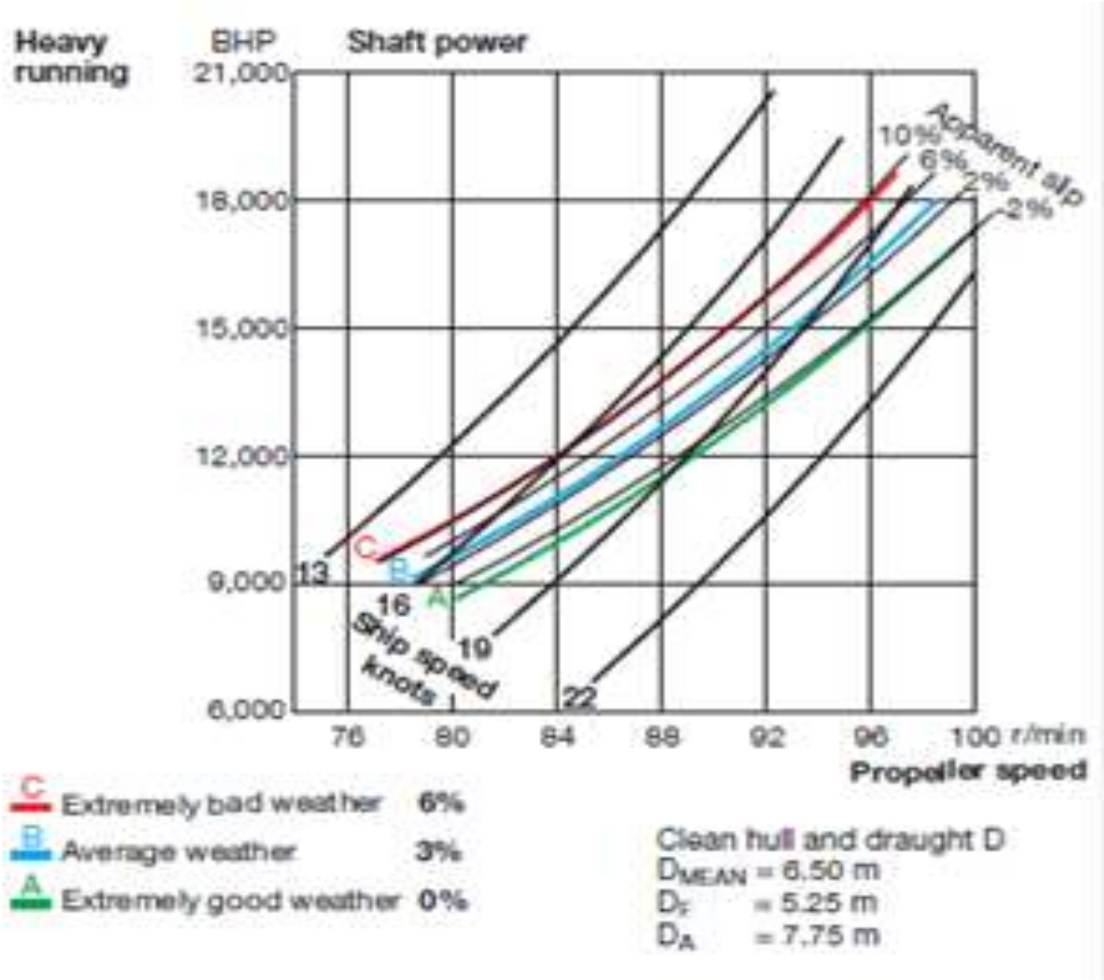
Materiality level:

- The quantitative threshold or cut-off point above which any erroneous entries inherent in the acquired data, individually or taken together, are considered to be material.
- In the same as above context, a materiality level default value in line with industry standards is 5%.

Correlation of propeller shaft RPM and power to TTW (log) speed data:

- The trinities of TTW (log) speed, propeller shaft RPM and power average data values, during each different voyage's daily reporting periods / intervals, are expected to be correlated in a certain predetermined pattern ("trend"), whereas their correlation is to compare in a technically and physically meaningful manner to the specific main engine and propeller data, and to similar main engines and propellers in general.
- This is not examined by simply comparing statically the reported shaft power values with the calculated ones, but instead by recalibrating / reconnecting the hydrodynamic models applicable for the above correlation, with the respective actual data, for achieving a best fit match between the reported and the calculated values of shaft power, which is equivalent to determining the most probable shaft power model definition of least uncertainty which will produce a, physically / technically significant and consistent, "mean" value ("of reasonable degree of certainty") of shaft power for all applicable (reported) combinations of RPM and TTW (log) speed data values.

Correlation steps #1 and #2:



Correlation of main engine SFOC, RPM and power data:

- SFOC is inversely proportional to the effective overall efficiency, which in turn is equal to the respective product of (mechanical efficiency) times (indicated efficiency).
- An “effective overall efficiency” value of ~ 0.50, for an MDO/MGO net energy – lower calorific value (LCV) reference value of 42.7 MJ/kgr, would be equivalent to a SFOC value of ~ 168 gr / KW hr.
- The trinities of SFOC, RPM and power average data values of the main engine are expected to be correlated in a certain predetermined pattern (“trend”), whereas the SFOC values are to compare in a technically and physically meaningful manner to the shop test SFOC values (curve) of the specific main engine, and of similar main engines in general.
- This is not examined by simply comparing statically the reported SFOC values with the calculated ones, but instead by recalibrating / reconnecting dynamic models for main engines’ mechanical efficiency and indicated efficiency (on terms of relevant thermodynamics, heat transfer and gas dynamics analyses) as well, with the respective actual engine data, for achieving a best fit / match between the reported and the calculated values of SFOC, which is equivalent to determining the most probable SFOC model definition of least uncertainty which will produce a, physically / technically significant and consistent, “mean” value (“of reasonable degree of certainty”) of SFOC for all applicable (reported) combinations of RPM and power data values.

Results from 10 Hellenic oil tankers equipped with auto-logging / data acquisition / "machine learning" (ML) embedded Hardware In the Loop (HIL), for acquiring, logging and analysing data in real time via high end embedded Field-Programmable Gate Arrays (FPGA) controllers fit for the above purpose:

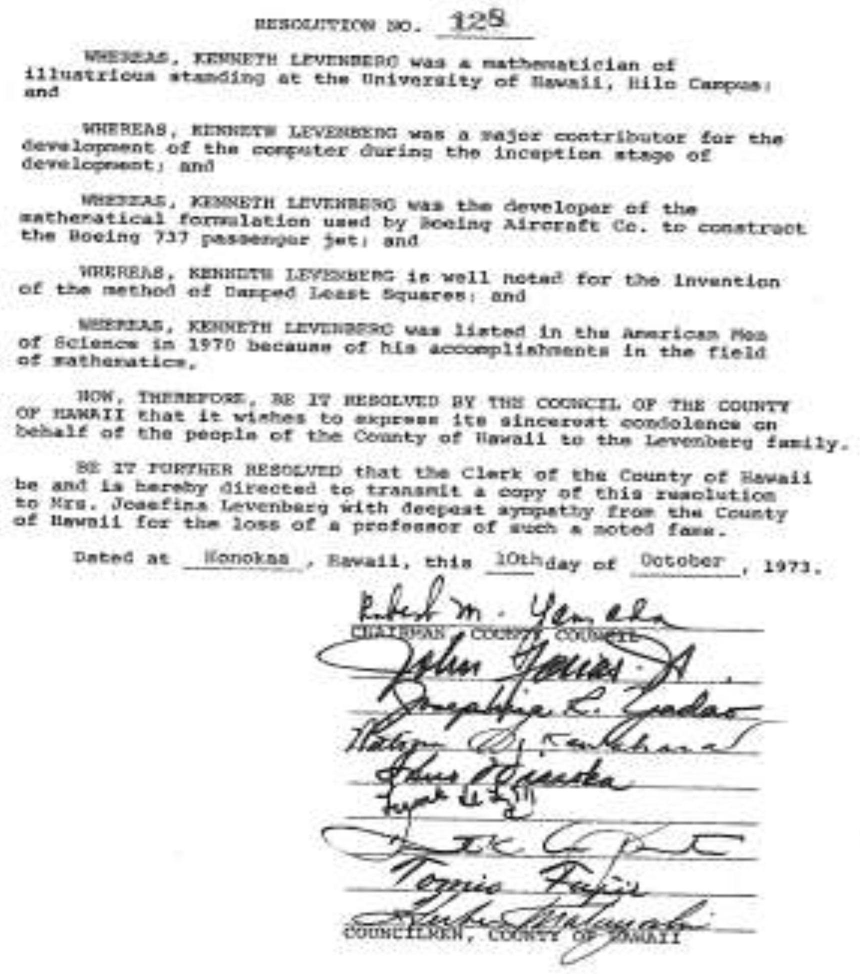
Vessel No.	Number of Legs	All Legs Power RPM RFOC Legs	All Legs STTW RPM RFOC Legs	Per Leg STTW RPM RFOC Legs	All Legs Power RPM RFOC Materiality	All Legs STTW RPM RFOC Materiality	Per Leg STTW RPM RFOC Materiality	Average Materiality To be less than or equal to 5%	All Legs Power RPM RFOC	All Legs STTW RPM RFOC	Per Leg STTW RPM RFOC	Average To be less than or equal to 5%
									% FOC of Legs with Uncertainty > 10%			
1	38	38	38	38	1.38%	2.72%	0.73%	1.61%	0.00%	10.63%	0.00%	3.54%
2	31	31	31	31	0.89%	4.13%	0.86%	1.96%	0.00%	9.43%	0.00%	3.14%
3	35	35	35	35	0.01%	2.02%	0.52%	0.85%	0.00%	4.64%	0.00%	1.55%
4	29	29	29	29	0.06%	1.39%	1.04%	0.83%	0.00%	0.00%	0.00%	0.00%
5	5	5	5	5	0.05%	0.85%	0.16%	0.35%	3.74%	3.73%	0.00%	2.49%
6	4	4	4	4	0.10%	0.36%	0.63%	0.36%	0.00%	0.00%	0.00%	0.00%
7	32	32	32	32	0.02%	2.02%	0.81%	0.95%	0.00%	1.76%	0.00%	0.59%
8	13	13	13	13	4.17%	1.13%	1.76%	2.35%	0.00%	5.85%	2.23%	2.69%
9	30	30	30	27	0.06%	2.96%	1.97%	1.66%	4.30%	7.24%	1.96%	4.50%
10	5	5	5	5	4.89%	1.18%	1.42%	2.50%	0.00%	0.00%	0.00%	0.00%
	222	222	222	219								

The edge, “big data” / “AI” / ‘ML’, multi – dimensional / non – linear, optimization technologies incorporated in the presented solution, are based on the ingenious and formidable work of **Kenneth Levenberg** (August 6, 1919 – September 1973), an American statistician and original author of the widely used nonlinear least squares fitting algorithm later improved by Donald Marquardt, known as the Levenberg–Marquardt algorithm. Levenberg first published the algorithm in 1944 while working at the Frankford Arsenal.[1] He later worked for Boeing where he developed mathematical models used to design the Boeing 737. He ended his career in the mathematics department at the University of Hawaii, Hilo and died in Hawaii in 1973.[2] Levenberg was listed in American Men of Science in 1970.[2]

References:

1.Kenneth Levenberg (1944). "A Method for the Solution of Certain Non-Linear Problems in Least Squares". Quarterly of Applied Mathematics. ***2****: 164–168. JSTOR 43633451.*

2."Resolution No. 128". Hawaii County council. 10 October 1973. Retrieved 4 February 2015.



RESOLUTION NO. 128

WHEREAS, KENNETH LEVENBERG was a mathematician of illustrious standing at the University of Hawaii, Hilo Campus; and

WHEREAS, KENNETH LEVENBERG was a major contributor for the development of the computer during the inception stage of development; and

WHEREAS, KENNETH LEVENBERG was the developer of the mathematical formulation used by Boeing Aircraft Co. to construct the Boeing 737 passenger jet; and

WHEREAS, KENNETH LEVENBERG is well noted for the invention of the method of Damped Least Squares; and

WHEREAS, KENNETH LEVENBERG was listed in the American Men of Science in 1970 because of his accomplishments in the field of mathematics.

NOW, THEREFORE, BE IT RESOLVED BY THE COUNCIL OF THE COUNTY OF HAWAII that it wishes to express its sincerest condolence on behalf of the people of the County of Hawaii to the Levenberg family.

BE IT FURTHER RESOLVED that the Clerk of the County of Hawaii be and is hereby directed to transmit a copy of this resolution to Mrs. Josefina Levenberg with deepest sympathy from the County of Hawaii for the loss of a professor of such a noted fame.

Dated at Honokaa, Hawaii, this 10th day of October, 1973.

CHAIRMAN, COUNTY COUNCIL

COUNCILMEN, COUNTY OF HAWAII

CERTH at a glance

- **Established:** in 2000 (CPERI existing since 1985)
- **Mission:**
  - High quality scientific research
  - Emphasis on Research – Development – Innovation (R&D&I)
  - Strong collaboration with the global industry
  - Innovative synergies with universities and research institutes in Greece and abroad
- **Legal form:** legal entity under private law with non-profit status. Supervised by General Secretariat for Research and Technology (GSRT) / Ministry of Education, Research and Religious Affairs
- **Personnel :** 700+ with majority engineers and scientists
- **Annual Turnover: ~** 25 M€
  - > 30% from bilateral industrial research contracts.
  - > 60% from competitive research projects and
  - < 10% as government institutional funding
- **Numerous awards and distinctions** (e.g. Descartes Prize, ERC Advanced Grant, Trading Agent Competition Award and many more)
- Involved in more than **1,200 competitive research grants**, with a **total budget exceeding 450 M€** and involving more than **1,100 international partner organizations**
- Listed among **top 20 EU Research Centers** with **the highest participation in H2020**

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CERTH/CPERI Strategy

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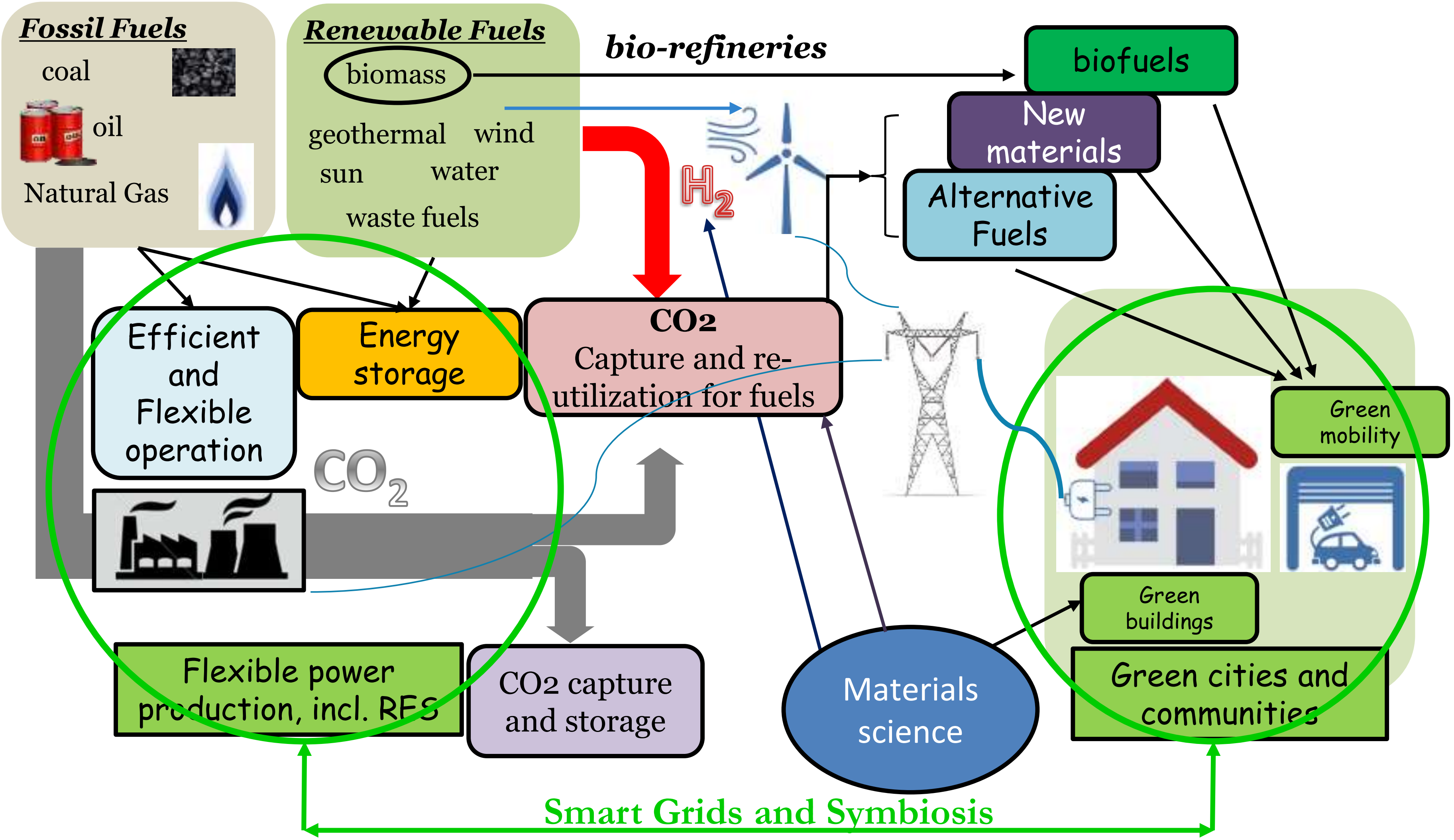

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Archipelago LNG

SUNIES
Greek - German project
Fuel Cell Island Energy Systems

LNG in Energy and Transport

Smart LNG Logistics in Greece

Challenges

- ✓ Particularities of Greek islands and continental area (Western Greece and Epirus) need for **flexible**, **sustainable** and **smart** solutions with small scale infrastructure in the areas concerned
- ✓ Integration of different **LNG transport and supply** modes
- ✓ Harmonization of the European legislation in the Greek **legal**, **social** and **political** framework
- ✓ **Social Acceptance**

Obstacles

- ✓ Matter of political stability, possible policy / administrative malfunctions and bureaucracy
- ✓ Economic / Tax status. Lack of subsidies and other financial support. Need for education & training on technical issues.
- ✓ Low availability and inflexibility of the banking system. Only possibility, the synergies with European and other funds
- ✓ Low-range plans for the LNG supply design. Lack of small-scale LNG terminals

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LNG utilization

Energy – Transport

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LNG utilization in Greek Archipelagos

- Cost Benefit Analysis for the development of LNG fuel supply chain in Greek shortsea shipping
- Environmental footprint evaluation of the LNG fuel supply chain
- Life Cycle Assessment for the LNG bunkering operation procedures and utilization in engines
- Social and political acceptance evaluation of LNG as fuel in Greek islands

Archipelago LNG

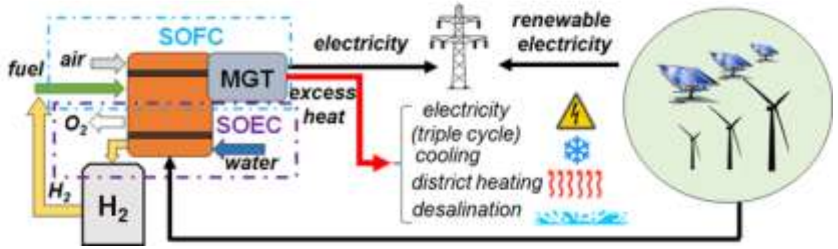
LNG as marine fuel and other uses in Eastern Mediterranean Area

- Air Pollution Measurement CO_2, SO_x, NO_x, PM in 5 ports (core ports): Piraeus, Igoumenitsa, Irakleio, Patra and Limassol
- Mapping of energy consumption in Patra and Igoumenitsa and technoeconomical assessment of LNG supply chain and use
- LNG supply chain study in Aegean and Ionian islands area in electricity generation, industry and transport sector

Innovative LNG concepts
Solid Oxide Fuel Cells Applications for isolated energy systems

- Development of fuel cells with LNG and RES as fuel (SOFCs)
- Development of new SOFC concepts suitable for isolated areas (Micro-Gas Turbines, Steam Turbines)
- Feasibility study of reverse operation SOFC/SOEC (RES to H2) concept for medium to large size application in isolated areas

SUNIES
Greek - German project
Fuel Cell Island Energy Systems



Activities related to LNG for the marine sector in Greece

(2014-2015) Archipelago LNG

Co-financed by the European Union
Trans-European Transport Network (TEN-T)

Key results

Supply from Revithoussa Terminal

Piraeus Port: Truck-To-Ship (2018-2020), LNG bunkering vessel (1,000-3,500 m^3) (2020 - ...)

Heraklion Port: LNG bunker/feeder vessel (1,000 m^3) (2020 - …) with intermediate small-scale LNG tanks of 500 m^3

RO-PAX LNG-fuelled vessels

Conversion budget (from € 3 to 10 million €), Depreciation of investment (6-10 years)

Depends on:

- ✓ Number of engines for retrofit, Volume of installed tanks, Type of retrofit or replacement of the existing engine
- ✓Operation profile (winter – summer / seasonality), Future development of the LNG - MDO price
- ✓ European and international regulations

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Activities related to LNG for the marine sector in Greece

CPERI
Chemical Process and Energy Resources Institute

Aiming to prepare a plan of infrastructure development in Eastern Mediterranean, so that LNG can be widely adopted as marine fuel for shipping operations.

POSEIDON MED LNG BUNKERING PROJECT

Archipelago LNG

Aiming to identify the key technical, economic and legislative framework of the small scale LNG as marine fuel value chain in the South Aegean Region

POSEIDON MED II (CEF Transport)

26 Partners

Facilitate all necessary actions to achieve maturity, build strong cooperation among stakeholders, explore and enhance synergies

Co-financed by the European Union
Connecting Europe Facility

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Activities related to LNG for the marine sector in Greece

CPERI
Chemical Process and Energy Resources Institute

Project Organization	Act. 1-3	Coordination – Management – Dissemination – Social/Public Consultation – Awareness
Ports & LNG Terminal Infrastructure	Act. 6-12	Environmental/Safety/Site Studies – Ports Master Plans updating – Supporting/Preliminary/Detailed Design Studies – Tender documents
Vessels Infrastructure	Act. 14	Technical retrofit studies for 10 selected vessels
Pilot case (Venice)	Act. 15	Executive Design and Construction of an Innovative LNG Vessel
Financial aspects	Act. 4-5	Installations Financial Assessment - Financial Instruments for the Global Projects Investments
Regulatory Framework	Act. 13	Adaptation of the Regulatory Framework
Sustainability-Synergies	Act. 16-17	Assessment of Efficient Supply Chain/Synergies – Sustainable LNG Pricing Patterns

CERTH Activities → **To aware and promote Green hydrocarbon fuels (LNG)**

Co-financed by the European Union
Connecting Europe Facility

Air Quality Measurements in Ports

Piraeus Port

4 - 9/5/2017 (Low Season)
27/7– 4/8/2017 (High Season)

Patras Port

11 - 14/5/2017 (Low Season)
4 - 9/8/2017 (High Season)

- ✓ 24-h measurements
- ✓ SO_x, NO_x, CO, O_2, $PM_{2.5}$, PM_{10}
- ✓ Maritime, Cruise (Piraeus, Heraklion)
- ✓ International Maritime (Patras, Igoumenitsa)

Heraklion Port

11 - 16/5/2018 (Low Season)
2 - 8/8/2018 (High Season)

Igoumenitsa Port

17 - 25/5/2018 (Low Season)
25/8– 31/8/2018 (High Season)

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CPERI
Chemical Process and Energy Resources Institute

CERTH's Air Emissions Measurement Equipment

Air Quality Portable Ground Station

Drone Pollution Sniffer

For detailed info, please contact sfetsioris@certh.gr

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LNG innovative applications

CPERI
Chemical Process and Energy Resources Institute

SUNICS
Greek - German project
Fuel Cell Island Energy Systems

gwi Gas- und Wärme-Institut Essen e.V.

UNIVERSITÄT DUISBURG ESSEN

MITSUBISHI HITACHI POWER SYSTEMS

Project main objectives

- Operability of a **SOFC Hybrid System** prototype (250 kW_e) under specific fuel and load conditions
- Development of new SOFC concepts for island applications
  -highly flexible "**Hybrid System**" composed of **(SOFC + MGT)**
  -highest efficiency "**Triple Cycle Concept**" **(SOFC+MGT+ST)**
- Feasibility assessment of a Reversible SOFC/SOEC concept on medium to large scale island applications

Project main activities

- Screening and determination of boundary conditions and selection of two Greek island cases
- Testing of the 250 kWe SOFC Hybrid System) performance & flexibility (electrical-thermal output, efficiency, stability, degradation) by using different fuels (Biogas, different NG compositions, NH3 etc.) under different boundary conditions
- Steady state and dynamic modeling simulations
- Business plans and Roadmap

LNG innovative applications

SUNICES
Greek - German project
Fuel Cell Island Energy Systems

SOCs: Solid Oxide Cells

SOFC

Fuel Cell
Fuel → Electricity

Electr | Fuel

Electrolyzer Cell
Electricity → Fuel

SOEC

- ✓ High **efficiency** (up to 60%)
- ✓ **Low CO_2** emissions
- ✓ **Fuel flexibility**: LNG, methanol, H_2, biogas
- ✓ **Assembly** in existing power plants (1kW – 10 MW)
- ✓ **Cogeneration** possibility (domestic hot water, district heating, desalination, etc).

- ✓ **Chemical energy storage/carrier**
- ✓ **Much higher temperatures** than the conventional electrolyzers (Alkaline & PEM)
- ✓ **Much less electricity consumption (3KWh/Nm³)**

Hybrid SOFC-GT

GT

Required for start up until SOFC reaches operability

Overall efficiency above 60%

Challenges

- ❖ Low TRL (SOEC)
- ❖ Slow start up
- ❖ Improve operational flexibility

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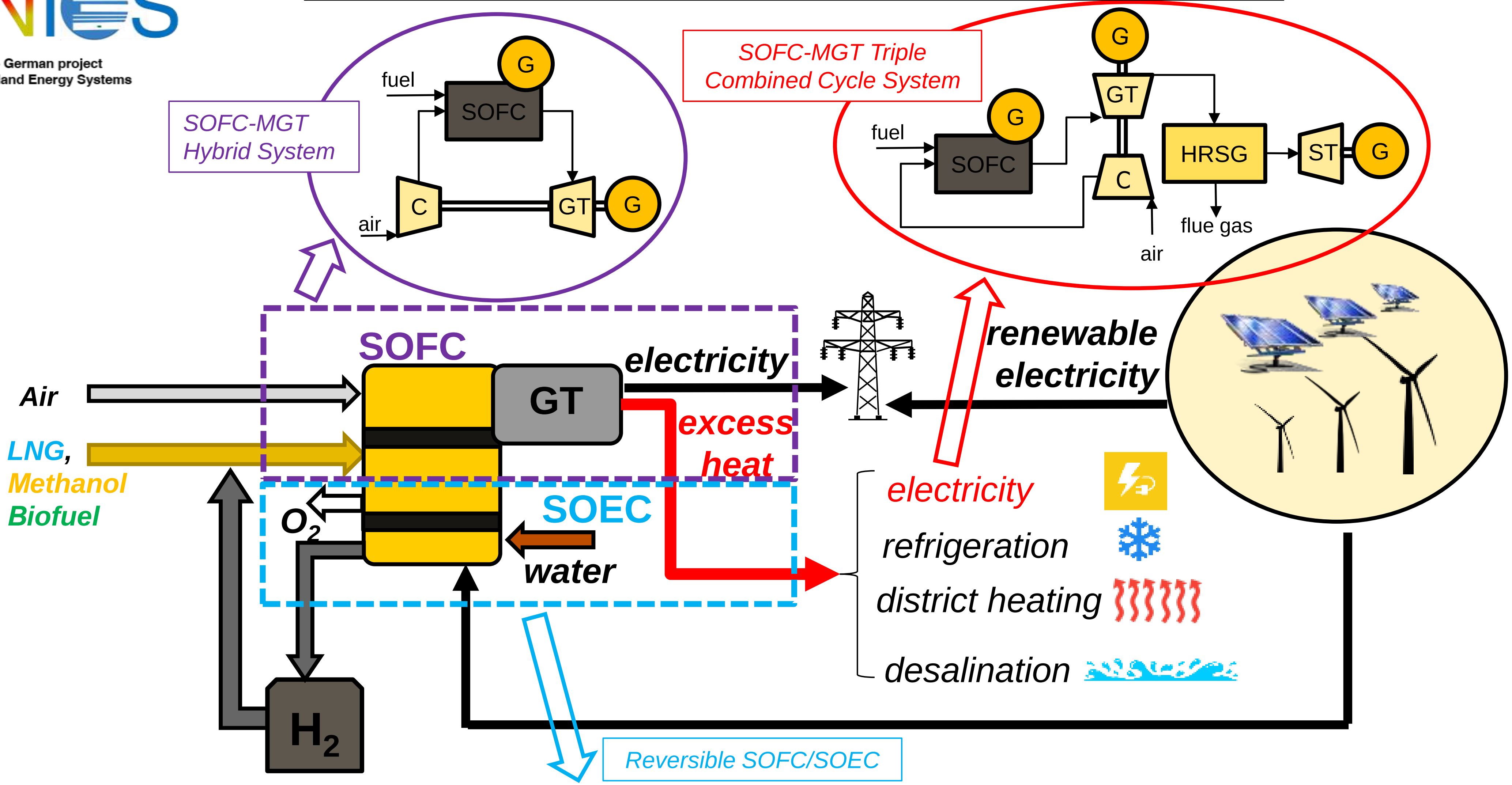
LNG innovative applications

CPERI
Chemical Process and Energy Resources Institute

SUNIES
Greek - German project
Fuel Cell Island Energy Systems

MGT integration for fast load response and flexible operation



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CO_2 hub

Oil to NG Transition

Efficient use of Hydrocarbons in Western Macedonia

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NG as case study in Western Macedonia

CPERI
Chemical Process and Energy Resources Institute

PPC – Agios Dimitrios Power Plant

Main Objectives

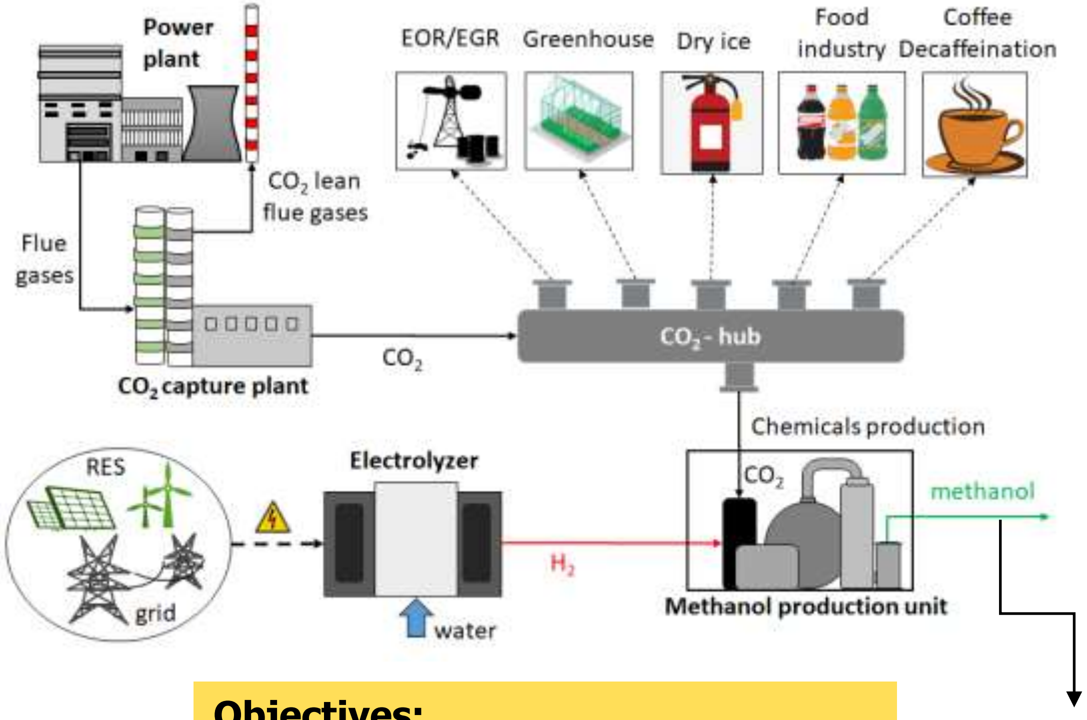
- ✓ Retrofit oil burners to have Natural Gas as fuel
- ✓ Develop and evaluate LNG-CNG supply chain
- ✓ Create synergies to supply LNG-CNG to other end uses (district heating, transport)

Key Results

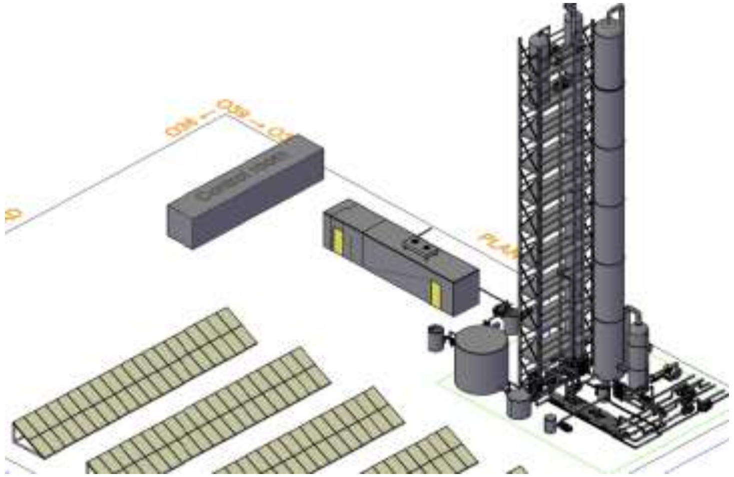
- **NG Retrofit of partial burners in a unit** is technically (minimum firing problems) and economically (high retrofit CAPEX) infeasible
- **NG Retrofit of all burners in a unit** is considered as feasible with LNG fuel supply chain (trucks from Revithoussa and storage tank in Agios Dimitrios) but it depends on future supply price (truck loading station in operation)
- **L-CNG station** can produce economies of scale in the region (urban and interurban transport).
- **NG pipeline** is the only available choice to supply all burners to all units of Agios Dimitrios and subsequently as main fuel for the complete power plant.

CO_2 hub Proposed Concept
Efficient use of hydrocarbons

- Installation of a Pilot CO_2 capture and utilization facility next to Agios Dimitrios power plant
- Appropriate CO2 purity for a number of different end uses
- CO_2 – Hub in Western Macedonia
- Reduction of Greenhouse Gas Emissions from power plants – development of a new supply value chain
- Demonstration of CO_2 utilization through the production of Methanol using Hydrogen, which will be produced in an electrolyzer



SOFC fuel cells



Objectives:

1. *Demonstration of CO_2 Capture technology with CO_2 avoidance cost of **<25 €/tonne***
2. *Efficient (>90%) capture*
3. ***Capture of 5500 tonnes/year***
4. *High purity methanol production from CO_2 and H_2*
5. *Technoeconomical and environmental evaluation of CO_2 Capture and Utilization technology*

Thank you for your attention!

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