I.P. HERCULES

HIGH – EFFICIENCY ENGINE R&D

ON COMBUSTION WITH

ULTRA-LOW EMISSIONS FOR SHIPS

Project partly funded by:

- The European Commission under Sixth Framework Programme (FP6)
  Contract # TIP3-CT-2003-506676
- The Swiss Government - Bundesamt für Bildung und Wissenschaft (BBW)

SCOPE and DESCRIPTION OF WORK

1. HERCULES I.P. will develop **new technologies**:

   - To drastically reduce gaseous and particulate emissions from marine engines
   - To increase engine efficiency and here-by to reduce specific fuel consumption, CO2 emissions and lifecycle cost
   - To increase reliability

2. The **objectives** will be attained through interrelated developments in:

   - Thermodynamics and mechanics of “extreme” parameter engines
   - Advanced combustion concepts
   - Multistage intelligent turbocharging
   - “Hot” engines with energy recovery and compounding
   - Internal emission reduction methods and advanced aftertreatment techniques
   - New sensors for emissions and performance monitoring
   - Adaptive control for intelligent engines

I.P. HERCULES VISION

I.P. HERCULES VISION	Year 2010	Year 2020
Reduction of fuel consumption and CO_2 emissions	3%	5%
Reduction of NOx (Relative to IMO 2000 standard)	30%	60%
Reduction of other emission components (PM, HC)	20%	40%
Improvement in engine reliability	20%	40%
Reduction of time to market	15%	25%
Reduction in lifecycle cost	10%	20%

* Percentage changes related to current Best-Available-Technology-In-Service (BAT-IS)

I.P. HERCULES OBJECTIVES

I.P. HERCULES OBJECTIVE	BAT-IS (2003)	Year 2007 Targets	Year 2010 Targets
Reduction of fuel consumption and CO_2 emissions	2-stroke: 170 g/kWh 4-stroke: 175 g/kWh	1%	3%
Reduction of NOx (Relative to IMO 2000 standard)	IMO 2000 limits (g/kWh) 17 N<130 rpm $45 \times (rpm)^{-0.2}$ 130<N<2000 9.8 N>2000 rpm	20%	30%
Reduction of other emission components (PM, HC)	< No limits for marine engines > Visible smoke limit FSN 1.1 Opacity 20%	5%	20%
Improvement in engine reliability	18,000 hours to overhaul of major components	10%	20%
Reduction of time to market	5 Years	10%	15%
Reduction in lifecycle cost - Initial cost - Fuel/lub-oil cost - Maintenance	< Costs depend on engine size >	 0% 1% 4%	 1% 3% 6%

* Percentage changes related to current Best-Available-Technology-In-Service (BAT-IS)

HERCULES I.P. METHODOLOGY:

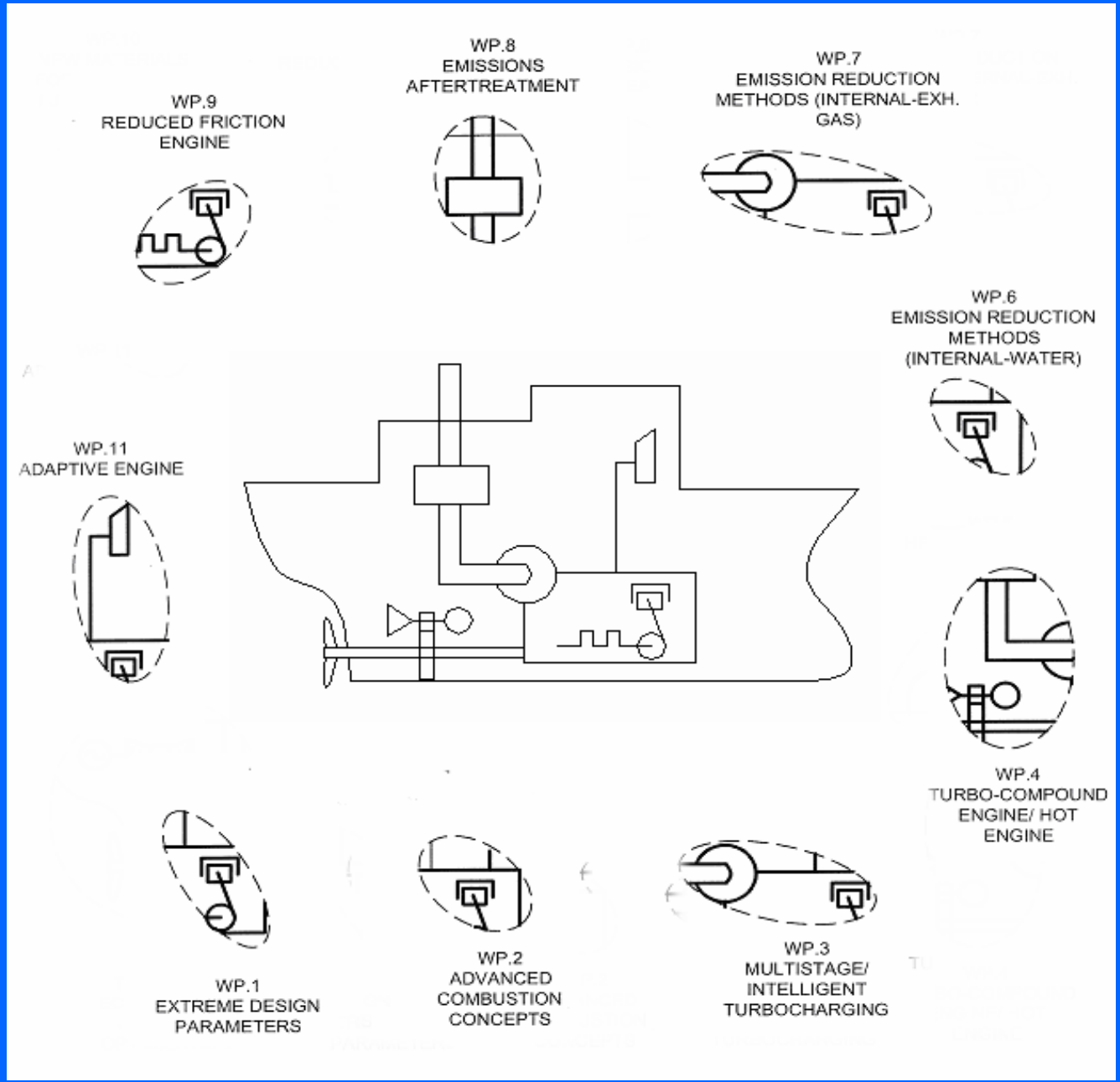
- Advanced process models and engineering software tools will be developed
- Prototype components will be manufactured and rig-tested
- Engine experimental designs will be assessed on testbeds
- Full-scale shipboard testing will demonstrate the benefits

Successive objectives for improvements to be available onboard ships are set for years 2010 and 2020.

STRUCTURE OF THE WORK

- Nine (9) Workpackages
- Eighteen (18) Tasks
- Fifty-four (54) Subprojects

Overview of I.P. HERCULES Workpackages



I.P. HERCULES INNOVATION ACTIVITIES

Some of the areas where innovations are considered in the I.P. HERCULES are:

- Engines with “extreme” boost, m.e.p. design parameters
- “New” combustion concepts
- “Intelligent” variable flow area, multistage turbochargers
- “Hot”-operating engine with combined steam cycle
- Marine engines with water injection
- Exhaust gas recirculation in heavy-fuel engines
- New aftertreatment methods for heavy fuels (plasma, scrubbers)
- New sensors and emission measurement methods
- “Low-friction” engines
- “Adaptive” control of engines

I.P. HERCULES – Partners

The participating organisations are from 10 countries:

- 9 are *EU Member Countries* (Austria, Czech Republic, Denmark, Finland, Germany, Greece, Italy, Sweden, United Kingdom)
- 1 is *Associated to FP6 Country* (Switzerland).

From the participants:

- 60% are *Industrial partners*
- 19% are *Universities*
- 12% are *Research organisations*
- 9% are *User / Operator companies*.

The two major partner groups, MAN-B&W (G), MAN-B&W (DK), WARTSILA (FI), WARTSILA (CH), cover together about 80% of the world's marine engine market (medium- and low-speed engines).

I.P. HERCULES PARTNERS

ID#	PARTNER	SHORT NAME	COUNTRY	W.P.	ACTIVITY / TYPE
1	ULEME E.E.I.G.	ULEME	Germany	13	Co-ordinating partner
2	Åabo Akademi University	AAUniv	Finland	2	University
3	Aalborg Industries A/S	AALBORG	Denmark	4	Boilers & Heat exchangers
4	ABB Turbo Systems Ltd	ABB	Switzerland	3,4	Turbochargers
6	AdaptaMat Ltd	ADAPTAMAT	Finland	9	Magnetic materials/ Actuators
9	Bodycote H.I.P. Ltd	BODYCOTE	UK	1	Development Analysis/ Materials
11	Chalmers University of Technology	CHALMERS	Sweden	8	University
12	Daido Industrial Bearings Europe Ltd	DIBE	U.K.	1	Bearings
13	Deutsches Zentrum fur Luft-und Raumfahrt	DLR	Germany	7	Aerosol formation studies
14	EMPA, Swiss Federal Laboratories	EMPA	Switzerland	7	Materials testing / measurements
15	ETH Zuerich	ETHZ	Switzerland	2	University
16	Federal Mogul Friedberg GmbH	FMO	Germany	1,9	Piston rings
18	Germanischer Lloyd AG	GL	Germany	7	Classification society
20	Hapag-Lloyd Container Linie GmbH	HLCL	Germany	4	Shipping company
21	Helsinki University of Technology	HUT	Finland	1,2,3	University
22	Industriale SRL	INDUSTRIALE	Italy	1	Piston rings
23	IST GmbH	IST	Germany	9	Tribilogy consultants
25	JOWA Germany GmbH	JOWA	Sweden	9	Supplier of environment equipment
26	Kemmerich Gummersbbach Elektromotoren	KEGUEL	Germany	3	Motor generators/ frequency converters
27	Kristen Navigation Inc.	KRISTEN	Greece	11	Shipping company
29	Lunds Universitet	ULUND	Sweden	2	University
30	M. Jurgensen GmbH & Co KG	JURGENSEN	Germany	1,4,9	Liners/ New materials
31	Mahle GmbH	MAHLE	Germany	4	Piston engine components
32	MAN B&W DIESEL A/S	MBD(DK)	Denmark	1-4,6-9,11	Engine manufacturer
33	MAN B&W DIESEL AG	MBD(D)	Germany	1-3,6-9,11	Engine manufacturer
35	Miba Gleitlager GmbH	MIBA	Austria	1, 9	Bearings
36	National Technical University of Athens / LME	NTUA/LME	Greece	1,2,3,8,11	University
37	O.M.T.-Officine Meccaniche Torino S.P.A.	OMT	Italy	6	Fuel injection system
39	Paul Scherrer Institut	PSI	Switzerland	2	Research Institute
40	PBS Turbo s.r.o. Velka Bites	PBST	Czechia	3	Turbochargers
41	Peter Brotherhood Ltd	PBL	U.K.	4	Steam engineering
42	A.P. Moller-Maersk A/S	APM	Denmark	6	Shipping company
45	SICK UPA GmbH	UPA	Germany	8	Measuring technology
46	Tampere University of Technology	TUT	Finland	9	University
50	Universitat Hannover, Institut f. Technische Verbrennung	UH/ITV	Germany	2	University
52	VTT Technical Research Centre Of Finland	VTT	Finland	9, 11	Rig tests, materials, control
53	Wallenius Marine AB	WM	Sweden	6	Shipping company
54	Wartsila Corporation	WFI	Finland	1-4,6-9,11	Engine manufacturer
55	Wartsila Schweiz AG	WCH	Switzerland	2,3,6,7,8	Engine manufacturer
57	Woodward International Inc.	WOODWARD	U.K.	9	Control, fuel injection

Overview of I.P. HERCULES Workpackages

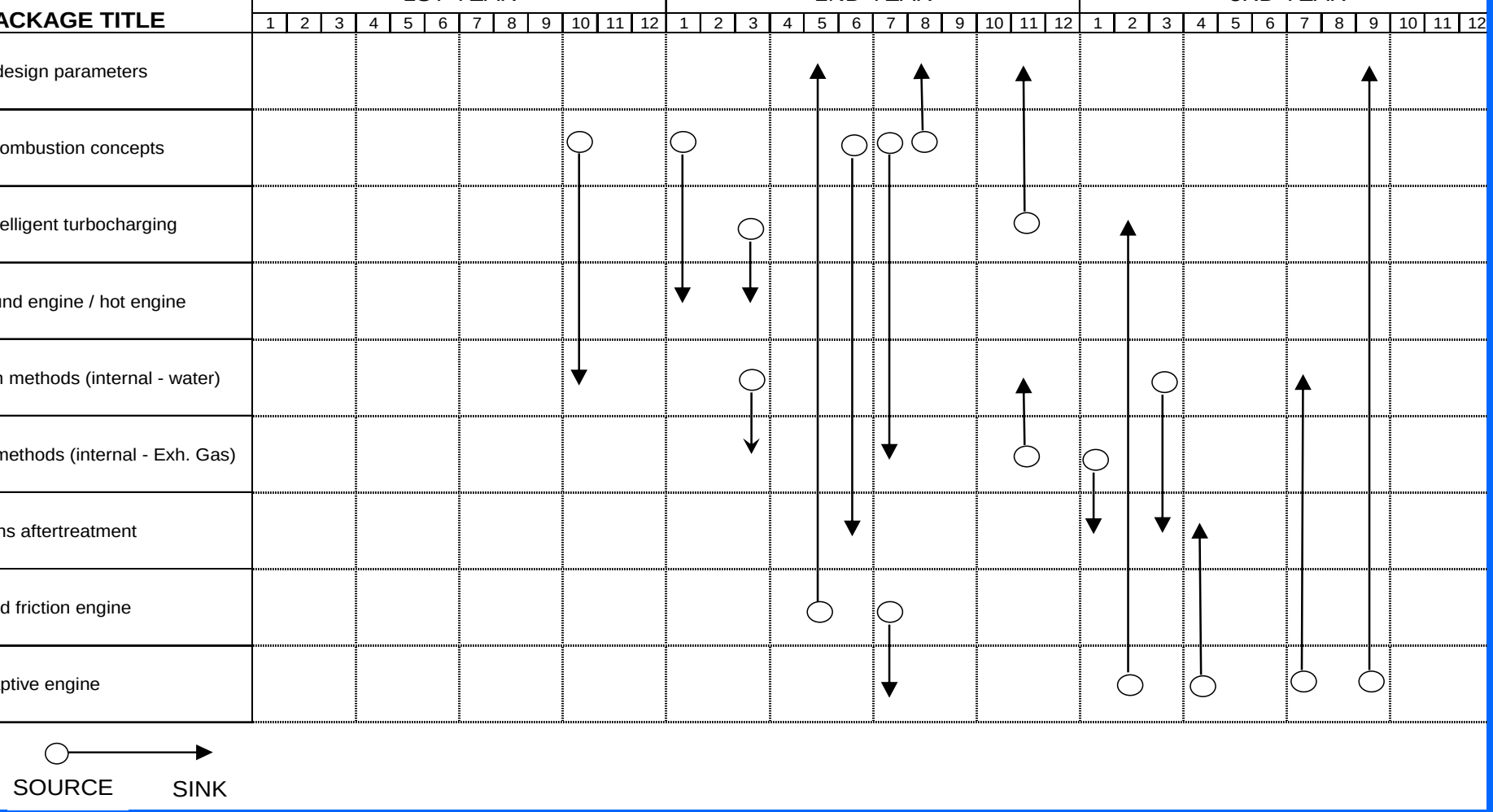
No	AREA	WORKPACKAGE TITLE	TASK TITLE	PARTNERS LIST
1	Thermofluid-dynamics	Extreme design parameters	Task 1.1: Mechanics of engine with extreme design parameters Task 1.2: Thermodynamics of engine with extreme design parameters	BODYCOTE, DIBE, HUT, FMO, INDUSTRIALE, JURGENSEN, MBD (DK), MBD (D), MIBA, NTUA/LME, WFI
2	Combustion	Advanced combustion concepts	Task 2.1: Combustion process simulation Task 2.2: Emission formation simulation	AAUniv, ETHZ, HUT, MBD (DK), MBD (D), NTUA/LME, PSI, UH/ITV, ULUND, WCH, WFI
3	Turbocharging	Multistage/intelligent turbocharging	Task 3.1: Variable turbocharging Task 3.2: Intelligent turbocharger	ABB, HUT, MBD (DK), MBD (D), NTUA/LME, PBST, KEGUEL, WCH, WFI
4	Combined cycle	Turbo-compound engine / hot engine	Task 4.1: Combined cycle Task 4.2: Hot engine	AALBORG, ABB, PBL, HLCL, JURGENSEN, MAHLE, MBD (DK), WFI
6	Emission reduction	Emission reduction methods (internal - water)	Task 6.1: Water injection techniques Task 6.2: Humidification methods	APM, MBD (D), MBD (DK), OMT, WCH, WFI, WM,

Overview of I.P. HERCULES Workpackages

No	AREA	WORKPACKAGE TITLE	TASK TITLE	PARTNERS LIST
7	Emission reduction	Emission reduction methods (internal - Exh. Gas)	Task 7.1: Internal measures Task 7.2: Emission reduction methods (internal - external exhaust gas recirculation and particulates)	DLR, EMPA, GL, MBD (D), MBD (DK), WCH, WFI
8	Emission reduction	Emissions aftertreatment	Task 8.1: After-treatment methods Task 8.2: New measurement methods	CHALMERS, MBD (D), MBD (DK), NTUA/LME, UPA, WFI, WCH
9	Tribology	Reduced friction engine	Task 9.1: Adaptive components Task 9.2: Tribo-optimisation	ADAPTAMAT, FMO, IST, JOWA, JURGENSEN, MBD (D), MBD (DK), MIBA, TUT, VTT, WFI, WOODWARD
11	Control, monitoring	Adaptive engine	Task 11.1: Adaptive control Task 11.2: Intelligent engine	KRISTEN, MBD (D), MBD (DK), NTUA/LME, VTT, WFI
13	Management	Project Management		ULEME

Interaction of I.P. HERCULES Workpackages

WP #	WORKPACKAGE TITLE
1	Extreme design parameters
2	Advanced combustion concepts
3	Multistage/intelligent turbocharging
4	Turbo-compound engine / hot engine
6	Emission reduction methods (internal - water)
7	Emission reduction methods (internal - Exh. Gas)
8	Emissions aftertreatment
9	Reduced friction engine
11	Adaptive engine



I.P. HERCULES Activities

Work comprises four types of activities

- RTD activities (all partners)
- Demonstration activities (industrial partners, shipping companies)
- Training activities (universities)
- Management activities (Coordinating partner)

WORKPACKAGE 1: Extreme design parameters

AIM: to increase engine power density and combustion cycle efficiency to drastically higher level than today's state-of-the-art. This will be performed by developing compression ignition engines designed for efficient and environmentally friendly operation under extreme working conditions.

Objectives:

- To create general knowledge about a diesel engine operating under extreme thermal and mechanical load
- To study the influence of advanced working cycles on engine performance and emissions
- To find design and material solutions to overcome the problems caused by the extreme conditions with regard both to mechanical and thermal load
- To develop new components and integrate them on engines
- To perform full-scale tests to evaluate the developed technologies

WORKPACKAGE 2: Advanced combustion concepts

AIM: to conduct specialised experiments allowing development of advanced models of key in-cylinder processes, to be used for investigating in depth new combustion concepts.

Objectives:

- Application of 3-D simulation tools to marine engine combustion; extension and adaptation of existing sub-models as well as development of new models.
- Development of advanced test facilities for fundamental experimental investigation of in-cylinder phenomena.
- Validation of models against experimental data.

WORKPACKAGE 3: Multistage / Intelligent Turbocharging

AIM: to examine multistage turbocharging providing charging pressures beyond today's state of the art and to investigate the potential of variable geometry turbocharger components and power take in / take out, in terms of wider operating range capabilities.

Objectives:

- To investigate the potential benefit of variable geometry turbocharger systems, as well as systems with power take in/out and multi-stage turbochargers.
- To develop and test prototype components on test-rigs as well as on lab engines.
- To study and develop new concepts for variable turbocharging and to demonstrate the potential of the concepts by means of prototype and full-scale tests.

WORKPACKAGE 4: Turbo-compound engine / hot engine

AIM: to examine low heat rejection engines and exhaust gas separation allowing improved emissions handling and increased efficiency through compound cycle systems .

Objectives:

- To study and evaluate turbo-compound systems that use the “hot engine” concept
- To design and test prototype combined cycle systems
- To validate the suitability and reliability of chosen solutions
- To implement the developed system on a seagoing vessel

WORKPACKAGE 6: Emission reduction methods (internal – water)

AIM: to investigate the optimal water-addition method regarding efficiency, emissions trade-off, reliability, design complexity and the safe operation on-board ships .

Objectives:

- To confirm the NOx-reducing potential observed in lab tests
- To model and simulate water injection processes
- To develop water injection systems
- To test the developed systems on-board

WORKPACKAGE 7: Emission reduction methods (internal – exhaust gas)

AIM: to optimise the use of exhaust gas recirculation for NOx reduction and its effects on particulate emission for heavy fuel engines.

Objectives:

- To investigate the viability of using (Exhaust Gas Recirculation) EGR in marine engines operating on different fuel qualities
- To design prototype EGR systems for selected fuel qualities for two and four stroke engines and test the prototype systems in laboratory
- Characterisation of particulate emissions from marine engines
- Identification of influence of operating conditions and parameters as well as of fuel quality on particulates

WORKPACKAGE 8: Emissions aftertreatment

AIM: to study in-depth and adapt various proposed aftertreatment methods and to develop measurement technologies for emissions monitoring in large heavy fuel marine engines

Objectives:

- Development of practical and reliable methods for emissions monitoring in service
- Extension of emissions measuring technologies for individual-cylinder measurements
- Further development of the Non Thermal Plasma (NTP) and Wet Scrubber (WS) technologies, including lab tests and study of the behaviour under real engine exhaust conditions
- Application of the developed systems to marine diesel engines – lab engine tests
- Demonstration of potential and associated expense of all technologies

WORKPACKAGE 9: Reduced friction engine

AIM: to investigate techniques for improving engine efficiency through reduced friction including optimum lubrication and adaptive/smart components.

Objectives:

- Identification of tribological measures having the highest potential to improve the engine efficiency
- Identification of the need for adaptive components of the engine and development of relevant specifications
- Development of engine components with reduced friction losses
- Development of adaptive components
- Demonstration of functionality and reliability by means of engine tests
- On line control of cylinder condition by optimum cylinder lubrication

WORKPACKAGE 11: Adaptive engine

AIM: to develop control and monitoring systems with embedded intelligence, for new generation of engines enabling goal-oriented performance.

Objectives:

- Feasibility study of the use of intelligent control systems
- Creation of engine systems and components, the characteristics of which can be adapted to various operational conditions as well as to the status of the component
- Self-learning system based on monitoring by reliable measuring equipment and standardised evaluation procedures with goal-oriented performance under all boundary conditions
- Engine operating mode changes based on manual or automated procedures

Full scale shipboard installations are foreseen in HERCULES in the following Workpackages:

- *Workpackage 4: Turbocompound engine/hot-engine:*

  Prototype components will be installed onboard a containership of Hapag Lloyd Container Linie GmbH.
  The objective will be to demonstrate the increased overall efficiency of the powerplant.

- *Workpackage 6: Emission reduction methods (internal-water).*

  Water preparation and water engine injection systems will be installed onboard ships of: A.P. Möller-Maersk A/S and Wallenius Marine AB. The objective will also be to demonstrate the reduction in NOx emissions with the water injection system.

- *Workpackage 11: Adaptive engine*

  An electronically controlled camless engine is expected to be installed onboard a newbuilt ship of Kristen Navigation Inc.
  The objective will be to demonstrate the suitability for the purpose and reliability of the "intelligent" control system.

I.P. HERCULES Training Activities

Specialised Advanced Training Seminars will be organised in the final year of the I.P. in three Areas of Marine Engine R&D:

- Experimental and Measurement methods (coordinator HUT)
- Computational Fluid Dynamics and Combustion (coordinator ETHZ)
- Process simulation (coordinator NTUA/LME)

Potential Exploitation items of I.P. HERCULES

Table 8 **POTENTIAL EXPLOITATION ITEMS** TIMESPAN: SHORT=S MEDIUM=M LONG=L

WORKPACKAGE	ITEM	TIME
WP1 Extreme design parameters	Engine components for extreme output operation (pistons, rings, bearings).	M
	Extreme value engine	L
WP2 Advanced combustion concepts	Combustion models	S
	Chemical kinetics models	S
	Full cycle simulation tools	S-M
WP3 Multistage/intelligent turbocharging	Variable geometry turbocharger	M
	Power take-in, take-out systems (Integration motor/generator/turbocharger)	M
	Multistage intercooled turbocharger	M
WP4 Turbo-compound / hot engine	Composite structures for hot-engine	L
	Engine compounding systems and components (boilers, TG, TCS)	S
WP6 Emission reduction methods (internal-water)	Direct water injection system	M
	Inlet air humidification system	S
	Control systems for above	S
WP7 Emission reduction methods (internal-Exh. Gas)	Exhaust gas recirculation system	M
	PM measuring techniques	S
WP8 Emissions after treatment	In-service emissions monitoring system	S
	Non-Thermal Plasma Technology	L
	Wet Scrubber Technology	M
	Select-cylinder emission measurement technology	M
WP9 Reduced friction engine	Low friction engine components (liner, pistons, rings, bearings, injection)	M
	In-service monitoring system for cylinder and lub feed rate adjustment	S
	Low friction engine	M
WP11 Adaptive engine	Onboard engine electronics	S-M

END OF PRESENTATION