Final Program

STW Perspectief Program

Clean Combustion Concepts (CCC)

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1. Executive Summary

This STW Perspectief Program aims to fill crucial knowledge gaps in applications using Clean Combustion Concepts (CCC's). CCC's are a set of new revolutionary combustion methods which combine very high efficiency with extremely low emissions of unwanted pollutants. Further development and application is considered to be essential to create a society with a sustainable energy supply. This program therefore fits very well within governmental policies. A further requisite is that future CCC's are fuel-flexible and can be operated equally well on future (bio)-fuels. Although being developed for completely different combustion systems (engines, gas turbines and furnaces), it is expected that the microscopic behavior of different CCC's is very similar. The development of CCC's by industrial parties is used as starting point for the research carried out within this program. Models and scientific knowledge on the smallest scales is developed using sophisticated modeling and measurement techniques. The micro-scale models are translated into generic macroscopic models, implemented in CFD codes (together with CFD developing institutes) and other design tools for industry. These design tools are used subsequently to steer the development of CCC's by industry. A lot of research and development is currently carried out to extend the existing knowledge in this field all over the world. This research program is unique in the sense that bridges between different methods and institutes are created by carrying out a set of interconnected projects and by emphasizing knowledge exchange.

2. Setting and Relevance

Combustion is used in practical devices for power generation and transport purposes, such as gas turbines (in aircraft engines or for power generation) and internal combustion engines (Diesel or spark ignited engines). Combustion is also used in many industrial processes (e.g. for manufacturing steel, cement, glass or chemicals and for incinerating waste). More than 80% of our current energy is generated by combustion of fossil fuels and it is well recognized that combustion of fossil and future (bio)-fuels will remain the primary energy source in the 21st century.

However, combustion has a strong impact on the environment as it produces pollutants: e.g. nitrogen oxides and fine particulates. This has led to more stringent environmental legislation, specifying the maximum allowed emissions in many countries. At a more basic level, the contribution of the main combustion product CO_2 to the enhanced greenhouse effect and global warming forces mankind to completely rethink and redesign its combustion technologies (e.g. using CO_2 capture and sequestration). Therefore the goal of mankind to create a society with a sustainable energy supply cannot be met without much cleaner and efficient combustion technologies. In particular, optimal fuel-flexibility and adaptation to future (bio)-fuels is of eminent importance, because a broad range of new fuels is expected to appear on the market in due time.

The discovery and development of such technologies requires a deepening of our understanding of combustion processes. While combustion research in the past has enabled substantial advance in all technological areas it impacts, the present understanding is not sufficient to face the enormous challenges of energy sustainability and global warming[1]. Revolutionary steps forward are needed which can only be achieved by collaborating much more on all levels (industry, research institutes and universities) and bringing together all existing knowledge to tackle these challenges.

3. Goals and Ambitions

Starting from problems and questions of the Dutch industry, this program intends to fill crucial knowledge gaps in existing and future ultra-clean and efficient combustion technologies. In the following this ambition is elaborated and put into the perspective of international developments.

3.1 Enable breakthrough of new clean combustion technologies

Industry is continually being challenged to develop new generations of clean combustion systems to meet future needs. But to be able to do so, more knowledge is needed on how ultra-clean combustion can be combined with stable and efficient conversion. The problem is that a large number of industrial problems cannot be solved at present because combustion processes are poorly understood on a micro-, meso- and macroscale. The questions that must be answered are:

- how are pollutants formed?
- how can their chemical formation pathways be altered, and
- how can we measure, understand, model, manipulate and control microscopic phenomena (such as the interaction between droplets, particles, turbulent motions, flame structures, acoustic waves, etc.) to promote complete and stable combustion, in combination with high efficiency and ultra-clean conversion?

To address these questions, the elementary physical and chemical processes underlying these phenomena must be elucidated. To do so, new measurement techniques to probe these microscopic processes and new physically and chemically accurate methods for modeling combustion phenomena are necessary. Furthermore, this knowledge has to be translated to practical guidelines for steering and controlling combustion processes.

In response to these challenges, the focus of this program is on new “Clean Combustion Concepts (CCC’s)”, revolutionary methods to produce energy from current and future fuels, with substantially enhanced efficiency and significantly reduced pollutant emissions. Examples of closely related emerging technologies for ultra-clean combustion are Premixed Charge Compression Ignition (PCCI) in engines, and High Efficiency Combustion (HEC) in gas turbines, furnaces and boilers. These concepts and similar ones such as “Controlled Auto-Ignition” (CAI), “Low-Temperature Combustion (LTC)” with high Exhaust Gas Recirculation (EGR) in engines, “High Temperature Air Combustion” (HiTAC), or “FLameless OXidation” (FLOX) in furnaces that have already been proposed should be brought to widespread

1 C.K. Law, Combustion at a crossroads: Status and prospects, Proc. Comb. Inst. 31 (2007) 1-29

application via the results of this program. On the other hand, proposals for other CCC's are invited for investigation in the program.

An important element in the successful application of CCC’s is the ability to adapt to changing fuel composition. The stable and clean combustion depends heavily on the fuel composition, while on the other hand, fossil fuels will be mixed/changed step-by-step by new fuels, e.g. derived from biomass, such as biomass/coal mixtures in furnaces and biodiesel, ethanol, dimethyl-ether biogas and hydrogen in engines and gas turbines. As a result, an important part of the activities in the CCC progam will be devoted to fuel-flexibility.

The CCC’s will be investigated in a coherent multi-disciplinary approach jointly by universities, knowledge institutes and industry integrating fundamental and applied research. Development of the CCC's will be based on new and quantitative understanding of combustion phenomena, providing explanations and control at a much more fundamental level than traditional engineering approaches. When the program is completed the participating companies can finish the development of new combustion systems (furnaces, engines, gas turbines, etc) incorporated with the new CCC’s, with improved efficiency and having emission levels well below the most stringent European norm.

Most of the techniques mentioned are still in a very early phase of development. Many technological problems and uncertainties exist. For instance, HCCI (Homogeneous Charge Compression Ignition), a forerunner of the currently investigated PCCI concept in future engines was abandoned because of restrictions in load and devastating pressure peaks in the engine. On the other hand, researchers currently trying to improve the PCCI concept, are facing problems with combustion controllability, which can possibly be solved in the future using other less reactive fuels. More adaptations and/or other variants are under investigation as well (like Low Temperature Combustion (LTC)). More detailed knowledge on all levels can assist engine OEM’s, like DAF, in their effort to produce ultra-clean engines for the future. If successful, DAF Trucks will have the knowledge to successfully complete the development of an ultra-clean Diesel engine with PCCI and/or LTC in 2016. Likewise, CORUS and SHELL will be able to confidently redesign process furnaces using flameless combustion technology.

3.2 Position of the Netherlands in a worldwide development

In the Netherlands, the first few applications of CCC’s have been initiated recently. Test HEC burners have been applied at the research station of the International Flame Research Foundation (IFRF), until recently at the CORUS site in IJmuiden. DAF started the development of their new ultra-clean Diesel engine for 2016 recently. However, the interest in CCC’s is not restricted to the Netherlands. There is a lot of interest in new combustion concepts such as HCCI/PCCI and HiTAC all over the world. Important studies have been realized, especially in Japan, Germany, France, USA and Sweden. But a coordinated effort to bridge the gap between fundamental understanding and new applications and covering a wide range of industries is missing. The present program addresses the need for such coordinated effort.

The publications of the Combustion Institute (the Journal Combustion and Flame, and the Proceedings of the Combustion Institute, in particular the “new concepts and technologies” section) demonstrate the worldwide interest in the fundamental aspects of clean combustion technologies. On the other hand, information on latest technology developments and commercial application can be found in more applied journals and in the proceedings of a series of conferences on HiTAC, the latest one being held in January, 2008[2]. These two types of activities focus on two different sides of the technology development problem: the more science oriented and the application oriented. The present STW program, following the general goals of the Technology Foundation STW, aims to strengthen both sides and bridge the currently existing gap between them.

Also the research groups in the Netherlands are already doing investigations on the new CCC's. The different groups work in different but related fields of combustion, each from their own discipline (chemistry, physics, mechanical engineering). Together they have a sophisticated and state-of-the-art set of recently developed modeling tools and laser-diagnostic measurement tools in their possession. The position of the Dutch combustion science in the international arena is already established. To give an indication: in the important 2006 International Symposium on Combustion, 60% of the Dutch papers were accepted (top position), while the average acceptance ratio was about 40%.

Current activities of the combustion research groups at the Dutch universities are related to different questions of individual industrial partners, even when concerning new CCC's. However, it has become clear that there is a common interest among many industrial partners, because the CCC’s such as PCCI and FLOX have much in common. From a “process technology” point of view it is clear that they all behave similarly on the smallest scales, the scales of fuel/air mixing and chemical to thermal energy conversion.

Therefore, the combination of models and the combined use of measurement techniques creates new possibilities to understand, model and measure the combustion processes. It will be possible to generate generic knowledge for CCC’s on small scales and with joint efforts it will become possible to translate this knowledge to practical implementation for the different industrial partners. The joint research focus on new exciting CCC’s will therefore lead to a much more coherent and stronger knowledge position of Dutch combustion technology sector. This goal can be reached via the STW *Perspectief programma* proposed here much easier than via the existing STW *Open Technologie Programma* because in the latter each subproject is evaluated independently, without reference to the contribution to a common wider goal. Workshops, courses and symposia will be organized to enforce a continuous exchange of knowledge between the different partners and projects carried out within this program.

3.3 Relation with public policy and funding programs

The proposed program fits very well within the focus of the Dutch Organization for Scientific Research (NWO) on sustainable energy. Execution of this program will

2 http://www.htacg2008.org

contribute significantly to the NWO theme ‘*Nieuwe methoden voor productie, transport, opslag en gebruik van energie*’.

This program also closely supports current Dutch governmental policy towards cleaner and more efficient use of energy (2% increase in energy efficiency per year, increase of the share of sustainable energy to 20% by 2020 and reduction of greenhouse gases with 30% by 2020). The goals of the government can only be met in combination with the application of CCC’s in the near future.

The program also fits with the EU 7th framework[3] and the Furore roadmap for the automotive branch[4] (Furore also mentions the HCCI and controlled auto-ignition (CAI) concepts using alternative bio-fuels in the coming decades and fuel cells on a much longer term).

This program nicely supports other energy-related research programs in the Netherlands. The CCC Perspectief program can be regarded as the fundamental branch supporting the more applied HTAS (High-Tech Automotive Systems) program from SenterNovem[5], which focuses on the development of future engines with the aim to reduce CO_2 emissions by 20% in 2020. Key elements in the other ongoing programs, like EOS[6] from SenterNovem, are ‘energy efficiency’, ‘biomass’, ‘new gas’, ‘clean fossil fuels’ by system integration, bioconversion, gasification, separation and storage of CO_2. *Combustion* in itself is not a key word in these current programs. But combustion is foreseen to remain our main energy conversion technique in the coming decades, also through the use of future fuels like ethanol, biodiesel, syngas and hydrogen. The knowledge generated by this program will also form a firm basis for current research and development programs on biomass conversion and gasification (=fuel-rich combustion). A significant contribution of this program is therefore expected to contribute to clean production and energy efficiency in the transport, process industry and energy production.

3.4 Summary

The CCC Perspectief program aims to support industry in the development and application of Clean Combustion Concepts, i.e. revolutions in combustion science and technology aiming at stable conversion processes of contemporary and future fuels with optimal efficiency and a minimum of pollutant emissions. Focus is on fundamental research disentangling and modeling the phenomena on the different scales, but the step towards real application with industry remains an essential ingredient. It is the idea to initiate a set of coherent projects with mutual interactions on a fundamental and applied level in such a way that cross-links between different CCC’s are created. The proposal supports Dutch governmental policy and the program fits well within the spectrum of current energy programs. If successful, this program will further strengthen the knowledge position of Dutch combustion research in the international arena.

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3 http://cordis.europe,eu/fp7

4 http://www.furore-network.com/publications.html

5 http://www.senternovem.nl/automotive/automotive_programma/

6 http://www.senternovem.nl/eos/

4. Research Topics

Proposals on CCC's in all application areas of combustion are acceptable. Preferred application areas are engines, gas turbine combustors, process burners and furnaces. However, to reach the goals formulated above, submitted proposals within a restricted set of research topics are preferred. Key elements of the program are 'emissions', 'efficiency' and 'fuel flexibility'. The reason for this is that the technological challenge for the coming decennia will be to achieve *maximum fuel efficiency* (minimum CO_2) with *minimum pollutant emissions* (NO_x, CO, particles, etc.) in the entire range of energy-conversion processes. Furthermore, to make optimal use of sustainable fuels, such as biogas, new high-efficiency, low-emissions conversion methods must be developed for these fuels as well. Research projects containing one or more of these elements fit very well into the program.

Essential requirements for projects to be acceptable are that they must:

- be about combustion
- be relevant for practical application
- have results which are transferable to industry
- must deliver a substantial improvement compared to existing technology
- concern medium to long term development

Strong preference is given to projects which have several of the following characteristics:

- explore a genuinely new concept in combustion, excluding catalytic combustion
- focus on the combustion process rather than on other (related) processes or overall process schemes
- provide a way to reduce unwanted emissions
- contribute to higher fuel flexibility, including combustion of biofuels
- deliver a breakthrough in advanced measurement and/or computation of combustion processes

As there are other running programs stimulating research on biomass conversion (e.g. pretreatment, pyrolysis, non-thermal conversion, ….), the CCC program does not cover topics in this area. Research proposals related to the (fuel-rich) combustion of biomass or combustion of biomass-derived Fischer-Tropsch fuels are within the scope of the program though.

Studies of secondary features such as noise generation, fouling, air separation etc, by themselves do not fit directly into the program. Only when they appear as essential bottleneck of a proposed combustion concept they might fit in a project proposal.

5. Scientific Goals

Due to the complexity of combustion processes, it is not surprising that combustion systems have traditionally been designed empirically: energy-conversion systems (burners) and energy-utilization systems (boilers/ovens/turbines) are designed independently, and their combinations optimized by trial-and-error and empirical rules of thumb. The engineering challenge for the coming years is to overcome the limitations of traditional combustion concepts based on "cut-and-try" methods by *organizing the microscopic processes* so that energy conversion can *be tailored to suit the utilization needs*.

This is not an easy task because the combustion of even the simplest fossil fuel, methane, is exceptionally complex[7] . Heat, which is locally liberated by the chemical reactions, is transported through the medium by convective, conductive and radiant heat fluxes. Fuel and oxidizer gases are converted into combustion products via a complicated chain of reactions in which hundreds of species play a role. Diffusive and convective transport fluxes balance the reactive processes. All these phenomena form a delicate balance and generally manifest themselves in spatial structures, often referred to as combustion wave fronts (or flame fronts), only a fraction of a millimeter thick, embedded in a flowing medium that is usually turbulent. The coupling of chemical reaction to transport renders the details of flame structure sensitive to external factors, and changes in fluid flow and heat transfer have a major impact on combustion stability and pollutant formation.

Most of the existing equipment operates in this so-called flamelet regime, where chemical reaction time scales are much faster than flow and turbulence time scales, leading to thin flame fronts flowing and propagating in a mostly turbulent flow. The available new combustion concepts such as PCCI/HCCI and HEC operate in relatively unexplored combustion regimes in which the time- and length scales of the combustion wave fronts are comparable to the time- and length scales of perturbations (such as flow and acoustic distortions). Phenomena in these regimes are as yet poorly understood. The understanding of these new combustion regimes requires a multi-disciplinary approach with both fundamental and applied research. Towards this end we need new experimental, theoretical and numerical knowledge from fluid mechanics, chemical kinetics and heat transfer, but also fresh input from related areas in physics, such as statistical physics, computational science, atomic and molecular physics, laser spectroscopy and plasma physics.

Modern combustion science has made great progress towards understanding the complexity described above. New insights, approaches and predictive models look very promising for designing, manipulating and controlling combustion processes in the near future. This development is related to the introduction and application of powerful laser-diagnostic methods to probe the distributions of species and temperature within the flame front, and of powerful computers and new physical models that enable numerical solutions of the conservation equations using detailed chemistry and transport. A lot of detail inside thin combustion wave fronts has been revealed, but the exploration has been far from complete and the models developed are far from universal. Our understanding of the combustion of the broad range of future bio-fuels is still in the beginning phase. Furthermore, the combustion of fossil fuels or bio-fuels with pure oxygen, followed by sequestration of CO_2 from the flue gases is very important, but hardly explored. After many years of research of the

7 For a modern introduction to combustion, see J. Warnatz, U. Maas, R.W. Dibble, Combustion, Springer, 4th edition, 2006

microscopic origins of combustion phenomena, we are now successful in applying the knowledge gained on the development of practical equipment.

The interaction of solid particles (for example, soot formation and combustion of coal) and fuel droplets with the reacting fluid flow is even less clear. Relatively simple models for evaporation, devolatilization, homogeneous and heterogeneous oxidation, growth and break-up have been developed, but many microscopic details are not yet available. Further, models for the interaction of reacting flows with clusters of particles (e.g. in a coal combustor) and droplets (e.g. in a Diesel spray) have not yet achieved the desired level of reliability, although much progress has been made in the last decade.

The main scientific challenge of the CCC program is to develop fundamental knowledge, related to innovative CCC's, to understand, measure, predict and model the combustion wave structures at the smallest scales of turbulent flowIncorporation of micro-scale models into models on the meso and macro-scale is equally important to develop a design toolkit for research institutes and industry in their development of new CCC's. New measurement techniques enabling the establishment of these phenomena on all scales are also of the utmost importance. Key scientific issues are:

- the chemical pathways of pollutant formation and destruction, and how they can be altered
- coupling of (turbulent) fluid flow to chemical reactions to yield different regimes of combustion
- microscopic interactions of combustion in multiphase flow
- the consequences of the identity of the fuel for the chemistry and physics of combustion processes
- the consequences of the use of new combustion concepts (LTC, HEC, PCCI) as compared to standard ones for the chemistry and physics of combustion processes
- development of physically and chemically correct models that capture the essence of new combustion phenomena at the different physical scales
- development of experimental techniques capable of probing the relevant physical and chemical phenomena at the different scales

New generic models are needed for all processes involved (fluid flow, heat transfer, chemical kinetics, flame-turbulence interaction, flame-droplet interaction, NOx and soot formation, etc.). It can be expected that they will build on and also modify existing paradigms in turbulent combustion research (laminar flamelet, Probability Density Function (PDF), conditional moment closure (CMC), multiple mapping conditioning (MMC)) and will resolve more and more of the turbulent fluctuations using Large Eddy Simulation (LES).[8] Also, laser-diagnostic measurement techniques are needed to visualize and quantify the behavior of all phenomena involved, extending known methods such as using Laser-Induced Fluorescence (LIF) for minor species, Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV) for the flow field, Coherent Anti-Stokes Raman Scattering (CARS) for temperature and Laser-Induced Incandescence (LII) for soot. It is also important to study the new phenomena using new measurement techniques. There is a need for combined techniques (e.g. PIV/LIF to study flow-chemistry interaction) in more dimensions and possibly temporally resolved. Of most value are studies integrating advanced

8 R.W. Bilger et al, Paradigms in turbulent combustion research, Proc.Comb. Inst. 30 (2005) 21-42

experiment and modeling.[9] Of special interest are measurement techniques which can also be applied at industrial scale.

6 Industrial Relevance & Utilization

The development and application of new Clean Combustion Concepts that result in higher energy efficiencies and lower emissions of CO_2, NO_x, SO_x and soot are of utmost importance for the Dutch industry. Key elements in the utilisation of the scientific knowledge gained in this program are:

- Development of new generic models for industry
- Macro-scale models as design tool for industry
- Consortia of universities, research institutes, CFD developers and industry
- Support of industrial partners in the development/optimisation of CCC's using new models and measurement techniques.

The Dutch industry is operating in a global, highly competitive environment, so a continuous effort to reduce (fuel) cost is essential. At the same time it is acknowledged that anthropogenic emissions of CO_2, NO_x, SO_x and soot are responsible for global warming, acid rain and smog. While environmental legislations are becoming more and more stringent, one of the key factors of success for the Dutch industry is to apply highly efficient and ultra-clean combustion technologies. Not only should the Dutch industry apply cutting edge combustion technologies in its own processes, but also fired equipment (such as internal combustion engines, industrial furnaces, incinerators, boilers and gas turbines) designed, manufactured and operated by the industry should be ultra-clean and highly efficient. A factor that increases the complexity of new combustion systems is the wide variety of fuels that is being introduced. Combustion systems should operate superbly not only with one fuel but with a wide variety of fuels (such as biogas, bio-oil, hydrogen, heavy fuel oil residues, etc.) and mixtures of fuels.

The sectors in the Dutch industry that will benefit from and intend to contribute to the research program are: petrochemical industry, metals industry, transport sector and electricity producers, boilers and furnace industry, gas industry, consumer electronics and SME.

- In the petrochemical industry, e.g SHELL, many furnaces are applied to heat oil prior to the refinery process. These furnaces are crucial units for continuous operation of the refineries. Hence the furnaces should be extremely robust. In addition, the furnaces typically use difficult heavy liquid fuels only available at refineries. Despite the complex chemical composition and difficult physical characteristics of these fuels they must be converted in a clean and efficient way. New combustion concepts must be investigated that increase fuel efficiencies and reduce emissions of environmentally harmful species in these applications without compromising the robustness. Specific research topics of interest are
    - scale up of new combustion concepts from laboratory and pilot scale to full industrial scale (i.e. burners of 10 MW and higher capacity)
    - operating principles of ultra low-NOx burners

9 Robert S. Barlow, Laser diagnostics and their interplay with computations to understand turbulent combustion, Proc. Comb. Inst. 31 (2007) 49-75

- combustion of very heavy fuel
  - fuel rich combustion at high pressure
  - flame stability in flares
- In the metals industries, e.g. CORUS, large furnaces, operating at high temperatures are frequently applied. These furnaces typically operate on natural gas, but it is not uncommon to use other gases like blast furnace gas (extremely low calorific), coke oven gas (high hydrogen content) or basic oxygen furnace gas (high carbon monoxide content). In these applications new combustion concepts like High Efficiency Combustion (HEC) can be applied, but there are no generic design tools available such as for conventional combustion systems. These generic design tools should be generated by fundamental research in
  - the interaction of fuel and air jets and the entrainment of combustion gases
  - influence of products and walls on the combustion characteristics
  - chemistry in the reaction zone
  - chemistry/turbulence interaction
- In the automotive industry, e.g. DAF, improved energy efficiency and reduced NO_x and soot emissions from internal engines using Diesel or bio-Diesel as fuel is required. New clean combustion concepts like Premixed Charge Compression Ignition (PCCI), Low Temperature Combustion (LTC) and Modified Kinetics (MK) are likely to meet these challenges, but a significant amount of research still is required before engines that use this combustion concept can be commercialized.
- In consumer electronics, e.g. Philips, there are two major areas of interest concerning combustion
  - production of glass using glass furnaces
  - processing of glass for lamp production

  In both areas reduction of costs are important, also the reduction of emissions of environmental harmful species. A specific issue at processing of glass for lamps is the development of burner constructions for specific heating profiles in the glass products. Thereby reducing the development time of new processes. Therefore research topics of interest are
  - ultra-clean combustion of natural gas, propane and hydrogen
  - cheap and clean oxy/fuel burner systems
- Boilers, produced and retrofitted by companies like NEM and household furnaces produced by SME's like Remeha and Atag also become more and more efficient. However, it appears that increasing the efficiency to the limits also increases the noise production of the utilities. Therefore research is required to find the correlation between flames and acoustic waves.

Besides the Dutch industry also research institutes such as TNO and ECN will benefit from the knowledge that is generated in this research program. Specific areas of interest mentioned by the different industrial parties and research institutes are:

- influence of type of fuel (natural gas, oil) and type of oxidant (preheated air, oxygen) on the heating efficiency and pollutant emissions
- combustion stabilities and interaction between burners
- possibility to apply High Efficiency Combustion in glass melting furnaces
- improving heating efficiency by measures that match the flame emission spectrum to the absorption spectrum of glass

- modelling and experimental investigation of Direct Injection (DI) and Premixed Charge Compression Ignition (PCCI) in Diesel engines for different types of fuels
- combustion and flame stability of low calorific fuel gas produced by air blown biomass gasification, off-gas from fuel cells and depleted syngas
- combustion of hydrogen/nitrogen mixtures
- combustion of liquid bio-fuels, such as bio-Diesel and gasoline-ethanol blends
- low NO_x combustion of NH_3-containing fuel gas and nitrogen containing bio-fuels
- combustion modelling of irregular non-spherical bio-fuels
- effect of mixing of different bio-fuels or biomass and coal on emissions (specifically NO_x and heavy metals)
- combustion of solid biomass or coal particles at high temperatures under sub-stoichiometric conditions
- temperature fluctuations around solid fuel particles in fluidised bed combustion
- gas-phase reactions between alkali metals or heavy metals, chloride and sulphur
- combustion of fossil fuels with pure oxygen and/or high pressure with separation and storage of CO_2
- soot formation from heavy hydrocarbons or CO in cracking or shift reactions meant to produce lighter hydrocarbons or H_2

The applications highlighted above clearly demonstrate the applications, problems and challenges of combustion in the Dutch industry. All combustion challenges boil down to the same fundamental problems: fuel-air mixing, chemical reactions, fluid flow, heat transfer, radiation, etc.. All need to be well understood at micro-, meso- and macroscale. Also, there is always fired equipment involved (e.g. engine, furnace, boiler, burner, incinerators, etc.) Therefore interaction of the fundamental processes and the mechanical device needs to be considered. Clean Combustion Concepts require a multi-disciplinary approach, taking into account Chemistry, Physics and Mechanical Engineering.

In the Clean Combustion Concepts program joint consortia between universities, research institutes, CFD developers and industrial partners (including SME members) are formed. The consortia deliver generic knowledge, models and measurement techniques to interpret the phenomena on the different scales. Based on micro models, that describe the detailed chemical and physical reacting structures, new macro scale models will be implemented in process models or in commercial CFD codes. Using new models and CFD tools coupled with experimental investigation results, new design rules and tools will be developed to improve current combustion applications and to apply new and existing combustion concepts in new combustion applications. Simultaneously, industrial partners will start with the development of new installations, products and processes, which are supported by new models of academia and design tools of research institutes. Regular CCC knowledge exchange workshops will be organized. They focus on joint interests (e.g. pollutant formation and reduction, combustion control, soot, etc.) between industrial partners, knowledge institutes and universities.

7. Coherence and Knowledge Transfer

To safeguard the coherence and optimise knowledge transfer between the projects within the program, the program committee with support of STW will:

- Investigate links between the projects and project partners,
- Coordinate interactions between the users committees of the different projects,
- Organize a CCC workshop each year to exchange knowledge,
- Organize CCC courses for industry, research institutes and SME's,
- Organize a CCC theme within the COMBURA Symposium each year,
- Install a CCC prize at COMBURA for the best CCC innovation each year,
- Intensify PR of CCC related issues and publish relevant news about this program (e.g. in the journal BRANDBRIEF published by STW),
- Attract other industrial partners, new consortia and branch organizations of SME's on combustion to CCC events,
- Intensify collaboration and coordination with NVV (Nederlandse Vlamvereniging) and the Combustion Institute,
- Intensify interactions with MKB (MKB Nederland) and HBO organizations
- Stimulate new spin-off companies to implement new CCC ideas.

8. Organization of the Program and Budget

Budget
For this call a budget of M€ 4.5 is available which must be matched by the contributions of potential technology users (companies/institutes) to a total of at least M€ 6. The maximum of project costs that can be requested from STW is € 750.000 per project. A contribution of potential "users" of at least 25% of the total project budget is compulsory and adds up to the requested amount.
The users do not have to co-finance up-front in the program but may contribute in-kind (materials, equipment, facilities etc.) and/or financially in the project wherein they will participate.
To realize the ambitions of the program a budget for conferences, workshops and events will be reserved on program level. This will be 5% of the funding made available by the STW board.

Who can apply
Scientists employed by Dutch universities or scientific institutes recognized by NWO are eligible to submit a (pre-)proposal (see OTP-guidelines for eligibility criteria). Since CCC is a multidisciplinary program, projects which involves two or more research groups with different backgrounds (e.g. mechanical engineering/chemical engineering, applied mathematics/physics) are preferred. In the project description it should be made clear what the added value of the multidisciplinary approach is for the project.

Proposals and selection
The selection of proposals will be done in two steps: a call for pre-proposals and an invitation to the applicants of pre-proposals to submit full proposals. The pre-

proposals will be evaluated by the program committee. The STW board will decide on the funding of the full proposals.

Funding

Project grants will cover:

- personnel costs (including PhD, postdoc positions, positions for technical assistants)
- material costs (including national travel costs)
- international travel costs
- costs for equipment

The institution(s) of the applicant(s) ensure(s) the required infrastructure, the supervision and fitting into the research program of the research institute. STW may verify this with the dean or the executive board of the institute.

The expertise required for the research must be available at the requesting institute(s), so that external consultants will not be necessary. If one co-operates with institutes that cannot apply for CCC funds, for example TNO or a foreign university, these parties take care of their own funding.

How to submit?

In order to minimize the time needed for writing and evaluating the proposals, it is compulsory to submit a preliminary proposal. All pre-proposals must be written in accordance with the formal guidelines. Only pre-proposals written in English and in accordance with the guidelines will be accepted for evaluation. **Pre-proposals should be send by email to STW (info@stw.nl).** Pre-proposals should be submitted to STW **before Monday 21 April 2008, 24.00 hrs**. Pre-proposals submitted after this deadline will **not** be accepted.

Pre-proposals

Pre-proposals should contain a short description (3 A4) of the proposed research, utilization paragraph and estimated budget. The proposal should make clear which potential users will contribute to the project. Support letters are optional for the pre-proposals but can be included (letters of intent are accepted).

The pre-proposals will be ranked by the program committee on the basis of how well they fit within the scope of the program. The members of the program committee will first assess the pre-proposals individually before being discussed plenary in the committee. The program committee will advise the applicants 1) to submit a full proposal or 2) to adjust the proposal so that it would fit better into the program or 3) not to enter the subsequent selection procedure.

Full proposals

Full proposals must consist of a detailed description of the expected results, planning of the research and a utilization paragraph. The utilization paragraph should include the important industrial challenges that will be solved, the time frame to implementation and the expected bottle-necks during the implementation. Companies and institutes, which will potentially contribute, should be involved bottom-up during the preparation of the proposal.

A full proposal will be evaluated only if it is preceded by a pre-proposal. The scientific quality and the utilization perspective of the full proposals will be evaluated individually by peer review. An independent jury of about eight (inter)national experts of universities and industry (applicants will be excluded) will rank the full proposals. Each jury member will give 3 marks for each proposal: one for scientific quality, one for utilization potential and one for the strategic fit within the program. The marks will be averaged with equal weight to one final score for the proposal which determines the ranking. In addition to the ranking by the jury the program committee will formulate an advice on the cohesion between the project proposals and their relevance for the program. The decision of the STW board will be based on the ranking by the jury and the advice of the program committee.

The guidelines for full proposals are based on the “Open Technology Program (OTP)” with as main difference that the potential technology users (companies/institutes) should contribute for at least 25% of the total project costs. The proposals should therefore be accompanied by a ‘letter of participation’ in which the contribution has been made explicit and in which details are given on what, when and how these contributions will be made available. For more details see “richtlijnen voor het open technologieprogramma" (www.stw.nl).

Assesment and selection criteria

Upon receiving a pre-proposal STW will decide on its admission (eligibility criteria). The program committee will assess the strategic fit within the research program and its topics. Each individual program committee member will give a mark for the strategic fit for each proposal. Then, in a plenary session the program committee will discuss all pre-proposals and formulate an advice to the applicants. This advice can be: 1) to submit a full proposal or 2) to adjust the proposal so that it would better fit into the program or 3) not to enter the subsequent selection procedure.

The program committee will evaluate the fit of the pre-proposals within the framework of the program and will use the following considerations:

- How well do the goals of the project fit within the ambition of the program. Do the expected results meet the industrial needs in the long term (2012-2016)?
- To what extent does the proposal fit within the research topics of the program?
- Does the program strengthen the Clean Combustion Concepts expertise in the Netherlands in general and of the participants in the project in particular?
- To which extent is the project proposal multidisciplinary? What are the positive effects from the interdisciplinary cooperation? How is interaction in between researchers and between university and industry organized?
- Do the proposals overlap each other and if so, what are the consequences for the funding?

Full proposals will be evaluated by peer review on scientific quality and utilization potential.

Scientific quality

- Originality and innovative character of the proposal
- Expected impact on the scientific community
- Research method
- Time schedule
- Budget
- Infrastructure

Utilization

- Potential economic impact
- Past performance in utilization by the applicants

- Contribution to the development of applied knowledge
- Impact on utilization if the project is carried out successfully
- Different steps needed (time path) to utilize the results
- Chance on patents and/or know how agreements
- Participation of users

The jury will be asked to assess the proposals on these aspects and also on the strategic fit within the program.

Time schedule CCC proposals

Call for pre-proposals open	Fri 7 March 2008
Deadline pre-proposals	**Mon 21 April 2008 24.00 hrs.**
Notification to applicants pre-proposal: Positive/negative advice to submit full proposal	Tue 6 May 2008
Deadline full proposals	Mon 23 June 2008
Start review by experts	Mon 30 June 2008
Deadline protocol ready	Mon 15 Sept 2008
Ranking by jury ready	Mon 20 Oct 2008
Advice Program Committee to STW board ready	Wed 29 Oct 2008
Proposal for funding send to STW board	Fri 31 Oct 2008
Decision by STW board on funding + notification to applicants	Fri 7 Nov 2008

Program Committee

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