IFRF

INTERNATIONAL FLAME RESEARCH FOUNDATION

IFRF

70th Anniversary

1948 2018

Seventy Years of Success

1948–2018

The International Flame Research Foundation (IFRF) is a compelling example of how a visionary, cross-frontier initiative can evolve into a prestigious, durable organisation that delivers and disseminates vital technological advances.

Firmly established as the world's R&D and networking hub for the combustion and flame technology community, IFRF has a clear focus: the development of significant new knowledge, understanding and expertise, and the sharing of these across industry and academia.

IFRF's emergence, expansion and regular realignment to meet changing times and fresh challenges is a story of achievement that already spans seven decades. This publication tells that remarkable story. It also looks ahead to the next chapter as IFRF embarks on and embraces a fascinating new phase in its ongoing evolution.

Looking Back, Forging Forward

Key Achievements

- Key research on flame emissivity, underpinning modern understanding of combustion (1950s).
- Development of NO_X-reburning technology (1970s–80s).
- Critical developments in low-NO_X burners (1970s–90s).
- Critical development/testing of laser-based techniques for flame diagnostics (1980s–90s).
- Development of leading-edge mathematical models of combustion (1980s–90s).
- Design/manufacture of industry-standard in-flame/in-furnace analytical probes for measurement and sampling (1990s–2000s).
- Launch of IFRF Solid Fuels Database (SFDB) for members' use (2010s).

Lighting the Flame
(1948–50)

IFRF's origins can be found in the ruins of post-Second World War Europe. The ravages of war had left the European iron and steel industry in desperate need of reconstruction and modernisation; furthermore, the return of peace had generated massive demand for steel to rebuild shattered infrastructure. Independently, steel producers in the Netherlands, France and the UK realised how crucial it was to cut costs and increase efficiency – but recognised the huge challenge of achieving this against a backdrop of scarce research funding.

These drivers were the catalyst for a 'meeting of minds' involving three organisations: KNHS (the Royal Dutch Blast Furnaces and Steel Company 'Hoogovens'), IRSID (France's Iron and Steel Research Institute) and BISRA (the British Iron and Steel Research Association). In November 1948, a BISRA note provided the basis for collaboration, while a follow-up note proposed a new KNHS furnace in IJmuiden as the location for an informal programme of joint experiments.

Aiming to boost performance of open-hearth furnaces and increase flame emissivity, these experiments began in 1949 – a year that also saw the first meeting of the Joint Committee that would provide governance for this ground-breaking initiative. With early momentum maintained in 1950 through the creation of a resident research team at IJmuiden drawn from the partner organisations, the decisive first steps in IFRF's development had been taken.

The Hoogovens research furnace, IJmuiden, NL

IFRF Research Station and the Gas and Oil (No. 1) Furnace at IJmuiden, circa 1955

Firm Foundations
(1951–69)

Even in the earliest stages of this pioneering project, it had become clear that achieving its immediate and longer-term ambitions would demand rapid development in three distinct directions: broader capabilities, wider membership and more extensive sources of financial support. Securing progress in all of these areas would, in turn, require a more robust organisational structure.

The next few years, then, were notable for an extraordinary burst of activity on multiple fronts:

- Two new research facilities were installed at IJmuiden: an oil- and gas-fired furnace and a pulverised-fuel-fired furnace.
- The scope of research expanded significantly – now including industrial applications beyond steelmaking, and coal-fired as well as oil- and gas-fired combustion.
- To supplement existing National Committees overseeing Dutch, French and British involvement, new committees covering the USA and Belgium were set up as more countries began to come on board.
- Core funding was secured from the European Coal and Steel Community.

In November 1955, this critical phase culminated in an event of enormous practical and symbolic significance: signature of the deed that formally created the IFRF Research Station, based at IJmuiden.

In research terms, the 1950s saw IFRF focus on oil- and gas-flame emissivity, fluid mechanics, in-flame mixing and, towards the end of the decade, coal combustion. Extensive development of specialised instruments was another key feature of these formative years. In the 1960s, new priorities emerged – reflecting the developing concerns and interests of IFRF's widening membership base. Particular emphasis was placed on combustion aerodynamics, with substantial activity targeting topics such as non-swirling jet flames and swirl-stabilised flames. Following finds of natural gas in the northern Dutch province of Groningen in 1965, natural gas combustion came under the spotlight too.

The Aerodynamics Laboratory 1965

Underpinning these developments and maintaining the momentum of IFRF's evolution, the 1960s also saw:

- Installation of an Aerodynamics Laboratory at IJmuiden.
- National Committees established in Italy and Sweden.
- Technical Panels playing an increasingly pivotal role, not simply providing IFRF with ready access to cutting-edge technical knowledge but also aiding effective dissemination of the findings from IFRF research.

In 1969, the first IFRF Conference took place at IJmuiden – in retrospect, a fitting event to mark the end of 20 years of growth and consolidation. The presence of around 120 attendees and delivery of a variety of technical papers underlined the importance that IFRF had already acquired as a forum for the exchange of ideas and information. Furthermore, the conference highlighted the organisation's rising reputation, status and influence within the global combustion and flame research community.

Eyes on the Environment
(1970–89)

The 1970s were a decade of new challenges. Awareness of the urgent need to reduce pollution was building steadily across governments, industry and the public at large, with power generation and industrial combustion – and especially their emission of oxides of nitrogen (NO_X) – a particular cause for concern. IFRF set about tackling this pressing problem with characteristic enthusiasm and imagination. Moreover, the shift in emphasis that this entailed was to have a profound impact on the future direction of the organisation.

As it began to develop in-furnace NO_X reduction technologies and mathematical models of NO_X formation, IFRF found itself increasingly involved in near-market activity. It was this that triggered a vital new strand in IFRF's work: contract R&D for industrial customers. Testing of low-NO_X burners, for example, was to be a key feature of the IFRF portfolio for over a decade, with nearly 30 trials undertaken for individual companies – complementing the development of an extensive range of technical services designed to meet the needs of the organisation's members. At the same time, important new public sector customers sought out IFRF's world-leading expertise, including the US Environmental Protection Agency (EPA) and the UK's Central Electricity Generating Board (CEGB).

As the 1980s dawned, environmental issues continued to strengthen their grip on the research agenda. The need to tackle oxides of sulphur (SO_X) – key precursors of acid rain, whose destructive effects were now increasingly evident in Europe and beyond – emerged as a particular priority. IFRF's work in this sphere included using its new Isothermal Plug Flow Reactor (IPFR) to study the direct capture of sulphur dioxide (SO_2) – pioneering research conducted in partnership with L & C Steinmüller and CERCHAR (the French centre for coal mining studies and research). Meanwhile, work continued on NO_X reduction, including development of:

- **New low-NO_X burner designs (made possible by a new laser visualisation technique devised by IFRF).**
- **NO_X-reburning technology – another significant advance in the battle to tackle combustion-related pollution.**

In 1988, a Finnish National Committee was set up, following establishment of a Japanese National Committee in 1977. From an operational perspective, the 1980s were notable for further enhancements to the research facilities at IJmuiden and the extension of IFRF's computational capabilities. The decade also saw a step change in the way the organisation operated, along with further innovations in its approach to the sharing of cutting-edge thinking and key research findings. For example, IFRF:

- **Began participating in big international research programmes, especially the International Energy Agency's (IEA's) Coal Combustion Sciences Programme and the European Commission's non-nuclear energy programme (JOULE) and clean coal technology programme (APAS).**
- **Established and led several industrial research consortia (including the Natural Gas NO_X Group) designed to target specific technical challenges.**
- **Delivered its first training course, focusing on flame research techniques.**
- **Held its first-ever Topic-Oriented Technical Meeting (TOTeM), hosted by Shell in Amsterdam. (By 2018, a total of 44 TOTeMs had been held.)**

Much like the first IFRF Conference in 1969, this inaugural TOTeM appropriately marked the end of another crucial period in IFRF's history – highlighting the organisation's continuing ability to evolve, innovate and find effective ways of meeting its objectives.

Into a New Millennium
(1990–2005)

Through the last decade of the 20th century, IFRF built further momentum on a host of fronts. Crucially, these initiatives made possible a comprehensive programme of investment that would refresh, renew and reinvigorate its impressive suite of specialised research facilities. This programme included the commissioning of a new $5MW_{th}$ (max) No.1 Furnace and a new $60kW_{th}$ (max) IPFR, as well as progressive upgrading of in-house computational facilities and installation of an array of state-of-the-art laser-based diagnostic tools.

In terms of technical focus, seamless continuity was maintained through ongoing delivery of European Commission-funded work, burner development tests and a variety of technical services, while three successful new collaborations were launched:

- **CEMFLAME: working with 17 cement producers to explore the use of a variety of fuels in cement kilns.**
- **OXYFLAM: an international consortium focusing on oxy-combustion of natural gas.**
- **EUROFLAM: a training consortium supported by the European Commission.**

The 1990s also saw increasing priority given to the scaling of combustion systems. For example, building on the success of the industrial research consortium model, IFRF established the Scaling 400 collaboration – a study that focused on the scaling of natural gas and pulverised-fuel flames from $30kW_{th}$ to $12MW_{th}$.

Other highlights included: further work on in-furnace NO_X control, leading to the development of the Internally Fuel-Staged Burner (IFSB); an extensive range of work relating to biomass combustion; and development of leading-edge software packages for mathematical modelling. One of the most significant achievements of all arose from IFRF's extensive and seminal work on coal characterisation – the creation of the IFRF Coal Database (later renamed the IFRF Solid Fuels Database).

Around the turn of the millennium, two major developments were to shape IFRF's future direction. The first was a radical restructuring exercise in 1998, with the organisation dividing into two complementary bodies:

- **IFRF Information Exchange: focused on extending and strengthening communications with members.**
- **IFRF Research Station BV: a limited liability, wholly-owned subsidiary continuing to drive influential innovations in combustion and flame technology.**

Secondly, as the 21st century arrived, it became evident that IFRF would need to find a new home. In view of the merger between existing host organisation Hoogovens (formerly KNHS) and British Steel, and the resulting new plans for the IJmuiden site, it was clear that the end of an extraordinary era was approaching – and that a new phase in the IFRF story was on the brink of beginning.

The IFRF Isothermal Plug Flow Reactor (IPFR), first commissioned in 1983

The Livorno Era
(2006–16)

IFRF already had strong links with the Italian energy company Enel, and its offer to host IFRF at its Research Facility in Livorno was therefore accepted enthusiastically and relocation took place successfully in 2006.

At its new home, IFRF benefited from an outstanding suite of experimental facilities, as well as strong links with the nearby University of Pisa. In addition to the relocated IPFR rig, the construction of a replica of No.1 Furnace – called FOSPER (FOrnace SPERimentale) – complemented Enel's existing semi-industrial-scale rigs, available for use by IFRF. These included: CASPER (CAldaia SPERimentale), a 6.5MW$_{th}$ (max) experimental boiler capable of running on liquid fuels or natural gas; and TAO (Turbina Accesso Ottico), a 400kW$_{th}$ (max) optical test rig for gas turbines.

As IFRF settled into its new home, its Members' Research Programme now adjusted its focus to concentrate on:

- **Characterisation of solid fuels.**
- **Validation of combustion modelling for coal and gas.**
- **Quantification of uncertainties, using a combination of computer-based studies and physical experiments.**

Integrated application of experimental rigs, analytical instruments and computational fluid dynamics (CFD) models generated valuable data on topics such as the co-combustion of fossil fuels with biomasses and novel combustion techniques – data that, for instance, significantly strengthened the IFRF Solid Fuels Database, which became available as an online resource in 2010.

Other key fields of activity that distinguished the Livorno era included burner testing undertaken as part of the European Commission's DEBCO project (DEmonstration of large-scale Biomass CO-firing and supply chain integration), and further development of IFRF's capabilities in the design, manufacture, calibration and servicing of in-flame and in-furnace probes for industrial use. A valuable by-product of this probe-related work was the introduction of a specialist service, available to both members and non-members, to undertake on-site testing of combustion equipment.

Into the 2010s, the pace of IFRF activities was sustained and further significant breakthroughs were secured, in terms of technology development and extending the boundaries of knowledge and understanding. Such advances included:

- **Development of an ultra-low-NO$_X$ hydrogen-fuelled burner for Enel and the Veneto region in northeast Italy.**
- **New insights into the formation of inorganic aerosols.**
- **Development of probes for oxy-firing and novel combustion.**
- **Characterisation of biomass-based fuels.**

The IFRF portfolio at this time encompassed key contributions to DEBCO and a number of other European Commission projects, participation in industrial collaborations, and undertaking of a variety of technical service contracts. Clearly, the move to Livorno had resulted in no reduction in IFRF's drive and determination to pinpoint new solutions to combustion-related concerns and challenges. As the middle of the decade arrived, however, change was in the air once more.

Enel's Livorno Research Facility (with IFRF's FOSPER and IPFR rigs to left of picture)

Fresh Thinking for the Future
(2017–present)

Enel's strategic focus was shifting. With issues such as renewable energy, smart grids and energy storage assuming a more dominant position on the company's agenda, the conclusion was unavoidable: it could no longer provide a natural home for IFRF. A fresh search was duly launched for a new host organisation that could offer IFRF not simply a stable, sustainable future but also the potential to seize the many new possibilities and opportunities that the future would bring.

From this process, the UK's University of Sheffield emerged as the successor to Hoogovens and Enel, and the perfect torchbearer for IFRF's continuing mission:

- **Once again, the new host could claim a deep connection with IFRF, dating back to the organisation's foundation in 1948.**
- **Working closely with the Livorno team to ensure the smooth and efficient transfer of equipment, archives, practices and processes, the new set-up began life in January 2017 with the establishment of not-for-profit organisation IFRF Ltd.**

This new era would deliver far more than a 'steady as she goes' arrangement. While maintaining many of IFRF's tried-and-tested features – features that had demonstrated their value over years and decades – this third incarnation of the organisation was to embody a fresh, flexible, more agile philosophy better reflecting the current needs and priorities of government, industry, academia, economy and society.

With IFRF focusing on its networking functions and the delivery of well-established services that have proved of enduring benefit to its members, PACT – in which the University of Sheffield is a key partner – has become IFRF's first-ever 'preferred research partner'. This places a phenomenal suite of R&D, pilot-scale facilities at IFRF's disposal (see 'IFRF Today – and Tomorrow').

Such a dynamic combination of the proven and the innovative delivers every confidence that this new era in IFRF's long history will be every bit as enthralling and rewarding as those preceding it – and provide the gateway to a future rich in further achievement.

Burner trials on IFRF's FOSPER test rig, Livorno 2006

Enel's TAO 400kW$_{th}$ (max) optical test rig for gas turbines

The University of Sheffield's Bioincubator – home of IFRF Ltd

IFRF Today – and Tomorrow

The IFRF of 2018 retains the key hallmarks of its impressive past. It continues to deliver the formidable array of services that members down the decades have found so constructive and productive. These include:

- A searchable online archive of over 500 reports and a comprehensive library of presentations delivered at IFRF conferences and workshops.
- The 'Monday Night Mail' e-newsletter.
- The 'Industrial Combustion' peer-reviewed online journal.
- The online 'Combustion Handbook'.
- A diary of technical events.
- Career and training opportunities.
- The Solid Fuels Database.
- The European Facilities Database.
- Regular TOTeMs.
- National 'Flame Days' and symposia.
- Specialist workshops.

In addition, with regard to R&D activities, IFRF now operates on a much more cost-effective platform, harnessing the PACT facilities as and when required rather than having to install, maintain and upgrade expensive in-house capabilities.

A not-for-profit UK-based collaboration, PACT (see www.pact.ac.uk/) is focused on research in fields such as advanced fossil fuel energy, biomass, energy from waste and carbon capture and storage. Located at the Universities of Sheffield, Cranfield, Nottingham and Edinburgh, and Imperial College London, its outstanding facilities comprise a suite of integrated and pilot-scale test rigs, complemented by both online and laboratory-based analytical facilities and leading-edge modelling and simulation capabilities.

Available on a collaborative and/or contract basis, these facilities now enable IFRF to bridge the gap between lab-scale R&D and industrial pilot-scale testing on an unprecedentedly cost-effective basis. Plans are currently in place to extend and diversify PACT's facilities substantially, as part of an initiative known as PACT-2. IFRF is also seeking to extend its research partnerships to leverage a broader range of experimental facilities at different scales.

The IFRF philosophy has always been to embrace change, push boundaries and explore new ways of tackling challenges. As further research partners come on board, offering even more facilities and specialist capabilities, so IFRF will be able to extend its research and services into new areas. This, in turn, will help to attract new members, partners and collaborators – allowing IFRF to broaden its reach, deepen its capabilities, widen its influence and further strengthen its unique contribution in the years and decades ahead.

Inventory of facilities available to IFRF as part of the present hosting agreement:

- 250kW$_{th}$ air/oxyfuel pulverised-fuel (biomass and/or coal) combustion plant.
- 150kW$_{th}$ air/oxyfuel pulverised-fuel combustion plant.
- 300kW$_{th}$ circulating fluidised bed (CFB) combustor/gasifier.
- 750kW$_{th}$ gas turbine burner with deposition probes.
- 300kW$_{th}$ grate combustor combined heat and power (CHP) energy system for biomass and waste.
- Two 330kW$_{th}$ (inlet) CHP gas turbines.
- 50kW$_{th}$ chemical looping facility.
- 1 tonne/day plant for post-combustion capture (PCC) of carbon dioxide (CO_2).
- Gas-mixing facility for modulation of real flue gases or generation of synthetic flue or industrial process gases.
- CO_2 transport flow rig.
- State-of-the-art laboratory facilities for fuel and solvent analysis (including spectrometry and spectroscopy).
- Online analytical facilities.
- Unique inductively-coupled plasma optical emission spectrometry (ICP-OES) capability for simultaneous analysis of up to 50 metal species in flue/process gases.
- Multi-point Fourier-transform infrared spectroscopy (FTIR) gas analysis.
- Conventional combustion gas analysers.
- Chemical solvent analysers.
- Fast real-time particle size analyser.
- Transportable mini-lab for on-site, long-term capture media testing under real operating conditions.
- Mobile DMS500 for submicron particle (aerosol) measurements from stacks.
- Modular 800°C 100bar flow reactor.
- Milling equipment with powders analysis.

"Reviewing seven decades of achievement provides an excellent opportunity to assess the incredible contribution that IFRF has made to combustion and flame research, international scientific co-operation and the wider energy landscape. Our new shape and structure offer fantastic potential for the coming years – a chance to drive further world-leading advances in knowledge and technology that benefit our members and the economic and environmental well-being of the world as a whole."

Philip Sharman, IFRF Director

IFRF Factfile

Status: Not-for-profit research foundation managed by a council of members' representatives.

Vision: To be the international reference point for industrial combustion that is clean, efficient and safe.

Mission: To advance applied combustion research and promote co-operation and information transfer throughout the international combustion community.

Members: Encompassing Africa, Asia, Australia, Europe, North America and South America, our 125-strong network includes: equipment designers, suppliers and end-users; universities and research institutions; engineers and consultants; trade associations; energy suppliers; and policy-makers.

National Committees: American Flame (AFRC), British Flame (BFRC), Finnish Flame (FFRC), French Flame (CF), German Flame (DVV), Italian Flame (CI), Netherlands Flame (NVV), Swedish Flame (SFRC); an Associate Member Group (AMG) co-ordinates services in regions not covered by these committees.

Key funding sources: Membership fees; contract research and technical services; European Commission programmes (1988-present). Past sources include: European Coal and Steel Community (1955-76), US Environmental Protection Agency (1972-78), International Energy Agency (1983-92).

Timeline

- **1948** Proposal to establish international research project
- **1949** Furnace experiments begin at IJmuiden, the Netherlands; first meeting of governance committee
- **1954** New oil- and gas-fired furnace installed
- **1955** IFRF established as not-for-profit organisation under Dutch law; new pulverised-fuel-fired furnace installed
- **1965** Aerodynamics Laboratory established
- **1969** Inaugural IFRF Conference
- **1975** Water-cooled experimental furnace installed
- **1983** Isothermal Plug Flow Reactor (IPFR) commissioned
- **1986** Computational Laboratory established
- **1988** IFRF delivers first training course
- **1989** IFRF holds first Topic-Oriented Technical Meeting (TOTeM)
- **1998** Restructuring into IFRF Information Exchange and IFRF Research Station BV
- **2006** IFRF moves to Livorno, Italy – hosted by multinational energy company Enel
- **2010** Establishment of IFRF Solid Fuels Database (SFDB) as a members' resource
- **2017** IFRF moves to University of Sheffield, UK – IFRF Ltd established
- **2018** IFRF celebrates 70th Anniversary

Getting in Touch

To find out more about IFRF's work, and for more information on how to become a member or how to access our services, please contact:

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