

**Power Cycle Chemistry Working Group (PCC WG)
Boulder, CO, 23rd to 28th June 2024**

Revision 1.1

Sunday 23 June: 11:00 – 16:00 Session

1. Introduction to PCC 2024 WG meeting

IAPWS 2024 PCC WG members were welcomed by David Addison who reviewed the schedule / agenda for the week with ICPWS sessions of interest to the WG and separate PCC WG meetings.

2. Adoption of Agenda and Minutes Approval

There were approximately 18 attendees at the PCC meeting. The agenda was adopted with the final version from the week attached as PCC Attachment A. Minutes from PCC 2024 were approved with no changes. IAPWS 2023 meeting presentations were noted as missing from the OPAL website.

Action: Addison to follow up and determine what the delay is and address.

3. Appointment of PCC WG Clerk of Minutes

Paul McCann (BIAPWS) was appointed as clerk.

4. Review of Actions from last PCC WG Meeting

See list below. The following points arising from the actions were also discussed:

22-3 ICRNs:

The formal procedure for ICRN approval was asked about which is as follows: Review by WG → review by National Committees → submit to EC for approval at meeting or by postal ballot → uploaded to IAPWS website.

22-7 International collaborations (ICs):

Barry Dooley noted that the intention of ICs is to encourage the participation of young scientists and preferably linked directly to WG activities. For PCC, electrode boiler chemistry could be a possibility to develop an IC for in 2025 due to common worldwide issues – work is in progress to consolidate issues. UNB may be able to explore small-scale electrode boiler installations; VTT (Finland) may also have this possibility.

22-16 Future PCC directions: Radiation chemistry and radiolysis collaboration.

Pam Yakabuskie stated that the IC proposed by PCAS requires an update before EC submission. The possibility of a radiolysis WG has been discussed but is currently on hold – this is linked to future PCAS/PCC collaboration opportunities.

5. IAPWS TGD Updates

An update was provided by Dooley on activities since 2023. Dooley emphasized that the main focus of PCC should be on developing and updating TGDs with the participation of WG members. The TGDs have had tremendous use and penetration around the world. The onus is on

PCC to keep the documents refreshed with latest understanding. The eleven TGDs were presented and some of the history described.

TGDs developments in progress:

- **Instrumentation** – There has been extensive work by all sub-task group (STG) members with the revision now completed and approved by editorial committee. The updated TGD will be submitted to EC for postal ballot at the 2024 meeting.
- **Corrosion products** – There has been extensive STG work including two complete revisions of the initial draft White Paper (WP). The latest draft WP includes proxy processes and the introduction of the IAPWS decay map with example applications; there is also extensive description about how to address non-optimum chemistries and shutdown protection. The new IAPWS Decay Map was presented and noted that the intention is for users to work with operators to understand the cause of any peaks in order to inform what improvements may be possible. The STG will meet during the week to finalise then circulate to PCC members. To progress to a TGD, the examples presented need to be expanded to include complete cases, i.e. to show decay profiles before and after improvement actions have been taken. Plants that have applied the draft procedure have reported favorably.
- **Film-forming substances (FFS) in nuclear plants** – This has been delayed due to external circumstances with no recent contact from the lead author. There had been discussion with steam turbine manufacturers where steam purity was frequently discussed for FFS application. Part of a skeleton was written in 2020 by Willy Cook. It was discussed whether to cancel the activity or put on-hold for the short-term. Instead a potential option for the Canadian Nuclear Laboratory (CNL) to pick up was identified following work on CANDU applications though with commercial sensitivity noted.

Action: Yakabuskie to see if CNL would take on TGD development.

- **Flue gas condensation** – The first draft of the WP was discussed. Written language needs reviewing and ideally the WP needs redrafting to make more international. It was agreed that the document can be issued as a WP after the language has been reviewed. It was also proposed to publish as a PPChem article which could be done by PPChem editors.

Action: Ben Loder to review for EN language then Nielsen to format for possible issue.

- **Geothermal** – Significant work has been done in New Zealand to validate data. The plan is to proceed straight to a draft TGD after review by Japanese manufacturers with the data considered robust enough for this. Geothermal plant in Iceland will also be contacted which also presents an opportunity to link with Nordic IAPWS.
- **Electrode boilers** – It was proposed to write a basic TGD as a first step to make knowledge available. Task Group to discuss how to progress during the meeting.
- **Dew point of low sulphur fuel gas** – This is being led by PCAS (Nobou Okita).

TGDs that may need refreshment:

- **Volatile and alkali** – Possible addition to cover knowledge now gained about use with aluminium materials, especially Heller dry cooling systems.
- **Carryover** – Addition to include measurement during load changes.
- **Steam purity** – Frank-Udo Leidich has previously suggested comments on customization as per VGB guidance.
- **Film-forming substances** – Update with knowledge gained after seven FFS conferences, e.g. possible non-commercial updates on instrumentation.

Other discussion points raised were as follows:

Addison raised the possibility of improving collaborative working within IAPWS using modern document management systems to improve work flow and management of revisions and comments plus record keeping of IAPWS documents (this is currently reliant on lead authors holding master copies).

Action: McCann / Addison to consider filesharing / collaborative working options during IAPWS website re-design.

White Papers – A clear approach is needed for the format and issuing of WPs. It was proposed to keep WPs on individual IAPWS WG website pages as they are WG products not formal IAPWS products so should not need formal review and approval by the Editorial Committee. A standard IAPWS WP template is needed which needs to be clearly different to the TGD format and would need EC approval (cont'd in later item).

Potential **future TGDs** were discussed with two suggestions to discuss further at the 2025 meeting:

- Industrial boiler chemistry guidance for steam raising plant is becoming increasingly important especially as energy markets become move diverse. Plant design is also a significant limitation that may make writing generic guidance difficult.
- BIAPWS has suggested that basic guidance is provided on how to apply the suite of TGDs. It was proposed to develop a basic roadmap for application though not as an immediate WG priority.

The need to have a **routine periodic TGD review process** was discussed. Dooley commented on the status of knowledge of each of the TGDs and noted that the majority of the TGD content remains current. The HP HRSG HP evaporator TGD may be possible to extend to boiler plant based on developing knowledge of boiler waterwall scale morphologies. Currently there is not considered to be enough data for this – more information is needed on morphology on heat transfer surfaces to understand conditions at which concentration effects can start.

The next IAPWS meeting for TGD approvals is 22-June 2024 (Helsinki meeting). To meet this date for issue, draft TGDs would need to be circulated to PCC WG members for comment by Feb-2025.

Tuesday 25th June: 1:30 – 16:00

PCC WG Meeting

a) Future Direction – PCC WG and IAPWS

Possible future directions for the PCC WG and IAPWS were discussed by McCann.

At the 2024 Turin meeting, possible technical areas of interest identified by the PCC WG were reminded as industrial plant, small modular reactors, carbon capture and storage, hydrogen products, electrode boilers and water re-use. The general consensus at Turin was that the WG should keep the focus on the water-steam cycle but move beyond fossil, focusing on plant in commercial use and tracking emerging industries and issues.

For wider IAPWS participation, McCann noted that the numbers attending meetings is declining. The power market is rapidly changing with more fragmentation of companies that makes routine attendance at annual meetings more difficult. It is also difficult to maintain engagement if a meeting is missed. Issues for IAPWS were generally characterized as 1. communication and visibility, 2. maintaining engagement with WG members and 3. lack of future strategy.

For the PCC WG, there are already new technical directions being developed and plans to improve visibility (e.g. webinars, LinkedIn). Dooley noted that WG priorities should be to maintain the TGDs as the leading worldwide guidance on power plant chemistry and that there remains a need for an FFS TGD. Future attendance could also be helped by ensuring that IAPWS plans annual meetings with the aim of limiting costs for participants (e.g. hold in easy locations to access, venue costs). If key gaps in industry knowledge are identified, it is possible to form IAPWS sub-groups to work to address.

b) Electrode Boiler WG (Addison)

The WG was established in Turin in 2023 following worldwide boiler problems. The WG main focus are immersion, electrode type, high voltage – no spray type boilers are used in Europe or NZ. A list of current issues was presented that includes: hot water boilers – generation and build up of corrosion products, hydrogen generation, explosions on shutdowns, electrode damage. There are similar issues at steam producing boilers and also other issues include arcing damage and trips. Hydrogen and oxygen are forming in the process with levels related to boiler startup, load and boiler water conductivity. The boilers use an AC power supply so hydrogen should not be generated and the mechanism for formation is not understood. Corrosion mechanisms have been inhibited by the use of film-forming amines, e.g. ODA. The WG plans to expand to include other users, consolidate issues and known answers, ideally with vendor engagement. It is also intended to publish technical papers to raise awareness. A subsequent stage will be to draft a possible TGD.

c) Report on a White Paper for Acid Gas Dewpoints - Nobuo Okita (Toshiba):

Significant work has been done by Okita to develop estimations of sulphuric acid dewpoints at low gas path temperatures at the outlet of HRSGs. This has been done by extending the data from conventional coal and oil plants and available literature to improve calculations. Three dewpoint curves and calculation formulas have been developed for the range of expected

sulphur concentrations (1 ppb to 1 ppm SO₃, 5 - 15%v H₂O) and water content in flue gases; the data has also been tabulated which may be more accurate. Error ranges have been estimated within $\pm 2-3K$. A draft WP has been prepared and circulated to Task Group members. This needs support from PCC in reviewing and providing input on reliable shutdown methods.

Action: McCann to review draft WP for EN language.

d) Filming Product Application for Use in PWRs/PHWRs - Iain Duncanson (EPRI)

Iain Duncanson (EPRI Nuclear) joined the meeting to provide an update on their filming product (FP) program. FPs have potential value in nuclear plant to reduce metal corrosion and minimise FAC. There has only been multiple applications so far using only ODAICON® (first at the Almaraz NPP in Spain). Candidate vendor products have been reviewed and a laboratory testing program is in progress and nearly complete using ODAICON, Steamate PAS6079 and PowerFilm 10000 as amine and non-amine products. No particular positive or negative impacts on general corrosion were identified. The neat amine-based solutions have a detrimental effect on elastomers; there were no significant impacts from dilute solutions. Overall the laboratory tests have shown no significant detrimental effects but also no significant drivers for application. A portable field test is being developed for the detection of an amine film on surfaces. No issues have been raised with occupational safety related to amine films on system surfaces which has been questioned in some fossil plant applications.

e) PCAS, IRS and PCC Joint Discussion

PCC current priority gaps in knowledge relate mainly to FFS (fundamentally how do they work) and electrode boiler chemistry. The electrode boiler issues described by Addison were expected to be of interest to PCAS electrochemistry specialists. The FFS TGD update would also be of significant PCAS interest. It was agreed to routinely include joint sessions at future IAPWS meetings.

Actions:

1. Addison to include joint PCC/PCAS/IRS sessions at future meetings.
2. Addison / Ken Yoshida (PCAS) to develop a list of priority topics to assist collaboration.

Wednesday 26th June: 13:30 – 15:00

PCC WG Meeting (cont'd)

a) IAPWS Website

The PCC WG will shortly have its own new page on the website. The WG description has been written and submitted to Allan Harvey. WPs will be held on the PPC website page.

b) WP Template

A draft WP template as a “TGD Draft Format” was developed by Addison with comment from other PCC members. This was approved by WG attendees for submission to the IAPWS Executive Committee (EC) for approval

Action: Addison to submit template to EC with proposal for holding on the WG website pages.

c) Corrosion Product WP

It was agreed that once the corrosion product WP was finalized and available on the IAPWS website, a summary article should be published by PPCHEM.

Action: Addison and Tapio Werder to arrange the PPCHEM publication.

d) Introducing Dutch IAPWS (Ludwin Daal)

Ludwin Daal introduced the Dutch power industry electricity production and organization in advance of formally applying for IAPWS membership. This is being done with full support of the asset owners. Members have various power plants including coal/biomass, CCGT, combined heat and power plants and one nuclear power plant. The power market is dynamic with plants cycling and mothballing and a range of water-steam cycle chemistries. Each year, the power plant chemists meet three times to discuss operating experience (two in person and one online). One meeting will be changed to an open invite to IAPWS members. The group already organizes round robin sampling campaigns and undertakes collaborative projects with a financing mechanism in place for these, e.g. TOC online measurement campaign; developing practical guidelines for condenser leak management; assessing future water use in the industry as the power market transitions away from fossil plant.

e) Hydrogen Generation and Future PCC Areas of Interest (Kirk Buecher)

Buecher provided an outlook on hydrogen generation and potential future areas of interest for the PCC WG. Gas turbines burning hydrogen can generate excess NO_x which may require water or steam injection with increased demineralized water use. Electrolysers for hydrogen production are currently either alkaline or proton exchange membrane (PEM) types. Alkaline electrolysers require temperature and conductivity control. PEM electrolysers have exotic materials for electrodes and expensive stacks that should last 5 - 7 years though the lifespan is heavily influenced by water quality (impurities blocking membrane pores and salts forming bridges). Current water quality requirements are usually either ASTM Type I or II unless manufacturers provide their own specification. Possible PCC interests include water quality requirements, corrosion mechanisms and behaviour of electrode materials. Green methanol and e-methane production was also described with various projects noted that are being developed in Finland. Water quality requirements and monitoring for electrolysers could be a potential future area for PCC. Steam generators are also often used in biofuel plants where chemistry guidance could be of value.

Action: Nielsen to explore contact with projects in Finland about possible needs.

Thursday 26th June: 09:00 – 15:00

PCC WG Meeting (cont'd)

a) PPC WG ICRNs**Conductivity of Electrolytes in Aqueous Solutions**

The draft ICRN has been reviewed. Comments received have been addressed and the ICRN will be submitted for postal ballot.

FFS

Addison has updated a draft ICRN on knowledge gaps identified from the series of FFS conferences. This will be submitted for postal ballot in the near future.

Action: Complete and submit the FFS ICRN (Addison).

Possible future ICRNs could be related to electrode boilers and corrosion and deposition processes in hydrogen electrolysers.

List of Active ICRNs

ICRN22 Turbine phase transition zone chemistry – this is already closed.

Action: Addison to request that EC confirms closed and to be moved off website.

ICRN25 Corrosion mechanisms related to contaminants in boiler water.

Action: Addison to request EC to extend to 2027.

ICRN26 Aluminium in steam-water cycles.

Action: Addison to confirm closure with EC.

b) Possible PCC Related Future International Collaborations (ICs)

Possible PCC IC opportunities were discussed. The UNB project on boiler water corrosion was described as a good example where funding provided a means of starting a project (funding equipment and setup) and also the ICs on corrosion product transport monitoring and assessment by Mads Skovbjerg and Maja Skou Jensen which also promoted student participation. These have provided good value to the PCC WG in recent years (though it was noted that overall IAPWS funds for ICs are limited). PCAS is submitting an IC on radiolysis. There were no current PCC suggestions for ICs.

c) PCC Communications

LinkedIn

Addison set up a PCC WG LinkedIn page during the meeting. Super-administrators are Addison, Nielsen, McCann and McAllister.

Webinars

The CCJ has agreed to host PCC webinars. The intention is to have the first webinar on the IAPWS TGDs and then to expand to deliver a program on power plant chemistry fundamentals. These will be recorded and made available on YouTube as training resources and to enhance PCC visibility and communications.

d) IAPWS 2025 Meeting – Helsinki, Finland, June 22 – 27 (Nielsen)

Nielsen introduced the next IAPWS meeting to be held in Helsinki, Finland (Hanaholmen / Hanasaari) on June 22 - 27. The conference hotel is ca. 7.5 km from Helsinki. Shuttles will also be put on from the city. Registration fees are ca. 800 EUR pp for the full week and 350 EUR for the symposium. Hotel room costs are ca. 144 - 164 EUR per night. The conference is being arranged with Mecca Concepts who have also supported recent IAPWS meetings. The symposium will include sessions on flue gas condensate water treatment, electrode boilers and industrial boilers.

e) AUSAPWS Update (McAllister)

The 2nd biennial AUSAPWS conference will be held on 25 – 27 March 2025 in Noosa, Queensland. The meeting is a technical event to share experiences also with workshops. Previous topics have included sessions on film-forming substances based on the latest understanding.

f) Presentations

Presentations from PCC members during the meeting were requested to be sent to Addison for uploading to the OPAL website.

g) TGD Final Updates at Meeting End

- Corrosion products – Expected to be 2-3 months to circulate as a WP as it is close to TGD status. Additional data is needed to complete the process but the majority of the document is otherwise close to TGD suitable content.
- Flue gas condensation – No further updates.
- Geothermal – It is close to being able to be issued as a TGD with submission expected with suitable timescales for approval at the Helsinki meeting.
- Electrode boiler chemistry – No further updates.
- Application of FFS in Nuclear Plants – No further updates.
- Instrumentation – Final document to be requested for postal ballot.
- Steam purity, FFS in fossil/biomass plant and Carryover – No further updates.

The definition of an IAPWS WP was extensively discussed. It was agreed to submit the corrosion product document once it is completed as this is of suitable quality by any possible definition and to review again in 2025. To canvas opinion, almost all PCC WG attendees voted in favor of making WPs available in ‘rough and ready’ format as opposed to having to develop all documents to near-TGD status.

h) Collaborative Working Practices and Tools

There is a risk related to the management of IAPWS documents without a centralized storage system. Addison recommended that the final versions of all TGDs are stored on the OPAL website subject to EC approval.

For longer-term secure document storage, Addison proposed that IAPWS considers using a Sharepoint system. This could also be used for collaborative working and potentially supported by a code of conduct for working together. This would require IAPWS purchasing a licence.

Actions:

1. Addison to recommend to EC that a copy of each of the final TGDs is held on the OPAL website.

2. Addison to recommend to EC that IAPWS considers a Sharepoint system for document management.

PCC WG Business

a) Progress Reports 2023/2024 and Future PCC Activities

Radiolysis – PCAS and PCC members met during the week to discuss how to progress. It was agreed to form a sub-task group which will be proposed to the EC.

Small Modular Reactors – Cook reported that a discussion was had about possible areas of IAPWS interest. This was recommended by Cook as an area to track. Nielsen commented that Mikko Vepsäläinen (VTT) is working on new technologies and will be invited to present on these next year.

Addison requested that any relevant interests from National Committees are fed up to the WG. It is intended to compile a priority list for PCC activities at the 2025 meeting.

b) PCC Public Relations / Contribution to Press Release

A PCC meeting highlights summary was prepared by Addison and submitted to the Editorial Committee.

c) Proposals for new TGDs summary

No additional discussion.

d) International Collaboration Projects

No ICs currently proposed.

e) ICRNs – Review and Possible New Additions

ICRN 32 to take to EC and Editorial Committee as stated previously.

FFS ICRN to be drafted by end-July for PCC circulation as stated previously.

f) Changes in PCC Membership and Election of Officers

New members voted into PCC:

- Tapio Werder, Switzerland/Germany
- Ludwin Daal, Netherlands

g) Other Business

McCann asked member to consider any photographs or images that be used on the new IAPWS website to illustrate IAPWS business and activities.

h) Adjournment

Meeting adjourned 15:20 PM June 27th, 2024.

ACTION LIST

#	PCC Area	Action	Owner	Due Date	Status	2024 update
Summary of Actions carried forward						
22-3	ICRN 32	Circulate ICRN to national committees during the week so decision can be made by EC at end of week	Addison	Before Dec. 2 nd 2022	In progress	Comments have been addressed. To be submitted to Editorial Committee.
22-4	Future PCC directions	Organize two webinars	Addison	Webinar 1: Q1 of 2023 and Webinar 2: Q3 of 2023	On hold till 2023/2024 – discussion later in PCC program	On-going. Presentation mechanism now available.
22-5	Future PCC directions	Assess scope and cross-over of hydrogen generation space with PCC and other WGs' mandates. To present his findings in Turin.	Beucher	Turin 2023	Discussion later in PCC program	Complete. Further presentations by de Vos and Buecher in 2024 meeting.
22-6	Future PCC directions	Draft future PCC document for circulation to PCC for further comment/review	Addison	Before Turin 2023	On hold till 2023/2024 – discussion later in PCC program	Superseded.
22-7	International collaborations	Submit plans or paperwork for desired upcoming international collaborations	PCC Members	Before Turin 2023	Issued – none received	Complete.
22-8	PCC description on IAPWS website	Update IAPWS website with more details and a refresh on the mandate of PCC	Addison	Before Turin 2023	Still in progress	Complete. PCC information submitted at the 2024 meeting.
22-16	Future PCC directions: radiation chemistry and radiolysis collaboration	Interface with PCAS on existing radiation chemistry activities and will propose a collaboration specific to radiolysis.	Yakabuskie	Prior to Turin 2023 meeting	Follow up with Dr. Yakabuskie.	Complete.

#	PCC Area	Action	Owner	Due Date	Status	2024 update
22-17	Future PCC directions: radiation chemistry and radiolysis collaboration	Circulate existing PCAS proposal submission on radiation chemistry task group to PCC	Addison or Dooley			Submission to be made to EC at 2024 meeting.
23-1	Dew Point at low sulphur	Addison to discuss with Andy (GE) for addition to TG	Addison			Complete.
23-2	FFA decomposition products	Int'l Collaboration Project draft for EC submission	Yoshida			Complete. IC submitted by PCAS at 2024.
23-3	FFA fouling on instrumentation	Int'l Collaboration Project draft for EC submission	Stansfield Cook			Stansfield now retired. Interest in a round-robin test program. Addison to contact Waltron to see if interest in continuing.
23-4	Flue gas condensate	Submit white paper for publication + begin TGD draft	Fogh			Superseded.
23-5	FFS in nuclear	Complete white paper draft for review	Fandrich	Dec2023		Superseded.
23-6	Water use in hydrogen electrolyzers	Contact and coordinate papers for PEM / SOEC for sessions at ICPWS 2024	Addison Beucher Cook Dooley Neilsen			Complete.
23-7	Corrosion products TGD	STG to review current comments and meet virtually to plan additions required	STG	Oct2023		On-going.
23-8	Instrumentation TGD	STG review and circulate comments / additions	STG	Oct2023		Complete.
23-9	White paper & Int'l Collaborations	Develop policy and process for promotion and release of these unofficial documents	Addison Dooley			Superseded.
23-10	Internal structure of PCC and	Close collaboration needs to be reestablished and	Addison			On-going. Discussions continuing.

#	PCC Area	Action	Owner	Due Date	Status	2024 update
	PCAS	working relationship strengthened - discussion between WG Chairs needed				Need to include all WGs.

Summary of New Actions from PCC 2024						
#	PCC Area	Action	Owner	Due Date	Status	
24-1	IAPWS meeting presentations on OPAL website	Raise at EC meeting that presentations from 2023 still need uploading. To confirm current procedure	Addison	June2024	Completed and resolved	
24-2	TGD on FFS in nuclear power plant	Ask if CNL can take this on.	Yakabuskie	June2025		
24-3	WP on flue gas condensation	Review draft WP for language.	Loder	Dec2024		
24-4	IAPWS website redesign	Check possibility to include fileshare system	McCann / Addison	June2025		
24-5	IAPWS WP proforma	Propose a common WP template to EC and recommend holding WPs on WG website pages.	Addison	Sept2024		
24-6	WP on sulphuric acid dewpoint	Review draft WP for language.	McCann	Aug2024		
24-7	PCC/PCAS joint sessions	Include a session in future annual meetings.	Addison / Yoshida	On-going		
24-8	PCC/PCAS priorities	PCC to develop a list of priority topics.	Addison / Yoshida	On-going		
24-9	Corrosion product WP	Publish a summary article in PPCHEM after the WP has been issued.	Addison / Werder	June-2025		
24-10	Hydrogen projects in Finland	Make contact with projects about possible areas of IAPWS interest.	Nielsen	June2025		
24-11	FFS ICRN	Complete and	Addison	July2024		

		submit to Editorial Committee.			
24-12	ICRN22	Request EC to close and move off website.	Addison	June2024	
24-13	ICRN25	Request EC to extend to 2027.	Addison	June2024	
24-14	ICRN26	Request EC to close.	Addison	June2024	
24-15	PCC TGD storage	Request EC that a final copy of TGDs are held on the OPAL website.	Addison	June2024	
24-16	IAPWS document storage	Request EC to consider a secure document management system, e.g. Sharepoint.	Addison	June2024	
24-17	New website images	Request for members to consider photos / images for the new IAPWS website	All members	June2025	