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Gordon research conference 2019: From the biophysics of natural and artificial photosynthesis to bioenergy conversion

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ABSTRACT

Here, we provide a brief report on the 2019 Gordon Research Conference (GRC) and Gordon Research Seminar (GRS) on photosynthesis. Both the GRC (July 21–26, 2019) and GRS (July 20–21, 2019) were held at Sunday River Resort, Maine, USA, bringing together the beginners as well as the established scientists to discuss recent advances in photosynthesis research.

1. Introduction

The 2019 Gordon research conference (GRC) on photosynthesis, "*From the Biophysics of Natural and Artificial Photosynthesis to Bioenergy Conversion*", was held at Sunday River Resort, Maine, USA, from July 21–26, 2019; it was chaired by Petra Fromme (Arizona State University, USA) with vice-chair Robert Burnap (Oklahoma State University, USA), both of whom are authors of this report. The complete program for the conference is available at https://www.grc.org/photosynthesis-conference/2019/#. This conference brought together both US and international scientists to engage in discussions on the recent progress in photosynthesis research. The meeting emphasized diverse topics pertaining to various disciplines ranging from the formation of oxygen and the unique oxygen-evolving catalysts to biomimetic complexes for the efficient harnessing of solar energy and more.

Fig. 1 shows the group photo of the participants at the GRC. The GRC had participants from 21 countries: Australia, Belgium, Cyprus, China, Czech Republic, Finland, France, Hungary, Germany, Mexico, United States, United Kingdom, Israel, Italy, Sweden, Taiwan, The Netherlands, New Zealand, Russia, Spain, and Japan.

We are delighted to note that six awards were given to outstanding poster presenters that included 2 women and 4 men. Fig. 2 shows the chair and vice chair of the GRC (Petra Fromme and Robert Burnap, respectively), and the co-chairs of GRS (Christopher Gisriel and Divya Kaur) with the following recipients of awards for poster presentations: Peter Adams (University of Leeds, Leeds, UK) for "*Observing light harvesting membrane proteins within aggregates and lipid bilayers: correlated fluorescence quenching (FLIM) and topographic mapping (AFM)*"; Anton Avramov (Oklahoma State University, Stillwater, USA) for "*The competition between Mn^{2+} and Ca^{2+} for Ca^{2+} binding site during the photoassembly of Photosystem II*"; David Flesher (Arizona State University, Tempe, USA) for "*Assessing light use efficiencies of benthic coral reef communities for spectral modeling applications*"; Krystle Reiss (Yale University, New Haven, USA) for "*Water network dynamics next to the oxygen-evolving complex of Photosystem II*"; Amit Srivastava (Institute of Microbiology of the Czech Academy of Science, Třebon, Czech Republic) for "*Cold-induced dormancy in cyanobacteria involves the re-localization of chlorophyll into Photosystem I- IsiA super-complexes*"; and, Carolyn Lubner (National Renewable Energy Laboratory, Golden, USA) for "*Studies of electron transfer reactions between the photosynthetic electron transport chain and peripheral redox pathways*". Each of the above-mentioned poster presenters were awarded a prize of a book (from the Series "Advances in Photosynthesis and Respiration", Springer) by Govindjee.

The conference began with a keynote session (Session 1): "**Advanced biophysical approaches for resolving molecular**

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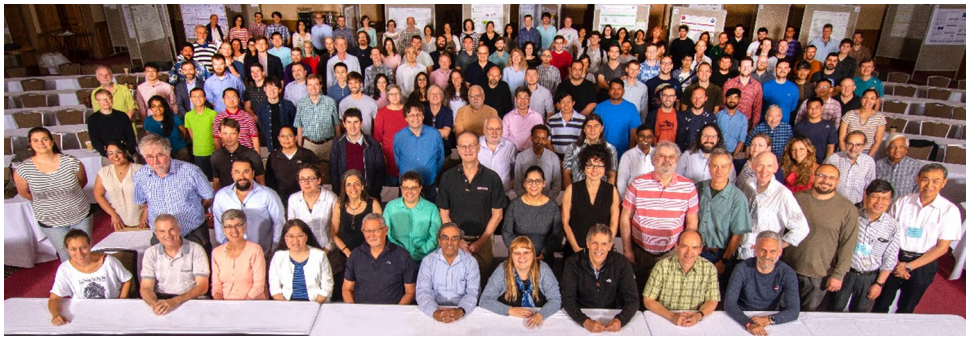

Fig. 1. A 2019 group photograph of most of the participants at GRC; reproduced with the permission of GRC.

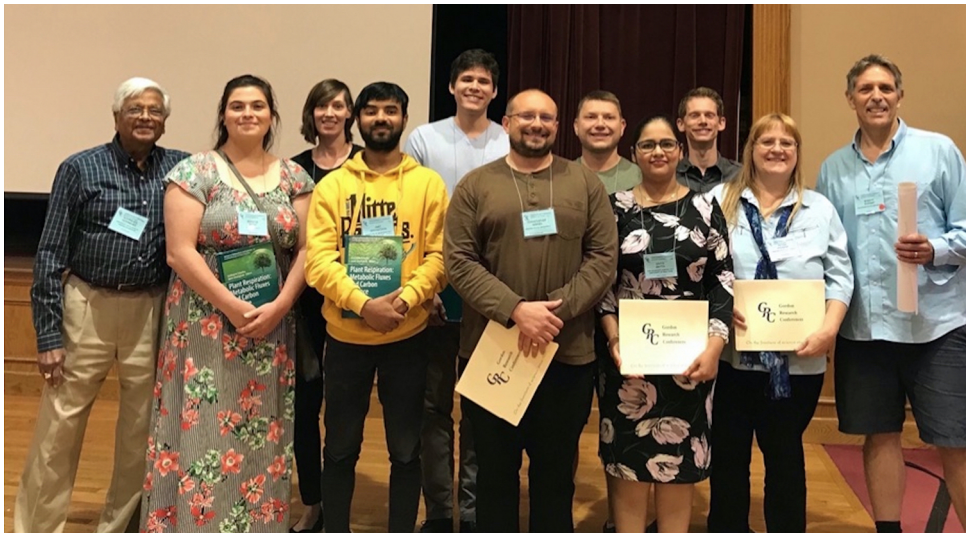

Fig. 2. *Front row* (left to right): Govindjee, Krystle Reiss, Amit Srivastava, Christopher Gisriel (GRS co-chair), Divya Kaur (GRS co-chair), Petra Fromme (GRC chair), Robert Burnap (GRC vice chair); *back row* (left to right): Carolyn Lubner, David Flesher, Anton Avramov, and Peter Adams. Source: Govindjee.

mechanisms of photosynthesis"; it was led by R. David Britt (University of California, Davis, USA) and included three talks: "*NPQ without LHCII*" by Roberta Croce (Vrije Universiteit Amsterdam, the Netherlands); "*Mechanisms of photosynthetic 'Light-reactions' revealed by a combination of advanced structural biology approaches*" by Jian-Ren Shen (Okayama University, Japan, Fig. 1, *row 2, 2nd from right*); and, "*Multidimensional spectroscopic studies of primary processes in purple bacteria*" by Jennifer Ogilvie (University of Michigan, USA, Fig. 1, *row 2, 5th from left*).

Session 2, "**Unraveling light harvesting mechanisms and energy coupling**", was led by Robert Blankenship (Washington University in St. Louis, USA, Fig. 1, *row 2, 6th from right*); it included five talks: "*Rate-limiting steps and light-induced reversible conformational changes in the closed Photosystem II reaction centers*" by Győző Garab (Biological Research Center, Hungarian Academy of Sciences, Hungary); "*Structural insights into pairs of PSII-LHCII supercomplexes excitonically connected across the stromal gap*" by Cristina Pagliano (Polotecnico di Torino, Italy); "*Electronic energy coupling by design*" by Elisabet Romero (Institute of Chemical Research of Catalonia (ICIQ), Spain, Fig. 1, *row 1, 1st from left*); "*Cryo-EM structure of Phycobilisome*" by Sen-Fang Sui (Tsinghua University, China, Fig. 1, *row 2, 1st from right*); and, "*How charge transfer states control the primary processes of photosynthesis*" by Rienk Van Grondelle (Vrije Universiteit Amsterdam, the Netherlands, Fig. 1, *row 2nd, 3rd from left*).

Session 3, "**Mechanisms of electron and proton transport**", was led by Gabriela Schlau-Cohen (Massachusetts Institute of Technology, USA) and included three talks: "*Following the protons associated with the oxygen evolving reactions in PSII*" by Marilyn Gunner (City College of New York, USA); "*Heliobacterial photosynthesis*" by Kevin Redding (Arizona State University, USA); and, "*Mimicking natural photosynthesis: Ultrafast charge transfer in PpcA-Ru(bpy)$_3$*" by Oleksandr Kokhan (James Madison University).

Session 4, "**Structure and function of protein complexes in photosynthesis**", was led by Raimund Fromme (Arizona State University, USA, Fig. 1, *row 3, 4th from left*); it included five talks: "*Subunit arrangement and energy transfer of Photosystem I*" by Mei Li (Institute of Biophysics, Chinese Academy of Sciences, China, Fig. 1, *row 1, 4th from left*); "*A targeted analysis of photoprotective energy dissipation in higher plants*" by Roberto Bassi (University of Verona, Italy, Fig. 1, *row 1,5th from left*); "*The structure of the PSI-IsiA super-complex from cyanobacteria*" by Yuval Mazor (Arizona State University, Tempe, AZ, USA); "*Structure of NDH: The complex I like molecule of photosynthesis*" by Karen Davies (Lawrence Berkeley National Laboratory, Berkeley, CA, USA, Fig. 1, *row 2, 7th from left*); and, "*Structural adaptations of photosynthetic complex I enable ferredoxin-dependent electron transfer*" by Marc Nowaczyk (Ruhr University Bochum, Germany, Fig. 1, *row 1, 1st from right*).

Session 5, "**Adaptation of photosynthesis to the environment**", was led by Barbara Demmig-Adams (University of Colorado, Boulder, CO, USA, Fig. 1, *row 1, 3rd from left*) and had three talks: "*Paradigm shift for climate-resilient crops: May less photoprotection be beneficial in some environments?*" by William Adams (University of Colorado, Boulder, USA, Fig. 1, *row 1, 2nd from left*); "*Handling photosynthesis in an iron-poor environment*" by Sabeeha Merchant (University of California, Berkeley, USA, Fig. 1, *row 2, 6th from left*); and, "*Chlorophyll f photochemistry in oxygenic photosynthesis*" by A. William Rutherford (Imperial College

London, London, UK, Fig. 1, *row 2, 4th from right*).

Session 6, "**Optimizing photosynthesis for bioenergy production**", was led by Shaun Bailey (Synthetic Genomics, USA) and included six talks: "*Realizing the benefits of delivering a source of concentrated CO_2*" by Bruce Rittmann (Arizona State University, Tempe, USA, Fig. 1, *row 2, 8th from left*); "*Applied photosynthesis" Putting photosystem I to work*" by Barry Bruce (University of Tennessee, Knoxville, USA); "*Redirecting photosynthetic electron flow into biofuels: Versatile function of the flavodiiron proteins*" by Yagut Allahverdiyeva-Rinne (University of Turku, Turku, Finland); "*Spectroscopic studies of the bioassembly intermediates of the Fe-Fe hydrogenase H-cluster*" by R. David Britt (University of California, Davis, USA); and, "*Fast growing cyanobacteria as photosynthetic cell factories for sustainable bioproduction*" by Himadri Pakrasi (Washington University in St. Louis, St Louis, USA, Fig. 1, *row 1, 5th from right*).

Session 7, "**Artificial photosynthesis and global solar energy conversion strategies**", was led by Victor Batista (Yale University, New Haven, USA) and included three talks: "*Water-oxidation catalysis for artificial photosynthesis*" by Gary Brudvig (Yale University, New Haven, USA, Fig. 1, *row 2, 5th from right*); "*Proton-coupled electron transfer drives long-range proton translocation*" by Ana Moore (Arizona State University, Tempe, USA) and "*A paradigm shift inspired by nature: Robust light-harvesting nanotubes through scaffold-assisted self-healing*" by Dorthe Eisele (City College of New York, New York, USA, Fig. 1, *row 2, 7th from right*).

Session 8, "**Mechanism of water-oxidation in natural and artificial photosynthesis**" was led by Nicholas Cox (Australian National University, Fig. 1, *row 3, 3rd from left*) and included four talks: "*X-ray crystallography and spectroscopy of Photosystem II using a femtosecond X-ray laser*" by Junko Yano (Lawrence Berkeley National Laboratory, Berkeley, USA); "*Spectroscopic and computational analysis of Mn_4Ca cluster transformations in the oxygen-evolving complex of Photosystem II*" by Yulia Pushkar (Purdue University, West Lafayette, USA); "*Probing the H-bond networks and substrate water near the Mn_4CaO_5 cluster with FTIR difference spectroscopy*" by Richard Debus (University of California, Riverside, USA); and, "*Proton transfer in Photosystem II*" by Hiroshi Ishikita (The University of Tokyo, Japan).

Finally, Session 9 included talks from several attendees who were chosen by a committee to give oral presentations based on their poster abstracts. Fig. 3 shows the GRC chair Petra Fromme and vice-chair Robert Burnap with speakers of this session. This session was led by Francis-André Wollman (UMR7141, Institut de Biologie Physico-Chimique, CNRS, Paris, France) and included six talks: "*Defining the biochemical functions of HoxHFU from Synechocystis 6803*" by Jacob Artz (National Renewable Energy Laboratory, Golden, USA); "*Microbial Electro-photosynthesis*" by Christine Lewis (Arizona State University, Tempe, USA); "*Bioinspired molecular-modified materials for solar fuel generation*" by Brian Wadsworth (Arizona State University, USA); "*Advancing functional genomics in photosynthesis: Low-coverage whole genome sequencing of a mutant collection and transcriptome profiling in Chlymodomonas reinhardtii*" by Setsuko Wakao (University of California, Berkeley, USA); "*Modification of the −OH dipole of a key tyrosine (M210) in bacterial photosynthetic reaction centers with non-canonical amino acids*" by Jared Weaver (Stanford University, USA); and, "*Charting the native molecular landscape of thylakoid membranes*" by Wojciech Wietrzynski (Max Planck Institute of Biochemistry, Munich, Germany).

2. Gordon research seminar

Preceding the GRC was the Gordon research seminar (GRS) which was held on July 20–21, 2019 and co-chaired by Christopher Gisriel (Arizona State University, USA), and Divya Kaur (The Graduate Center of the City University of New York, USA). The GRS was entitled "*Approaches for Understanding Water Splitting and Light-Harvesting Processes in Oxygenic Photosynthesis*". The complete program for the GRS is available at https://www.grc.org/photosynthesis-grs-conference/2019/. The seminar provided an excellent platform that brought together graduate students and post-doctoral researchers to present their research through talks and poster presentations. These were focused not only on the mechanistic pathways involved in photosynthesis but also on advanced techniques being employed for research.

The seminar included four session topics. It began with a keynote session (Session 1) "**Photosynthetic oxygen production: Mechanisms and consequences**", led by Casper de Lichtenberg (Umea University, Sweden). This keynote session had a talk "*The quantum design of solar-energy conversion in photosynthesis*", given by Elisabet Romero (Institute of Chemical Research of Catalonia (ICIQ), Barcelona, Spain, Fig. 1, *row 1, 1st from left*).

Session 2, "**Advances in method development for photosynthesis research**", was led by Doran Bennett (Southern Methodist University, Dallas, USA, Fig. 1, *row 3, 5th from right*). This session included five talks: "*Designing light harvesting proteins de novo*" by Nathan Ennist (University of Washington, Seattle, USA, Fig. 1); "*Hole-burning spectroscopy reveals the same low-energy trap states for the baseplates of Cfx. Aurantiacus and Cb. tepidium*" by Mahboobe Jassas (Kansas State University, Lawrence, USA, Fig. 1, *row 2, 2nd from left*); "*Molecular anatomy of plant photoprotective switches: The sensitivity of PsbS to the environment, residue by residue*" by Nicoletta Liguori (Vrije Universiteit Amsterdam, The Netherlands, Fig. 1, *row 3, 3rd from right*); "*Does Photosystem II convert nascent oxygen into singlet oxygen?*" by Heta Mattila (University of Turku, Turku, Finland); and, "*Charting the native architecture of thylakoid membranes with Cryo-EM tomography*" by Wojciech Wietrzynski (Max Planck Institute of Biochemistry, Munich, Germany).

Session 3, "**Metabolism and mutagenesis of photosynthetic systems**", was led by Yuval Milrad (Tel Aviv University, Tel Aviv, Israel). This session had five talks: "*Photoprotection in Chlamydomonas grown in physiological conditions*" by Wojciech Nawrocki (Vrije Universiteit Amsterdam, The Netherlands); "*Comparison of the energy transfer dynamics in structural and spectral variants of the light-harvesting complex 2 of purple bacteria*" by Olivia Fiebig (Massachusetts Institute of Technology, Boston, USA): "*Rewiring photosynthesis for biohydrogen production*" by Andrey Kangyin (Arizona State University, USA): "*Investigation of the molecular mechanism of sustained energy dissipation, qH in Arabidopsis*" by Jingfang Hao (Umea University, Umeå, Sweden); and "*Regulation of translation in response to chloroplastic reactive oxygen by protein kinase GCN2*" by Ansul Lokdarshi (University of Tennessee, Knoxville, USA).

Session 4, "**Biomimetic photosynthesis**", was led by Brian Wadsworth (Arizona State University, USA, Fig. 2 *front row*). It had two talks : "*Proteoliposomes as energy transferring nanomaterials: Enhancing the spectral range of light-harvesting proteins using lipid-linked chromophores*" by Ashley Hancock (University of Leeds, UK); and, "*Chromophore-protein assemblies: Multiple binding and interactions in de novo proteins*" by Valentin Maffeis (Institute of Chemical Research of Catalonia), Barcelona, Spain).

A key feature of our conference was the inclusion of "***The GRC Power Hour***" that stimulated discussions among the participants to address various challenges facing women in science and issues regarding diversity and inclusion. The *Power Hour* was organized by Marilyn Gunner (City College of New York, USA) and Gary Moore (Arizona State University, USA). Our data shows that 2019 GRC had ~20 % women and ~80 % men, while the GRS had ~40 % women and ~60 % men participants. There were nine sessions in the GRC in which 2 female and 7 male scientists served as discussion leaders. The ratio of the speakers was 14 women and 17 men. 126 posters were presented by 30 women and 96 men. In the GRS, out of 53 posters, 22 were presented by women and 31 by men.

3. Concluding remarks

The process of oxygenic photosynthesis involves the release of oxygen by oxidation of water, using five redox states of the oxygen-

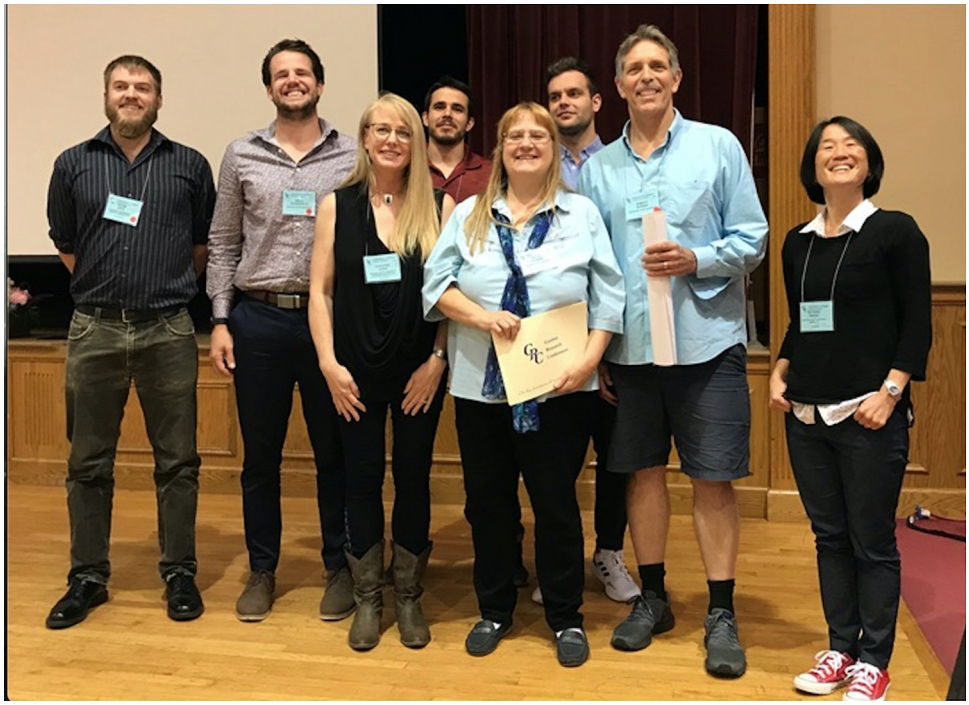

Fig. 3. *Front row* (left to right): Jacob Artz, Brian Wadsworth, Christine Lewis, Petra Fromme, Robert Burnap; Setsuko Wakao; *back row* (left to right): Jared Weaver, and Wojciech Wietrzynski. Source: Govindjee.

evolving complex (OEC): S_0 (highly reduced), S_1, S_2, S_3 and S_4 (oxidized to different levels) [1]. One of the open questions that still needs to be answered is the mechanism of O_2 formation and the nature of the short-lived oxygen-forming S_4 state. Other important questions relate to the detailed structure of the hydrogen bond networks around the OEC in different states assisting proton transfer [2–5], the substrate water delivery [6] and the protonation states of water molecules of the OEC [7], and the surrounding residues in S-state transitions [8,9]. Much of the recent research has been done to understand the intricate mechanism of these processes, however a consensus is yet to be established [10]. X-ray free electron laser (XFEL) studies [11–14] have now provided individual S-state structures, but the protein in the crystal has produced mixture of these intermediate states, providing challenges in data processing.

In our view, the main success of both the 2019 GRC and GRS was the valuable opportunities they provided to both the beginning and established scientists. There was an abundance of formal and informal discussion amongst attendees about the recent advances in the understanding and exploitation of photosynthesis research for the benefit of our society and the planet we inhabit. Furthermore, the conference and seminar provided opportunities for graduate students and post-doctoral researchers to present their research and receive feedback during or after sessions.

Reports on earlier conferences (both GRC and GRS) are available in *Photosynthesis Research* (see: Gisriel et al. [15], Govindjee et al. [16], Rappaport et al. [17] and Moore et al. [18]); they also contain photographs of the participants.

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