

# RMW10

The 10th Workshop on Reactive Metal Processing

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March 20 (Fri.) - 21 (Sat.), 2015 @ MIT  
Cambridge, Massachusetts, USA

## Organizers

**Donald R. Sadoway**, *Massachusetts Institute of Technology*

**Toru H. Okabe**, *IIS, The University of Tokyo*

**Antoine Allanore**, *Massachusetts Institute of Technology*

## Program Coordinators

**Katsuhiro Nose**, *The University of Tokyo (currently at MIT)*

**Jungshin Kang**, *The University of Tokyo (currently at KIGAM)*

# The 10th Workshop on Reactive Metal Processing

March 20 (Friday) - March 21 (Saturday), 2015, MIT, Cambridge, MA

## Time:

- 1st day: on March 20 (9:00 - 17:40 and Banquet in 18:30)
  - 2nd day: on March 21 (9:00 - 12:20)
- Refreshments will be served around 8:30 AM at the Grier room in both days.

## Venue:

- **Grier Room for Workshop (Building 34, Room 401)** (*see page 12*)  
Poster session is held at the Grier Room on March 20, 2015.
- **MIT Museum for Banquet** (*see page 12 or <http://web.mit.edu/museum>*)

## Organizers:

- Prof. Donald R. Sadoway**, *Massachusetts Institute of Technology*
- Prof. Toru H. Okabe**, *IIS, The University of Tokyo*
- Prof. Antoine Allanore**, *Massachusetts Institute of Technology*

## Program Coordinators:

- Dr. Katsuhiko Nose**, *The University of Tokyo (currently at MIT)*
- Dr. Jungshin Kang**, *The University of Tokyo (currently at KIGAM)*

## Sponsors:

A part of the workshop is financially supported by Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation by JSPS (P.I.: Prof. T.H. Okabe), The Rare Metal Research Workshop (RC-40: directed by Prof. T.H. Okabe), one of the Special Research Group organized by the Foundation for the Promotion of Industrial Science (FPIS), SEIKEN Symposium No. 80 by the Foundation for the Promotion of Industrial Science (FPIS), and Grant-in-Aid for Scientific Research (S) by JSPS.

## Registration Fee:

\$200 / person (including banquet)

NOTICE: Please prepare to pay the registration fee in cash!

## Contact Address:

**Jungshin Kang**, *Institute of Industrial Science, The University of Tokyo*  
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# Workshop Program

## Day 1

Morning, March 20 (Friday), 2015

@ Grier Room

8:30 – 9:00      **Coffee & Breakfast Service**

9:00 – 9:10      **Opening Remarks**

*Prof. Donald R. Sadoway*, Massachusetts Institute of Technology

*Prof. Toru H. Okabe*, IIS, The University of Tokyo

Session Chair: *Prof. Toshiyuki Nohira*

9:10 – 9:40      **“Waste to energy conversion”**

Uday B. Pal<sup>1</sup> and Soobhankar Pati<sup>2</sup>

<sup>1</sup>Division of Materials Science and Engineering, Boston University

<sup>2</sup>Indian Institutes of Technology (IIT) Bhubaneswar

9:40 – 10:10    **“Thermodynamic treatment of particulates sintering processes”**

Yiannis G. Kipouros<sup>1</sup>, Paul Burke<sup>2</sup>, George Jarjoura<sup>2</sup>, and Georges J. Kipouros<sup>2</sup>

<sup>1</sup>McMaster University

<sup>2</sup>University of Saskatchewan

10:10 – 10:20    Break

Session Chair: *Prof. Tetsuya Uda*

10:20 – 10:50    **“Novel molten carbonate electrolysis for a low-carbon future”**

Dihua Wang<sup>1</sup>

<sup>1</sup>Wuhan University

10:50 – 11:20    **“Anode processes during electrowinning of aluminium”**

Geir Martin Haarberg<sup>1</sup>, Henrik Åsheim<sup>1</sup>, Rauan Meirbekova<sup>1,2</sup>,

Guðrún Sævarsdóttir<sup>2</sup>, and Thor Anders Aarhaug<sup>3</sup>

<sup>1</sup>Department of Materials Science and Engineering,  
Norwegian University of Science and Technology

<sup>2</sup>School of Science and Engineering, Reykjavik University

<sup>3</sup>SINTEF Materials and Chemistry

11:20 – 11:50    **“Electrolytic nature of molten sulfides electrolyte”**

Samira Sokhanvaran<sup>1</sup>, Sangkwon Lee<sup>1</sup>, Guillaume Lambotte<sup>1</sup>, and  
Antoine Allanore<sup>1</sup>

<sup>1</sup>Department of Materials Science and Engineering, MIT

11:50 – 13:00    Lunch

Session Chair: *Prof. Georges J. Kipouros*

13:00 – 13:30      **“Electrodeposition of solar grade Si film on graphite in molten CaCl<sub>2</sub>”**

Huayi Yin<sup>1</sup>, Donald R. Sadoway<sup>1</sup>, and Allen Bard<sup>2</sup>

<sup>1</sup>Massachusetts Institute of Technology

<sup>2</sup>University of Texas at Austin

13:30 – 13:55      **“Fundamental study on new recycling technology for Ti metal scraps”**

Yu-ki Taninouchi<sup>1</sup>, Yuki Hamanaka<sup>1,2</sup>, and Toru H. Okabe<sup>1</sup>

<sup>1</sup>Institute of Industrial Science, The University of Tokyo

<sup>2</sup>Department of Materials Engineering, The University of Tokyo

13:55 – 14:10      Break

Session Chair: *Prof. Antoine Allanore*

14:10 – 14:40      **“Sodium secondary batteries with amide ionic liquids”**

Toshiyuki Nohira<sup>1,2</sup>, Rika Hagiwara<sup>2</sup>, Kazuhiko Matsumoto<sup>2</sup>, Changsheng Ding<sup>2</sup>,  
Chih-Yao Chen<sup>2</sup>, Takayuki Yamamoto<sup>2</sup>, Koma Numata<sup>3</sup>, Atsushi Fukunaga<sup>3</sup>,  
Shoichiro Sakai<sup>3</sup>, and Koji Nitta<sup>3</sup>

<sup>1</sup>Institute of Advanced Energy, Kyoto University

<sup>2</sup>Graduate School of Energy Science, Kyoto University

<sup>3</sup>Sumitomo Electric Industries, Ltd.

14:40 – 15:10      **“Screening of effective ionic liquid for extraction of rare earth elements”**

Etsuro Shibata<sup>1</sup>, Mariusz Grabda<sup>1</sup>, Mrutyunjay Panigrahi<sup>1</sup>, Dmytro Kozak<sup>1</sup>, and  
Takashi Nakamura<sup>1</sup>

<sup>1</sup>Institute of Multidisciplinary Research for Advanced Materials (IMRAM),  
Tohoku University

15:10 – 15:40      Photo & Break

Session Chair: *Dr. Jungshin Kang*

15:40 – 16:40      **3-min short presentation by poster presenters**

16:40 – 17:40      **Poster Session**

18:30 –              Banquet      @ MIT Museum

## Day 2

Morning, March 21 (Saturday), 2015

@ Grier room

8:30 – 9:00 **Coffee & Breakfast Service**

9:00 – 9:10 **Opening Remarks**

*Prof. Antoine Allanore*, Massachusetts Institute of Technology

Session Chair: *Prof. Geir Martin Haarberg*

9:10 – 9:40 **“Quantum beam technology: catalytic materials prepared by ion beam irradiation for electrochemical device applications”**

Tetsuya Yamaki<sup>1</sup>, Sho Kato<sup>2</sup>, Tetsuya Kimata<sup>2</sup>, Shunya Yamamoto<sup>1</sup>, Teruyuki Hakoda<sup>1</sup>, Tomohiro Kobayashi<sup>3</sup>, Akihiro Suzuki<sup>2</sup>, and Takayuki Terai<sup>2</sup>

<sup>1</sup>Quantum Beam Science Center, Japan Atomic Energy Agency (JAEA)

<sup>2</sup>Department of Nuclear Engineering and Management, The University of Tokyo

<sup>3</sup>Atomic Physics Laboratory, RIKEN

9:40 – 10:10 **“High temperature electrolysis of REs and relevance for RE's recycling”**

Ana Maria Martinez<sup>1</sup> and Egil Skybakmoen<sup>1</sup>

<sup>1</sup>SINTEF Materials and Chemistry

10:10 – 10:20 Break

Session Chair: *Dr. Katsuhiko Nose*

10:20 – 10:45 **“Recovery of cobalt from aqueous solution by utilizing gel precipitation and solvent extraction”**

Sakae Shirayama<sup>1</sup> and Tetsuya Uda<sup>1</sup>

<sup>1</sup>Department of Materials Science and Engineering, Kyoto University

10:45 – 11:10 **“New smelting process of titanium using liquid bismuth”**

Akihiro Kishimoto<sup>1</sup>, Kazuki Tsuchihashi<sup>1</sup>, and Tetsuya Uda<sup>1</sup>

<sup>1</sup>Department of Materials Science and Engineering, Kyoto University

11:10 – 11:15 **Information for the Next RMW**

*Prof. Donald R. Sadoway*, Massachusetts Institute of Technology

11:15 – 11:20 **Closing Remarks**

*Prof. Donald R. Sadoway*, Massachusetts Institute of Technology

11:20 – **Laboratory Tour (for applicants)**

## List of Poster Presentations

- 1. “Electrodeposition mechanism of titanium in NaCl-KCl”**  
Yuuki Yamada<sup>1</sup>, Akihiro Kishimoto<sup>1</sup>, and Tetsuya Uda<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, Kyoto University
- 2. “Electrolytic process for SiO<sub>2</sub> reduction using liquid Zn cathode in molten CaCl<sub>2</sub>”**  
Takeyuki Shimao<sup>1</sup>, Xiao Yang<sup>2,3</sup>, Kouji Yasuda<sup>1,4</sup>, Toshiyuki Nohira<sup>2,3</sup>, Rika Hagiwara<sup>1</sup>,  
Koki Ichitsubo<sup>5</sup>, Kenta Masuda<sup>5</sup>, and Takayuki Homma<sup>3,6</sup>  
<sup>1</sup>Graduate School of Energy Science, Kyoto University  
<sup>2</sup>Institute of Advanced Energy, Kyoto University  
<sup>3</sup>JST-CREST, Japan  
<sup>4</sup>Environmental, Safety, and Health Organization, Kyoto University  
<sup>5</sup>R&D Center, Taiheiyo Cement Corporation  
<sup>6</sup>Faculty of Science and Engineering, Waseda University
- 3. “Electrodeposition of crystalline Si films utilizing water-soluble KF-KCl molten salts and SiCl<sub>4</sub> as a Si source”**  
Kazuma Maeda<sup>1</sup>, Kouji Yasuda<sup>1,2</sup>, Toshiyuki Nohira<sup>3,4</sup>, Rika Hagiwara<sup>1</sup>,  
and Takayuki Homma<sup>4,5</sup>  
<sup>1</sup>Graduate School of Energy Science, Kyoto University  
<sup>2</sup>Environment, Safety, and Health Organization, Kyoto University  
<sup>3</sup>Institute of Advanced Energy, Kyoto University  
<sup>4</sup>JST-CREST, Japan  
<sup>5</sup>Faculty of Science and Engineering, Waseda University
- 4. “Thermodynamic properties of tellurium in molten steel”**  
Shun Ueda<sup>1</sup> and Kazuki Morita<sup>1</sup>  
<sup>1</sup>Department of Materials Engineering, The University of Tokyo
- 5. “Development of new recovery process for rhenium from nickel-base superalloy scraps”**  
Ryohei Yagi<sup>1,2</sup> and Toru H. Okabe<sup>2</sup>  
<sup>1</sup>Department of Materials Engineering, The University of Tokyo  
<sup>2</sup>Institute of Industrial Science, The University of Tokyo
- 6. “Development of new technique for concentrating and separating platinum group metals”**  
Tetsuo Watanabe<sup>1</sup>, Yu-ki Taninouchi<sup>2</sup>, and Toru H. Okabe<sup>2</sup>  
<sup>1</sup>Department of Applied Chemistry, Kogakuin University  
<sup>2</sup>Institute of Industrial Science, The University of Tokyo

7. **“Recycling technologies for low-grade titanium scraps utilizing molten-salt-based reactions”**  
Yuki Hamanaka<sup>1,2</sup>, Yu-ki Taninouchi<sup>2</sup>, and Toru H. Okabe<sup>2</sup>  
<sup>1</sup>Department of Materials Engineering, The University of Tokyo  
<sup>2</sup>Institute of Industrial Science, The University of Tokyo
  
8. **“A laboratory study of partial anode effects during aluminium electrolysis”**  
Henrik Åsheim<sup>1</sup>, Ole S. Kjos<sup>2</sup>, Espen Sandnes<sup>1,3</sup>, Thor Anders Aarhaug<sup>2</sup>, Asbjørn Solheim<sup>2</sup>, and Geir Martin Haarberg<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, NTNU  
<sup>2</sup>SINTEF Materials and Chemistry  
<sup>3</sup>Primary Metal Technology, Hydro Aluminium ASA
  
9. **“Influence of sulfur impurities on current efficiency in aluminium smelting processes”**  
Rauan Meirbekova<sup>1,2</sup>, Geir Martin Haarberg<sup>1</sup>, Jomar Thonstad<sup>1</sup>, Arne Petter Ratvik<sup>3</sup>, Ole S. Kjos<sup>3</sup>, Thor Anders Aahaug<sup>3</sup>, and Guðrún Sævarsdóttir<sup>2,3</sup>  
<sup>1</sup>Department of Materials Science and Engineering, NTNU  
<sup>2</sup>Reykjavik University  
<sup>3</sup>SINTEF Materials and Chemistry
  
10. **“Extraction of potassium by electrolysis from molten K-feldspar at high temperature for fertilizer applications”**  
Carole Gadois<sup>1</sup> and Antoine Allanore<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, MIT
  
11. **“Hydrosyenite: a new potassium fertilizer”**  
Davide Ciceri<sup>1</sup>, Carole Gadois<sup>1</sup>, Sonja Postak<sup>1</sup>, and Antoine Allanore<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, MIT
  
12. **“Fundamental study on vaporization behavior of molten sulfides for molten sulfide electrolysis”**  
Katsuhiro Nose<sup>1,2</sup> and Antoine Allanore<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, MIT  
<sup>2</sup>Institute of Industrial Science, The University of Tokyo
  
13. **“Ultra high temperature rare earth metal extraction by electrolysis”**  
Bradley R. Nakanishi<sup>1</sup>, Guillaume Lambotte<sup>1</sup>, and Antoine Allanore<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, MIT
  
14. **“The effect of Fe(II) ions on copper electrolysis”**  
Mary Elizabeth Wagner<sup>1</sup>, Sangkwon Lee<sup>1</sup>, and Antoine Allanore<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, MIT

- 15. “In situ measurements of current density for a galvanically coupled electrode”**  
Brian Chmielowiec<sup>1</sup> and Antoine Allanore<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, MIT
- 16. “Porous carbon anodes for supply of methane during electrowinning of aluminium”**  
Babak Khalaghi<sup>1</sup>, Tommy Mokkelbost<sup>2</sup>, Ole Kjos<sup>2</sup>, Henrik Gudbrandsen<sup>2</sup>, and  
Geir Martin Haarberg<sup>1</sup>  
<sup>1</sup>Department of Materials Science and Engineering, NTNU  
<sup>2</sup>SINTEF Materials and Chemistry
- 17. “Introduction of the recycling of spent automotive and petrochemical catalysts in Tanaka Precious Metal”**  
Akihiko Okuda<sup>1</sup> and Tomoko Yanagisawa<sup>1</sup>  
<sup>1</sup>Tanaka Kikinzoku Kogyo K.K., Tanaka Holdings Co., Ltd.



## History of RMW

- 2006 **The 1st Workshop on Reactive Metal Processing (RMW1)**  
March 17 (Fri.) - March 19 (Sat.), Cambridge, MIT
- 2006 **The 2nd Workshop on Reactive Metal Processing (RMW2)**  
November 16 (Thurs.) - November 17 (Fri.), Tokyo, The University of Tokyo
- 2007 **The 3rd Workshop on Reactive Metal Processing (RMW3)**  
March 2 (Fri.) - March 3 (Sat.), Cambridge, MIT
- 2008 **The 4th Workshop on Reactive Metal Processing (RMW4)**  
March 14 (Fri.) - March 15 (Sat.), Cambridge, MIT
- 2010 **The 5th Workshop on Reactive Metal Processing (RMW5)**  
February 18 (Thurs.) - February 19 (Fri.), Seattle, Red Lion Hotel on 5th Avenue
- 2011 **The 6th Workshop on Reactive Metal Processing (RMW6)**  
March 4 (Fri.) - March 5 (Sat.), Pasadena, Caltech
- 2012 **The 7th Workshop on Reactive Metal Processing (RMW7)**  
March 16 (Fri.) - March 17 (Sat.), Cambridge, MIT
- 2013 **The 8th Workshop on Reactive Metal Processing (RMW8)**  
March 8 (Fri.) - March 9 (Sat.), Cambridge, MIT
- 2014 **The 9th Workshop on Reactive Metal Processing (RMW9)**  
February 21 (Fri.) - February 22 (Sat.), Pasadena, Caltech

RMW1 in 2006 at MIT



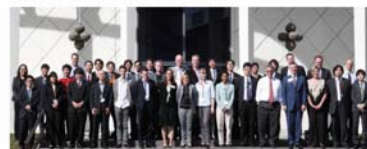
RMW2 in 2006 at IIS, the University of Tokyo



RMW5 in 2010 in Seattle



RMW6 in 2011 at CALTECH



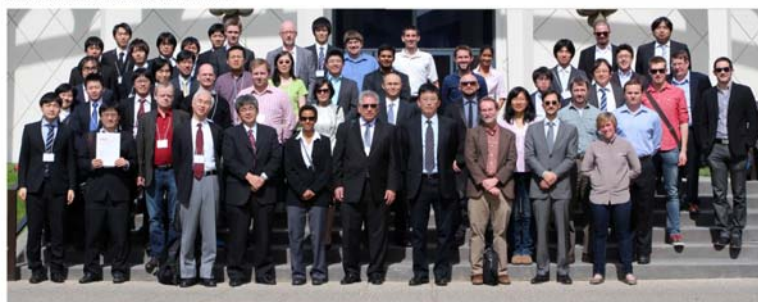
RMW7 in 2012 at MIT



RMW8 in 2013 at MIT



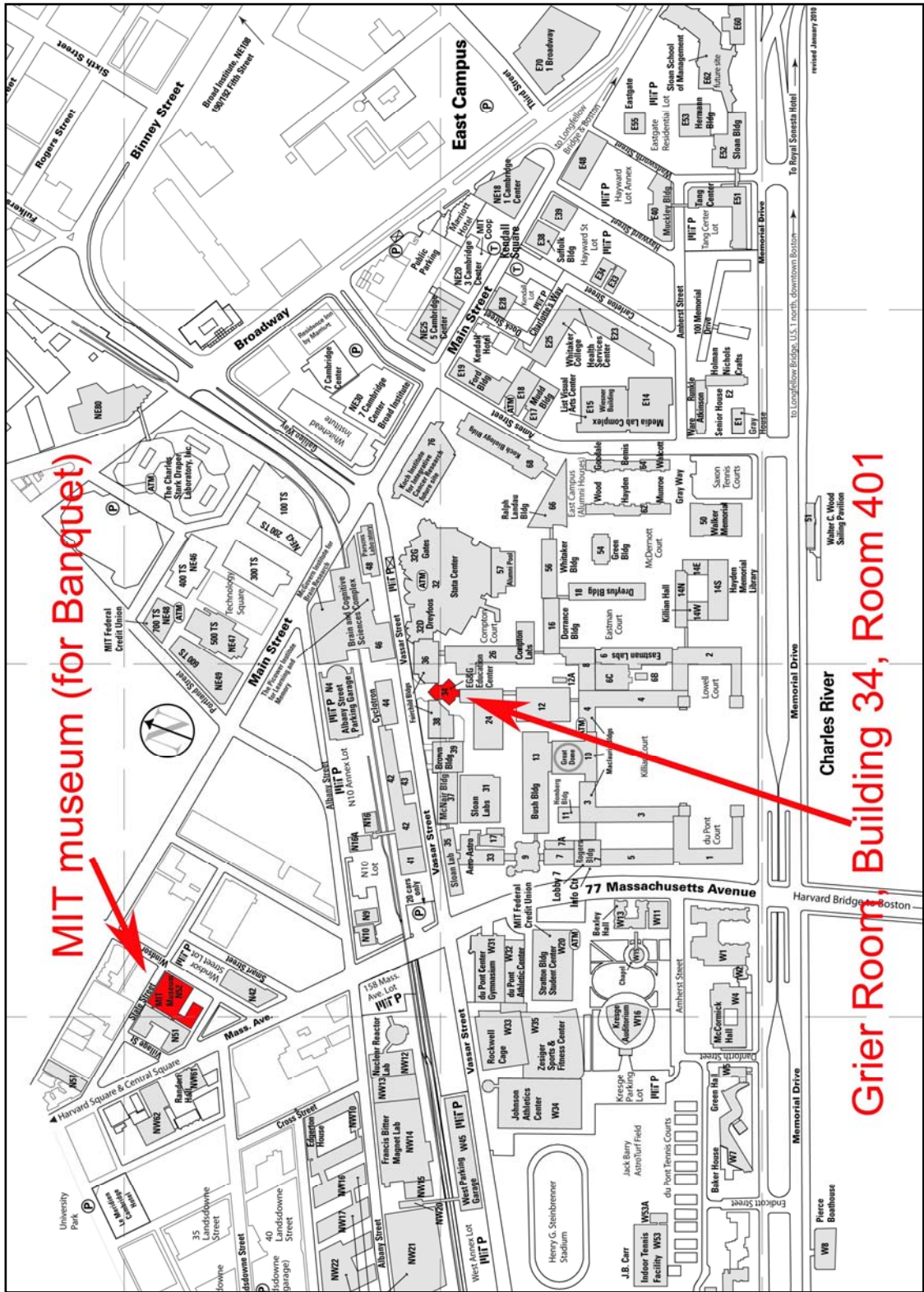
RMW9 in 2014 at CALTECH



## List of Participants

Adam C. Powell, IV	Chief Technology Officer	INFINIUM, Inc.
Akihiro Kishimoto	Ph.D Candidate	Kyoto University
Akihiro Sato	Senior Researcher	IHI Corporation
Ana Maria Martinez	Senior Research Scientist	SINTEF Materials and Chemistry
Antoine Allanore	Assistant Professor	MIT
Ayaka Kono	Administrative Staff	The University of Tokyo
Babak Khalaghi	Ph.D Candidate	NTNU
Bradley R. Nakanishi	Ph.D Candidate	MIT
Brian Chmielowiec	Research Engineer	MIT
Brian Spatocco	Graduate Researcher	MIT
Camilla Sommerseth	Ph.D Candidate	NTNU
Carole Gadois	Postdoctoral Associate	MIT
Daphne Allanore		Prof. Allanore's spouse
Davide Ciceri	Postdoctoral Associate	MIT
Dihua Wang	Professor	Wuhan University
Donald R. Sadoway	Professor	MIT
Egil Skybakmoen	Research Director	SINTEF Materials and Chemistry
Etsuro Shibata	Associate Professor	Tohoku University
Fei Chen	Visiting Scholar	MIT
Geir Martin Haarberg	Professor	NTNU
Georges J. Kipouros	Professor	University of Saskatchewan
Guðrún Sævarsdóttir	Professor	Reykjavik University
Henrik Åsheim	Ph.D Candidate	NTNU
Hilary Sheldon	Administrative Staff	MIT, Prof. Sadoway's secretary
Hongmin Zhu	Professor	Tohoku University
Huayi Yin	Postdoctoral Associate	MIT
Jie Song	Visiting Scientist	MIT
Jungshin Kang	Senior Researcher	KIGAM
Katsuhiko Nose	Project Research Associate	The University of Tokyo
Kazuma Maeda	Master Student	Kyoto University
Kouji Yasuda	Research Associate	Kyoto University
Mary Elizabeth Wagner	Undergraduate Student	MIT
Matt Earlam	Manager	INFINIUM, Inc.
Matthew Watson	Business Development Executive	TANAKA KIKINZOKU INTERNATIONAL (AMERICA) Inc.
Ole S. Kjos	Research Scientist	SINTEF Materials and Chemistry
Qian Xu	Professor	Shanghai University
Rauan Meirbekova	Ph.D Student	NTNU, Reykjavik University
Rebecca Rosenberg		Prof. Sadoway's spouse
Ryohei Yagi	Graduate Student	The University of Tokyo
Sakae Shirayama	Ph.D Candidate	Kyoto University
Samira Sokhanvaran	Postdoctoral Associate	MIT
Shun Ueda	Graduate Student	The University of Tokyo
Su Shizhao	Ph.D Candidate	Boston University
Takanari Ouchi	Senior Postdoctoral Associate	MIT

Takashi Nakamura	Professor	Tohoku University
Takeyuki Shimao	Master Student	Kyoto University
Tetsuo Watanabe	Undergraduate Student	Kogakuin University
Tetsuya Uda	Professor	Kyoto University
Tetsuya Yamaki	Principal Investigator	JAEA
Timothy C. Davenport	Post-doctoral Scholar	CALTECH
Tomoko Yanagisawa	Leader of Marketing Dept.	TANAKA HOLDINGS CO., LTD
Toru H. Okabe	Professor	The University of Tokyo
Toshiyuki Nohira	Professor	Kyoto University
Uday B. Pal	Professor	Boston University
Xiao Yang	Project Research Associate	Kyoto University
Xingli Zou	Lecturer	Shanghai University
Yihong Jiang	Ph.D Candidate	Boston University
Yuichi Nishiyama	Manager	IHI INC.
Yuimi Makizako	Administrative Staff	The University of Tokyo
Yuki Hamanaka	Graduate Student	The University of Tokyo
Yu-ki Taninouchi	Research Associate	The University of Tokyo
Yuuki Yamada	Graduate Student	Kyoto University



MIT museum (for Banquet)

Charles River Building 34, Room 401

Grier Room

# Announcement for Next Workshop

## RMW11

The 11th Workshop on  
Reactive Metal Processing



February 19 (Fri) – 20 (Sat), 2016 @ MIT, Cambridge

(After TMS 2016, February 14 – 18, 2016 @ Nashville, Tennessee)

Organizers

**Donald R. Sadoway**, *Massachusetts Institute of Technology*

**Toru H. Okabe**, *IIS, The University of Tokyo*

**Antoine Allanore**, *Massachusetts Institute of Technology*

Program Coordinators

**Yu-ki Taninouchi**, *IIS, the University of Tokyo*

**Sakae Shirayama**, *The University of Tokyo*

<http://www.okabe.iis.u-tokyo.ac.jp/core-to-core/rmw/>