



Disaster Prevention Research Institute  
Kyoto University, Uji, Kyoto, Japan  
京都大学 防災研究所

# *DPRI Award 2016*

*for Outstanding Contributions  
in Research and Education*

(研究教育貢献賞)

Dr. Keith William Hipel  
*Professor of the University of Waterloo*

選考経緯・業績紹介・講演資料

Feb. 23, 2016



## 目 次

DPRI Award 設立の趣旨および第 3 回 DPRI Award 受賞者決定の経緯	2
Keith W. Hipel 教授の御略歴	4
Keith W. Hipel 教授 防災研究所への招へいの足跡	6
論文リスト	7
講演要旨	38
Technology and Policy Options for a Low-Emission Energy System in Canada	
講演内容に関連した論文	40
“Technology and Policy Options for a Low-Emission Energy System in Canada”, Report of the Expert Panel on Energy Use and Climate Change : Overview	

## DPRI Award 設立の趣旨および第3回 DPRI Award 受賞者決定の経緯

研究教育担当副所長 西上欽也

防災研究所では、自然災害に国境はないことから、従来から国際交流協定の締結、国際共同研究、海外災害調査や留学生・海外共同研究者の受け入れなど積極的に取り組んできています。平成22年度からは共同利用・共同研究拠点として認定され、また、平成23年以降2回の世界防災研究所サミットの開催と世界防災研究所連合（GADRI）の設立およびその事務局担当など、頻発する国内外での自然災害に備えるための国際防災研究拠点としての地位を確立するために、様々な新しい取り組みをしてきています。

これらの一環として平成23年3月に「京都大学防災研究所国際表彰規程」が制定され、DPRI Award が設立されました。その表彰の要件は概略下記のようになっています。

- 1) 防災研において、客員教員や共同研究者などとして滞在し、セミナーや共同研究などを実施し、防災研の研究教育に成果を上げた方
- 2) 防災研が主催する研究集会等において、基調講演、招待講演等を務め、又は企画運営に携わり、防災研の活動に貢献した方
- 3) 防災研が実施する国際共同研究及び現地調査等において貢献した方

平成25年度には第1回の防災研究所国際表彰 DPRI Award をカリフォルニア工科大学名誉教授の金森博雄博士に授与いたしました。また、平成26年度には第2回の DPRI Award をメキシコ自治大学教授のサンチェズセスマ博士に授与いたしました。

今回平成27年度の国際表彰について、平成26年10月に防災研究所の多々納教授から推薦があり、表彰委員会で慎重に審議した結果、ウォータールー大学教授のキース・ウィリアム・ハイペル博士を第3回の防災研究所国際表彰 DPRI Award の受賞者として所長に推薦すること、その賞の副題は「研究教育貢献賞」とすることを決定いたしました。その後、所長の承認を受け、これを教授会に諮り承認されました。

ハイペル教授は 1946 年カナダに生まれ、1975 年にウォータールー大学工学研究科から工学博士を取得後、1976 年に同大学工学部助手に着任、1981 年に准教授、1985 年に教授に昇任されました。2007 年には大学著名教授 (University Professor) の称号を授与されています。この間、40 年にわたり社会システム工学の第一人者として、社会・技術・環境の間のインターフェイスに内在する複雑階層システムとその問題に対するコンフリクト解決、多属性意思決定分析、時系列分析など常に最先端の学際的研究をされてきました。その研究成果は膨大な量の研究論文として発表されており、現在でも毎年数多くの研究論文を発表されています。ハイペル教授は、2013 年からカナダ王立協会科学アカデミーの会長を務められています。また、システム工学の賞として世界最高の評価を得ているノーバート・ウィーナー賞 (IEEE(米国電気電子工学会)SMC 学会、2000 年)、米国水資源協会名誉会員賞 (2011 年)、ジョン・ウィリアム・ドーソン メダル (カナダ王立協会、2011 年) など多くの賞を受賞されています。

防災研究所においては、外国人客員教授として 1999 年度に 8 ヶ月、招へい外国人学者として 2000 年度、2002 年度、2004 年度、2008 年度、2012 年度および 2013 年度にそれぞれ 1~2 ヶ月滞在され、「コンフリクト解決のためのグラフモデル」や「意思決定支援システムの開発」などをテーマに共同研究を進められました。また、これらの研究内容に関連した講義・ゼミナールを行い、社会防災に関係する分野の学生・若手研究者への教育を熱心に行われました。

これらハイペル教授との共同研究や彼の学生・若手研究者への長年にわたる研究・教育の実績は防災研究所の国際プレゼンスの向上に大いに寄与してきました。ハイペル教授にはこれまでのご貢献に深く感謝するとともに、今後も受賞者に授与される終身称号の DPRI Fellow として、防災研究所の研究・教育に大所高所からご指導・ご助言いただければ大変ありがたいと思っています。

## Keith W. Hipel 教授の御略歴

氏名 : Keith William Hipel  
(キース ウィリアム ハイペル)

生年月日 : 1946 年

国籍 : カナダ

称号 : University Professor, PhD, PEng, FRSC,  
FIEEE, FCAE, FAWRA, FINCOSE, FEIC



所属機関名 : University of Waterloo(ウォータールー大学)

部局 : Faculty of Engineering(工学部)

Department of Systems Design Engineering (システムデザイン工学科)

所在地 : Waterloo, Ontario, N2L 3G1, Canada

(ウォータールー市, オンタリオ州, N2L 3G1, カナダ)

現職名 : University Professor(大学著名教授)

President, Academy of Science, Royal Society of Canada

(カナダ王立協会科学アカデミー 会長)

専門分野 : Systems Design Engineering

(社会システム工学・安全システム)

主な学歴 : 大学以降の学位を取得した機関名、学位及び取得年

University of Waterloo, B.A.Sc. (Civil Engineering) 1970

University of Waterloo, M.A.Sc. (Systems Design) 1972

University of Waterloo, Ph.D. (Civil Engineering) 1975

主な職歴 機関名・部局：

1975年10月1日～1976年3月31日

Visiting Professor, Federal University (Brazil)・Engineering Faculty

1976年4月1日～1981年6月30日

Assistant Professor, University of Waterloo (Canada)・Faculty of Engineering

1981年7月1日～1985年6月30日

Associate Professor, University of Waterloo・Faculty of Engineering

1985年7月1日～2007年6月15日

Full Professor, University of Waterloo・Faculty of Engineering

2007年6月16日～現在

University Professor, University of Waterloo・Faculty of Engineering

受賞（主要なものから記載）：

- Norbert Wiener Award (IEEE SMC Society) ノーバート・ウィーナー賞 (IEEE (米国電気電子工学会) SMC学会) (2000)
- 2011 American Water Resources Association (AWRA) : Honorary Membership Award 米国水資源協会名誉会員賞 (2011)
- 2011 Sir John William Dawson Medal (Royal Society of Canada (RSC)) ジョン・ウィリアム・ドーソン メダル (2011)
- 2011 Outstanding Engineering Educator Award (IEEE Canada) 優秀工学教育者賞 (2011)
- Fellow of the Royal Society of Canada (FRSC) カナダ王立協会フェロー (1998)
- University Professor (University of Waterloo) 大学著名教授 (ウオータールー大学) (2007)
- Docteur Honoris Causa from École Centrale de Lille エコール・セントラル・ドゥ・リール大学名誉博士号 (2007)
- Icko Iben Award (The American Water Resources Association) イコ・イベン賞 (アメリカ水資源協会) (2004)
- Fellow of the Institute of Electrical and Electronic Engineers (IEEE) 米電気電子工学会フェロー (IEEE) (1996)
- Fellow of the Canadian Academy of Engineering (CAE) カナダ工学アカデミーフェロー (1997)
- 2011 Best Peer-Reviewed Paper (American Society of Civil Engineers (ASCE)) アメリカ土木学会最優秀論文賞 (2011)

## Keith W. Hipel 教授 防災研究所への招へいの足跡

1999年（平成11年）度： 外国人客員教授

1999年5月10日～1999年12月31日

2000年（平成12年）度： 招へい外国人学者

2001年3月1日～2001年4月23日

2002年（平成14年）度： 招へい外国人学者

2003年3月2日～2003年3月30日

2004年（平成16年）度： 招へい外国人学者

2004年11月15日～2004年12月14日

2008年（平成20年）度： 招へい外国人学者

2009年3月9日～2009年3月24日

2012年（平成24年）度： 招へい外国人学者

2013年3月1日～2013年3月31日

2013年（平成25年）度： 招へい外国人学者

2014年1月28日～2014年3月31日

## Distinguished Contributions of Keith W. Hipel to Scholarly Research

**Overview:** Keith Hipel is *University Professor* of Systems Design Engineering at the University of Waterloo, *Past President* of the Academy of Science within the Royal Society of Canada, *Senior Fellow* of the Centre for International Governance Innovation, *Fellow* of the Balsillie School of International Affairs, and *Coordinator* of the Conflict Analysis Group at Waterloo. He is globally renowned for his unique interdisciplinary research from a *Systems Engineering* perspective on the development of *conflict resolution*, *multiple criteria decision analysis (MCDA)*, *time series analysis* and other *decision-making methodologies* for addressing challenging *system of systems engineering* problems lying at the confluence of society, technology and the environment, with applications in *water resources management*, *hydrology*, *environmental engineering*, *energy*, and *sustainable development*.

**Conflict Resolution:** Keith Hipel and his research team are the originators of the *Graph Model for Conflict Resolution (GMCR)* which constitutes the most comprehensive and flexible formal approach available for systematically investigating real world conflict. The solid mathematical design of GMCR for representing and understanding disputes permits one to model interactive decision making realistically, forecast compromise solutions, and furnish valuable strategic insights. The GMCR methodology includes a novel *theoretical structure* for modelling the key characteristics of conflict; innovative *preference elicitation* methods for capturing stakeholders' value systems; operational techniques for handling *preference uncertainty* (unknown, fuzzy and grey) and *strength of preference*; stability concepts for analyzing different kinds of *human behaviour* under conflict; *policy analysis*; *agent-based modelling* using a GMCR perspective; formal consideration of the influence of psychological factors such as *attitudes*, *emotions* and *misunderstandings* (hypergames); *coalition analysis* for reaching cooperative win/win resolutions; extensive *implementation algorithms* some of which are based on a new matrix approach for equivalently defining GMCR; *hierarchical conflicts*; *third party intervention* using inverse GMCR; and a *decision support system* called GMCR II for permitting practical applications in diverse fields (used by 72 user groups in 25 countries). A 1993 Wiley (New York) book entitled *Interactive Decision Making: The Graph Model for Conflict Resolution* that Hipel wrote with L. Fang and D.M. Kilgour, received excellent reviews. A comprehensive new book on conflict resolution is currently being written.

**Multiple Criteria Decision Analysis (MCDA):** In MCDA, a set of alternative solutions for solving a given problem is evaluated and compared according to a range of criteria such as costs, benefits, environmental effects, and social impacts. Hipel and his co-workers have designed formal methods for taking *interdependence* among alternatives into account when a final resolution may consist of a combination of alternatives, such as a regional government faced with selecting a mixture of groundwater, lake water and conservation alternatives for

satisfying future water demands. They have developed different kinds of *classification techniques* to handle the elimination of inferior solutions, *sorting* of alternatives into groups ranked according to preference, and placing alternatives into *nominal categories*. As well, they have proposed special MCDA methods for use in *group decision making* and *negotiation*. To handle uncertainty, they have contributed to both *fuzzy and grey MCDA*. Their MCDA methods have been applied to societal decision problems in water supply planning, varying water levels in the Great Lakes, electrical generation, third world infrastructure redevelopment, inventory management and business.

**Time Series Modelling:** The classic book on *Time Series Modelling of Water Resources and Environmental Systems* (Elsevier, Amsterdam, 1994) that Hipel wrote with A.I. McLeod brings together contributions in stochastic hydrology, statistical water quality modelling and statistics, to create a unified and comprehensive approach to *environmetrics* – the development and application of statistics in the environmental sciences. They also produced an associated decision support system called the *MH Time Series Package*. A great strength of Hipel's research in environmetrics is the integrative employment of exploratory data analysis tools, intervention models (special types of transfer-function noise models), regression analysis and nonparametric trend tests for detecting, modelling, and estimating the magnitudes of trends in environmental time series. This type of *environmental impact assessment* is essential for many important societal activities related to sustainable development including the determination of the effects of land use changes upon the environment, and the effectiveness of pollution abatement policies. Other research in environmetrics to which Hipel made significant contributions includes solving a famous hydrological problem called the *Hurst Phenomenon*, designing algorithms and procedures for use in *model construction*, developing *simulation* algorithms for employment with short and long-memory models, and completing extensive split-sample experiments to ascertain which types of models are most suitable for *forecasting* nonseasonal and seasonal hydrological time series.

**Other Decision Making Methodologies:** Based on the extensive form of a game, Hipel and his team have constructed *compliance models* for systematically assessing the effectiveness of a range of policies for enforcing and encouraging adherence by firms to environmental laws and regulations. The cost-effectiveness of inducing compliance is assessed in terms of factors such as the private gain for violators, the costs of inspection by agencies and the social value of encouraging sustainable development. Utilizing concepts from economics, ethics, hydrology, and cooperative game theory, a complex optimization approach called the *Cooperative Water Allocation Model* has recently been developed for equitably allocating fresh water among competing users in a river basin with application to both the Aral Sea and South Saskatchewan River Basins. A journal paper on this topic that Hipel wrote with L. Wang and L. Fang won the *2012 Best Publication Award in Environment and Sustainability* from INFORMS (Institute for Operations Research and the Management Sciences). Other contributions of Hipel to *decision*

*making under uncertainty* include a systems approach to *risk analysis* and *information-gap modelling* in water resources.

**System of Systems (SoS) Engineering:** Large-scale SoS problems possess great complexity, deep uncertainty, a diversity of agents, conflicting values, interconnections, and emergent behaviour (surprises), as evidenced by the ongoing interdependent problems of climate change, energy shortages, the food crisis, over-population, lack of fresh water, economic instability, widespread pollution and regional wars. Accordingly, Hipel's foregoing research contributions are employed within an SoS framework when addressing complex interconnected problems using *integrative and adaptive governance in a participatory and interdisciplinary fashion*. Hipel and his group are developing a more general theory of SoS engineering and related governance implications to tackle the many pressing SoS problems now facing society and the natural environment.

**Impacts:** For his valuable contributions to research, mentoring and service, Hipel has received 49 prestigious awards including an important Japanese science prize (*Japan Society for the Promotion of Science Eminent Scientist Award* for which the previous 6 out of 7 recipients are Nobel Prize Laureates); highest international distinction in systems engineering research (*Norbert Wiener Award* from the IEEE Systems, Man and Cybernetics Society); top prizes in water resources research (*Honorary Diplomate, Water Resources Engineers (Hon.D.WRE)* from the American Academy of Water Resources Engineers within the American Society of Civil Engineers; *Honorary Member in the American Water Resources Association (AWRA)*); awards for interdisciplinary research (*Sir John William Dawson Medal* (Royal Society of Canada); *Icko Iben Award* (AWRA)); professional engineering recognition (*Engineering Medal for Research and Development* (Ontario)); and teaching awards (*Outstanding Engineering Educator Award* from IEEE Canada; *Distinguished Teacher Award* (University of Waterloo)). Hipel has influenced academia through the *publication* of highly-cited leading-edge research (4 books, 12 edited books, 289 refereed journal papers and numerous conference articles; high Hirsch Index of 48, over 10,080 citations); *mentoring students* (32 PhD and 47 Master's students have graduated; taught over 5,000 students in Canada and 1,000 more overseas); *curriculum development*; *internationalization of university education* via the establishment of successful student exchange programs with three Japanese universities and a Chinese university; and founding an ongoing sequence of water resources *conferences*. Hipel has further contributed to *technology transfer* via carrying out advanced *consulting* with engineering firms, utilities and government agencies. He was Co-Chair of the *Expert Panel on Energy Use and Climate Change* (Council of Canadian Academies) which produced the report "*Technology and Policy Options for a Low-Emission Energy System in Canada*" (2015).

January 20, 2016

## RESEARCH PUBLICATION SUMMARY

(Status as January 20, 2016)

- (a) **Books** - 4 refereed books have been published.
- (b) **Edited Books** - 12.
- (c) **Refereed Journal Papers** – 289.
- (d) **Discussions, Comments and Replies in Refereed Journals** - 7.
- (e) **Invited Articles in Books, Encyclopedia, and Conference Proceedings** - 173.
- (f) **Refereed Conference Papers** - 97.
- (g) **Technical Reports** - 57.
- (h) **Magazine, Newspaper and Newsletter Articles** - 10.

Research publications under categories (a) to (h) are not directly listed in this document. Instead, representative publications are classified according to research topics.

### RESEARCH TOPICS

In this section, relevant refereed journal papers, encyclopedia articles, conference papers and books are categorized according to research topics.

#### **Graph Model for Conflict Resolution**

##### **Book**

1. Fang, L., Hipel, K.W., and Kilgour, D.M. "Interactive Decision Making: The Graph Model for Conflict Resolution", Wiley, New York, 221 pp., 1993.

##### **Edited Books**

1. Hipel, K.W. (Editor), "Conflict Resolution, Volume 1", Eolss Publishers, Oxford, United Kingdom (ISBN-978-1-84826-120-4 (Adobe e-Book), ISBN-978-1-84826-570-7 Library Edition (Hard Cover)) (Earlier versions of the papers appeared in the Encyclopedia of Life Support Systems.), 2009.
2. Hipel, K.W. (Editor), "Conflict Resolution, Volume 2", Eolss Publishers, Oxford, United Kingdom (ISBN-978-1-84826-121-1 (Adobe e-Book), ISBN-978-1-84826-571-4 Library Edition (Hard Cover)) (Earlier versions of the papers appeared in the Encyclopedia of Life Support Systems), 2009.

##### **Encyclopedia Articles**

1. Hipel, K.W., Kilgour, D.M., and Fang, L., "The Graph Model for Conflict Resolution", in Wiley Encyclopedia of Operations Research and Management Science, edited by J.J. Cochran (Editor-in-Chief) with L.A. Cox, P. Keskinocak, J.P. Kharoufeh, and J.C. Smith (Area Editors), Wiley, New York, Vol. 3 of 8, pp. 2099-2111, 2011.

2. Hipel, K.W., Kilgour, D.M., and Fang, L., "Conflict Analysis and Resolution", McGraw-Hill Yearbook of Science and Technology, 2006, McGraw-Hill, New York, pp. 75-77, 2006.
3. Hipel, K.W., "Conflict Resolution", theme overview paper, in Conflict Resolution, Encyclopedia of Life Support Systems (EOLSS), Eolss Publishers, Oxford, United Kingdom, [<http://www.eolss.net>], 2002.
4. Hipel, K.W., "Formal Models for Conflict Resolution and Case Studies", topic overview paper, in Conflict Resolution, Encyclopedia of Life Support Systems (EOLSS), Eolss Publishers, Oxford, United Kingdom, [<http://www.eolss.net>], 2002.

### **Overviews**

1. Hipel, K.W. and Bernath Walker, S., "Conflict Analysis in Environmental Management", *Environmetrics*, published online in Wiley Online Library on 7 June 2010, DOI: 10.1002/env.1048, Vol. 22, pp. 279-293, 2011.
2. Kilgour, D.M. and Hipel, K.W., "Conflict Analysis Methods: The Graph Model for Conflict Resolution", In Kilgour, D.M. and Eden, C. (Editors), "Handbook of Group Decision and Negotiation", Springer, Dordrecht, The Netherlands, pp. 203-222, 2010.
3. Kilgour, D.M., and Hipel, K.W., "The Graph Model for Conflict Resolution: Past, Present, and Future", *Group Decision and Negotiation*, Vol. 14, No. 6, pp. 441-460, 2005.
4. Hipel, K.W., Kilgour, D.M., Fang, L., and Li, W., "Resolution of Water Conflicts between Canada and the United States", invited paper published as Section 4.3 in "State-of-the-Art Report on Systems Analysis Methods for Resolution of Conflicts in Water Resources Management", edited by K.D.W. Nandalal and S.P. Simonovic, a Report prepared for the Division of Water Sciences, United Nations Educational, Science and Cultural Organization (UNESCO), Paris, France, pp. 62-75, 2003.
5. Hipel, K.W., Fang, L., and Kilgour, D.M., "Decision Support Systems in Water Resources and Environmental Management", Keynote Paper, Proceedings of the Third International Conference on Water Resources and Environment Research, edited by G.H. Schmitz, held at the Dresden University of Technology, Dresden, Germany, July 22-25, 2002, vol. I, pp. 287-300, 2002.
6. Hipel, K.W., Fang, L., and Kilgour, D.M., "Game Theoretic Models in Engineering Decision Making", invited paper, *Journal of Infrastructure Planning and*

Management, Japan Society of Civil Engineering, No. 470/IV-20, pp. 1-16, July 1993.

7. Hipel, K.W., Radford, K.J., and Fang, L., "Multiple Participant Multiple Criteria Decision Making", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-23, No. 4, pp. 1184-1189, 1993.

### **Theory**

1. Fang, L., Hipel, K.W., and Kilgour, D.M., "Conflict Models in Graph Form: Solution Concepts and their Interrelationships", European Journal of Operational Research, Vol. 41, No. 1, pp. 86-100, 1989.
2. Kilgour, D.M., Hipel, K.W., and Fang, L., "The Graph Model for Conflicts", Automatica, Vol. 23, No. 1, pp. 41-55, 1987.

### **Preference Elicitation**

1. Bristow, M., Fang, L., and Hipel, K.W., "From Values to Ordinal Preferences for Strategic Governance", IEEE Transactions on System, Man, and Cybernetics: Systems, DOI: 10.1109/TSMC.2014.2308154, published online on April, 15, 2014, Vol. 44, No. 10, pp. 1364-1383, 2014.
2. Ke, Y., Fu, B., De, M., and Hipel, K.W., "A Hierarchical Multiple Criteria Model for Eliciting Relative Preferences in Conflict Situations", Journal of Systems Science and Systems Engineering, DOI: 10.1007/s11518-012-5187-0, Vol. 21, No. 1, pp. 56-76, 2012.
3. Ke, Y., Li, K.W., and Hipel, K.W., "An Integrated Multiple Criteria Preference Ranking Approach to the Canadian West Coast Port Congestion Problem", Expert Systems with Applications, DOI: 10.1016/j.eswa.2012.02.086, Vol. 39, Issue 10, pp. 9181-9190, August 2012.

### **Attitudes**

1. Bernath Walker, S., Hipel, K.W., and Inohara, T., "Dominating Attitudes in the Graph Model for Conflict Resolution", Journal of Systems Science and Systems Engineering, DOI: 10.1007/s11518-012-5198-x, Vol. 21, No. 3, pp. 316-336, 2012.
2. Bernath Walker, S.G., Hipel, K.W., and Inohara, T., "Attitudes and Preferences: Approaches to Representing Decision Maker Desires", Applied Mathematics and Computation, DOI: j.amc.2011.11.102, published online since January 11, 2012, Vol. 218, Issue 12, pp. 6637-6647, February 2012.
3. Bernath Walker, S., Hipel, K.W., and Inohara, T., "Strategic Decision Making for Improved Environmental Security: Coalitions and Attitudes in the Graph Model for

Conflict Resolution", Journal of Systems Science and Systems Engineering, special issue on Strategic Decision Making for Global Security from a Systems Engineering Perspective in the Post-911 Environment, Vol. 18, No. 4, pp. 461-476, 2009.

4. Inohara, T., Hipel, K.W., and Walker, S., "Conflict Analysis Approaches for Investigating Attitudes and Misperceptions in the War of 1812", Journal of Systems Science and Systems Engineering, Vol. 16, No. 2, pp. 181-201, 2007.

### **Fuzzy Preferences**

1. Bashar, M.A., Obeidi, A., Kilgour, D.M., and Hipel, K.W., "Modeling Fuzzy and Interval Fuzzy Preferences within a Graph Model Framework", IEEE Transactions on Fuzzy Systems, accepted for publication subject to making a minor change on April 13, 2015.
2. Bashar, M.A., Hipel, K.W., Kilgour, D.M., and Obeidi, A., "Coalition Fuzzy Stability Analysis in the Graph Model for Conflict Resolution", Journal of Intelligent and Fuzzy Systems, DOI: 10.3233/IFS-141336, accepted for publication on June 11, 2014.
3. Bashar, M.A., Kilgour, D.M., and Hipel, K.W., "Fuzzy Option Prioritization for the Graph Model for Conflict Resolution", Fuzzy Sets and Systems, DOI: 10.1016/j.fss.2014.02.11, appeared online on February 26, 2014, Vol. 246, pp. 34-48, 2014.
4. Bashar, Md.A., Kilgour, D.M., and Hipel, K.W., "Fuzzy Preferences in the Graph Model for Conflict Resolution", IEEE Transactions on Fuzzy Systems", DOI: 10.1109/TFUZZ.2012.2183603, Vol. 20, No. 4, pp. 760-770, August 2012.
5. Hipel, K.W., Kilgour, D.M., and Bashar, M.A., "Fuzzy Preferences in Multiple Participant Decision Making", Scientia Iranica, Transactions D: Computer Science & Engineering and Electrical Engineering, special publication dedicated to the lifelong achievements of Professor Lotfi A. Zadeh, Vol. 18, No. 3(D1), pp. 627-638, June 2011.
6. Al-Mutairi, M.S., Hipel, K.W., and Kamel, M.S., "Fuzzy Preferences in Conflicts", Journal of Systems Science and Systems Engineering, Vol. 17, No. 3, pp. 257-276, 2008.
7. Al-Mutairi, M.S., Hipel, K.W., and Kamel, M.S., "Trust and Cooperation from a Fuzzy Perspective". Mathematics and Computers in Simulation, online since April 6, 2007, doi:10.1016/j.matcom.2007.04.006, Vol. 76, pp. 430-446, 2008.

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# **Technology and Policy Options for a Low-Emission Energy System in Canada**

Findings of an Expert Panel on Energy Use and Climate Change

Seminar Presented by

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## **Abstract**

A synopsis is presented on the key findings of the Council of Canadian Academies' Expert Panel Report on energy use and climate change, which was released in late October of 2015. The evidence is clear: increased greenhouse gas emissions from human activity are causing pervasive changes to the Earth's climate, and significant and rapid efforts will be needed to reduce these emissions in the coming decades. The Panel's report is an up-to-date, accessible review of options for reducing greenhouse gas emissions and moving Canada toward a low-emission future. It provides an overview of Canada's energy system, an analysis of different energy sources and technologies, and an exploration of the public policies available to support a shift toward low-emission energy sources and technologies. Moreover, the investigation is guided by a systems thinking approach, recognizing the interconnectedness of society and the natural environment supporting it. Overall, the Panel acknowledged that the technologies needed for moving toward a low-emission energy system and the policies required for promoting the use of those technologies, already exist, are well-understood and are constantly improving. Optimal strategies and policies for advancing reductions in greenhouse gas emissions will need to be adaptive by evolving as necessary in response to emission trends, new technological developments, and other social, economic, and political changes. They will also benefit from system level principles of resilience, sustainability, fairness, and integration across jurisdictions and disciplines. The report constitutes an indispensable resource for private sector decision-makers, different levels of government, and the public as they seek to better understand energy use and the options available to combat climate change.

## Acknowledgement

This seminar presentation is entirely based on the following Expert Panel Report, which was orchestrated and published by the Council of Canadian Academies (CCA) located in Ottawa, Ontario, Canada. The Expert Panel consisted of a multidisciplinary group of eight experts, for which K.W. Hipel and P.R. Portney were the Co-Chairs, as well as an Assessment Team from the CCA. Magna International Inc. kindly funded the project.

## Expert Panel Report

Council of Canadian Academies (CCA), “*Technology and Policy Options for a Low-Emission Energy System in Canada*”, Report of the Expert Panel on Energy Use and Climate Change, Report released on October 27, 2015, by the CCA, Ottawa, Ontario, Canada K2P 2K3, 2015.

(This report can be downloaded free of charge at <http://www.scienceadvice.ca>)

## Speaker Biography

**Keith W. Hipel** is *University Professor* of Systems Design Engineering at the University of Waterloo where he is *Coordinator* of the Conflict Analysis Group. He is *Past President* of the Academy of Science within the Royal Society of Canada, *Senior Fellow* of the Centre for International Governance Innovation, *Fellow* of the Balsillie School of International Affairs, and *Past-Chair* of the Board of Governors of Renison University College. Dr. Hipel thoroughly enjoys mentoring students and is a recipient of the *Distinguished Teacher Award*, *Faculty of Engineering Teaching Excellence Award*, and the *Award of Excellence in Graduate Supervision* from the University of Waterloo, as well as the *2011 Outstanding Engineering Educator Award* from IEEE Canada. His major research interests are the development of conflict resolution, multiple criteria decision analysis, time series analysis and other decision-making methodologies for addressing complex interdisciplinary system of systems engineering problems lying at the confluence of society, technology and the environment, with applications in water resources management, hydrology, environmental engineering, energy, and sustainable development. Prof. Hipel is the author or co-author of 4 books, 12 edited books, more than 285 journal papers, as well as many conference and encyclopedia articles (over 10,160 citations; H-index = 49, i10-index = 211). Dr. Hipel is the recipient of the *Japan Society for the Promotion of Science (JSPS) Eminent Scientist Award*; *Joseph G. Wohl Outstanding Career Award* from the IEEE Systems, Man and Cybernetics (SMC) Society; *IEEE SMC Norbert Wiener Award*; *Docteur Honoris Causa* (France); *Doctor Honoris Causa* (Hungary); *Sir John William Dawson Medal* (Royal Society of Canada); and *Engineering Medal for Research and Development* from Professional Engineers Ontario.

# “Technology and Policy Options for a Low-Emission Energy System in Canada”, Report of the Expert Panel on Energy Use and Climate Change : Overview<sup>\*</sup>

The Expert Panel on Energy Use and Climate Change  
Council of Canadian Academies (CCA)

A reliable energy system is essential for a functioning society, and improvements in humanity’s capacity to harness energy from a range of sources have helped raise living standards around the world. Canada, like many countries, relies on fossil fuels for most of its energy. Coal, oil, and natural gas together account for 72% of Canada’s energy supply, and they are the dominant sources of energy used for transportation, space heating, many industrial processes, and electricity generation in some provinces. The burning of these fuels is increasing the amount of carbon dioxide in our atmosphere and causing pervasive changes in the Earth’s climate. The resulting widespread and substantial risks to society and ecosystems justify significant, accelerated efforts to reduce greenhouse gas emissions from human activity over the coming decades. The Council of Canadian Academies (the Council) was tasked with synthesizing the evidence on select energy sources and technologies, as well as public policies, that would be involved in a transition to a low-emission energy system in Canada. This charge came in response to frustration among some business leaders that stemmed from a lack of clarity about key facts relating to energy technologies and climate change, and policy options to address this challenge. To address this charge, the Council convened a multidisciplinary, eight-member expert panel (the Panel) comprising people with expertise in economics, public policy, engineering, and energy systems and technologies. From its discussion and review of the evidence, the Panel identified three key findings.

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\* This paper is a part of the report “Technology and Policy Options for a Low-Emission Energy System in Canada”, Report of the Expert Panel on Energy Use and Climate Change” by the Expert Panel on Energy Use and Climate Change, Council of Canadian Academies (CCA). The report is available at <http://www.scienceadvice.ca> .

## Finding 1: Canada could achieve major emission reductions with the adoption of commercially available technologies.

Over the course of the next several decades, a transition to a low-emission energy system would involve three main strategies: improvements in energy efficiency, a shift from high-emission to low-emission energy sources (i.e., energy substitution), and possibly the adoption of carbon capture and storage (CCS) technologies. Improvements in energy efficiency can result in early gains and provide a foundation for the cost-effective introduction of low-emission technologies, but deeper emission reductions will require energy substitution and potentially the application of CCS in conjunction with Technology and Policy Options for a Low-Emission Energy System in Canada with continued fossil fuel use. Taking advantage of existing technologies in these areas and across the transportation, building, and industry sectors could result in emission reductions on a large scale. Promising options for reducing emissions include:

- **Transportation:** Ongoing efficiency gains for all vehicles, increasing reliance on low-emission electricity for passenger transportation, expanding use of biofuels in freight transportation, and long-term urban planning and investments in transportation infrastructure.
- **Buildings:** Ongoing efficiency gains in new buildings or in conjunction with building renovations, transitioning to electricity for space heating in highly energy-efficient buildings, and selective adoption of community heating systems that capture and use waste heat and/or rely on renewable energy sources.
- **Industry:** Ongoing efficiency gains in industrial processes, reduction of fugitive emissions, application of CCS in suitable industrial processes, and electrification and enhanced use of biomass in applicable industrial applications. However, given the higher cost of these technologies relative to conventional options, they are unlikely to be widely adopted unless stringent, compulsory policies are introduced. Further innovation and technological development is also essential for reducing the costs of low-emission energy technologies over time.

## Finding 2: Low-emission electricity is the foundation for low-emission energy systems.

Switching to low-emission electricity eliminates carbon dioxide emissions from power generation and allows for further emission reductions as the transportation, building,

and industry sectors gradually increase their use of electricity as an energy source. Many Canadians live in jurisdictions that already benefit from low-emission electricity; however, future emission reductions will require a transition in provinces that still depend on emission-intensive electricity sources such as coal, as well as expanding low- and non-emitting generation in all provinces to meet growing demand. This expansion will require careful planning to integrate higher shares of electricity generation from intermittent renewable sources (such as solar, wind, and run-of-river hydro) with additional energy storage capacity and other dispatchable energy sources (such as hydropower, nuclear, geothermal, biomass, and coal or natural gas with CCS). Investments in electricity transmission lines, interconnections, and grid modernization can Executive Summary xiii also enhance flexibility and enable greater reliance on low-emission generation technologies. The costs of low-emission electricity generation technologies, while still generally higher than those for fossil fuel-fired power plants, have been falling rapidly. Given the relatively low electricity prices in Canada in most jurisdictions, the increased cost of electricity from low-emission energy sources is not likely to pose a major burden for most consumers and businesses.

**Finding 3: A transition to a low-emission energy system is achievable with the right combination of stringent and flexible policies.**

There is no one right policy for reducing energy-related emissions. However, experience to date has shown that voluntary measures alone are insufficient, and policies that focus exclusively on further technological progress offer no guarantee of emission reductions. Stringent, compulsory, economy-wide emission reduction policies are therefore essential if Canada is to successfully undertake an energy system transition. Carbon taxes, cap-and-trade systems, and other regulations are all possible approaches. Regardless of the instrument, certain design features can improve performance of such policies across a range of criteria. These include linking policies to binding and increasingly stringent emission limitations, or to binding and increasingly high carbon prices; including appropriate monitoring and penalty provisions; providing extensive compliance flexibility; treating new and existing firms fairly; harmonizing policies across Canada and establishing international linkages; compensating groups that are adversely impacted by policies (at least on a transitional basis); and involving the public in decision-making. In addition to compulsory policy, enabling policies are very important for supporting emission reductions. These include direct government investment, adjustment of subsidies, enabling infrastructure, innovation support, and

making regulatory processes more efficient. Support for energy innovation can accelerate the adoption of low-emission technologies by making them more affordable. With flexible economy-wide policies in place, individuals, businesses, and other decision-makers can choose the technology and energy responses that are right for their context and adjust these choices over time to adapt to further scientific progress, technological developments, and emission reduction trends. xiv *Technology and Policy Options for a Low-Emission Energy System in Canada*.

## MOVING FORWARD

Addressing climate change will ultimately require globally coordinated action to protect a common resource — the Earth’s atmosphere — and society must be willing to pay now for benefits that accrue largely to future generations. However, climate change as a technological and policy problem may not be as complex as is often assumed. Both the consequences of climate change and its potential solutions have been extensively studied and are now well understood. While energy system transitions typically require many decades due to the long-lived nature of infrastructure and massive investments required, they can be accelerated with strategic policy support, and they are already under way in many jurisdictions across Canada. Due to the risk of getting locked in to new emission intensive capital and infrastructure, delaying mitigation increases the cost of meeting emission reduction goals over time. Ensuring that transitions are fully realized will require policies that are adaptive to changing economic, technological, and environmental conditions and persistent over time. With appropriately stringent and flexible policies in place, large emission reductions from Canada’s energy system are achievable over the course of several decades. This transition will not be without cost for consumers, businesses, or the economy as a whole. It can, however, be achieved without jeopardizing Canada’s long-term economic growth and competitiveness.





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