

30 YEARS OF THERMAL ENERGY STORAGE – A REVIEW OF THE IEA ECES STOCK CONFERENCES

B. Nordell

Luleå University of Technology, Luleå, Sweden, bon@ltu.se

S. Gehlin

Swedvac, Stockholm, Sweden, gehlin@emtf.se

ABSTRACT

The international "Stock" Conferences starting in 1981 have since been the major event for networking and sharing knowledge and experience on thermal energy storage (TES) technology. The first conference was initiated by the US Department of Energy (DOE) and the conferences in 1983 and 1985 by national agencies. However, since 1988 the conferences have been arranged within the framework of International Energy Agency (IEA) Implementing Agreement Energy Conservation through Energy Storage (ECES). The "Stock" Conferences have worked as a showcase and driving force of performed, ongoing, and planned TES R&D. Current review illustrates how the conference series reflects the development of TES technologies over the past 30 years, from a small group of researchers with focus on modeling and field tests on compressed air energy storage (CAES) and TES, till today's multicultural conferences covering latent, sensible and thermo-chemical TES.

1. BACKGROUND

The first international conference on seasonal Thermal Energy Storage (TES) and Compressed Air Energy Storage (CAES) was initiated by the US Department on Energy (DOE). The background was that DOE recognized TES as "crucial to our thrust for energy independence". It was also hoped that "a similar conference can be convened in the future to review Seasonal TES and CAES after additional significant advances have occurred in these technologies." This came true in what was later called the "Stock" Conferences.

The International Energy Agency (IEA) was not involved in these conferences before the 1988 conference in Versailles but since then the Stock conferences have been organised in collaboration with the IEA Energy Conservation through Energy Storage Implementing Agreement (IEA ECES IA). For a list of all Stock conference proceedings, see Appendix 1.

2. SEASONAL TES CONFERENCES

The two first conferences, in Seattle and Stockholm, did not include "Stock" in its name and the three first conferences were biannual. Since the Toronto conference, Enerstock 85, Stock has been part of the name and conferences have been held every third year.

Until 1985 most of the papers concerned theories, simulation models, laboratory tests, small scale pilot tests, and a few field tests. This meant a rather fast development and it was useful to meet every second year. The following years several large scale demonstration plants were started. Long construction time and several years of measurements were needed for evaluation. It was therefore decided to hold the conference every third year.

Not until the fifth conference, in Helsinki, the number of the conference was included in its name and this was kept ever since, until today when we are having our 11th Stock conference, see Table 1.

Table 1. Stock Conferences 1981-2009

1	1981	Seasonal Thermal Energy Storage and CAES	Seattle	USA
2	1983	Subsurface Heat Storage in Theory and Practice	Stockholm	Sweden
3	1985	ENERSTOCK	Toronto	Canada
4	1988	JIGASTOCK	Versailles	France
5	1991	THERMASTOCK	Scheveningen	The Netherlands
6	1994	CALORSTOCK	Espoo	Finland
7	1997	MEGASTOCK	Sapporo	Japan
8	2000	TERRASTOCK	Stuttgart	Germany
9	2003	FUTURESTOCK	Warsaw	Poland
10	2006	ECOSTOCK	Pomona, N.J.	USA
11	2009	EFFSTOCK	Stockholm	Sweden

Seattle, USA (1981)

The Seattle conference on “Seasonal Thermal Energy Storage and Compressed Air Energy Storage” was divided into two parts; Seasonal TES and Compressed Air Energy Storage (CAES). The main focus was on Seasonal TES. More than 200 participants, representing 16 countries, attended this three days conference. The pronounced aim of this first conference was providing an opportunity to:

- Meet with other professionals engaged in R&D activities in STES and CAES
- Obtain an overview of international activities in STES and CAES
- Review perspectives on current R&D in STES and CAES
- Discuss applications of STES and CAES technologies under a variety of geographical, economic and political structures.

Several STES projects, Aquifer Thermal Energy Storage (ATES), Borehole Thermal Energy Storage (BTES)¹ in clay and bedrock, and Cavern Thermal Energy Storage (CTES), were discussed. The focus was, however, on STES methodology, modelling, and economics. During the conference 83 papers and 9 posters were presented.

The conference was prepared for U.S. Department of Energy by Pacific Northwest Laboratory and Battelle Memorial Institute.

Stockholm, Sweden (1983)

The theme of the Stockholm conference “Subsurface Heat Storage in Theory and Practice” was “managing Energy through Energy Storage” and the emphasis was on heat storage, a key problem to be solved when introducing solar heating, the utilization of waste heat, and better efficiency in energy management. 274 participants from 19 countries attended the conference at which 103 papers were presented. These were arranged according to type of technology;

- ATES, BTES, CTES and Pits.
- Simulation models
- Technical and economic comparisons
- The role of heat storage in national energy systems.

¹ The abbreviation BTES was not used in 1981.

The conference was organised by the Swedish Council for Building Research in collaboration with U.S. Department of Energy, and National Research Council of Canada.

Toronto, Canada (1985)

The theme of “ENERSTOCK 85” in Toronto was “Energy Storage for Building Heating and Cooling”. It attracted 175 participants who presented 105 papers. The conference was divided into five parts;

- ATES covered by 30 papers
- BTES (22)
- Ice Systems (8)
- Water storage (17)
- System studies (27).

Most of the interest was at this time on ATES systems and system studies. BTES was still relatively small while hot water storage, often as part of solar systems, was a rather hot area. It should be noted that at this time PCM and Thermo-chemical storage were not part of the conference.

The conference was organised by Public Works Canada.

Versailles, France (1988)

The theme of the 4th storage conference “JIGASTOCK 88” was the same as for the previous “Energy Storage for Building Heating and Cooling”. It attracted 270 participants who all together presented 152 papers. The conference was divided into several sessions;

- National and regional aspect of geothermal energy and storage (11)
- Theoretical studies and modelling of heat storage (16)
- Heat storage in reservoirs and cavities, misc. storages
 - Reservoirs (3)
 - Cavities (6)
 - Latent heat storage (3)
 - Compressed air (2)
 - Oil and gas storage (3)
- ATES (13)
- Geothermal energy – theory and reality (18)
- Ground coupled heat pumps
 - ATES (11)
 - BTES (6)
 - Ground heat exchangers (2)
- Corrosion, clogging and environment (18)
- Economic evaluation and optimization of operation (14)
- Perspective, prognosis and technical development (16)

The main interest was on ATES with at least 42 papers including the problems of clogging and corrosion. An increasing interest in rock cavern storage systems was seen and compressed air energy storage was again discussed. BTES was still a relatively small subject.

The conference was organised by Agence Français pour la maîtrise de l’énergie.

Scheveningen, the Netherlands (1991)

The 5th conference on thermal energy storage “THERMASTOCK 91” was focussed on long term heat storage. During the conference, which was smaller than the previous conferences, 92 papers were presented to the 144 participants. This conference was divided into two main sections with respect to storage time:

- Long term heat storage;
 - applications and field experiments (29)
 - engineering tools (14)
 - recent results and new prospects (15)
- Short term storage
 - applications and field experiments (7)
 - system and component development (8)
 - engineering tools (7)
 - recent R&D results (9)
- Additional papers (3)

Most of the papers (36) dealt with applications and field experiments. 24 papers were on recent R&D results and new prospects, while 22 were on engineering tools. ATEs systems were dominating the presentations, though water storage tanks connected to solar systems also had a great share. Some BTES and CTES were included and short term cold storage systems were also discussed

Netherlands Agency for Energy and Environment, NOVEM, was hosting and organising the conference.

Espoo, Finland (1994)

The subtitle of the 6th thermal energy storage conference “CALORSTOCK 94” was “Thermal Energy Storage – Better Economy, Environment, and Technology”. 182 participants attended the conference and 106 papers were presented. The presentations were divided into the following sessions:

- Aquifer Storage (11)
- Integration into Energy Systems (11)
- Simulation Models and Design Tools (15)
- IEA Energy Conservation Through Energy Storage Workshop (5)
- Earth Coupled Storage (8)
- District Heating and Utilities (8)
- Chemical Storage (11)
- Heat Storage and Environment (9)
- Central Solar Heating Plants with Seasonal Storage (10)
- Water Storage Pits and Tanks (8)
- Cooling (6)
- National Activities (5)

Here, there was no really dominating field. Chemical storage, which was included for the first time in a Stock conference, ATEs and Integration all contained 11 papers. The biggest session was in Simulation models and design tools but this session included all different types of storage technologies.

The conference was organised by Helsinki University of Technology.

Sapporo, Japan (1997)

The purpose of Megastock'97 was pronounced not only to provide an opportunity for engineers, researchers and administrators to exchange the latest information on thermal energy storage, but also to contribute to the development of energy conservation and environmental policies by promoting thermal energy storage.

A total of 166 papers were received from 21 countries, and covered long-term to short-term storage, including ATES, BTES, water and ice storage, PCM and chemical storage. Not only storage technologies, but also environmental and economical aspects, as well as applications, were considered. As many as 450 attendants from 23 countries took part of the conference, which was held at Hokkaido University in Sapporo.

The organizing committee, chaired by Professor Kiyoshi Ochifuji of Hokkaido University, arranged the conference in cooperation with a number of local and international organizations, among them IEA ECES, ICTES, Federation of Electric Power Companies, The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE), the Hokkaido Government, City of Sapporo and the TOSTEM foundation.

Stuttgart, Germany (2000)

The Terrastock 2000 conference, held at the University of Stuttgart, intended to underline the central role of the earth (latin: *terra*) in our lives, not only as a natural resource and environment, but also as a great reservoir of ambient energy. The main theme of the conference indicated that the turn of the Millennium should be a turn of world-wide awareness of the value of energy and the ways of its sustainable use.

253 attendants from 20 countries came to take part of the 137 scientific papers, presented at Terrastock. The sessions were organized in themes including ATES, BTES, UTES, Ground thermal properties, seasonal storage, diurnal storage, PCM, thermo-chemical storage and cold storage, national overviews and international activities.

The conference was organized and hosted by the Institute of Thermodynamics and Heat Technology of the University of Stuttgart, and was supported by the German Federal Ministry of Economics and Technology. An industrial exhibition was held in conjunction with the conference.

Warsaw, Poland (2003)

Futurestock 2003 addressed present problems of energy conservation and storage, and the future of energy saving and conversion solutions. The conference gathered around 180 participants from 22 countries, and presented 108 scientific papers, 35 of them as posters. The sessions were divided into themes including ATES, UTES, Ground source heat pumps, PCM, Thermochemical storage, Latent and sensible TES, Theories & design tools, Systems & Applications, National overviews and International activities.

The conference was organized and hosted by Warsaw University of Technology – Institute of Heat Engineering, in cooperation with IEA ECES, Ministry of Scientific Research and Information Technology, and Polish Academy of Sciences – Committee of Thermodynamics and Combustion.

Stockton N.J., USA (2006)

Ecstock 2006 was organized and hosted by Richard Stockton College of New Jersey in cooperation with IEA ECES, and was supported by US Department of Energy, Energy Storage Program.

The main purpose was to encourage awareness and solutions for energy conservation through energy storage. The conference was arranged as two parallel sessions during three days, and gathered around 180 participants from 31 countries. The 98 scientific papers were organized in sessions with themes including General overviews, UTES, ATES & Thermal Response Test (TRT), TES systems, PCM/Thermochemical/Solar, Solar applications, Water and Ice storage, Modelling TES, Geothermal systems, Transportation and TES.

Stockholm, Sweden (2009)

The current conference - Effstock 2009 - Thermal Energy Storage for Energy Efficiency and Sustainability is held at Stockholm International Fairs, Sweden, under the patronage of H.M. King Carl XVI Gustaf. The official host organisation of Effstock 2009 is Swedvac, the Swedish Society of HVAC Engineers, celebrating its centenary in 2009. The main financial supporter is the Swedish Energy Agency.

170 scientific papers from 31 countries are presented, covering theories, models, case studies and field tests within latent, sensible and thermo-chemical TES. More than 350 participants are taking part of the conference, which also holds a business exhibition with 29 exhibitors.

Conference topics

The first three conferences, until 1985, were held every second year and since then every third year. The main reason was that the character of ongoing research changed from theoretical work and small scale testing to large scale demonstration plants. These required a long construction time and also some years of measurements before conclusions could be drawn about the performance of the plants. More detailed data is found in Appendix 2.

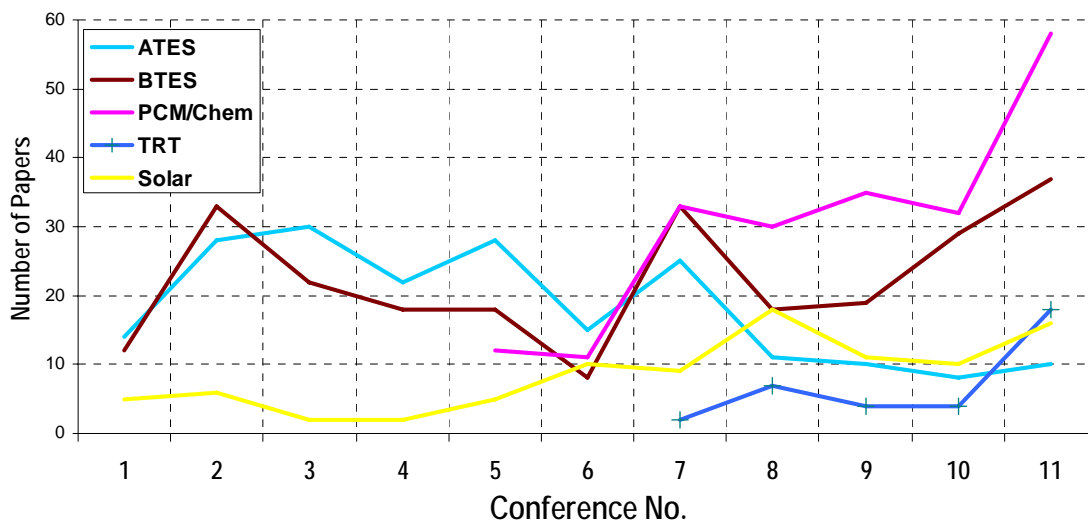


Figure 1. Some selected topics at the performed Stock Conferences 1981-2009.

ATES has always been part of the conferences though it was more important in the beginning. In 1985 there were 30 papers on ATES while the last four conferences included about 10 ATES related papers. The number of presented BTES papers has on the other hand been relative constant though it increased during the last three conferences.

At the beginning of thermal energy storage research the focus was mainly on heat storage. During the last 15 years, however, cold storage has been of greater interest. At the same time storage of solar heat, which during the five first conferences had about 5 papers, has increased to more than 10 during the five latest.

The most obvious change, during the last 30 years concerns TRT and PCM (including thermo-chemical storage). There was one PCM paper already in 1981, but then did not occur again until 1991. Since then PCM has been the major topic during the conferences. The increasing interest in TRT, which was introduced in 1997, resulted in special sessions at the conferences. PCM and TRT have 58 and 18 papers at the Effstock conference, respectively.

Another type of PCM is snow and ice, which was represented by ~10 papers in each of the last five conferences. Compressed Air Energy Storage (CAES) which represented almost half of the first conference has since not been shown much interest even though a few papers have appeared at later conferences.

Increasing interest in Stock Conferences

The number of countries has varied over the years but we can also see an increasing interest in recent years. The three first conferences attracted attendees from 16-19 countries, the following six conferences 19-26 countries, while the two latest conferences had 31 participating countries. The average number of participants is ~250 and the number of presented papers ~125, see Figure 2. More detailed data is found in Appendix 2.

The countries dominating the Stock conferences have varied over the years. Table 2 shows the three most dominating countries in number of participants during the last five conferences.

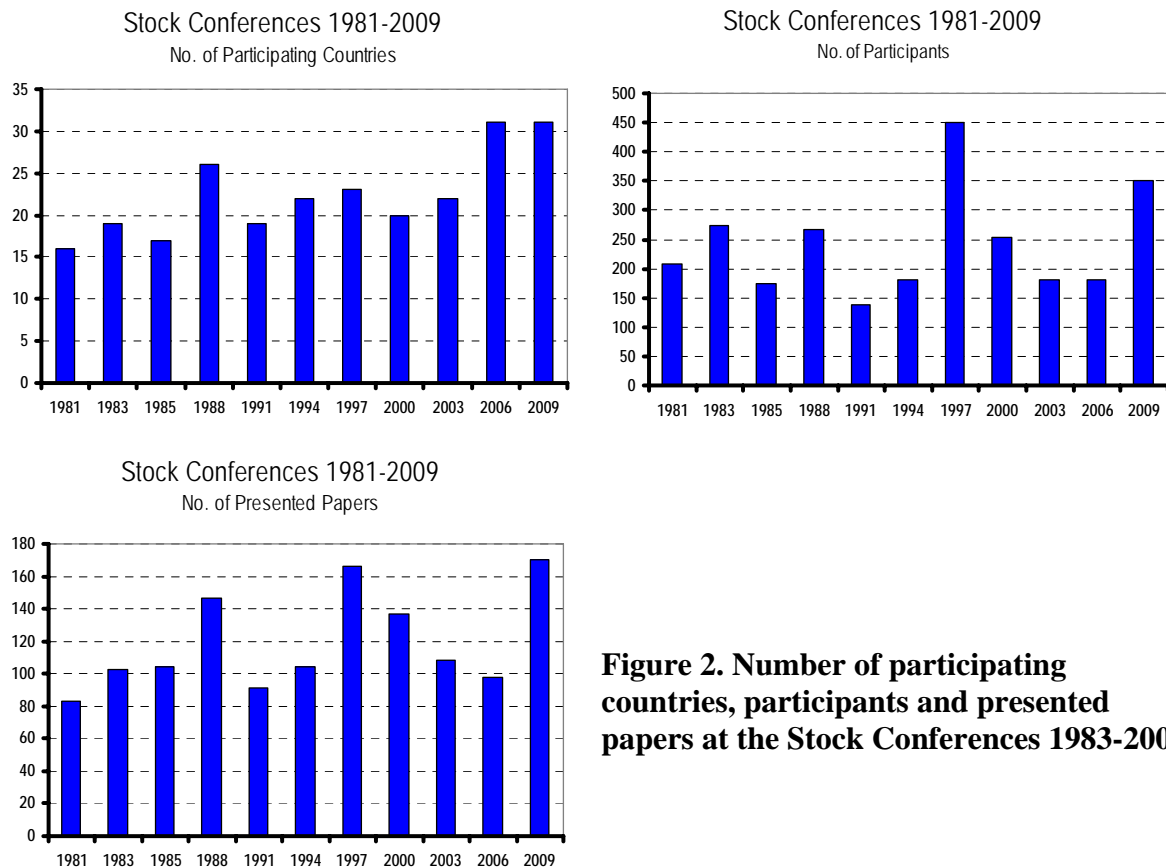


Figure 2. Number of participating countries, participants and presented papers at the Stock Conferences 1983-2009.

The host country always had a large number of participants. Japan, Germany and Sweden have contributed with most participants. Sweden sent big delegations during the early conferences; Japan has the strongest group during several conferences while Germany sent most participants during the last two years. Spain has the third largest group during current conference.

Table 2. Dominating Countries in Participants, 1997-2009

	Megastock	Terrastock	Futurestock	Ecostock	Effstock
1	Japan*	Japan	Japan	Germany	Germany
2	Sweden	Germany*	Poland*	Japan	Sweden*
3	Germany	Sweden	Germany	USA*	Spain

*/ host country

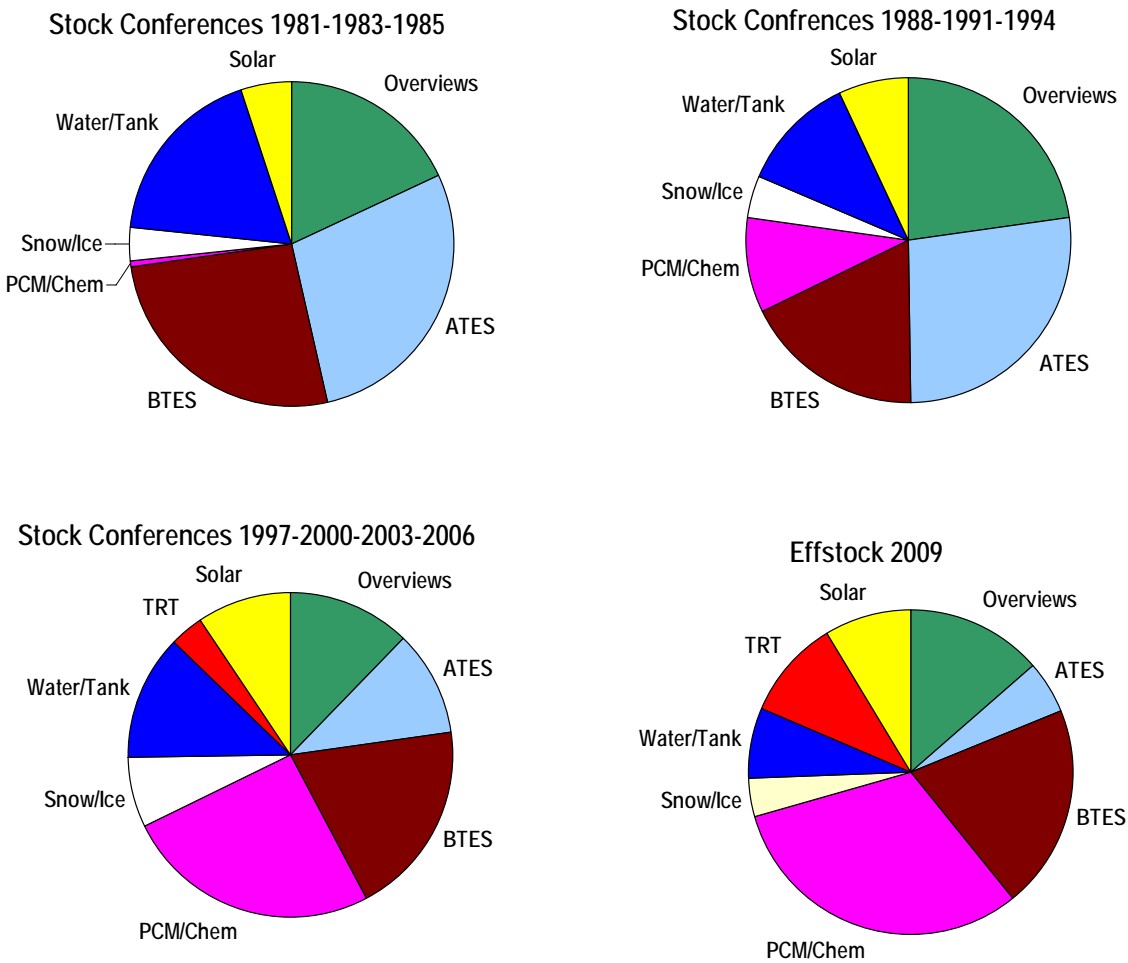


Figure 3. The paper topics at the Stock Conferences have varied over the years. Here, the topics are grouped for 1981-1983-1985; 1988-1991-1994; 1997-2000-2003-2006; and Effstock which is given its own circle.

3. THE FUTURE

There is a strong link between the IEA activities within the ECES IA and the Stock conferences. This is indicated by the fact that people engaged in such IEA activities also present their research at the Stock conferences. Completed ECES IA annexes have dealt with ATES, BTES, PCM, Thermo-chemical storage for both heat and cold storage applications. It is therefore most likely that planned or just started ECES activities reflect what we should expect as the main focus at future Stock conferences.

Development on special applications should therefore be expected e.g. TES applications in greenhouses, optimised industrial process heat and power generation with TES, and transportation of thermal Energy by TES Technology. We can also foresee that the already established technologies will be improved and spread by best practise TRT guidelines and Material Development to improve TES systems.

TES will play a major role in the world wide efforts to reduce energy consumption, in order to reduce cost and counteract the global warming. Fossil fuels will be increasingly replaced by renewable energies. The large-scale utilization of renewable energy requires energy storage.

IEA ECES IA and the Stock conferences have during the last 30 years been a natural meeting place for people engaged in thermal energy storage research. We foresee that TES and the performed research discussed and presented at the Stock conferences, will become increasingly important in the future.

LIST OF ABBREVIATIONS

ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
CAES	Compressed Air Energy Storage
CTES	(Rock) Cavern Thermal Energy Storage
PCM	Phase Change Materials
STES	Seasonal Thermal Energy Storage
TRT	Thermal Response Test
UTES	Underground Thermal Energy Storage

PROCEEDINGS OF STOCK CONFERENCES 1981-2006

1. Proceedings International Conference on Seasonal Thermal Energy Storage and Compressed Air Energy Storage. Seattle, USA. CONF-811066 Pacific Northwest Laboratory. Seattle, USA, October 19-21, 1981.
2. Proceedings International Conference on Subsurface Heat Storage in Theory and Practice, Swedish Council for Building Research. D18:1983. Stockholm, Sweden, 6-8 June 1983.
3. Proceedings ENERSTOCK 85, International Conference on Energy Storage for Building Heating and Cooling. Toronto, Canada, 22-26 September 1985.
4. Proceedings JIGASTOCK 88 International Conference on Energy Storage for Building Heating and Cooling. October 18-21, 1988. Versailles, France. A.F.M.E.
5. Proceedings THERMASTOCK 91. 5th International Conference on Thermal Energy Storage. Scheveningen, May 13-16, 1991. The Netherlands.
6. Proceedings CALORSTOCK 94. 6th International Conference on Thermal Energy Storage. Better Economy, Environment, Technology. August 22-25, 1994, Espoo, Finland.
7. Proceedings Megastock'97. (1997). 7th International Conference on Thermal Energy Storage, June 18-21, 1997. Hokkaido University, Sapporo, Japan.
8. Proceedings TERRASTOCK 2000. (2000). 8th International Conference on Thermal Energy Storage, August 28-September 1st, 2000. Campus Universität Stuttgart, Stuttgart, Germany.
9. Proceedings FUTURESTOCK 2003. (2003). 9th International Conference on Thermal Energy Storage, September 1-4, 2003. Warsaw University of Technology. Warsaw, Poland.
10. Proceedings ECOSTOCK 2006. (2006). 10th International Conference on Thermal Energy Storage, May 31-June 2, 2006, The Richard Stockton College of New Jersey, Pomona, USA.
11. Proceedings EFFSTOCK 2009. (2009). 11th International Conference on Thermal Energy Storage for Energy Efficiency and Sustainability, June 14-17, 2009, Stockholm International Fairs. Stockholm, Sweden.

Stock Conference Statistics. This data is compiled from conference proceedings.

CONFERENCE	YEAR	LOCATION	NO PARTICIPANTS	NO COUNTRIES	NO PAPERS
Seasonal Thermal Energy Storage and CAES	1981	Seattle, USA	209	16	83
Subsurface Heat Storage - in Theory and Practice	1983	Stockholm, Sweden	274	19	103
Enerstock	1985	Toronto, Canada	175	17	104
Jigastock	1988	Versailles, France	266	26	147
Thermalstock	1991	Scheveningen, Netherlands	139	19	91
Calorstock	1994	Espoo, Finland	182	22	104
Megastock	1997	Sapporo, Japan	450	23	166
Terrastock	2000	Stuttgart, Germany	253	20	137
Futurestock	2003	Warsaw, Poland	180	22	108
Ecostock	2006	Pomona, New Jersey, USA	180	31	98
Effstock	2009	Stockholm, Sweden	350	31	170

Stock Conference Statistics. This data is compiled from conference proceedings.

Conf	Seattle	Stockholm	Enerstock	Jigastock	Thermastock	Calorstock	Megastock	Terrastock	Futurestock	Ecostock	Effstock
Chair	J.R. Raymond	Arne Boysen	Edward Morofsky	Jacques Despois	Gijs van Mourik	M.T. Kangas	Kyoshi Ochifuji	EWP Hahne	Roman Domanski	Lynn Stiles	Bo Nordell
Overviews	10	9	27	11	14	30	24	14	17	8	25
ATES	14	28	30	22	28	15	25	11	10	8	10
BTES	12	33	22	18	18	8	33	18	19	29	37
PCM/Chem	1				12	11	33	30	35	32	58
Snow/Ice		1	8	3	5	2	14	10	5	7	7
Water/Tank	8	21	17	6	13	9	31	19	9	5	13
TRT							2	7	4	4	18
(Solar)	5	6	2	2	5	10	9	18	11	10	16