NREL
NATIONAL RENEWABLE ENERGY LABORATORY

2011 Photovoltaic Module Reliability Workshop

Degradation modeling
PV materials and components
Evolution of PV standards
Systems performance

Crystalline Silicon

- Failure modes
- Cell cracking
- Arc faults & hot spots
- System voltage degradation

Thin Film

- Flexible barrier packaging
- Edge seals
- Metastabilities

Concentrating

- Lens materials
- Degradation modes
- Ratings

February 16–17, 2011, at the Denver Marriott West
Golden, Colorado, USA
www.nrel.gov/pv/pvmrw.html

2011 PV Module Reliability Workshop

Web: http://www.nrel.gov/pv/pvmrw.html
Information: pvmrw@nrel.gov

I would like to welcome you to the 2011 PV Module Reliability Workshop (PVMRW) in Golden, Colorado, February 16–17, at the Denver Marriott West. Similar to the 2010 PVMRW, the objective of this 2011 workshop is for participants to share information leading to the improvement of PV module reliability. Such improvement reduces the cost of solar electricity and promotes investor confidence in the technology—both critical goals for moving PV technologies deeper into the electricity marketplace.

We are seeking active participation with at least one contribution from each attending organization, typically in poster format. There is no registration fee; however, an abstract from the first participant from each organization is required at the time of registration. **The registration deadline is January 18, 2011.**

The content of this year's oral sessions was chosen based on feedback from you, the PV module community. Themes include how to ensure long-term PV module performance by testing and monitoring, and choosing the best materials, constructions, and testing methods for evolving module paradigms. Module durability topics are also addressed in the Crystalline Silicon, Thin Film, and Concentrating PV Parallel Sessions.

Considering that author-contributed presentations (oral and poster) will be placed on the DOE Solar Technologies Web site to serve as a proceeding of the conference, there is a **No Photography Policy.** We will have two poster sessions, with all posters displayed during the two days of the workshop. Poster presenters should mount their posters on the morning of February 16 and remove them after the closing session on February 17. Before the start of their session, oral presenters should provide their presentations to the session chair with a USB flash drive. Poster presenters should do so during the poster sessions for inclusion in the proceedings.

Finally, I want to thank everyone on the organizing committee who made this workshop a reality. I wish you safe travels to and from the workshop.

See you soon,
Peter Hacke, 2011 PVMRW Chair

Schedule at a Glance

Wednesday February 16

7:00 AM	Registration opens; Continental breakfast, provided
8:00 AM	Plenary Sessions
12:15 PM	Lunch, provided
1:30 PM	Plenary Sessions
4:50 PM	Plenary Discussions
5:30 PM	Poster Session I (until 7:00 PM)

Thursday February 17

7:00 AM	Continental breakfast, provided
8:00 AM	Parallel Sessions and Discussions
10:30 AM	Poster Session II
12:00 PM	Lunch, provided
1:15 PM	Parallel Sessions and Discussions
3:15 PM	Closing Session (until 3:30 PM)

Lodging Information

Conference Hotel: Denver Marriott West, 1717 Denver West Boulevard, Golden, CO 80401. The hotel is adjacent to the National Renewable Energy Laboratory's research campus. For reservations, map, directions, and information, see: http://www.marriott.com/hotels/travel/denwe-denver-marriott-west. The **Hotel Reservation Deadline** is Tuesday, January 25, 2011. After that date, we cannot guarantee the rate or availability. To make reservations, call the Denver Marriott West directly at 1-303-279-9100 or Marriott Central Reservations at 1-888-238-1803. Request the discounted group rate for "NREL PV Reliability."

NATIONAL RENEWABLE ENERGY LABORATORY

2011 Photovoltaic Module Reliability Workshop (PVMRW)

Preliminary Agenda

February 16–17, 2011, at the Denver Marriott West

DAY 1: WEDNESDAY, FEBURARY 16, 2011

(All talks on Wednesday are plenary presentations)

7:00 AM	***..... Continental Breakfast Provided .....***	
SESSION A: DIAGNOSTICS OF FAILED AND DEGRADED MODULES ***Chairs: Sarah Kurtz and Jim Sites***		
8:00	**NREL/DOE**	**Opening Remarks**
8:15	**David DeGraaff**, *SunPower Corporation*	**Degradation Mechanisms in Si Module Technologies Observed in the Field, Their Analysis, and Statistics**
8:45	**Geoffrey Kinsey**, *Amonix, Inc.*	**Building for 25-Year Durability in CPV Power Plants**
9:15	**Markus Beck**, *First Solar, Inc.*	**Lessons Learned from Thin-Film Module Reliability Testing**
9:45	***..... Break (30 min).....***	
SESSION B: METHODOLOGIES FOR PERFORMANCE, RELIABILITY, AND DURABILITY DETERMINATION: BABY STEPS TOWARD DETERMINATION OF 25-YEAR WARRANTY **Chairs:** ***Kenneth Sauer and Michael Quintana***		
10:15	**Harry Guo**, *ReliaSoft Corporation*	**How to Set Up a Reliability Program for Photovoltaic Modules**
10:45	**Michael Köhl**, *Fraunhofer ISE*	**Estimation of the Location-Dependent Weathering Stresses on Modules**
11:15	**Keith Emery**, *NREL*	**Instrumentation and Methodologies for Outdoor Performance Testing**
11:45	**Dirk Jordan**, *NREL*	**Methods for Analysis of Outdoor Performance Data**
12:15	***..... Lunch (Provided).....***	

DAY 1: WEDNESDAY, FEBURARY 16, 2011 (continued)		
SESSION C: UPSTREAM MATERIALS, MODULE COMPONENTS, AND STANDARDS ***Chairs: Kaitlyn VanSant and David Miller***		
1:30 PM	**A. William Lingnell**, *Insulating Glass Manufacturing Alliance*	**Insulating Glass—25-Year Field Correlation Study**
2:00	**James Webb,** *Corning Incorporated*	**Physical Properties of Glass and the Requirements for Photovoltaic Modules**
2:20	**Govindasamy Tamizhmani,** *TÜV Rheinland PTL, LLC*	**Reliability and Durability Evaluation of PV Cable Connectors**
2:40	**France Antelme**, *Enphase Energy*	**Durability Testing Requirements for PV-Integrated Microinverters**
3:00	**John Wohlgemuth,** *NREL*	**How Standards Control the Module Design for Better or Worse**
3:20	**Christopher Flueckiger,** *Underwriters Laboratories, Inc.*	**Photovoltaic and Balance of System Safety and Performance**
3:40	***….. Break (20 min) …..***	
SESSION D: CUSTOMER EXPERIENCES WITH MODULES AND BALANCE OF SYSTEMS ***Chairs: Jennifer Granata and Neelkanth Dhere***		
4:00	**Hugh Kuhn,** *Solar Power Partners, Inc.*	**An Owner's View: The Role of PV Reliability in Financing, Operations, and Performance—Holding Your Breath for 20 Years**
4:25	**Bradley Hibberd,** *Borrego Solar Systems, Inc.*	**PV Reliability and Performance—A Project Developer's Experience**
4:50–5:20	**DISCUSSION** ***Chairs: Peter Hacke and Kurt Scott, Panelists***	
5:30–7:00 PM	**POSTER SESSION I**	

DAY 2: THURSDAY, FEBRUARY 17, 2011

(All talks on Thursday are given in technology-specific parallel sessions)

7:00 AM	***..... Continental Breakfast .....***

1. CPV SESSION *Chairs: Sarah Kurtz and Steven Seel*	
8:00 AM	**What Not To Do** **Peter Hebert,** *Spectrolab*
8:20	**Modeling Thermal Fatigue in CPV Cell Assemblies** **Nick Bosco,** *NREL*
8:40	***DISCUSSIONS*** **Quantitative predictions about failure mechanisms, targets for making quantitative predictions**
Chairs: Peter Hebert and Nick Bosco	
9:00	**LCPV Reliability and Durability Issues** **Roger French,** *Case Western Reserve University*
9:20	**Reliability Testing of High-Concentration PV Modules and Soiling Issues** **Michael Winter,** *Emcore Solar Power, Inc.*
9:40	***DISCUSSIONS*** **Reliability issues facing CPV**
10:00	**CPV Qualification Standards for Cell Assemblies** **Ian Aeby,** *Emcore Solar Power, Inc.*
10:10	***DISCUSSIONS*** **Will the proposed standards meet the needs?**

2. CRYSTALLINE SILICON *Chairs: Dan Doble and Dave Degraaff*	
8:00	**Origin and Consequences of Micro-Cracks in Crystalline Silicon Solar Modules** **Marc Köntges,** *ISFH*
8:25	**Systematic Investigation of Crack Development and Crack Growth in Embedded Crystalline Solar Cells under Thermal and Mechanical Loads** **Sascha Dietrich,** *Fraunhofer CSP*
8:55	***DISCUSSIONS*** **Cracks and their effect on durability of PV modules**
Chairs: G. Mani and Michael Köhl	
9:15	**Potential Induced Degradation of Cells and Panels** **Bill Richardson,** *SOLON SE, LLC*
9:40	**Overview of Reliability Testing of PV Modules Using High-Voltage Bias Monitoring** **Neelkanth G. Dhere,** *University of Central Florida/FSEC*
10:05	***DISCUSSIONS*** **System bias influence on degradation rate in the lab and in fielded modules—next steps**

3. THIN FILM *Chairs: Ryan Gaston and Samuel Graham*	
8:00	**Goals and Strategies for Moisture-Hardening the CIGS Device** **Ingrid Repins,** *NREL*
8:20	**Life Prediction for CIGS Solar Modules** **Dennis Coyle,** *GE Global Research*
8:45	**Systems Approach to High-Performance CIGS Materials Set Including Flex Ultra-Moisture Barrier and Hi-Temp MLI Substrate** **Ken Leffew,** *E.I. du Pont de Nemours and Co.*
9:10	**Durability of Ultra Barrier Solar Films for Flexible PV Applications** **Mark A. Roehrig,** *3M Company*
9:35	**Calcium-Based Test Method For Evaluation of Photovoltaic Edge-Seal Materials** **Mike Kempe,** *National Renewable Energy Laboratory*
10:00	***DISCUSSIONS*** **Future of packaging for moisture-sensitive thin-film active layers**

10:30	**POSTER SESSION II**
12:00 –1:15	***..... Lunch (Provided)....***

DAY 2: THURSDAY, FEBURARY 17, 2011 (continued)					
1. CPV SESSION ***Chairs: Ian Aeby and Geoff Kinsey***		**2. CRYSTALLINE SILICON** ***Chairs: John Wohlgemuth and Yoshihito Eguchi***		**3. THIN FILM** ***Chairs: Markus Beck and Ingrid Repins***	
1:15 PM	**Minimizing Variation In Outdoor CPV Power Ratings** **Matthew Muller,** *NREL*	**1:15**	**Failure Modes and Degradation Rates from Field-Aged Crystalline Silicon Modules** **Tony Sample**, *EC DG-JRC-Ispra*	**1:15**	**Reliability Challenges for Flexible Thin-Film BIPV Modules** **Samir Sharma**, *UNI-SOLAR*
1:35	**Proposed Standards for Power and Energy Rating** **Sarah Kurtz,** *NREL*				
1:45	***DISCUSSIONS*** **Standards: 900 W/m² irradiance; adjustment for variable spectrum, temperature**	**1:45**	**Analysis of Hot Spots in Crystalline Silicon Modules and Their Impact on Roof Structures** **Daniel Cunningham,** *BP Solar*	**1:45**	**Intrinsic Chemical Instability and Metastability in Photovoltaic Devices** **Angus Rockett,** *University of Illinois*
2:15	**Acrylic Materials in PV Applications—Making an Informed Choice** **Peter Colburn**, *Evonik Cyro, LLC*	**2:15**	**Solar Module Arc Fault Modeling and Analysis** **Jason Strauch,** *Sandia National Laboratories*	**2:15**	**Alternate Methods to Obtain Stabilized Power Performance of CdTe and CIGS PV Modules** **Joe del Cueto,** *NREL*
2:45	***DISCUSSIONS*** **Applications for silicon on glass and acrylics**	**2:45**	***DISCUSSIONS*** **Pressing module safety issues and path forward**	**2:45**	***DISCUSSIONS*** **Status of understanding of metastabilities, most pressing concerns, and future research goals**
3:15–3:30	**Summaries, Best Poster Awards, Wrap-Up**				

POSTER PRESENTATION SESSION I – WEDNESDAY FEBRUARY 16, 2011 5:30 PM – 7:00 PM				
Poster Number	**Name**	**Organization**	**Presentation Title**	**Area**
1	Dr. Nicoleta Sorloaica-Hickman	University of Central Florida	Quantifying Degradation Rates and Mechanisms of PV Modules and Systems Installed in Florida Through Comprehensive Experimental and Theoretical Analysis	general
3	Dr. Chris Gotwalt	SAS Institute	Estimating the Degradation Rate of Photovoltaic Arrays Using a Two Component Nonlinear Model	general
5	Dr. Min Xiao	Plextronics	Plextronics OPV Outdoor Testing	general
7	Dr. Khalid Radouane	EDF EN	Photovotaic Modules: EDF EN Quality Control	general
9	Dr. David Miller	NREL	The Durability of Polymeric Encapsulation Materials for Concentrating Photovoltaic Systems	CPV
11	Mr. Steve Scott	Reflexite	Materials for HCPV Optic	CPV
13	Mr. Sandheep Surendran	Surya Design	CPV Module Acceptance Angle Characterization	CPV
15	Prof. Roger French	Case Western Reserve University	Performance of a Low-Cost, Low-Concentration, Photovoltaic System	CPV
17	Mr. Kurt Scott	Atlas Materials Testing Technology LLC	Durability Testing of OPV	TF
19	Ms. Annegret Reithe	Solarion AG	From Rigid to Flexible: The Real Challenge of CIGS Module R&D	TF
21	Mr. Stefan Jarnason	CSG Solar	Combined Cycle Testing	TF
23	Dr. Osamu Akaike	Mitsubishi Plastics Inc	High Moisture Barrier Flexible Front Sheet for CIGS	TF
25	Dr. Lawrence Dunn	Atonometrics	Literature Review of Light Soaking Effects on PV Modules	TF
27	Prof. James Sites	Colorado State University	Electroluminescence to Track Cell and Module Changes	TF
29	Mr. Jason Hevelone	Abound Solar	Stress Testing and Failure Analysis Methods for Determining the Reliability of Metal Buss Tapes	TF
31	Dr. Sang Hyun Park	Korean Institute of Energy Research	Temperature Study on a-Si:H Solar Cell Degradation with Different Loading Conditions	TF
33	Ms. Elsa Kam-Lum	Total, S.A.	Energy Production Comparison of Four Representative Solar Cell Technologies: c-Si, a-Si, CIGS and OPV	TF
35	Ms. Ondine Suavet	Nanosolar, Inc.	Design for Reliability: Keeping the Water out During 25 Years	TF
37	Mr. Julien Dupuis	Apollon Solar	IEC Certification and Extended Ageing Test of NICE Modules	c-Si
39	Dr. DongJi Xie	Flextronics	Solar Cell Cracking Analysis in Photovoltaic Module Assembly	c-Si
41	Dr. Matthias Ebert	Fraunhofer Center for Silicon Photovoltaics CSP	Mechanical Issues on Solar Modules and Encapsulated Components	c-Si
43	Dr. Nicolas Bogdanski	TÜV Rheinland	Outdoor Weathering of c-Si PV Modules in Various Climates	c-Si
45	Dr. Nicolas Bogdanski	TÜV Rheinland	Transport Simulation of PV Modules	c-Si
47	Mr. Joseph McCabe	ASES	Reliability Factors for Salvage Value of Photovoltaics	c-Si
49	Prof. Glenn Alers	Univ. California - Santa Cruz	Automated Extraction of Cell Parameters in a Fully Packaged Solar Module	c-Si
51	Dr. Børge Bjørneklett	REC Solar	Junction Box Qualification at REC Solar	c-Si
53	Mr. Tony Tang	Suntech Power Co., Ltd.	Study on Anti-reflection Coated Glass for Photovoltaic Modules	c-Si
55	Mr. Howard Barikmo	Sunset Technology, Inc.	PV Standards. What Does the IEC Have for You?	c-Si
57	Ms. Anna Keeley	Dow Corning Corporation	Silicone Module Encapsulation - Real Life Efficiency Gains	c-Si
59	Mr. Paul Parker	SolarBridge Technologies	PV-Integrated Microinverters in High-Reliability Rooftop Applications	c-Si
61	Mr. Masashi Nakamura	Mitsubishi Electric Corp	Improvement of Reliability Using Four Bus Bar Cell	c-Si
63	Dr. Rafal Mickiewicz	Fraunhofer CSE	Characterization of the Mechanical Behavior and Material Properties of PV Modules	c-Si
65	Dr. Annelene Dethlefsen	SCHOTT Solar AG	Multi-Crystalline Silicon Solar Cell Modules: Crack Formation and Development Due to Climate Chamber Thermal Cycle Testing	c-Si
67	Dr. Takuya Doi	National Institute of Advanced Industrial Science and Technology	New Acceleration Test for PV Modules Such as Burns or Interconnector Failures	c-Si
69	Mr. Chris Stapelmann	SolarWorld Industries America	Prediction of Critical Hot Spots in Modules Caused by Shunts in Silicon Solar Cells Using In-line Thermography	c-Si
71	Mr. Yi-Hung Chou	Delsolar Co,.Ltd	Accelerated Test Method and Statistics Model Analysis of Degradation Performance for PV Module Lifetime Prediction	c-Si
73	Ms. Alelie Funcell	Renewable Energy Test Center, RETC LLC	c-Si PV Thresher Test	c-Si

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POSTER PRESENTATION SESSION II – THURSDAY FEBRUARY 17, 2011 10:30 AM – 12:00 Noon				
Poster Number	**Name**	**Organization**	**Presentation Title**	**Area**
2	Mr. John Fulton	Skyline Solar	Why Leveraging Industry Standard Components Is Not as Simple as It Sounds	general
4	Dr. Peter Hacke	NREL	Requirements for a Standard Test to Rate the Durability of PV Modules at System Bias	general
6	Mr. Liang Ji	Underwriters Laboratories Inc	Development of UL1699B Standard on PV DC AFCI	general
8	Dr. Jinsuk Lee	NREL	Statistical Modeling of Photovoltaic Reliability Using Accelerated Degradation Techniques	general
10	Dr. Xiaohong Gu	NIST	Linking Accelerated Laboratory and Outdoor Exposure Results for PV Polymeric Materials	general
12	Mr. Jay Johnson	Sandia National Laboratories	Module Degradation Arcing Frequency Measured by a Remotely Located Detector	general
14	Ms. Cassi Sweet	NREL	Correlations in Characteristic Data of Concentrator Photovoltaics	CPV
16	Mr. Pete Marks	Evonik Cyro	Acrylics for CPV	CPV
18	Dr. Gatien Fleury	CEA-LITEN	On the Development of Accelerated Aging Tests Based on Thermal Stress Impact to Assess the Reliability of 1000 Suns CPV Modules	CPV
20	Mr. Kevin Fine	Banyan Energy	Impact of DNI and Diffuse Radiation Uncertainty on CPV System Performance Modeling	CPV
22	Mr. Paul Lamarche	Solar Junction	Five Stages of a Solar Cell	CPV
24	Mr. Deepak Shivaprasad	Novasolar Technologies Inc	Product Reliability Challenges Due to Packaging in A-Si Thin Film Modules	TF
26	Mr. Antonio Bonucci	SAES Getters S.p.A.	Edge Sealing Getter Tape for Ultra-Long Lifetime of Thin Film CIGS PV Modules up to 3000 Hours	TF
28	Mr. Cole Rickers	Ascent Solar Technologies	Highly Accelerated Weathering of CIGS Photovoltaics	TF
30	Dr. Duncan Harwood	D2Solar	Performance and Reliability Characterization of Conductive Inks for Solar Cell Front Grids and Busbars	TF
32	Mr. Raymund Schäffler	Würth Solar GmbH & Co KG	Accelerated Ageing and Reliability of CIGS Thin Film Solar Cells	TF
34	Mr. Jim Baratuci	Truseal Technologies, Inc.	Effects of Desiccant and Seal Dimensions on Moisture Penetration in TFPV	TF
36	Mr. Timothy O'Neil	ADCO Products, Inc	Solar Attachment Adhesives for BAPV with Superior Bond Strength	TF
38	Dr. Deepak Nayak	Solopower	Effect of Long-term Light Soaking on Shunts and Pmax in CIGS Solar Cells and Modules	TF
40	Prof. Samuel Graham	Georgia Institute of Technology	Strategies for Developing Barrier Films for Photovoltaics	TF
42	Dr. Matthew Lloyd	NREL	Understanding Degradation Pathways in Organic Photovoltaics	TF
44	Dr. Genmao Chen	Canadian Solar Inc.	Progress on e-Module Research and Production	c-Si
46	Dr. Tsuyoshi Shioda	Mitsui Chemicals, Inc.	Volume Resistivity of EVA Encapsulant Sheet	c-Si
48	Mr. James Bratcher	Honeywell Specialty Materials	Materials Considerations for c-Si Modules	c-Si
50	Mr. Kusato Hirota	Toray Industries, Inc.	Durability Test of Poly-Ethylene-Terephthalate (PET) Film for Backsheet	c-Si
52	Dr. Yuzuru Ueda	Tokyo Institute of Technology	Comparison Between Outdoor Performances and Manufacturers' Flash Test Results of Crystalline Si PV Modules	c-Si
54	Ms. Bethanne Felder	Applied Materials	Qualification and Lifetime Testing for Back Contact Modules	c-Si
56	Dr. Shuying Yang	Solaria	Characterization and Aging Study of Encapsulant (EVA) and Backsheet for PV Modules	c-Si
58	Mr. Yoshihito Eguchi	Sharp Corporation	Evaluation and Analysis of 15 Years Exposure PV Module	c-Si
60	Dr. Mike Van Iseghem	EDF R&D	Damp Heat Testing Longer than IEC Standards	c-Si
62	Dr. Bill Brennan	Dupont-Teijin Films Ltd	Developments In Weatherable Polyester Films	c-Si
64	Mr. Steve Seel	Semprius	Silicone Yellowing Due to Material Interaction in a CPV Application	c-Si
66	Mr. Vivek Gade	Jabil	Photovoltaic Module Certification, Reliability Testing and Failure Analysis at Jabil	c-Si
68	Mr. Herbert Schueneman	Westpak, Inc.	Solar Module Logistics Current Packaging Methodologies	c-Si
70	Mr. Michele Vannini	Coveme s.p.a.	Advanced Fluoropolymer-free, Polyester-based Backsheet Materials	c-Si
72	Mr. Kenneth Sauer	Yingli Green Energy	Sensitivity of PV System Degradation Rates to Data Filtration	c-Si
74	Dr. Bengt Jaeckel	Q-Cells SE	Fast and Reproducible Test Method to Investigate Hot-spot Sensitivity of c-Si Solar Cells	c-Si
75	Mr. Robert Pleydon	Saint-Gobain Performance Plastics	Durability and Reliability of ETFE Frontsheet	c-Si

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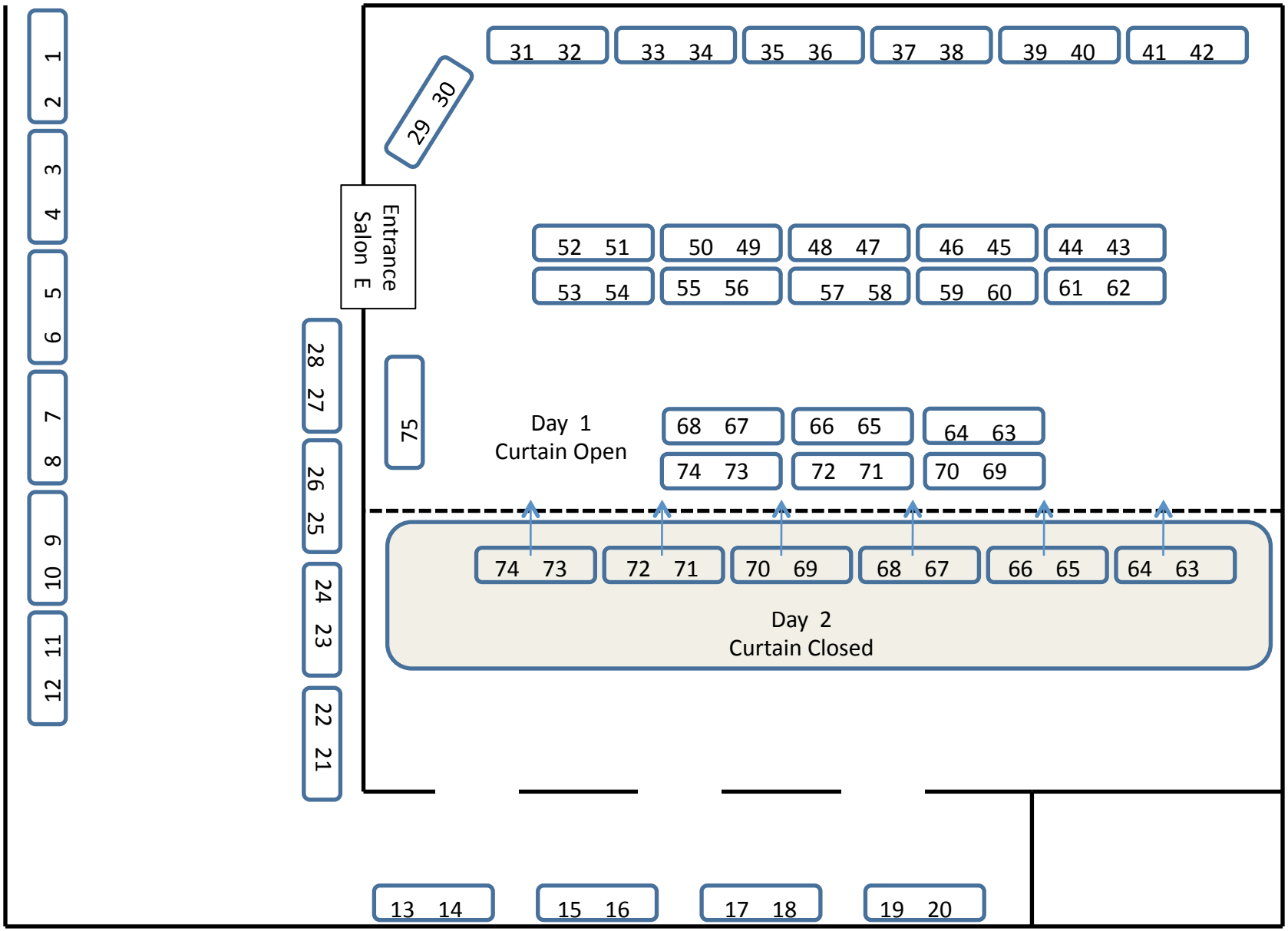
Poster Map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Day 2
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