

Integrating Data Mining into Technology Roadmapping

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Abstract

This paper demonstrates the use of bibliometrics, patent analysis and social network analysis in identifying technical experts and leading organizations for technology roadmapping projects, thus addressing the challenge of identifying the right experts for varying roadmapping workshops as well as the technologies existing or under development.

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Objective

- Technology Roadmapping is a very effective methodology to work with experts to develop R&D action plans to address strategic goals
- However it is critical to identify the right experts. The types of experts needed for different workshops held to develop the roadmap are different.
- Similarly it is critical to identify existing technologies and development work to avoid any reinvention
- This paper presents the use of bibliometrics, patent analysis and social network analysis in identifying technical experts, leading organizations for different roadmapping workshops as well as technologies critical to the topic under investigation
- The approach is applied in the energy efficient lighting area in collaboration with Bonneville Power Administration

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Roadmap

“A roadmap is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of the change”

Robert Galvin

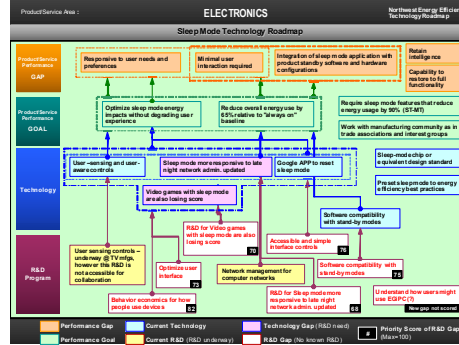
Former Motorola chairman and advocate of science and technology roadmaps



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What is Technology Roadmapping?

- Futuristic strategic planning method detailing the goals, barriers and strategies required to achieve set mission (Winebrake, 2003)
- Planning tool to support the development and implementation of a strategy (Phaal et al., 2004; Daim and Oliver, 2008)
- Approaches can change depending on the roadmap objective (Phaal et al., 2004; Amer and Daim, 2010; Fenwick et al., 2009)



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Social Network Analysis

- Social Network Analysis (SNA) is the mapping and measuring of relationships and flows between entities, such as people, groups, organizations, computers, etc., (McCulloh et al, 2013; Ozcan and Islam, 2014; Senghore et al., 2014)
- Centrality
 - Degree – Number of direct connections in a network for actor i .
 - Betweenness – Number of shortest paths between two actors that actor i resides on,

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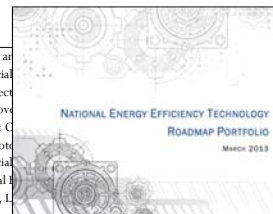
Methodology

- Case Study
 - Lighting Roadmap from National Energy Efficiency Roadmap
- Identification of Experts and Organizations
 - Use of Bibliometrics, Patent Analysis and Social Network Analysis
- Identification of Technological Trends
 - Use of Bibliometrics, Patent Analysis and Social Network Analysis

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Case Study: Lighting Roadmap

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| <p>I. Building Design/Envelope Roadmaps</p> <ul style="list-style-type: none"> 1.1 Deep Retrofits for Residential and Commercial 1.2 Retrofit and New Construction Labeling 1.3 Solar/Smart Roofing 1.4 Retrofit Insulation 1.5 New Construction Insulation 1.6 Retrofit and New Construction Air / Water Management 1.7 Zero Net Energy Buildings 1.8 Manufactured Housing / Modular / Pre Manufactured Systems / Offices 1.9 Fenestration & Daylighting <p>II. Lighting Roadmaps</p> <ul style="list-style-type: none"> II.1 General Lighting II.2 Solid State Lighting II.3 Task/Ambient Lighting II.4 Lighting Controls II.5 Luminaires II.6 Daylighting <p>III. Electronics Roadmaps</p> <ul style="list-style-type: none"> III.1 Direct Current (DC) Power III.2 Use and Virtualization III.3 Component-Level Efficiency III.4 Complete Electronic System III.5 Power Management Control and Communication | <p>IV. Heating, Ventilation, and Air Conditioning Roadmaps</p> <ul style="list-style-type: none"> IV.1 Commercial IV.2 Fault Detection IV.3 Heat Recovery IV.4 Heating & Cooling IV.5 HVAC Motors IV.6 Commercial IV.7 Residential IV.8 Modeling, Simulation <p>V. Sensors, Meters, and Energy Management System Roadmaps</p> <ul style="list-style-type: none"> V.1 Smart Device-Level Controls Responsive to User and Environment V.2 Easy / Simple User Interface Controls V.3 Energy Management Services V.4 Low-Cost Savings Verification Techniques V.5 Real-Time Smart Electric Power Measurement of facilities V.6 Enterprise Energy and Maintenance Management Systems <p>VI. Industrial Food Processing Roadmaps</p> <ul style="list-style-type: none"> VI.1 Heating VI.2 Cooling VI.3 Mechanical VI.4 Infrastructure <p>VII. Combined Heat and Power Roadmaps</p> <ul style="list-style-type: none"> VII.1 Production VII.2 Resources VII.3 Delivery |
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Data Sources

R&D Stage	Typical Source
Basic Research	Science Citation Index
Applied Research	Engineering Index
Development	Patents
Application	Newspaper Abstracts Daily
Social Impacts	Business and Popular Press

- Experts identified from three separate databases and approaches:
 - Basic Research (Citations and publications) – these experts would be ideal to know about the ongoing R&D and to be invited to the workshop focusing on identification of R&D efforts
 - Applied Research (Co-author network) – these experts would be ideal to know about the available technologies and be invited to the workshop focusing on identification of technologies
 - Development (Patent count) - these experts would be ideal to know about the available products and be invited to the workshop focusing on identification of products

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Metrics and Assumptions

- Metrics
 - CIT stands for citations, meaning that the authors were identified by their number of citations.
 - PUB stands for Publication count,
 - DEG stands for Degree Centrality,
 - BET stands for Betweenness Centrality,
 - COUNT stands for Patent Count,
- Experts with high publications count are active in the field, experts with high betweenness are important for linking different groups of experts together, and experts with high number of citations have potentially high impact research. This gives us a range of potential experts, since if one metric identified irrelevant experts then the other methods might not.

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Basic Research

Author Initials	Author Affiliation	Selected By
Shur, M.S	Rensselaer Polytechnic Institute	Cit
Setlur, A.A	GE Global Research	Cit
Phillips, J.M	Sandia National Lab.	Cit
Krames, M.R	Philips Lumileds Lighting Co	Cit
Ohno, Y	National Institute of Standards and Technology	Cit
Kim, J.K	Rensselaer Polytech Institute	Cit
Dai, Q.Q	Oak Ridge National Lab.	Cit
Dupuis, RD	Georgia Inst Technology	Cit

Basic Research is done at academic, government and industry labs – showing technology maturity

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Basic Research

Author/Initials	Article Title	Focus
Shur, MS	1. Solid-state lighting: Toward superior illumination	1. Solid-state lighting
Setlur, A.A	1. Energy-Efficient, High-Color-Rendering LED Lamps Using Oxyfluoride and Fluoride Phosphors	1. Solid-state lighting
Phillips, JM	1. Research challenges to ultra-efficient inorganic solid-state lighting	1. Solid-state lighting
Krames, MR	1. Research challenges to ultra-efficient inorganic solid-state lighting	1. Solid-state lighting
Ohno, Y	1. Research challenges to ultra-efficient inorganic solid-state lighting	1. Solid-state lighting
Kim, JK	1. Transcending the replacement paradigm of solid-state lighting	1. Solid-state lighting
Dai, QQ	1. Semiconductor-Nanocrystals-Based White Light-Emitting Diodes	1. Solid-state lighting
Dupuis, RD	1. History, development, and applications of high-brightness visible light-emitting diodes	1. Solid-state lighting

Solid State Lighting is the focus in Basic Research

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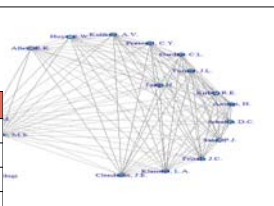
Basic Research

- Academic Institutes
 - Rensselaer Polytechnic Institute was identified as the key academic institute leading the basic research in lighting technology are
 - Georgia Tech also came out as a critical player. In another analysis on transmission technologies, Georgia Tech came out as the major player. Further analysis showed that they have an established competence in power engineering
- Government
 - Sandia and Oak Ridge came out as the leaders among the National Labs
 - National Institute of Standards and Technology also came out as a key contributor
- Industry
 - GE Global Research and Philips Lumileds Lighting Co were listed as the industrial leaders contributing to basic research
- Topic
 - Solid State Lighting is the focus in Basic Research

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Applied Research

Author Initials	Author Affiliation	Selected By
Brodrick,J.	U.S. Department of Energy	Pub
Agogino,A.M.	University of California, Berkeley	Pub
Wetzel,C.	Rensselaer Polytechnic Institute	Pub
Granderson,J.	Lawrence Berkeley Nat. Lab	Deg
Narendran,N.	Rensselaer Polytechnic Institute	Pub, Deg, Bet
Andersen,M.	Massachusetts Institute of Technology	Pub, Deg, Bet
Matthews,D.H.	Carnegie Mellon University	Deg
Freyssinier,J.P.	Rensselaer Polytechnic Institute	Pub, Deg, Bet
Swensen,J.S.	Pacific Northwest National Laboratory	Deg
Yulao Zhou	Rensselaer Polytechnic Institute	Deg, Bet
Tu,J.	Philips Lighting,	Bet
Brown,J.J.	Universal Display Corporation	Bet
Nicklas,M.	Innovative Design	Bet
Meek,C.	University of Washington	Deg



Applied Research Leaders are similar to Basic Research Leaders – National Labs, Industry and Key Universities such as RPI

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Applied Research

Author/Initials	Article Titles	Focus
Brodrick, J.	<ol style="list-style-type: none"> 1. Choosing the right light 2. Control systems & LEED 3. Squeezing the Watts out of fluorescent lighting 4. Solid-State Lighting, Part 1 5. Lighting and Standard 90.1 6. Inorganic LEDs 	<ol style="list-style-type: none"> 1. General 2. Solid-state lighting
Agogino, A.M.	<ol style="list-style-type: none"> 1. Personalized dynamic design of networked lighting for energy-efficiency in open-plan offices 2. Control of wireless-networked lighting in open-plan offices 3. Wireless networked lighting systems for optimizing energy savings and user satisfaction 4. Towards embedded wireless-networked intelligent daylighting systems for commercial buildings 	<ol style="list-style-type: none"> 1. Control 2. Daylighting
Wetzel, C.	<ol style="list-style-type: none"> 1. The quantum efficiency of green GaInN/GaN light emitting diodes 2. Wavelength-stable rare earth-free green light-emitting diodes for energy efficiency 3. Development of high efficiency green and deep green light emitters in piezoelectric group-III nitrides 	<ol style="list-style-type: none"> 1. Solid-state lighting
Granderson, J.	<ol style="list-style-type: none"> 1. Standardization of user interfaces for lighting controls 2. Towards embedded wireless-networked intelligent daylighting systems for commercial buildings 	<ol style="list-style-type: none"> 1. Control 2. Daylighting
Detchprohm, T.	<ol style="list-style-type: none"> 1. The quantum efficiency of green GaInN/GaN light emitting diodes 2. Phosphor-free white 3. Wavelength-stable rare earth-free green light-emitting diodes for energy efficiency 	<ol style="list-style-type: none"> 1. Solid-state lighting

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Solid State Lighting and Control are the leading topics in Applied Research

Applied Research

- Rensselaer was a clear leader here as well
- Other academic institutes leading in applied research were MIT, Berkeley, Carnegie Mellon and University of Washington. These did not come up in the basic research area
- National labs leading in this are LBNL and PNNL
- Phillips was one of the three industry leaders in applied research
- Key conclusion here is that while academy, government and industry are all taking part in both basic and applied research, there are very established institutes which are leaders in one or the other while Rensselaer has a key competency in both.
- Solid State Lighting and Control are the leading topics in Applied Research

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Development

Author/Initials	Author Affiliation	Selected By
Negley, G.H	Cree LED Lighting Solutions	Count
Morgan, F.M	Philips Solid-State Lighting Solutions, Inc.	Count
Dowling, K.J	Philips Solid-State Lighting Solutions, Inc.	Count
Mueller, G.G	Philips Solid-State Lighting Solutions, Inc.	Count
Pickard, P.K	Cree LED Lighting Solutions	Count
Lys, I.A	Philips Solid-State Lighting Solutions, Inc.	Count
Briggs, GE	Arkalumen Inc.	Count
Verfueth, N.R	Orion Energy Systems, Inc.	Count
Gordin, M.K	Musco Corporation	Count
Rains, J.C	ABL IP Holding LLC	Count
Macadam, R.L	Lutron Electronics, Co., Inc	Count

Development leaders are clearly in the Industry

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Development

Author/Initials	Patent Title	Focus
Negley, G.H	<ol style="list-style-type: none"> 1. Light emitting diode (LED) lighting systems including low absorption, controlled reflectance enclosures 2. Lighting device which includes one or more solid state light emitting device 3. Lighting device with multi-chip light emitters, solid state light emitter support members and lighting elements 4. 	<ol style="list-style-type: none"> 1. Solid-state lighting
<ul style="list-style-type: none"> • Morgan, F.M • Dowling, K.J • Mueller, G.G • Lys, I.A 	<ol style="list-style-type: none"> 1. Controlled lighting methods and apparatus 2. Methods and apparatus for controlled lighting based on a reference gamut 3. Methods and apparatus for controlling devices in a networked lighting system 4. Universal lighting network methods and systems 5. Wireless lighting control methods and apparatus 	<ol style="list-style-type: none"> 1. Lighting Controls
Pickard, P.K	<ol style="list-style-type: none"> 1. Active thermal management systems for enclosed lighting and modular lighting systems 2. Conversion kit for lighting assemblies 3. Lighting assemblies and components for lighting assemblies 4. Lighting device with multi-chip light emitters, solid state light emitter support members and lighting elements 	<ol style="list-style-type: none"> 1. Solid-state lighting 2. General Lighting

Solid State Lighting is the leading topic in Development as well

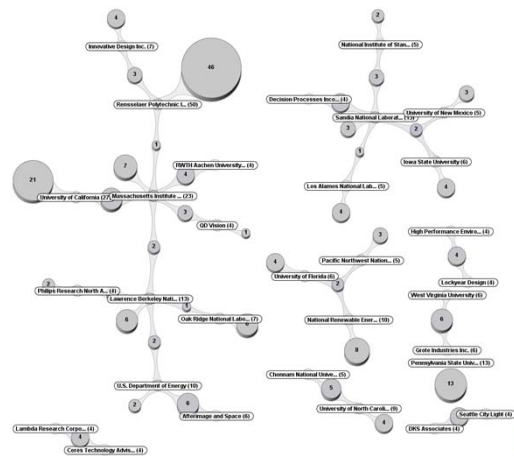
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Development

- As expected, industrial corporations are dominant in this area.
- Phillips is the key leader. Its presence in both basic and applied research as well may indicate that presence in research will lead to leadership in development. This may be an interesting hypothesis to explore further.
- Solid State Lighting seems to be of interest at all phases

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Organisational Linkages



Organizational mapping identified organization which were not thought about before

Vantage Point SW was used for this analysis

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Organizations Linkages

- Mapping organizations showed interesting clusters.
- In the original road mapping workshops, PNNL and NREL were represented. They seem to be in a cluster in our map.
- This may also indicate that clusters may act as barriers. So methods such as snow ball sampling can be ineffective in reaching out to key leaders

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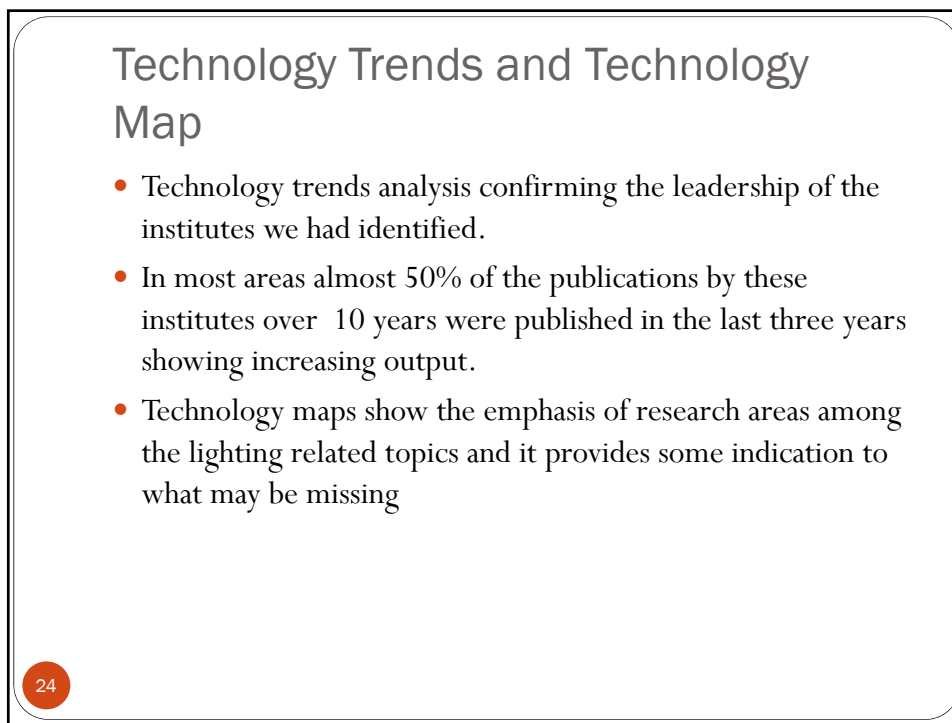
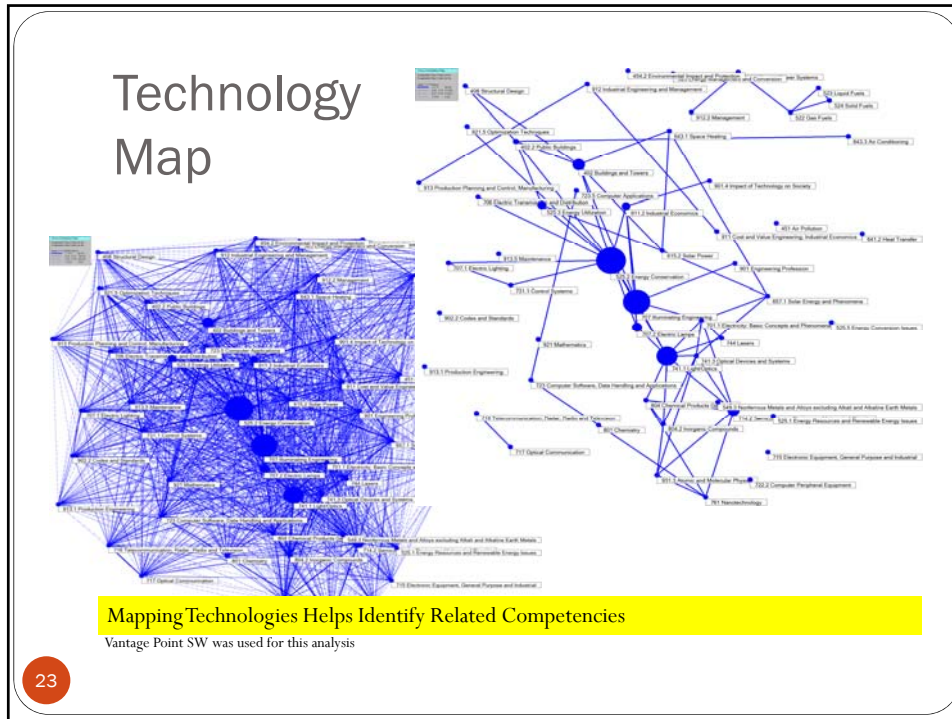
Technology Trends

Number of Records	Technology Term	Range of Years	Percentage of Records in Last-3 Years	Top Authors	Top Organization Names
277	525.2 Energy Conservation	2003 - 2013	48% of 277	Brodrick, James [11]; Wetzel, Christian [7]; Liebel, Brian [6]; Narendran, Nadarajah [6]	Rensselaer Polytechnic Institute [27]; University of California [13]; Lawrence Berkeley National Laboratory [11]
253	707 Illuminating Engineering	2003 - 2013	53% of 253	Freyssinier, Jean Paul [10]; Narendran, Nadarajah [10]; Tsao, Jeffrey Y [7]	Rensselaer Polytechnic Institute [31]; Massachusetts Institute of Technology [16]; University of California [14]
198	741.1 Light/Optics	2003 - 2013	54% of 198	Narendran, Nadarajah [14]; Freyssinier, Jean Paul [10]; Wetzel, Christian [7]	Rensselaer Polytechnic Institute [34]; University of California [12]; Massachusetts Institute of Technology [12]
116	402 Buildings and Towers	2003 - 2013	47% of 116	Nicklas, Michael [6]; Han, Seung-Hoon [5]; Kim, Kyoung-Hee [5]	University of North Carolina [9]; Innovative Design Inc. [7]; Rensselaer Polytechnic Institute [6]; National Renewable Energy Laboratory [6]
110	714.2 Semiconductor Devices and Integrated Circuits	2004 - 2013	33% of 110	Bulovic, Vladimir [6]; Shirasaki, Yasuhiro [6]; Bawendi, Moungi G [6]; Supran, Geoffrey J [6]; Kaul, Anupama B [6]	Rensselaer Polytechnic Institute [18]; Sandia National Laboratories [7]; Pennsylvania State University [6]; Engineering Directorate, National Science Foundation [6]; Massachusetts Institute of Technology [6]

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Recent focus in leading organizations may lead to disruptive technology identifications

Vantage Point SW was used for this analysis



Conclusions

- Rensselaer was identified as a critical resource
- National labs had played a critical role in the development of the roadmap and this analysis shows them as critical players in this field
- Further analysis of the organizational linkages is indicating that possibly organizational clusters is causing an artificial barrier to cluster members to go outside the cluster.
- Solid State Lighting is a technology of the highest focus in this area.
- Publications by the leading institutes are increasing at a faster pace during the recent years

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Conclusions

- Integration Bibliometrics, Patent Analysis and Social Network Analysis provided further intelligence to building technology roadmaps
 - Experts and organizations which were not thought of before were identified and will be invited to the next series of workshops when the roadmap will be updated.
 - Identification of technology trends were found to be beneficial to populating the roadmap documents prior to the roadmapping workshops

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References

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