Check for updates

DOI: https://doi.org/10.34069/AI/2024.84.12.1

Chernbumroong, S., Phunsathitwong, S., Premphet, P., Ramingwong, S., & Jintana, J. (2024). Development of a strategic roadmap for plasma technology in Thailand: The hub of talents initiative. *Amazonia Investiga*, *13*(84), 9-27. https://doi.org/10.34069/AI/2024.84.12.1

Development of a strategic roadmap for plasma technology in Thailand: The hub of talents initiative

การพัฒนาแผนยุทธศาสตร์สำหรับเทคโนโลยีพลาสมาในประเทศไทย: โครงการศูนย์กลางผู้เชี่ยวชาญ

Received: November 1, 2024 Accepted: December 30, 2024

Written by:
Sainatee Chernbumroong[1]
https://orcid.org/0000-0003-1701-0849
Suchada Phunsathitwong[2]
https://orcid.org/0009-0003-4855-2154
Pongsawat Premphet[3]
https://orcid.org/0009-0008-4792-6675
Sakgasem Ramingwong[4]
https://orcid.org/0000-0002-1727-6391
Jutamat Jintana[5]
https://orcid.org/0000-0002-2644-9178

Abstract

This paper presents the development process and results of a strategic roadmap for plasma technology in Thailand, as part of the Hub of Talents for Plasma Technology initiative. Through a comprehensive methodology including literature review, expert interviews, workshops, and stakeholder consultations, a 5-year roadmap was created to guide research, development, and application of plasma technology in the country. The roadmap identifies six priority areas: research and development in plasma science and technology, industrial applications, upskilling existing talent, capacity building for new talent, networking, and ecosystem development. Key projects are outlined across these priority areas to drive implementation. This strategic planning aims to position Thailand as a leader in plasma technology expertise in the ASEAN region. The roadmap provides a framework to align research

บทคัดย่อ

บทความนี้นำเสนอกระบวนการพัฒนาและผลลัพธ์ของแผนที่นำทางเชิงกลยุทธ์สำหรับเทคโนโลยีพลาสมาในประเทศไทย ซึ่งเป็นส่วนหนึ่งของโครงการศูนย์รวมบุคลากรที่มีความสามารถด้านเทคโนโลยีพลาสมา ผ่านระเบียบวิธีวิจัยที่ครอบคลุม ซึ่งประกอบด้วยการทบทวนวรรณกรรม การสัมภาษณ์ผู้เชี่ยวชาญ การจัดประชุมเชิงปฏิบัติการ และการหารือกับผู้มีส่วนได้ส่วนเสีย จึงได้มีการจัดทำแผนที่นำทางระยะ 5 ปี เพื่อเป็นแนวทางในการวิจัยพัฒนาและประยุกต์ใช้เทคโนโลยีพลาสมาในประเทศ แผนที่นำทางนี้ระบุพื้นที่สำคัญ 6 ด้าน ได้แก่ การวิจัยและพัฒนาด้านวิทยาศาสตร์และเทคโนโลยีพลาสมา การประยุกต์ใช้ในภาคอุตสาหกรรม การยกระดับทักษะบุคลากรที่มีอยู่ การสร้างขีดความสามารถสำหรับบุคลากรใหม่ การสร้างเครือข่าย และการพัฒนาระบบนิเวศ โดยมีการวางโครงการสำคัญครอบคลุมทุกพื้นที่เพื่อขับเคลื่อนการดำเนินงาน การวางแผนเชิงกลยุทธ์นี้มีเป้าหมายเพื่อวางตำแหน่งประเทศไทยให้เป็นผู้นำด้านความเชี่ยวชาญเทคโนโลยีพลาสมาในภูมิภาคอาเซียน แผนที่นำทางนี้ให้กรอบการดำเนินงานเพื่อจัดแนวทางการวิจัย

[1] Ph.D. Department of Management and Entrepreneurship, Chiang Mai University Business School, Chiang Mai University, Thailand. WoS Researcher ID: AED-3963-2022 - Email: sainatee.c@cmu.ac.th
[2] Meng, Faculty of Innovation Technology & Creativity, The Far Eastern University, Thailand. WoS Researcher ID: JCD-9533-2023 - Email: suchada@feu.ac.th
[3] PhD. Supply Chain and Engineering Management Research Unit, Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Thailand. WoS Researcher ID: JPL-5367-2023 - Email: ppremphet@gmail.com
[4] PhD. Supply Chain and Engineering Management Research Unit, Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Thailand. WoS Researcher ID: ABA-1212-2021 - Email: sakgasem.ramingwong@cmu.ac.th
[5] PhD. Faculty of Innovation Technology & Creativity, The Far Eastern University, Thailand. WoS Researcher ID: LUY-9204-2024 - Email: jutamat@feu.edu

efforts, strengthen industry collaboration, develop human capital, and create an enabling ecosystem for plasma technology innovation in Thailand.

Keywords: strategic roadmap, plasma technology, hub of talents, Thailand research and development.

เสริมสร้างความร่วมมือกับภาคอุตสาหกรรม พัฒนาทุนมนุษย์ และสร้างระบบนิเวศที่เอื้อต่อนวัตกรรมเทคโนโลยีพลาสมาในประเทศไทย

คำสำคัญ: แผนยุทธศาสตร์; เทคโนโลยีพลาสมา; ศูนย์กลางผู้เชี่ยวชาญ; การวิจัยและพัฒนาของประเทศไทย.

Introduction

Plasma technology has emerged as a versatile and promising field with applications spanning diverse sectors including materials processing, energy, medicine, agriculture, and environmental remediation (Chu & Lu, 2013). As the fourth state of matter, plasma offers unique properties that enable novel industrial processes and solutions to pressing societal challenges (Adamovich et al., 2017). The ability of plasma to generate highly reactive species, produce high-energy electrons, and create intense electromagnetic fields has opened up new possibilities for technological innovation across multiple disciplines.

In materials processing, plasma technologies are revolutionizing surface modification techniques, enabling the creation of advanced coatings with properties tailored for specific applications. The semiconductor industry, in particular, has heavily relied on plasma-based processes for etching and deposition in the fabrication of microelectronic devices. In the energy sector, plasma research holds promise for fusion energy development, as well as improving the efficiency of conventional power generation through plasma-assisted combustion.

The medical field has seen growing interest in plasma applications, ranging from sterilization of medical equipment to direct therapeutic use in wound healing and cancer treatment (Chutsirimongkol et al., 2016).

In agriculture, cold plasma treatments are being explored for seed germination enhancement, pest control, and food preservation. Environmental applications of plasma technology include water treatment, air pollution control, and waste management, offering potentially more efficient and environmentally friendly alternatives to conventional methods.

Recognizing the strategic importance of this technology, many countries have launched initiatives to develop expertise and capabilities in plasma science and engineering (Batani et al., 2023). These efforts often involve significant public investment in research infrastructure, human capital development, and industry-academia collaborations. For instance, the European Union has established a comprehensive roadmap for fusion energy research, while countries like South Korea and Japan have implemented national strategies to promote plasma technology across various industrial sectors.

In Thailand, efforts to advance plasma technology research and development have been growing in recent years, with several universities and research institutes establishing dedicated plasma laboratories and programs (Chutsirimongkol et al., 2016; Buaruk et al., 2019). Notable developments include the establishment of specialized research facilities, growing research output in areas such as agricultural applications of plasma, and the recent launch of Thailand's first tokamak fusion experiment (Laoharojanaphand et al., 2016).

However, these efforts have been largely fragmented, lacking coordination and a unified strategic direction at the national level. The absence of a comprehensive strategy has led to potential duplication of efforts, missed opportunities for synergies, and challenges in translating research outcomes into industrial applications. Furthermore, the development of human capital in plasma science and engineering has not kept pace with the growing demand from both academia and industry.

To address these gaps and capitalize on Thailand's existing strengths in plasma technology, the Hub of Talents for Plasma Technology initiative was launched in 2023 as a collaborative platform to bring together expertise from academia, industry, and government. This initiative aims to create a coordinated ecosystem for plasma technology development in Thailand, fostering innovation, enhancing human capital, and strengthening the country's competitiveness in this emerging field.

A key objective of this initiative is to develop a strategic roadmap to guide plasma technology development in Thailand over the next 5 years. This roadmap aims to align research priorities, strengthen industry-academia collaboration, develop human capital, and create an enabling ecosystem for plasma technology innovation. By setting clear goals and outlining specific actions, the roadmap seeks to accelerate the development and adoption of plasma technologies in key sectors of the Thai economy. The ultimate vision is to position Thailand as a leader in plasma technology expertise within the ASEAN region, contributing to the country's technological advancement and economic competitiveness.

This paper presents the systematic process undertaken to develop this strategic roadmap, including the methodology, key findings, and resulting roadmap framework. By documenting this process, we aim to provide insights that may be valuable for similar strategic planning efforts in other emerging technology fields or national contexts. The paper is structured as follows: Section 2 provides an overview of strategic technology roadmapping and reviews existing plasma technology roadmaps from other countries. Section 3 details the methodology used in developing the Thai roadmap, including literature review, expert interviews, and stakeholder workshops. Section 4 presents the key elements of the resulting roadmap, including vision, objectives, priority areas, and implementation plan. Finally, Sections 5 and 6 discuss the implications of the roadmap and conclude with reflections on its potential impact and future research directions.

Literature review or theoretical framework

The literature review for this study covers three main areas: strategic technology roadmapping as a planning tool, plasma technology roadmaps, and the development of roadmaps for emerging technologies.

Strategic Technology Roadmapping

Technology roadmapping has emerged as a widely used foresight and strategic planning tool to support innovation management and policy (Phaal et al., 2004). Roadmaps provide a structured visual representation of the evolution of technologies, products, and markets over time, helping to align technological capabilities with business or policy objectives (Kostoff & Schaller, 2001; Ramingwong et al., 2024).

The process of roadmapping typically involves bringing together diverse stakeholders to develop a shared vision and action plan (Phaal & Muller, 2009). Key benefits include improved communication across functional silos, identification of gaps in R&D programs, and prioritization of investments (Amer & Daim, 2010). While initially developed for corporate technology planning, roadmapping has been increasingly adopted at industry and national levels to guide science and technology policy (Li et al., 2015).

Plasma Technology Roadmaps

2022 Plasma Roadmap, representing a diverse group of leading experts in the field of low-temperature plasma science and technology, have identified several notable examples of plasma technology roadmaps developed by various countries and regions. These roadmaps provide valuable insights into the strategic priorities and development trajectories for plasma science and technology around the world (Adamovich et al., 2022).

Several countries and regions have developed roadmaps specifically focused on plasma technology development. Notable examples include the roadmap for fusion energy development by US Department of Energy's Fusion Energy Sciences Advisory Committee (Carter et al., 2020), the roadmap to realize fusion energy by 2050 by the European Union's EURO fusion consortium (Nordlund, 2018). These roadmaps share common elements such as identifying priority research directions, outlining infrastructure and human resource development needs, and defining timelines for key technology milestones. However, they also reflect the specific national contexts, existing capabilities, and strategic priorities of each country or region.

Roadmaps in Other Emerging Technologies

The development of strategic roadmaps has been crucial for guiding various emerging technologies. In the field of quantum technologies, roadmaps have been instrumental in directing research and development efforts in quantum computing, communication, and nanotechnology applications. These roadmaps

highlight how quantum phenomena can revolutionize computing, communication, and nanoscale exploration while identifying key challenges in translating laboratory discoveries into practical applications (Laucht et al., 2021).

In flexible electronics and sensors, comprehensive roadmaps have addressed critical challenges in commercialization and market adoption. These roadmaps emphasize key factors such as dimensional scaling, functional performance, and mechanical compliance while considering environmental concerns and ethical implications. Strategic planning in this sector has helped align research efforts across disparate communities and accelerate scientific breakthroughs (Luo et al., 2023).

The intersection of information technology and biotechnology presents another crucial area where roadmapping has proven valuable. Recent roadmaps in this domain focus on addressing environmental challenges through sustainable practices, outlining short-term, medium-term, and long-term goals while considering technical, financial, and ethical barriers. These roadmaps emphasize the importance of cross-industry collaboration and the role of various stakeholders in fostering sustainable growth (Asimiyu, 2024).

Common themes across these roadmaps include integration of sustainability considerations, focus on stakeholder engagement and collaboration, emphasis on translating research into practical applications, address of ethical and regulatory challenges, development of human capital and infrastructure. These examples from other emerging technology fields offer valuable insights for plasma technology roadmap development, particularly in areas such as stakeholder engagement and consensus-building, integration of research and industrial applications, human capital development strategies, infrastructure and facility planning and policy and regulatory frameworks.

Plasma Technology Development in Thailand

Research on plasma technology in Thailand dates back to the 2000s, with initial focus areas including materials processing and environmental applications (Tippayawong & Khongkrapan, 2009). Key milestones include the establishment of the Plasma and Beam Physics Research Facility at Chiang Mai University in 1998, which became a center for low-temperature plasma research, the launch of Thailand's first tokamak fusion experiment, Thailand Tokamak-1, at the Thailand Institute of Nuclear Technology in 2020 (Wisitsorasak et al., 2024) and the growing research on agricultural and food applications of plasma technology at several Thai universities (Sarinont et al., 2016).

While these developments demonstrate Thailand's growing capabilities in plasma technology, the research landscape remains fragmented. A comprehensive national roadmap could help align efforts and accelerate progress in priority areas.

Government Policy and Private Sector Demand in Thailand

The development of plasma technology in Thailand has been influenced by both government policies and growing private sector demand. Key government agencies have recognized plasma technology's potential and implemented supportive policies. The Ministry of Higher Education, Science, Research and Innovation included plasma technology in its National Science, Technology, and Innovation Policy and Plan (2021-2027) as a key enabling technology (MHESI, 2021). The Thailand Institute of Nuclear Technology prioritized plasma and fusion research, establishing the Thailand Tokamak-1 facility (Laoharojanaphand et al., 2016). The National Science and Technology Development Agency has supported plasma technology research through various funding programs (NSTDA, 2022), while the Board of Investment included plasma-based manufacturing processes in its investment promotion list. In the private sector, demand for plasma technology applications has grown across several industries. The electronics manufacturing sector has shown interest in plasma-based processes for surface modification and thin film deposition (Wiboonsak et al., 2018). The food and agriculture sector is exploring cold plasma technology for food preservation and agricultural applications (Ruamrungsri et al., 2023). The medical device industry is investigating plasma sterilization technologies (Chutsirimongkol et al., 2016), while textile manufacturers are exploring plasma treatment for fabric modification (Wongsawaeng et al., 2017). Environmental applications of plasma technology are also gaining attention (Quyen et al., 2017). Despite this growing interest, adoption of plasma technologies in Thai industry remains limited compared to more advanced economies, facing challenges such as high investment costs, lack of skilled personnel, and limited awareness among smaller enterprises. This review highlights the need for coordinated efforts to bridge the

gap between research capabilities and industrial application, insights that shaped the development of the Hub of Talents Plasma Technology Roadmap.

Methodology

The development of the Hub of Talents Plasma Technology Roadmap followed a multi-stage process combining desk research, expert consultation, and stakeholder engagement. The key stages were:

Literature Review and Environmental Scanning

An extensive review of academic and grey literature was conducted to understand the global state-of-the-art in plasma technology, identify emerging trends and applications, and analyze existing roadmaps from other countries. This review covered both scientific publications and policy documents.

Bibliometric analysis was performed using the Scopus database to map Thailand's research output in plasma technology and identify key institutions and researchers. This analysis helped benchmark Thailand's capabilities against leading countries in the field.

Bibliometric Process

1. **Database Selection:** The Scopus database was selected for this bibliometric analysis due to its comprehensive coverage of scientific literature in the field of plasma technology. Scopus is one of the largest abstracts and citation databases of peer-reviewed literature, covering scientific journals, books, and conference proceedings.
2. **Time Frame:** The analysis covered publications from January 1, 1962 to December 31, 2023. This extensive time frame was chosen to capture the full evolution of plasma technology research, from its early developments to the most recent advancements.
3. **Search Strategy:** A search query was constructed to identify relevant publications:

TITLE-ABS-KEY ("Plasma Technology")

This query searched for the term "Plasma Technology" in the title, abstract, and keywords of publications.

1. **Data Extraction:** The following data were extracted for each publication, i.e., publication year, authors, affiliations, countries, document type, subject areas, citations and keywords.
2. **Data Cleaning:** The extracted data was cleaned to remove duplicates and correct any inconsistencies in author names or affiliations.
3. **Analysis Tools:** Several tools were used for the bibliometric analysis:

    - VOSviewer: For creating co-authorship, co-occurrence, and collaboration network visualizations.
    - Bibliometrix R-package: For generating bibliometric indicators and trend analyses.
    - Microsoft Excel: For basic data manipulation and chart creation.

4. **Bibliometric Indicators:** Key bibliometric indicators calculated included:

    - Publication output over time.
    - Top contributing countries and institutions.
    - Most productive authors.
    - Most cited papers.
    - Subject area distribution.
    - Collaboration patterns.

5. **Visualization:** Various visualizations were created to represent the bibliometric data:

    - Time series plots of publication trends.
    - Co-authorship networks.
    - Keyword co-occurrence networks.
    - Country collaboration networks.

- TreeMap of subject áreas.

6. **Focus on Thailand:** A specific analysis was conducted focusing on Thailand's research output, identifying key institutions, researchers, and collaboration patterns within the country.

Bibliometric Results Summary

The bibliometric analysis revealed a total of 3,934 documents related to plasma technology published between 1962 and 2023. The analysis showed an increasing trend in publications over time, with a significant acceleration in recent years (see Figures 1-3).

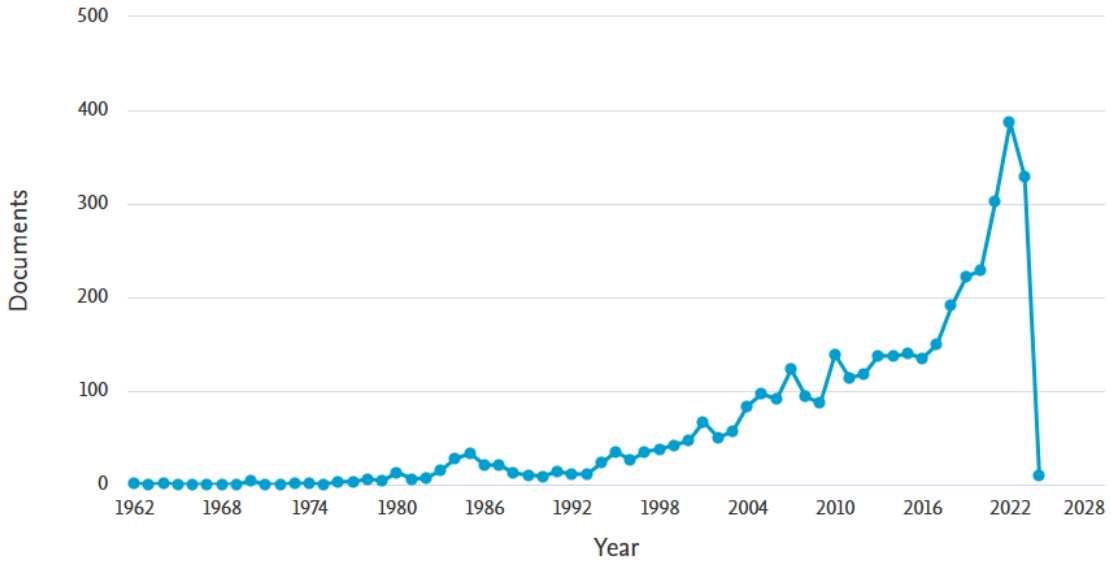

Figure 1. Publication on plasma technology.
Note: own authorship

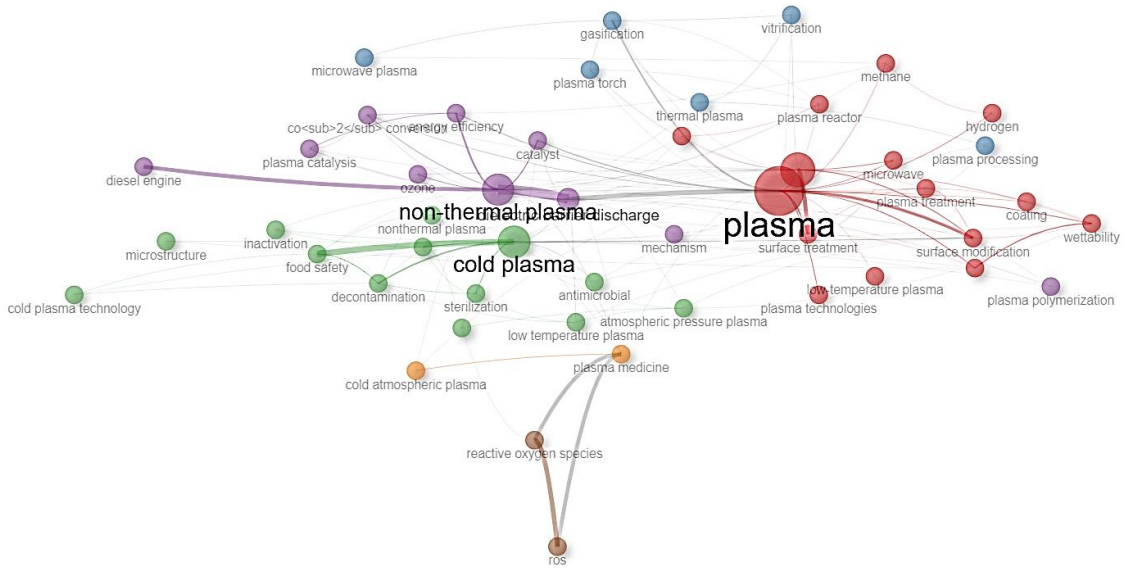

Figure 2. Co-occurrence Network on plasma technology.
Note: Created by author using bibliometrix R-package

Figure 2 displays a network visualization of key terms and concepts in plasma technology research. The largest node, "plasma", sits at the center, indicating its central role in this field. Branching out from it are various related concepts and applications, such as "non-thermal plasma" and "cold plasma". This network structure illustrates the diverse and interconnected nature of plasma technology research, spanning multiple

subfields and applications. The different colors likely represent distinct clusters or subdomains within plasma research, showcasing how various aspects of the technology are interconnected yet form their own specialized areas of study.

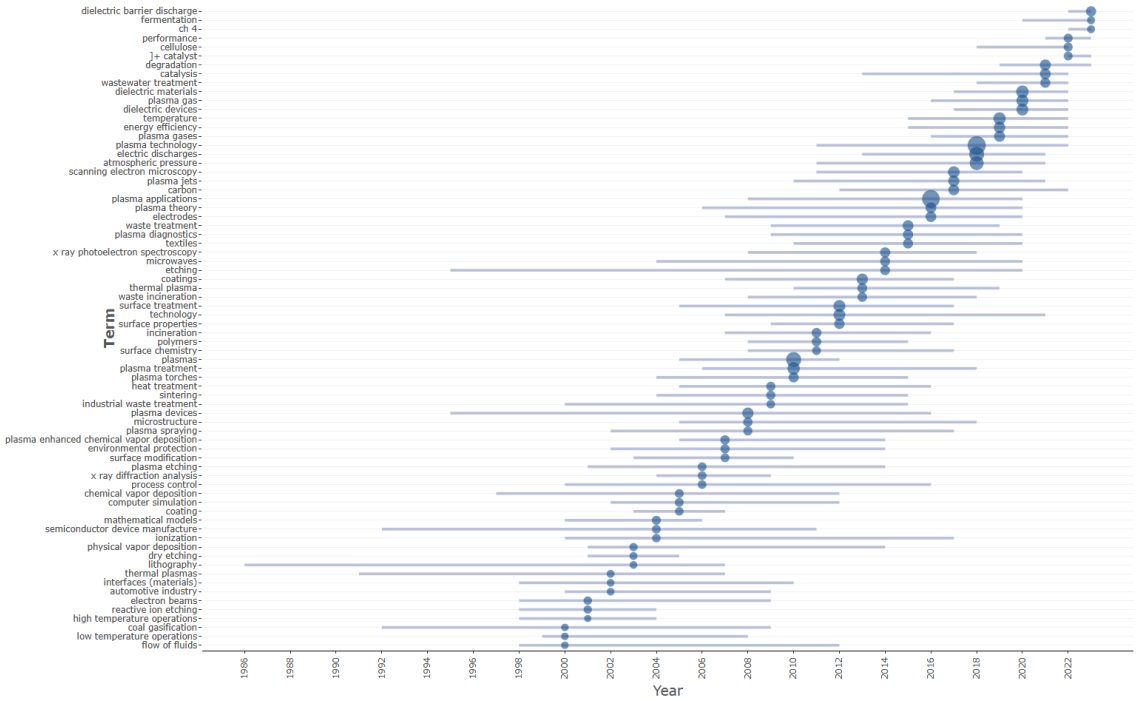

Figure 3. Trend Topics on plasma technology.
Note: Created by author using bibliometrix R-package

Figure 3 presents a timeline of research output in plasma technology, with each row representing a specific topic or keyword and the blue dots indicating publication activity over time. The increasing density of blue dots towards the right side of the chart clearly demonstrates the growing research interest and output in plasma technology over recent years. This visualization effectively captures the evolution of the field, showing which topics have been consistently studied over time and which ones have emerged more recently. The varying lengths of the rows also suggest differences in the longevity and intensity of research focus on different aspects of plasma technology.

Based on Scopus database, China has emerged as the leading country in terms of publication output, followed by the United States, Russia, Germany, and India, reflecting a shift in the global research landscape. Notably, Thailand has secured the 22nd position globally in plasma technology research output, indicating its growing presence in this advanced scientific field.

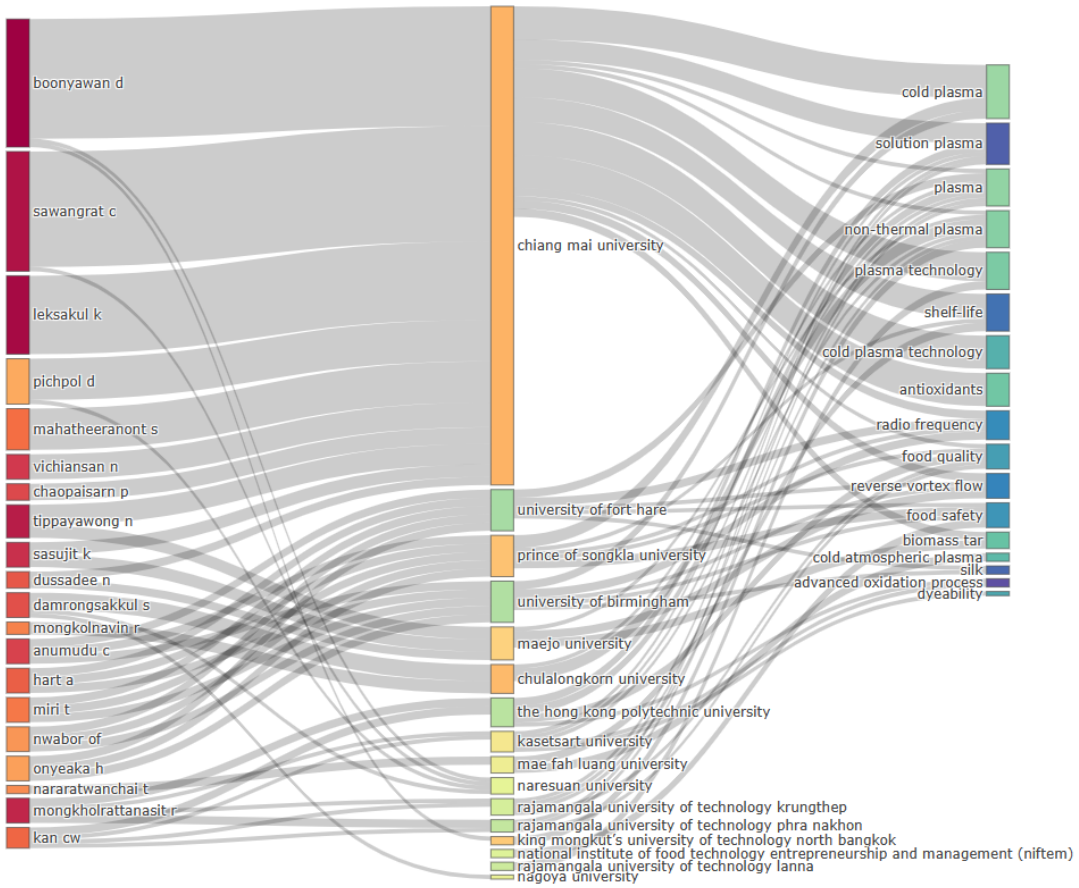

Figure 4. Three-Field Plot on plasma technology in Thailand.
Note: Created by author using bibliometrix R-package

The analysis of Thailand's research landscape reveals significant progress, with key institutions such as Chiang Mai University and the Thailand Institute of Nuclear Technology playing pivotal roles. Several other universities in Thailand are also contributing substantially to the field, as evidenced by Figures 4-6 in the roadmap. This positioning of Thailand in the global plasma technology research arena underscores the country's increasing investment in science and technology, particularly in cutting-edge fields. The growth in research output suggests a strategic focus on developing stronger capabilities in plasma technology, likely driven by factors such as increased funding, development of specialized research facilities, and international collaborations. Thailand's performance not only highlights its potential for further growth and impact in plasma technology but also indicates a broader trend of Southeast Asian countries increasing their presence in advanced scientific fields. This shift in the research landscape emphasizes the increasingly global nature of plasma technology research and underscores the importance of international collaboration in advancing the field.

Figure 5. Collaboration Network – Institutions on plasma technology in Thailand
Note: Created by author using bibliometrix R-package

This collaboration network visualization (Figure 5) provides valuable insights into the landscape of plasma technology research in Thailand. The network structure reveals a complex web of institutional collaborations, with one central institution serving as a major hub for research and partnerships. This central node's prominence suggests it plays a key role in driving plasma technology research and fostering collaborations across the country.

Surrounding this central hub are several distinct clusters of institutions, indicating the formation of specialized research groups or regional collaborations. These clusters likely represent focused efforts on specific aspects of plasma technology or applications in particular industries. The varying sizes of nodes and the density of connections between them illustrate the different scales of research activity and the intensity of collaborations among institutions.

However, the network also highlights some challenges in the research ecosystem. Several smaller clusters and individual nodes appear relatively isolated from the main network, suggesting there are institutions or research groups working on plasma technology with limited connection to the broader national research community. These isolated groups may represent untapped potential for knowledge sharing and collaboration that could enhance the overall research output and innovation in plasma technology across Thailand.

Figure 6. TreeMap on plasma technology in Thailand.
Note: Created by author using bibliometrix R-package

This bibliometric approach provided a comprehensive overview of the global and Thai research landscape in plasma technology, informing the roadmap development process by identifying strengths, trends, and potential collaboration opportunities.

Expert Interviews

In-depth interviews were conducted with more than 10 leading plasma technology researchers, including both Thai experts and internationally renowned scientists, representing key universities and research institutes. These semi-structured interviews explored:

- Current research focus areas and capabilities.
- Perceived strengths and weaknesses of Thailand's plasma technology ecosystem.
- Priority application areas for Thailand.
- Key challenges and enablers for advancing plasma technology in the country.
- Vision for Thailand's position in plasma technology by 2030.

The interviews were recorded, transcribed, and analyzed using thematic coding to identify common themes and priorities.

Stakeholder Workshops

The roadmap development process included two key stakeholder workshops. The first workshop brought together 74 participants to review preliminary findings from the literature review and expert interviews. Through facilitated discussions and group exercises, participants validated and refined the vision statement for the Hub of Talents initiative, identified priority research areas and applications for Thailand, and proposed potential projects and initiatives to advance plasma technology. A second workshop involved 50 participants and focused on developing the structure and content of the roadmap. Activities included defining key milestones and timelines for priority research areas, mapping required infrastructure and human resource development, and identifying potential funding sources and policy support needed. Both workshops employed participatory methods such as small group discussions, plenary sessions, and voting exercises to build consensus around roadmap priorities. This collaborative approach ensured that the resulting roadmap reflected a broad range of stakeholder perspectives and priorities.

Roadmap Development and Validation

Based on inputs from the literature review, expert interviews, and stakeholder workshops, a draft roadmap was developed by the core project team. This draft was then circulated to key stakeholders for feedback and refinement through an iterative process.

A final validation workshop was later held to review and approve the roadmap structure, content, and implementation plan. This ensured broad stakeholder buy-in for the final roadmap.

Results and discussion.

The resulting roadmap provides a strategic framework to guide plasma technology development in Thailand over the next 5 years (2024-2028). Key elements of the roadmap are presented below.

Vision and Objectives

Vision
"Thailand as the ASEAN hub for high-level talent in plasma technology"

Objectives

1. To create a collaborative network of plasma technology experts, positioning Thailand as a leader in the field within ASEAN.
2. To drive the application of plasma technology to address key national and regional challenges.
3. To promote and stimulate greater utilization of plasma technology in Thailand and ASEAN.
4. To elevate the role and visibility of Thai plasma technology research and innovation internationally.

Priority Areas and Projects

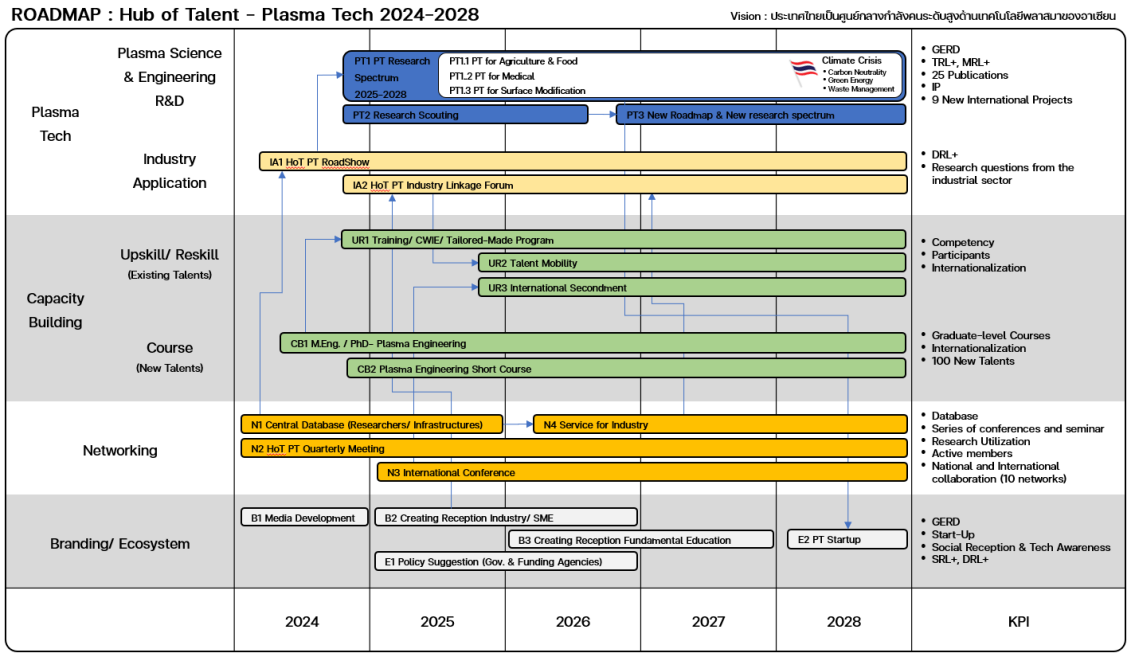

Figure 7. Thailand hub of talents - plasma technology roadmap.
Note: Created by author

The roadmap (see Figure 7.) is structured around six interconnected priority areas, each with specific projects and initiatives:

(PT) Plasma Science and Technology R&D

PT1: Elevating research across the plasma technology spectrum (see Figure 8.)

- Aims to enhance research capabilities across different plasma technology applications.
- Includes funding support for research projects and equipment upgrades.
- Focuses on agriculture, medicine, and surface modification applications.

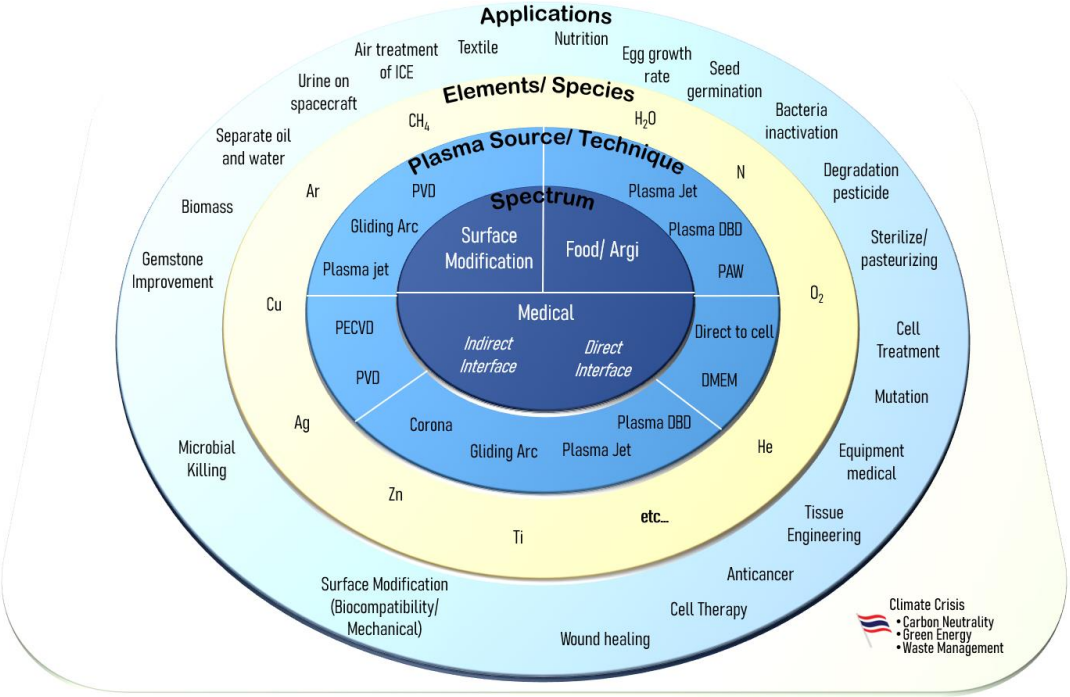

Figure 8. Thailand hub of talent - plasma technology spectrum mapping.
Note: Created by author

PT2: Future technology exploration and scanning

- Involves systematic monitoring of emerging plasma technologies globally.
- Includes scenario planning workshops to identify promising future directions.
- Aims to keep Thailand at the forefront of plasma technology developments.

PT3: Roadmap development and new research spectrum identification

- Periodic review and updating of the plasma technology roadmap.
- Identification of new research areas based on global trends and local strengths.
- Ensures alignment of research priorities with national needs and capabilities.

(IA) Industrial Applications

IA1: Hub of Talent Roadshow

- Mobile exhibitions and seminars to showcase plasma technology applications.
- Targets industrial clusters across Thailand to raise awareness.
- Includes live demonstrations of plasma technology equipment.

IA2: Industry Forum

- Regular meetings between researchers and industry representatives.

- Platform for discussing industry needs and research capabilities.
- Aims to foster collaborative R&D projects.

(UR) Upskilling/Reskilling of Existing Talent

UR1: Training programs / Cooperative and Work-Integrated Education

- Short courses and workshops for industry professionals on plasma technology.
- Cooperative education programs placing students in industry for hands-on experience.
- Aims to bridge the gap between academic knowledge and practical skills.

UR2: Talent Mobility to Industry

- Program to place academic researchers in industry for short-term projects.
- Facilitates knowledge transfer and practical application of research.
- Helps align academic research with industry needs.

UR3: International Talent Mobility

- Exchange programs with leading international plasma technology institutions.
- Includes both outgoing Thai researchers and incoming foreign experts.
- Aims to elevate Thai expertise to international standards.

(CB) Capacity Building for New Talents

CB1: Development of graduate programs in plasma technology

- Establishment of specialized Master's and PhD programs in plasma science and engineering.
- Curriculum development in collaboration with industry partners.
- Aims to create a pipeline of highly skilled plasma technology specialists.

CB2: Development of short courses in plasma technology

- Modular, intensive courses on specific plasma technology applications.
- Targets both students and working professionals.
- Flexible delivery including online and blended learning options.

(N) Networking

N1: Database of research, researchers, and infrastructure

- Comprehensive online database of plasma technology resources in Thailand.
- Includes researcher profiles, publications, patents, and available equipment.
- Facilitates collaboration and efficient use of resources.

N2: Quarterly meetings of Hub of Talent

- Regular gatherings of plasma technology researchers and stakeholders.
- Includes research presentations, discussions, and networking opportunities.
- Aims to foster a strong community of practice in plasma technology.

N3: International conferences and workshops

- Hosting of international plasma technology conferences in Thailand.
- Organization of specialized workshops with leading global experts.
- Positions Thailand as a key player in the international plasma technology community.

N4: Development of service platform for industry

- Online platform connecting industry with plasma technology expertise and services
- Includes equipment booking, consulting services, and collaborative project matching
- Aims to lower barriers for industry adoption of plasma technology

(BE) Branding and Ecosystem Development

B1: Development of promotional media

- Creation of high-quality multimedia content showcasing Thai plasma technology capabilities.
- Includes videos, infographics, and interactive online materials.
- Targets both domestic and international audiences.

B2: Raising awareness in industry

- Targeted campaigns to educate specific industry sectors on plasma technology applications.
- Includes case studies, ROI analyses, and sector-specific demonstrations.
- Aims to drive adoption of plasma technology in Thai industries.

B3: Public awareness campaigns

- General public outreach to build understanding and support for plasma technology.
- Includes school programs, science museum exhibitions, and media partnerships.
- Aims to inspire the next generation of plasma technology researchers and innovators.

E1: Policy recommendations and research funding proposals

Development of evidence-based policy briefs for government stakeholders

- Preparation of funding proposals for large-scale plasma technology initiatives.
- Aims to create a supportive policy and funding environment for plasma technology development.

E2: Plasma technology startups

- Incubator program for plasma technology startups.
- Provides mentoring, seed funding, and access to research infrastructure.
- Aims to commercialize plasma technology innovations and create new industries.

Key Performance Indicators

To track progress and impact, the roadmap includes the following key performance indicators (KPIs) to be achieved over the 5-year period:

- 25 publications in Q1-Q2 journals (Scopus or ISI indexed).
- 9 new international grant proposals submitted.
- 3 new graduate programs focused on plasma technology.
- 15 faculty/researchers collaborating with industry annually.
- 100 new researchers/engineers/technicians/innovators trained.
- 10 new national and international network partnerships established.
- 2 cases of shared use of plasma research infrastructure in year 1.
- 2 follow-on research grants secured after project completion in year 1.
- 1 networking event (conference/seminar) organized in year 1.
- 1 billion THB economic impact from commercialization of plasma technology research by 2032.
- New plasma technology startups supported.

Implementation Timeline and Budget

The roadmap outlines a phased implementation approach over 5 years, with a total proposed budget of 160 million THB. Key phases include:

2024-2025: Establishing foundations

- Launch graduate programs and short courses.
- Develop researcher/infrastructure database.
- Initiate regular Hub of Talent meetings.

2025-2026: Expanding activities

- Begin industry engagement (roadshows, forums).
- Launch talent mobility programs.
- Organize international conferences.

2027-2028: Accelerating impact

- Conduct future technology scanning.
- Develop service platform for industry.
- Support plasma technology startups.

Discussion

The Hub of Talents Plasma Technology Roadmap represents a significant step towards coordinating and focusing Thailand's efforts in this emerging field. Several key aspects of the roadmap and its development process merit further discussion:

Balancing Basic and Applied Research

The roadmap aims to strike a balance between advancing fundamental plasma science and promoting industrial applications. This reflects the current state of plasma technology globally, where breakthroughs in basic understanding continue to enable new applications (Adamovich et al., 2017). For Thailand, maintaining strength in foundational research while accelerating technology transfer will be crucial to long-term competitiveness.

Human Capital Development Focus

A strong emphasis on human capital development is evident throughout the roadmap, from graduate programs to industry mobility schemes. This aligns with findings from other national plasma technology initiatives, which have identified skilled workforce development as a key enabler. The challenge will be ensuring that the skills developed match evolving industry needs.

Regional Positioning

The vision of becoming an ASEAN hub for plasma technology expertise is ambitious but potentially achievable given Thailand's existing research base. However, this will require careful positioning relative to other countries in the region investing in similar capabilities, such as Singapore and Malaysia. Cultivating unique strengths and fostering regional collaboration will be important strategies.

Implementation Challenges

While the roadmap provides a comprehensive framework, successful implementation will face several challenges:

- Securing sustained funding across multiple agencies and budget cycles.
- Maintaining stakeholder engagement and commitment over the 5-year period.

- Adapting to rapid technological changes and emerging application areas.
- Overcoming potential institutional silos and fostering genuine collaboration.

Addressing these challenges will require strong governance mechanisms and regular review and adjustment of the roadmap.

Implications of Priority Areas

The six priority areas identified in the roadmap have significant implications for Thailand's plasma technology development:

- Plasma Science and Technology R&D (PT): The emphasis on foundational research alongside industrial applications reflects a strategic balance crucial for long-term competitiveness. This dual focus could enable Thailand to both contribute to global plasma science advancement and develop locally relevant applications. However, success will require sustained funding and research infrastructure development.
- Industrial Applications (IA): The focus on industry engagement through roadshows and forums addresses a critical gap in technology transfer. These initiatives could accelerate the adoption of plasma technology in Thai industries, particularly in sectors like electronics and agriculture where Thailand has existing strengths. The success of these programs could directly impact economic outcomes and industry competitiveness.
- Upskilling/Reskilling (UR): The comprehensive approach to talent development, combining domestic training with international mobility, could create a multiplier effect in building Thailand's plasma technology capabilities. This could lead to the formation of a self-sustaining ecosystem of expertise, though careful attention must be paid to retention of trained personnel.
- Capacity Building (CB): The development of specialized graduate programs could establish Thailand as a regional education hub for plasma technology. This could have long-term implications for ASEAN regional leadership in this field, while addressing critical workforce needs.
- Networking (N): The emphasis on both domestic and international networking could position Thailand as a connector in the global plasma technology community. This could facilitate knowledge transfer and research collaboration, though maintaining active networks will require ongoing effort and resources.
- Branding and Ecosystem Development (BE): The focus on ecosystem development could help create a sustainable foundation for plasma technology innovation. However, success will depend on effective coordination among multiple stakeholders and sustained policy support.

Study Limitations

Several limitations of this study should be acknowledged:

- Long-term Forecasting: The rapid pace of technological change makes it challenging to predict plasma technology evolution beyond the 5-year timeframe, particularly in emerging application areas.
- Resource Assumptions: The roadmap's implementation relies on assumptions about available funding and resources that may need adjustment based on changing economic conditions.
- Regional Context: While the roadmap aims to position Thailand within ASEAN, input from regional stakeholders was limited, which may affect the comprehensiveness of regional considerations.
- Implementation Challenges: The study primarily focuses on strategic planning rather than detailed implementation mechanisms, which may need further development.

Conclusion

The Hub of Talents Plasma Technology Roadmap represents a pioneering initiative that goes beyond traditional technology roadmapping by integrating human capital development with technological advancement. This novel approach recognizes that sustainable technological leadership requires not just research and infrastructure, but also a robust talent ecosystem. By explicitly linking talent development to technological progress, the roadmap offers an innovative model that could be valuable for other emerging economies seeking to develop advanced technology capabilities.

The roadmap's unique contribution lies in several aspects. First, it demonstrates how a middle-income country can strategically position itself in an advanced technology field through careful alignment of research, industry, and human capital development. Second, it provides a framework for regional leadership that balances national capability building with international collaboration. Third, it introduces a comprehensive stakeholder engagement model that could be adapted for other technology development initiatives.

While the roadmap provides a strategic framework for the next five years, its impact could extend well beyond this timeframe and beyond Thailand's borders. The emphasis on creating self-sustaining ecosystems rather than just technological capabilities suggests potential long-term effects on Thailand's innovation capacity. Moreover, the roadmap's approach to building regional leadership through talent development rather than just technological advancement offers insights for other countries seeking to establish themselves in emerging technology fields.

Future Research Directions

Several important areas for future research emerge from this work:

- Impact Assessment: Longitudinal studies tracking the implementation and impact of the roadmap's various initiatives, particularly measuring the development of human capital and industry adoption of plasma technology.
- Comparative Analysis: Systematic comparison of this roadmap with plasma technology development strategies in other emerging economies, particularly examining different approaches to talent development and ecosystem building.
- Policy Implementation: Research into the effectiveness of various policy instruments and support mechanisms in promoting plasma technology development and adoption.
- Regional Integration: Studies examining how regional collaboration in plasma technology develops and its impact on ASEAN technological capabilities.
- Ecosystem Development: Investigation of the dynamics between various stakeholders in the plasma technology ecosystem and how these relationships evolve over time.

These future research directions could provide valuable insights for both policy makers and practitioners involved in technological development initiatives, while contributing to our understanding of how emerging economies can successfully develop capabilities in advanced technology fields.

The success of this roadmap will ultimately depend on sustained commitment from all stakeholders and effective coordination of various initiatives. However, by providing a comprehensive framework that addresses both technological and human capital aspects of development, it represents a significant step toward establishing Thailand as a leader in plasma technology within the ASEAN region. The approach taken here may also serve as a model for other countries seeking to develop capabilities in emerging technologies while building sustainable innovation ecosystems.

Acknowledgement

This work was supported by the Supply Chain and Engineering Management Research Unit, Chiang Mai University.

Bibliographic references

Adamovich, I., Baalrud, S. D., Bogaerts, A., Bruggeman, P. J., Cappelli, M., Colombo, V., ... & Vardelle, A. (2017). The 2017 Plasma Roadmap: Low temperature plasma science and technology. *Journal of Physics D: Applied Physics*, *50*(32), 323001.

Adamovich, I., Agarwal, S., Ahedo, E., Alves, L.L., Baalrud, S., Babaeva, N., Bogaerts, A., Bourdon, A., Bruggeman, P.J., Canal, C., & Choi, E.H. (2022). The 2022 Plasma Roadmap: low temperature plasma science and technology. *Journal of Physics D: Applied Physics*, *55*(37), 373001.

Amer, M., & Daim, T. U. (2010). Application of technology roadmaps for renewable energy sector. *Technological Forecasting and Social Change*, *77*(8), 1355-1370.

Asimiyu, Z. (2024). *Towards a Sustainable Tomorrow: Roadmapping Innovations in Information Technology and Biotechnology*. [File PDF]. Retrieved from https://acortar.link/HfcRAa

Batani, D., Colaïtis, A., Consoli, F., Danson, C.N., Gizzi, L.A., Honrubia, J., Kühl, T., Le Pape, S., Miquel, J.L., Perlado, J.M., & Scott, R.H.H. (2023). Future for inertial-fusion energy in Europe: a roadmap. *High Power Laser Science and Engineering*, *11*, 83.

Buaruk, S., Makmool, T., Promping, J., Onjun, T., Sangaroon, S., Wisitsorasak, A., Garcia, J., & Chatthong, B., (2019). Comparisons of the plasma performance of future thailand tokamak using various external heating schemes. *Plasma and Fusion Research, 14*, 3403153-3403153.

Carter, T., Baalrud, S., Betti, R., Ellis, T., Foster, J., Geddes, C., Gleason, A., Holland, C., Humrickhouse, P., Kessel, C., & Lasa, A. (2020). *Powering the future: Fusion & plasmas.* US Department of Energy (USDOE), Washington, DC (United States). Office of Science.

Chu, P. K., & Lu, X. (Eds.). (2013). *Low temperature plasma technology: Methods and applications.* CRC Press.

Chutsirimongkol, C., Boonyawan, D., Polnikorn, N., Techawatthanawisan, W., Kundilokchai, T., Bunsaisup, C., Rummaneethorn, P., Kirdwichai, W., Chuangsuwanit, A., & Powthong, P. (2016). Non-thermal atmospheric dielectric barrier discharge plasma, medical application studies in Thailand. *Plasma Medicine*, *6*(3-4).

Kostoff, R. N., & Schaller, R. R. (2001). Science and technology roadmaps. *IEEE Transactions on Engineering Management*, *48*(2), 132-143.

Laoharojanaphand, S., Cherdchu, C., Sumitra, T., Sudprasert, W., Chankow, N., Tiyapan, K., Onjun, T., & Bhanthumnavin, D. (2016). The recent status of nuclear technology development in Thailand. *E-Journal of Advanced Maintenance*, *15*(2), 21-27.

Laucht, A., Hohls, F., Ubbelohde, N., Gonzalez-Zalba, M.F., Reilly, D.J., Stobbe, S., Schröder, T., Scarlino, P., Koski, J.V., Dzurak, A., & Yang, C.H. (2021). Roadmap on quantum nanotechnologies. *Nanotechnology*, *32*(16), 162003.

Li, X., Zhou, Y., Xue, L., & Huang, L. (2015). Integrating bibliometrics and roadmapping methods: A case of dye-sensitized solar cell technology-based industry in China. *Technological Forecasting and Social Change*, *97*, 205-222.

Luo, Y., Abidian, M.R., Ahn, J.H., Akinwande, D., Andrews, A.M., Antonietti, M., Bao, Z., Berggren, M., Berkey, C.A., Bettinger, C.J., & Chen, J. (2023). Technology roadmap for flexible sensors. *ACS nano*, *17*(6), 5211-5295.

MHESI. (2021). *National Science, Technology and Innovation Policy and Plan (2023-2027)*. Ministry of Higher Education, Science, Research and Innovation, Thailand. Retrieved from https://waa.inter.nstda.or.th/stks/pub/2022/20221223-Thailand_SRI_Plan_5_Years_[2023-2027]_Complete_Edition.pdf

NSTDA. (2022). *NSTDA Annual Report 2021.* National Science and Technology Development Agency, Thailand. Retrieved from https://www.nstda.or.th/en/images/Printed-Media/ENG_Annual2021.pdf

Nordlund, K.H. (2018). *European research roadmap to the realisation of fusion energy*. EUROFUSION.

Phaal, R., Farrukh, C. J., & Probert, D. R. (2004). Technology roadmapping—a planning framework for evolution and revolution. *Technological Forecasting and Social Change*, *71*(1-2), 5-26.

Phaal, R., & Muller, G. (2009). An architectural framework for roadmapping: Towards visual strategy. *Technological Forecasting and Social Change*, *76*(1), 39-49.

Quyen, N.T., Traikool, T., Nitisoravut, R., & Onjun, T. (2017). Improvement of water quality using dielectric barrier discharge plasma. *In Journal of Physics: Conference Series* (Vol. 860, No. 1, 012031). IOP Publishing.

Ramingwong, S., Sopadang, A., Anantana, T., Sinthavalai, R., & Santiteerakul, S. (2024). Industrial research and development capacity building. *Amazonia Investiga*, *13*(81), 9-23. https://doi.org/10.34069/AI/2024.81.09.1

Ruamrungsri, S., Sawangrat, C., Panjama, K., Sojithamporn, P., Jaipinta, S., Srisuwan, W., Intanoo, M., Inkham, C., & Thanapornpoonpong, S.N. (2023). Effects of using plasma-activated water as a nitrate source on the growth and nutritional quality of hydroponically grown green oak lettuces. *Horticulturae*, *9*(2), 248.

Sarinont, T., Amano, T., Attri, P., Koga, K., Hayashi, N., & Shiratani, M. (2016). Effects of plasma irradiation using various feeding gases on growth of Raphanus sativus L. *Archives of Biochemistry and Biophysics*, *605*, 129-140.

Tippayawong, N., & Khongkrapan, P. (2009). Development of a laboratory scale air plasma torch and its application to electronic waste treatment. *International Journal of Environmental Science & Technology*, *6*, 407-414.

Wiboonsak, S., Lohawet, K., Duong, B.A.T., Kumnorkaew, P., & Koetniyom, W. (2018). Simple ITO surface treatments induced better performance for low cost organic solar cells. *Chiang Mai Journal of Science*, *45*, 2178-2189.

Wisitsorasak, A., Shimizu, A., Sangaroon, S., Ogawa, K., Chatthong, B., Suksaengpanomrung, S., Tamman, A., Poolyarat, N., & Isobe, M. (2024). Feasibility study of a Heavy Ion Beam Probe for the Thailand Tokamak-1. *Fusion Engineering and Design*, *198*, 114068.

Wongsawaeng, D., Khemngern, S., & Somboonna, N. (2017). Environmentally-friendly RF plasma treatment of thai silk fabrics with chitosan for durable antibacterial property. *Engineering Journal*, *21*(1), 29-43.