Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

From academic research to industrial application: a model of applied innovation for the energy sector.

From academic research to industrial application: An applied innovation model for the energy sector

From academic research to industrial application: a model of applied innovation for the energy sector

Marina Seixas Pereira
Federal University of Uberlândia

Summary

This article proposes MIA-Energia, a conceptual model of applied innovation, designed to organize the transition of energy technologies from academic research to industrial environments. The problem investigated is the loss of continuity that often occurs between proof of concept, demonstration at a relevant scale, and investment decision. The research adopts a qualitative and exploratory approach, supported by a narrative and documentary review of scientific literature, technical standards, and institutional reports published up to 2025. The synthesis articulates the Triple Helix, Open Innovation, Pasteur's Quadrant, Technological Maturity Levels, and techno-economic evaluation. The resulting model comprises four movements: joint definition of the problem; co-development and validation in a relevant environment; integrated evaluation of performance, risks, and costs; preparation for demonstration and scaling. MIA-Energia is not presented as an empirically validated method, but as an analytical framework amenable to testing. It is concluded that explicit progression criteria, early participation of industrial users, and documentation of uncertainties can improve the quality of decisions, provided that the model is adapted to the technological context and subjected to...

prospective evaluation.
Keywords: energy innovation; technology transfer; technological maturity; biomass; techno-economic evaluation.

Abstract

This article proposes MIA-Energia, a conceptual applied innovation model designed to organize the transition of energy technologies from academic research to industrial environments. The study addresses the discontinuity that often arises between proof of concept, demonstration at a relevant scale, and investment decisions. It adopts a qualitative and exploratory approach based on a narrative and documentary review of scientific literature, technical standards, and institutional reports published through 2025. The synthesis combines the Triple Helix, Open Innovation, Pasteur's Quadrant, Technology Readiness Levels, and techno-economic assessment. The resulting model comprises four movements: joint problem definition; co-development and validation in a relevant environment; integrated assessment of performance, risks, and costs; and preparation for demonstration and scale-up. MIA-Energia is not presented as an empirically validated method, but as an analytical framework to be tested.

The article concludes that explicit progression criteria, early participation of industrial users, and documentation of uncertainty may improve decision quality, provided that the model is adapted to each technological context and prospectively evaluated.
Keywords: energy innovation; technology transfer; technology readiness; biomass; techno-economic assessment.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

1. Introduction

The energy transition depends not only on the availability of technical solutions. It also requires that the knowledge produced in universities and research centers cross The stages of validation, demonstration, financing, and industrial incorporation. This passage is... particularly demanding in capital-intensive sectors, where failures of scale can compromising safety, operational continuity, and economic return. The problem, therefore, is not simply about discovering a promising technology. It is necessary to build sufficient evidence to decide when to move forward, redesign, or discontinue the development (IEA, 2020; IRENA, 2023; MARKARD, 2018).

The literature on socio-technical transitions shows that profound changes result from interaction between technology, infrastructure, regulation, organizational behavior and Markets. Isolated innovations rarely alter energy systems without networks of actors. capable of testing, funding, and integrating them into existing practices. This helps explain why that the scientific quality of a discovery does not guarantee its adoption and why technologies with Similar laboratory performance can lead to very different industrial trajectories. (GEELS et al., 2017; MARKARD, 2018).

The challenge becomes apparent when a technology leaves the proof-of-concept phase, but still... does not have sufficient operational history, scale, or economic predictability to receive Implementation investments. The expression "Valley of Death" describes this period, although its Limits vary depending on the sector and type of project. In energy and chemical processes, plants Pilot and demonstration units play a crucial role, as they allow us to observe phenomena that They are not fully manifested in benchtop settings, such as thermal integration, variability of raw materials, maintenance, reliability and equipment behavior (HELLSMARK et al., 2016).

The investment context reinforces the relevance of this discussion. The International Agency of The Energy Ministry estimated that global investment in energy would reach US$3.3 trillion in 2025. Of that total, approximately US$2.2 trillion would be allocated to energy technologies. Clean, double the amount projected for oil, natural gas, and coal. The expansion of capital, However, this does not eliminate the need to select technically sound projects and economically defensible (IEA, 2025).

This article aims to propose a conceptual framework to support this selection and To organize cooperation between research and industry. MIA-Energia brings together contributions from

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

innovation management and process engineering, without claiming universal validity or results not yet observed. The guiding question is: how does a model Governance can be linked to technological maturity, experimental evidence, and evaluation. economic and institutional responsibility in the transition from energy research to Industrial application?

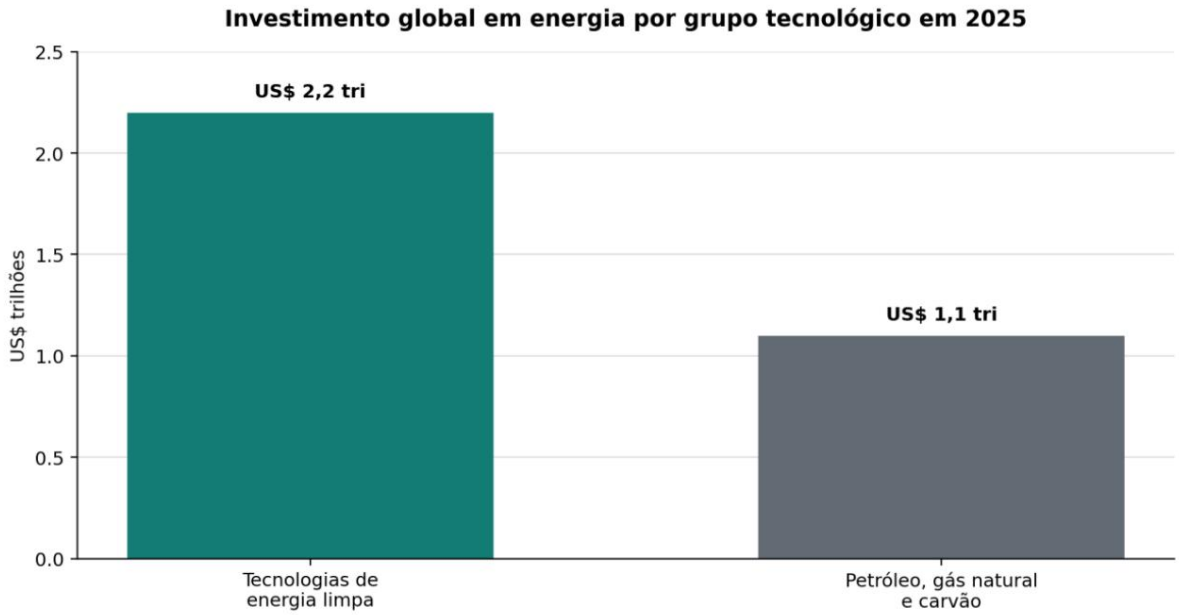

Chart 1: Global investment in energy by technology group in 2025

Source: compiled by the author using data from the International Energy Agency and World Energy. Investment 2025. Estimated values for 2025.

2 Methodology

The research is qualitative, exploratory, and propositional in nature. The work was developed as a narrative and documentary review, suitable for integrating concepts from distinct fields and the formulation of an analytical framework. This is not a systematic review, meta-analysis or bibliometric study. For this reason, the article does not present the flowchart. PRISMA, the total number of records retrieved, nor quantitative inferences about the The body of literature.

The selection of documents was intentional and guided by relevance to five themes: interaction between university, industry and government; application-oriented research; open innovation and Technology transfer; maturity, demonstration and scaling; energy transition. biomass and techno-economic evaluation. Seminal works necessary for Definition of the most recent concepts and publications, up to 2025, capable of updating the context.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

energy and institutional.

The corpus combines peer-reviewed articles, reference books, standards, and reports.
Organizations with technical or regulatory responsibility. Institutional sources include...
the International Energy Agency, the International Renewable Energy Agency, the Panel
Intergovernmental Panel on Climate Change, the Energy Research Company and the Agency
National Institute of Petroleum, Natural Gas and Biofuels. The presence of institutional documents.
This stems from the need to address investments, public policies, energy matrix, and regulations.
Research and development based on primary data.

The analysis took place in three stages. First, recurring problems were identified.
Coordination, maturity, financing, scale, and risk assessment. Next, the concepts...
They were compared and organized according to the moment in which they influence the trajectory.
technological. Finally, these elements were synthesized into four movements of the MIA-
Energy. The model's propositions were drafted as analytical recommendations, not as
Proven results.

The main methodological limitation lies in the conceptual nature of the research. They were not
Interviews, plant observations, experiments, contract analyses, or studies were carried out.
The article also does not estimate causality between the adoption of the case study with primary data.
The model and the results regarding cost, time, or performance. Validation will depend on applications.
future developments in real-world projects, accompanied by a prospective protocol, and indicators previously established.
defined and auditable documentation.

3. The transition from science to industrial application.

The relationship between knowledge and application does not follow an automatic sequence. Rosenberg
(1982) showed that innovation is characterized by learning, feedback and problem-solving.
of problems during development. Stokes (1997), in formulating Pasteur's Quadrant,
He also questioned the rigid separation between basic science and applied research.
Research can seek fundamental understanding and, at the same time, be guided by a
usage problem. This combination is relevant for energy technologies, in which the
Research decisions need to consider operating conditions from the outset.

The concept of Open Innovation broadened this understanding by recognizing that organizations utilize...
internal and external knowledge to accelerate development and explore different
market pathways (CHESBROUGH, 2003). In the energy sector, this principle can

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

take the form of cooperative projects, licensing, consortia, joint centers and
contracting specialized infrastructure. Opening up, however, does not eliminate the need for
Governance. Intellectual property, confidentiality, publication and liabilities.
Techniques should be agreed upon according to the stage of the project.
The Technological Maturity Levels offer a common language for discussing the
Evolution of a technology. Scale does not measure scientific merit, profitability, or impact.
environmental; describes the maturity achieved in a given application context. Mankins
(2009) emphasizes that the evaluation depends on the definition of the system, the requirements and the environment.
Relevant. Using TRL as a generic rating, without recording the evidence that justifies each level,
It reduces its usefulness.

Pilot and demonstration plants occupy a strategic position in this process. They produce
technical knowledge, but they also allow for coordination between suppliers, operators,
researchers, funders and regulators. Hellsmark et al. (2016) show that these
Facilities can fulfill distinct functions throughout development and learning.
A technique for network formation and uncertainty reduction. Its value should not be assessed solely
based on nominal capacity or immediate revenue generation.
The transition to industrial scale therefore requires a documented sequence of questions.
Was the relevant phenomenon reproduced outside the test bench? The mass and energy balances
Do they close under representative conditions? Does the product quality meet its intended use?
Have safety risks been assessed? Are there resources, maintenance, and waste disposal procedures in place?
Are they compatible with the operation? MIA-Energia starts with these questions to prevent the
Scientific maturity should not be confused with industrial readiness.

4 Institutional cooperation and governance

The Triple Helix model describes innovation as a result of the interactions between
University, industry, and government, whose functions may overlap without becoming identical.
(ETZKOWITZ; LEYDESDORFF, 2000). Universities contribute with research, training
and infrastructure; companies bring operational requirements, market access, and capacity to
Implementation; governments regulate, finance, and define public priorities. Cooperation is
Productive when these differences are recognized and transformed into responsibilities.
clear.

In Brazil, the oil and gas sector has a specific mechanism for inducing research by

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

through the investment clause in Research, Development and Innovation foreseen in certain contracts. ANP Resolution No. 918/2023 governs the application of these resources. It defines conditions for projects and implementing institutions. It is not an obligation. uniform for all energy companies, nor an automatic allocation to them. universities. The framework depends on the contracts and rules in force (ANP, 2023).

The governance of a collaborative project should be proportional to the risk. In the initial phases, the Agreements can focus on scientific issues, access to data, and defining ownership of results. As the project progresses, plans become necessary to... safety, acceptance criteria, change control, equipment responsibilities and decisions regarding escalation. ABNT NBR ISO 56002 provides guidelines for escalation systems. innovation management, but it does not replace specific technical standards nor does it determine a single one. development process (ABNT, 2020).

Defining publication and intellectual property rights in advance reduces conflicts. provided that it doesn't turn the project into an inflexible structure. Embargo periods, forms of Licensing and profit sharing should be negotiated according to the nature of the... Technology, the contribution of each party, and applicable legislation. The MIA-Energia does not set a universal deadline for these decisions. It only requires that sensitive information or Significant investments should be recorded before they are committed.

Another element is the independence of the evaluation. The team responsible for the technology has in-depth knowledge, but also a legitimate interest in its continuity. Reviews External techniques, with known criteria, can reduce biases and improve decision-making. decision. This does not mean removing autonomy from researchers. It means separating the production evidence of authorization to undertake new capital commitments, especially when the Demonstration involves operational or environmental risks.

5 Biomass in the context of the energy transition

Biomass occupies a relevant position in the energy debate because it can provide electricity. Heat, fuels, and carbon molecules are used in the production of chemicals. In Brazil, Experience with sugarcane, agro-industrial waste, and bioenergy has created skills. scientific and productive accumulated over decades (FURTADO; SCANDIFFIO; CORTEZ, 2011; EPE, 2025). This history, however, does not authorize treating every route based on biomass as a sustainable or economically viable option.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

The climate performance of bioenergy depends on its life cycle. Origin of the raw material, land use change, fertilizers, transport, conversion, co-products and time horizon They alter the emissions balance. For this reason, the expression "carbon neutrality" should not be used. to be applied automatically. The IPCC recognizes the potential contribution of bioenergy, but It also highlights its limitations, risks, and the differences between production systems (IPCC, 2022).

The concept of a biorefinery aims to utilize different fractions of biomass to produce energy. fuels, materials, and chemicals. The integration of streams can expand the Utilizing resources and distributing revenue among products of different values. (CHERUBINI, 2010). Viability, however, depends on the stability of supply, on composition of raw materials, demand for products, water and energy consumption and regarding the disposal of the waste.

Thermochemical routes, such as pyrolysis and gasification, are being studied to convert biomass. in gases, liquids, and energetic solids. In the case of fast pyrolysis, temperature control, Residence time, heat transfer, and food quality influence the The yield and properties of bio-oil. The upgrading step may require hydrogen. Catalysts and additional treatment are factors that should be integrated into the analysis from the outset. (BRIDGWATER, 2012).

The function of the proposed model is not to pre-select a route. The MIA-Energia organizes The comparison between alternatives requires that the technical benefits be examined. along with the environmental impacts, costs, and implementation conditions. One Technology with high benchtop performance may lose its appeal in the face of logistical challenges. biomass or the need for pretreatment. Another, less efficient conversion method, may To provide greater operational robustness, the decision must reflect the entire system.

6. Scaling and technical-economic evaluation

Scaling up chemical processes doesn't consist of multiplying geometric dimensions. Changes in volume alter the relationships between area and capacity, mixing, and heat transfer. and mass, residence time, and control. Heterogeneous raw materials exhibit variation. moisture, density, ash content, and contaminants. Therefore, bench data should to be accompanied by explicit hypotheses about behavior on a larger scale.

The techno-economic evaluation allows relating experimental performance to investments, operating costs, and product value. It is most useful when

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

It follows the development process, rather than appearing only in the final report. In the initial phases,
The results present significant uncertainty and should be expressed in ranges, scenarios, and...
Sensitivity analyses. Overly precise numbers can create a false sense of security.
Indicators such as levelized cost of energy, minimum selling price, and net present value.
They depend on financial assumptions, scale, capacity factor, useful life, input prices, and...
of regulatory conditions. The appropriate indicator varies depending on the technology and the decision.
Comparisons are only valid when they utilize system boundaries, currency, base year, and assumptions.
compatible. MIA-Energia requires that these assumptions remain aligned with the outcome.
presented.
Environmental assessment should proceed in conjunction with economic assessment. Gains in a
This stage can shift impacts to another, such as increased hydrogen consumption, of
electricity or transportation. Life cycle analyses help to identify these.
Transfers, but they also depend on methodological choices. The goal is not to produce
It's not about a single, indisputable number, but rather understanding which variables alter the conclusion and where.
Additional data is more valuable.

The proposed decision points should cover three possibilities: move forward, reformulate, or
Interruption. Interruption does not necessarily represent scientific failure. In projects
In capital-intensive sectors, identifying a mismatch early can preserve resources and guide...
new questions. For this learning to be effective, the reasons for the decision need to be understood.
to be documented, including evidence, uncertainties, and conditions that allow for reassessment of the route.
in the future.

7 MIA-Energy Structure

The first step of MIA-Energia is the joint definition of the problem. The team records
the industrial need, the solution user, the application environment, the constraints
regulatory requirements and minimum expected performance. It also distinguishes between mandatory requirements.
and desirable attributes. This step reduces the risk of developing a technically flawed solution.
Interesting for a problem that is not a priority, lacks infrastructure, or clearly lacks demand.
identified.

The second step is co-development and validation in a relevant environment.
Researchers maintain the scientific approach, while operational and safety professionals...
Engineering and design contribute to real-world usage conditions. The division of functions is not fixed by TRL.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

It depends on the skills required for each task. Advancement requires evidence.
Experimental testing, data traceability, failure analysis, and defining the next test.
The third movement brings together performance evaluation, risk, environment, and economics. The data
Experimental experiments provide data for balance sheets, scale estimates, and financial scenarios. The uncertainties
They are classified according to their influence on the decision. When a given variable
The outcome is what dominates; the project should prioritize measuring it before scaling up. This logic
It brings research closer to the value of information, avoiding essays that add data but do not
They reduce decisional uncertainty.

The fourth movement prepares for demonstration and scaling. In this phase, governance incorporates the...
operation, maintenance, supply, quality, safety, licensing and plans
Test termination. The project must define in advance what constitutes success.
inconclusive result or need for reformulation. The demonstration ceases to be a
It's a technological showcase that becomes an industrial experiment with verifiable objectives.
The four movements are iterative. An economic evaluation may reveal the need for
Change the product; a test in a relevant environment can redefine the industrial requirement; a
Regulatory change may require a new process design. The MIA-Energia does not eliminate
These revisions. He seeks to make them visible and documented. His contribution lies in...
integrating questions that are frequently handled by separate teams and at different times.
disconnected.

8. Validation Agenda and Indicators

The MIA-Energia assessment should begin with prospective studies. Participating projects
They can record their initial level of maturity, critical hypotheses, progression criteria, and...
Indicators should be kept before applying the model. This precaution prevents success from being predetermined.
retrospectively. The comparison can be made with previous projects from the same organization.
or with initiatives driven by different processes, respecting technological differences.
Process indicators include the time between decisions and the proportion of critical hypotheses.
tested, the completeness of the documentation, user participation, and the number of
Well-founded reformulations. Technical indicators can monitor stability.
Operational indicators include balance sheets, product quality, and maturity evolution.
Economic indicators should record cost and sensitivity ranges, not just point values.
The results of technology transfer require a longer-term perspective. Licensing,

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

adoption, subsequent investment, continued partnerships, and skills development can
Changes should be observed, but should not be automatically attributed to the model.
Market factors, prices, regulation, and business strategy also influence the trajectory. The analysis
You need to distinguish between association and causality.
Transparency is essential. Projects subject to confidentiality can be published.
Protocols, indicator categories, and aggregated results without revealing trade secrets.
The important thing is to allow the evaluators to understand how the decisions were made.
Without this documentation, the model risks becoming just a new name.
for existing practices.
Validation across different domains is also necessary. Biomass, hydrogen, energy capture
Carbon, storage, and digitization present risks and development timelines.
distinct. A useful model should preserve common principles and allow for adaptations. Studies
Future researchers should investigate which components remain stable and which are sector-dependent.
and under what conditions does the structure effectively improve the quality of decisions.

Conclusion

The transition from academic research to industrial application is a production problem.
evidence and coordination. In energy technologies, the difficulty increases because the
Demonstrations require capital, infrastructure, security, and integration with systems.
existing. Scientific excellence is a necessary but not sufficient condition for readiness.
industrial.

The literature reviewed allows us to understand this journey without reducing innovation to a single...
Linear sequence. Pasteur's Quadrant brings research and use closer together; the Triple Helix
It situates institutional interaction; Open Innovation explains the circulation of knowledge; TRLs
They organize the discussion about maturity; and the techno-economic evaluation relates to...
Performance in relation to scaling decisions.

The synthesis of these elements resulted in MIA-Energia, structured around the definition of the problem,
Co-development, integrated evaluation, and preparation for demonstration. The model proposes that
Requirements, assumptions, evidence, and responsibilities should be documented throughout the process.
development. Its purpose is to improve the quality of the decision, not to promise success.
technological.

In the case of biomass, this caution is particularly important. The availability of

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

Resources do not automatically imply low impact or low viability. Origin of
raw materials, logistics, conversion, energy integration, co-products and land use can
alter the outcome. The analysis should cover the entire lifecycle and avoid generic statements of
carbon neutrality.

The growth in investments in clean energy expands opportunities, but also
This increases responsibility in project selection. IEA data for 2025 shows the extent of this.
of the capital mobilized, not the effectiveness of each technology. Governance models can
to contribute to ensuring that demonstration decisions are supported by transparent criteria.
and comparable.

MIA-Energia remains a conceptual contribution. The article does not include interviews.
It does not attribute reductions in time, cost, or risk to industrial experiments or case studies, nor does it attribute them to the model.
This delimitation preserves the validity of the argument and establishes a verifiable agenda for
Your rating.

The next step should be to apply the framework prospectively, with defined indicators.
Before the start of monitoring. Documentation of decisions, reformulations and results.
This will allow you to identify which components generate value and which need to be reviewed. Publications
Future generations should also expand the specific literature on each technological route analyzed.

It can be concluded that the convergence between science and industry depends less on universal formulas.
more than the ability to formulate good questions, register uncertainties, and make decisions based on
evidence. MIA-Energia offers an initial architecture for this work. Its relevance
Scientific accuracy will be determined by the transparency with which it is tested and the possibility of its...
results can be examined, reproduced, and critiqued.

References

NATIONAL AGENCY OF PETROLEUM, NATURAL GAS AND BIOFUELS.
ANP Resolution No. 918, of March 10, 2023. Regulates compliance with the investment obligation arising from the research, development and innovation clause. Brasília, DF: ANP, 2023.

Brazilian Association of Technical Standards. ABNT NBR ISO 56002:2020.
Innovation management: innovation management system: guidelines. Rio de Janeiro: ABNT, 2020.
BRIDGWATER, AV Review of fast pyrolysis of biomass and product upgrading. Biomass and Bioenergy, v. 38, p. 68–94, 2012. DOI: 10.1016/j.biombioe.2011.01.048.
CHERUBINI, F. The biorefinery concept: using biomass instead of oil for producing energy and chemicals. Energy Conversion and Management, vol. 51, n. 7, p. 1412–1421, 2010. DOI: 10.1016/j.enconman.2010.01.015.

CHESBROUGH, HW Open Innovation: The New Imperative for Creating and Profiting from Technology.
Boston: Harvard Business School Press, 2003.
Energy Research Company. National Energy Balance 2025: Base Year

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 05/09/2026 | Accepted: 08/09/2026 | Publication: 11/09/2026

2024. Rio de Janeiro: EPE, 2025.
ETZKOWITZ, H.; LEYDESDORFF, L. The dynamics of innovation: from National Systems and Mode 2 to a Triple Helix of university-industry-government relations. Research Policy, vol. 29, no. 2, p. 109–123, 2000. DOI: 10.1016/S0048-7333(99)00055–4.
FURTADO, AT; SCANDIFFIO, MIG; CORTEZ, LAB The Brazilian sugarcane innovation system. Energy Policy, vol. 39, no. 1, p. 156–166, 2011. DOI: 10.1016/j.enpol.2010.09.023.

GEELS, FW et al. Sociotechnical transitions for deep decarbonization. Science, vol. 357, no. 6357, p. 1242–1244, 2017. DOI: 10.1126/science.aao3760.
HELLSMARK, H.; FRISHAMMAR, J.; SÖDERHOLM, P.; YLINENPÄÄ, H. The role of pilot and demonstration plants in technology development and innovation policy. Research Policy, vol. 45, no. 9, p. 1743-1761, 2016. DOI: 10.1016/j.respol.2016.05.005.
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report. Cambridge: Cambridge University Press, 2022. DOI: 10.1017/9781009157926.
INTERNATIONAL ENERGY AGENCY. Energy Technology Perspectives 2020: Special Report on Clean Energy Innovation. Paris: IEA, 2020.
INTERNATIONAL ENERGY AGENCY. World Energy Investment 2025. Paris: IEA, 2025.
INTERNATIONAL RENEWABLE ENERGY AGENCY. World Energy Transitions Outlook 2023: 1.5°C Pathway. Abu Dhabi: IRENA, 2023.
MANKINS, JC Technology readiness assessments: a retrospective. Acta Astronautica, v. 65, no. 9-10, p. 1216-1223, 2009. DOI: 10.1016/j.actaastro.2009.03.058.
MARKARD, J. The next phase of the energy transition and its implications for research and policy. Nature Energy, vol. 3, p. 628–633, 2018. DOI: 10.1038/s41560-018-0171-7.
ROSENBERG, N. Inside the Black Box: Technology and Economics. Cambridge: Cambridge University Press, 1982.
STOKES, DE Pasteur's Quadrant: Basic Science and Technological Innovation. Washington, DC: Brookings Institution Press, 1997.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.