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Work-in-Progress: A Holistic Energy Curriculum Redesign to Prepare Students for Emerging Global Energy Challenges

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1. Introduction

Global energy systems are undergoing a transition driven by technological innovation and shifting societal demand. The exponential growth of artificial intelligence, cloud computing, and data-center infrastructure is projected to more than double electricity consumption within the next decade, while widespread electrification of transportation and buildings continues to increase energy demand across sectors. At the same time, international climate goals and decarbonization commitments call for substantial reductions in carbon emissions, accelerating a global transition toward more sustainable energy systems. Together, these developments place new demands on the energy workforce and underscore the need for higher-education models that prepare graduates to address complex, interdisciplinary energy challenges, particularly those requiring integrated technical understanding, economic analysis, and policy awareness.

In response to these challenges, scholars in engineering and energy education have examined how energy curricula can be designed to better prepare students for complex, interdisciplinary problem solving. Prior research on energy education has explored curriculum development at multiple scales, ranging from program-level redesigns to targeted course or module innovations [1-4]. One program-level study presents an in-depth examination of curriculum planning within an energy engineering master's program, drawing on student surveys, faculty interviews, and analysis of core course content [5]. Their findings underscore the importance of strategic curriculum design that aligns learning outcomes, instructional approaches, and assessment across courses, emphasizing coherence, faculty coordination, and continuous feedback as central components of effective energy education reform. Related studies further highlight the interdisciplinary nature of energy education. A study examining how students from engineering and social science backgrounds conceptualize energy reveals persistent disciplinary differences: engineering students often emphasize technical performance and career relevance, while social science students focus on policy, environmental impact, and societal context [6]. These findings suggest that integrating technical content with socio-environmental awareness is critical for preparing students to address energy challenges. Another study investigating undergraduate energy education models that incorporate project-based and systems-oriented learning indicates that success in the clean energy workforce requires not only technical knowledge, but also professional skills and practical experience [7]. Collectively, these studies demonstrate that while traditional disciplinary programs often prioritize depth within a single field, modern energy challenges call for curricula that intentionally integrate technical, societal, and contextual perspectives. In response, this paper presents a work-in-progress redesign of an undergraduate Energy concentration within the Integrated Science and Technology (ISAT) program at James Madison University (JMU). The purpose of this paper is to document the curricular framework guiding this redesign, specifically, how student learning is structured across breadth, depth, and application, rather than to report finalized outcomes. At the time of writing, the proposed curriculum remains under development and is pending formal approval through the university's governance processes.

2. Program and Institutional Context

The ISAT program at James Madison University offers an interdisciplinary Bachelor of Science degree. The curriculum begins with foundational coursework in science and technology and progresses into concentration areas that allow students to develop deeper expertise in fields such as Biotechnology, Environment and Sustainability, and Energy. Throughout the program, students are encouraged to think holistically, applying technical knowledge within social, economic, and institutional contexts, consistent with ISAT's emphasis on systems thinking and interdisciplinary integration.

The Energy concentration within ISAT prepares students to apply principles of energy science to the design and evaluation of energy systems, improvements in energy efficiency, sustainable energy development, and analysis of how policy and economics influence energy infrastructure and demand. Coursework includes laboratory and project-based experiences in data collection, analysis, and instrumentation, reinforcing the program's applied approach to learning.

Several factors shape the ongoing curriculum development process. ISAT's interdisciplinary student population enters the program with varied backgrounds in mathematics, science, and technical fields, requiring a curriculum that is both accessible to non-specialists while providing appropriate technical depth for energy concentrators. Credit limits and institutional sequencing policies require careful coordination of prerequisites and course progression. Additionally, faculty coordination and systematic review through established governance processes influence both the pace and structure of curriculum revisions. These factors frame the opportunities and conditions within which the Energy concentration redesign has been developed.

3. Rationale for Energy Concentration Redesign

The Energy concentration is being redesigned to provide students with a more coherent, interdisciplinary, and forward-looking educational pathway. This effort is motivated both by evolving societal energy challenges and by internal programmatic reflection on how students progress through energy-related coursework.

In earlier iterations of the curriculum, introductory energy courses emphasized strong technical content that was well aligned with the needs at the time. Over time, faculty observations, student feedback, and program-level assessment have pointed to the value of a clearer learning progression, one that supports foundational energy literacy for a broad student population while also enabling deeper analytical engagement for concentrators. This reflection responds to evolving concentration-level goals, student pathways, and the expanding scope of contemporary energy challenges.

The proposed redesign aligns more closely with ISAT's interdisciplinary mission by establishing an intentional sequence that builds breadth first, followed by depth for concentrators, and culminating in applied practice. This structure reflects the reality that modern energy challenges demand not only scientific rigor, but also fluency in technology, economics, policy, and management. By reorganizing course content and refining learning goals, the redesigned Energy concentration aims to better prepare students for leadership roles in energy-related careers and advanced study.

4. Curriculum Development Process (Work-in-Progress)

The curriculum redesign is being developed through an iterative, faculty-driven process led by a formal Energy Academic Team. This team meets regularly to coordinate course content, review sequencing, and ensure coherence across the proposed concentration. Rather than approaching curriculum change as a one-time revision, the team has adopted a reflective and incremental model informed by teaching experience, ongoing dialogue among faculty, student feedback, and evolving disciplinary needs.

The development process began with a comprehensive review of existing energy courses to identify areas of overlap, misalignment, and opportunity. Faculty then proposed targeted updates to course content, titles, and prerequisites to clarify learning progression and reduce redundancy. At this stage of development, informal inputs such as student feedback, observations from project-based learning, and outcomes from applied assignments have been intentionally used to inform design decisions. These inputs provide timely insight into how students engage with course material, supporting refinement of the curriculum prior to formal implementation.

At the time of writing, the curriculum has not yet been formally submitted for institutional approval. Submission is planned for the end of Spring 2026. As such, the curriculum described in this paper represents a work-in-progress, intended to document design rationale and share transferable insights rather than to report finalized outcomes.

5. Proposed Energy Concentration Structure

5.1 Overview of the Proposed Seven-Course Sequence

The proposed Energy concentration is structured as a seven-course sequence spanning the junior and senior years. The sequence is designed to scaffold learning across three complementary dimensions:

- Breadth: foundational literacy in energy technologies and global energy challenges
- Depth: advanced scientific and analytical understanding of energy systems

- Application: practical skills in energy efficiency, economics, policy, and management

Figure 1 illustrates the conceptual learning progression model. The junior-year courses establish foundational systems-level literacy and contextual awareness, while senior-year coursework progressively increases analytical rigor and applied integration.

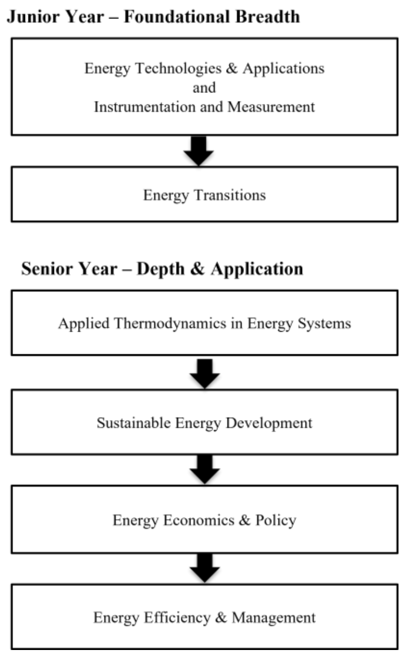

Figure 1. Conceptual learning progression model illustrating the sequencing of foundational, analytical, and applied coursework.

This progression reflects both the interdisciplinary nature of energy systems and the diverse academic backgrounds of ISAT students.

5.2 Junior-Year Foundation Courses (Proposed)

During the junior year, students complete three required courses (two 3 credit course, and one credit lab course) that establish shared literacy across technology, application, and context.

Energy Technologies and Applications introduces the dominant energy technologies that power modern society, including lighting systems, mechanical work devices, electric power generation and storage, and heating and cooling systems. The course emphasizes how these technologies function in real-world contexts and introduces conceptual thermodynamic cycles and energy-flow analysis without advanced mathematical modeling. This approach ensures accessibility for all ISAT students while preparing Energy concentrators for more advanced coursework.

Instrumentation and Measurement introduces the acquisition of data from representative energy systems and enables students to analyze these data to deepen their understanding of various energy forms.

Energy Transitions situates energy technologies within broader social, economic, and political frameworks. The course examines global energy supply and demand, the persistence of fossil fuels, the growth of electrification and renewable energy, and the economic and policy drivers shaping energy transitions. By focusing on how and why energy systems evolve, this course complements the technology-focused perspective of Energy Technologies and Applications and provides essential contextual literacy.

5.3 Senior-Year Advanced and Applied Courses (Proposed)

In the senior year, students engage in four concentration-specific courses that deepen analytical depth and emphasize application. These courses build progressively on the conceptual foundation established in the junior year, ensuring sufficient analytical preparation before students undertake advanced system design and applied evaluation. The senior sequence is structured with Applied Thermodynamics positioned early to establish quantitative grounding, and Energy Efficiency and Management serving as the culminating course, integrating technical, economic, and policy perspectives.

Applied Thermodynamics in Energy Systems develops the scientific and quantitative foundation required for advanced study in energy systems. Positioned early in the senior sequence, this course builds on prior exposure to energy technologies and introductory quantitative analysis. Emphasis on thermodynamic laws, energy transformations, and thermal science provides the analytical framework necessary for subsequent coursework.

Energy Economics and Policy examines the intersection of technology, markets, and governance. Recommended sequencing places this course after students have developed both systems-level literacy (Energy Technologies and Applications) and social, economic, and political frameworks (Energy Transition). While the course title and structure remain unchanged, updated content strengthens the energy economics component, including market analysis, project financing, and metrics such as levelized cost of energy (LCOE), net present value (NPV), and internal rate of return (IRR), along with examination of energy market structures.

Sustainable Energy Development builds on this analytical foundation by focusing on the science and application of renewable and low-carbon energy systems. Students engage in system-level modeling and design activities that require integration of technical understanding developed in earlier courses. Recent updates expanded coverage of solar and wind systems, introduced nuclear energy as a complementary low-carbon resource, and incorporated project-based analysis using industry tools such as NREL's System Advisor Model (SAM) and HelioScope.

Energy Efficiency and Management serves as the applied capstone of the concentration. Positioned at the culmination of the sequence, this course integrates technical, economic, and policy perspectives in real-world decision-making contexts. Students apply prior analytical and contextual learning to energy auditing, benchmarking, and demand-side management scenarios, reinforcing synthesis across technical, economic, and policy domains.

6. Design Rationale: Breadth, Depth, Context, and Application

The proposed curriculum is intentionally organized to support a clear and coherent learning progression across the Energy concentration. Rather than treating courses as standalone units, the sequence is designed so that each course serves a distinct functional role in developing student understanding over time.

Energy Technologies and Applications and Instrumentation and Measurement provide a broad on-ramp that establishes shared systems-level literacy for students during their junior year. Their primary function is to provide a common conceptual foundation, ensuring that all students develop familiarity with how energy technologies operate within real-world systems. Energy Transitions introduces students to the economic and policy dimensions of energy systems, establishing a shared framework for more advanced study.

Applied Thermodynamics in Energy Systems then functions as the analytical core of the sequence, providing the technical depth required for energy concentrators to engage deeply with energy conversion principles and thermodynamics. Positioned after foundational exposure to energy technologies and systems, this course enables students to develop analytical competence while connecting theory to the systems they have already encountered.

Energy Economics and Policy plays a complementary role by situating technical understanding within broader economic, policy, and institutional contexts. Its function within the sequence is to help students contextualize technical decisions, evaluate tradeoffs, understand energy markets, and examine non-technical drivers shaping energy systems. By integrating these perspectives alongside technical coursework, the curriculum reinforces interdisciplinary thinking rather than isolating context within a single course.

Sustainable Energy Development further expands this foundation by providing students with opportunities to deepen their understanding of renewable and low-carbon energy technologies and to engage in the design and evaluation of integrated energy systems. This course bridges technical analysis and applied system design, preparing students for more complex, real-world applications.

Finally, Energy Efficiency and Management serves as the applied course of the concentration. Its role is to provide students with opportunities to synthesize technical knowledge, economic analysis, and policy considerations in applied decision-making contexts. Positioned at the end of the sequence, this course supports the transition from academic study to professional practice by emphasizing real-world systems and operational constraints.

Taken together, this design balances accessibility with technical depth and reflects the competencies required for graduates to address modern energy challenges. By intentionally sequencing courses according to their functional roles (foundation, depth, context, and application), the redesigned Energy concentration reinforces ISAT's interdisciplinary mission while supporting meaningful learning progression across the junior and senior years.

7. Early Design Insights and Informal Observations

Although the redesigned Energy concentration has not yet been implemented as a fully integrated sequence, several courses reflecting elements of the proposed structure have been offered in revised form. These course offerings provide an opportunity to observe how individual components of the redesigned sequence function in practice prior to formal program adoption.

During these offerings, mid-semester surveys and end-of-course evaluations were collected to gather student feedback on course organization, engagement, and perceived integration of technical and contextual content. Across the most recent offerings, a majority of respondents indicated that the revised structure improved clarity regarding how technical concepts relate to broader economic and policy considerations. Students frequently highlighted the value of connecting technical content to real-world systems and applications, as well as the intentional progression from systems-level understanding to more advanced analytical work.

In addition, students engaged in structured hands-on and project-based activities aligned with the redesigned learning goals. These activities included energy system modeling exercises using industry tools, renewable system design projects integrating technical and economic analysis, quantitative thermodynamic problem-solving applied to real systems, and policy evaluation assignments. These applied components were intentionally incorporated to strengthen interdisciplinary integration and experiential learning.

Also, faculty teaching these courses have made formative observations regarding student learning and performance. Instructors noted improvements in the quality of assignments, projects, and applied analyses, particularly in students' ability to integrate technical concepts with economic, policy, and systems-level considerations. While these observations are qualitative in nature, they align with the intended learning progression articulated in the curriculum design.

At this stage, the available feedback is being used as formative input to guide continued refinement of course sequencing, assignment design, and instructional emphasis. The observations presented here reflect early implementation insights rather than formal evidence of program-level effectiveness.

8. Planned Assessment and Evaluation Strategy

While Section 7 summarizes early course-level observations, formal program-level assessment of the redesigned Energy concentration is planned following institutional approval and implementation as a fully integrated sequence.

The planned assessment framework includes both course-level and program-level components. At the course level, clearly defined learning outcomes will be evaluated through structured assignments, applied projects, and examinations using rubric-based criteria. These measures are intended to assess technical competence, economic reasoning, policy literacy, and applied decision-making skills.

At the program level, the Energy Academic Team plans to examine longitudinal indicators such as student progression through the concentration, performance in senior-level coursework, and the quality of integrative applied projects. Particular attention will be given to evidence of interdisciplinary synthesis across technical and contextual domains. Student feedback instruments and targeted reflection prompts will supplement these measures to identify strengths and areas for improvement.

Given the work-in-progress status of the curriculum, no formal summative assessment data are reported in this paper. Instead, this section outlines the structured evaluation framework that will guide systematic assessment once the concentration is fully implemented. The ongoing role of the Energy Academic Team is intended to ensure that assessment findings directly inform continuous curriculum refinement and instructional decisions.

9. Transferability to Other Institutions

Although the proposed Energy concentration is situated within ISAT program, many elements of the redesign are transferable to other institutions seeking to update or develop undergraduate energy curricula. In particular, the emphasis on intentional sequencing and interdisciplinary integration may be relevant across engineering, applied science, and multidisciplinary programs.

One transferable aspect of the redesign is the breadth–depth–application framework used to structure the curriculum. By introducing energy systems through accessible, systems-level courses before requiring advanced analytical engagement, programs can support varied student backgrounds while still providing appropriate technical depth for concentrators. Importantly, this framework is adaptable and does not depend on a specific program structure or set of course titles.

Finally, the redesign highlights the value of integrating technical, economic, and policy perspectives throughout the curriculum rather than isolating them in standalone courses.

Programs preparing students for contemporary energy careers may find this integrated approach adaptable to their own institutional missions, resources, and constraints.

10. Conclusion and Next Steps

This paper has presented a work-in-progress redesign of an interdisciplinary undergraduate Energy concentration within the ISAT program at James Madison University. Motivated by rapid changes in global energy demand, decarbonization goals, and evolving workforce needs, the proposed curriculum seeks to provide students with a coherent and intentional learning pathway that integrates breadth, depth, context, and application.

The redesigned sequence emphasizes systems-level literacy in the junior year, followed by increased analytical depth and applied practice in the senior year. Through coordinated course updates and the formation of an Energy Academic Team, the curriculum aims to strengthen coherence across the concentration while remaining accessible to students with diverse academic backgrounds. This approach reflects an effort to align interdisciplinary education with the complexity of contemporary energy systems.

Although the full seven-course concentration remains subject to institutional review and approval, the guiding design principles (intentional sequencing, interdisciplinary integration, and competency-based progression) extend beyond the formal structure of the concentration itself. Elements of the redesign are already influencing course-level revisions and instructional practices within the program. Even if aspects of the proposed package are modified during the approval process, the curricular architecture and sequencing framework described here remain transferable and adaptable within interdisciplinary energy education contexts.

The next phase of this work involves formal submission of the curriculum, planned for the end of Spring 2026. Following formal implementation, future efforts will focus on systematic assessment of student learning outcomes, evaluation of curricular effectiveness, and continued refinement informed by evidence and feedback. Through this ongoing process, it is anticipated that insights will be contributed to broader conversations in engineering education regarding effective and intentionally structured models for interdisciplinary energy curriculum development.

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