**PROJECT TITLE: Power-electronics Circuits for Minnesota’s Renewable Energy Future**

**I. PROJECT STATEMENT:**

The electrical power system in Minnesota is witnessing unprecedented transitions in form and function with the integration of renewable resources of energy (e.g., solar and wind), flexible loads (e.g., electric vehicles), and energy-storage devices. Renewable resources accounted for 24.9% of Minnesota’s electricity generation portfolio in 2017, implying that the 25%-by-2025 target set by the state’s Renewable Electricity Standard will be assuredly surpassed.1 Energy conversion for electricity generation in the power system today is undertaken through synchronous generators: large electrical machines that convert thermal energy stored in fossil fuels to electrical energy that is ultimately delivered to our homes and businesses. The next-generation power system will be dominated by power-electronics circuits: semiconductor-device based technologies that can convert, e.g., electromagnetic energy in incident solar irradiation to electrical energy (with no moving parts!). According to some estimates, up to 80% of electricity will be processed by power-electronics circuits by 2030. Ensuring the reliability and efficiency of power-electronics circuits is therefore critical to realizing a sustainable and environmentally benign electricity infrastructure across the state and around the world.

Efficiency advancements in power-electronics circuits can be achieved by reducing conduction and switching losses in constituent semiconductor devices. In recent years, ultra-wide-bandgap (UWBG) semiconductor devices have been recognized to provide size, efficiency, and cost advantages compared to conventional Silicon-based devices. UWBG devices are innately better suited to power conversion because they can sustain higher voltages in a smaller spatial footprint. This increases current density and switching frequencies, and further minimizes the size and weight of packaged circuits. Taken together, these attributes contribute to improved efficiency and reliability of power-electronics circuits realized with UWBG devices. However, to unlock the full potential of these devices, significant R&D is required to address engineering challenges spanning thermal management, device fabrication, circuit topologies, and design optimization. The nascency of UWBG technology also implies that economic and policy-related drivers—that are critical to ensure widespread adoption—are far from understood.

***Our project involves engineering techno-economic solutions that will propel pertinent stakeholders in Minnesota to the forefront of advances in next-generation UWBG power-electronics circuits for renewable energy applications***. ***The primary project deliverable will be a residential-scale photovoltaic (PV) inverter with industry-leading efficiency (>95%), reliability (surface temperature <60o), and power-density (50W/in3) specifications built with Minnesota-made UWBG devices.*** Successful project completion will promote and demonstrate Minnesota capabilities across critical manufacturing and technology value chains ranging from advanced materials to consumer-grade electronics. The project team includes broad-based expertise across materials engineering (**Wang**), semiconductor device fabrication (**Koester**), circuit design (**Choi**), systems optimization (**Dhople**), and law/policy (**Anderson**). Specific project tasks will include:

1. Engineering UWBG thin films for industry-leading electrical and thermal properties;
2. Fabricating semiconductor devices using UWBG materials with tailored functionalities;
3. Prototyping and demonstration of a photovoltaic (PV) inverter built with UWBG devices;
4. Evaluating techno-economic barriers and opportunities for MN-based industry in this technology space.

Project tasks are centered around beta-gallium oxide (-Ga2O3, the most stable form of gallium oxide) serving as the UWBG material of choice given its unique electro-thermal properties. However, program activities are architected from the bottom-up and without loss of generality so that project completion will ultimately bring UWBG-based power-electronics circuits closer to widespread adoption. The proposed effort is thematically, philosophically, scientifically, and programmatically aligned with Minnesota’s 2025 Energy Action Plan authored by the Department of Commerce.2

**II. PROJECT ACTIVITIES AND OUTCOMES:**

Through the 3-year duration,our project promises innovations in three interrelated domains: i) materials & devices, ii) circuits & systems, and iii) economic analysis & policy assessment.

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| **Activity 1:** Initial device characterization, circuit design, and PV inverter modeling **[ENRTF BUDGET: $139,378]**  **Description:** *In Activity 1, the team will focus on engineering the electro-thermal properties of bulk & thin-film UWBG -Ga2O3 material and on initial circuit design and modeling for the PV inverter.* | |  |
| **Outcome** | **Comp. Date** |
| *1. Establishment of structure-thermal property relationships of bulk & thin-film -Ga2O3* | *Dec. 31, 2020* |
| *2. Fabrication and test of field-effect transistor devices built with -Ga2O3* | *Jun. 30, 2021* |
| *3. Investigation of optimal PV inverter circuit topology* | *Jun. 30, 2021* |
| *4. Formulation of physics-based models for system (devices + PV inverter)* | *Jun. 30, 2021* |
| **Activity 2:** Design optimization of PV inverter built with proposed devices **[ENRTF BUDGET: $142,008]**  **Description:** *In Activity 2, the team will focus on prototyping the PV inverter topology and design optimization of the UWBG devices. Feedback from circuit design will be leveraged to improve device performance.* | |  |
| **Outcome** | **Comp. Date** |
| *1. Optimization of electro-thermal material properties of bulk & thin-film -Ga2O3* | *Dec. 31, 2021* |
| *2. Enhancement of efficiency & reliability of field-effect transistor devices built with -Ga2O3* | *Dec. 31, 2021* |
| *3. Laboratory prototyping of PV inverter topology* | *Jun. 30, 2022* |
| *4. Development of control algorithms for grid-compliant operation of PV inverter* | *Jun. 30, 2022* |
| **Activity 3:** Demonstration of PV inverter and techno-economic assessment **[ENRTF BUDGET: $191,261]**  **Description:** *In Activity 3, the team will demonstrate the optimized PV inverter prototype with industry-leading efficiency and reliability specifications. Broader economic and policy impacts will be investigated.* | |  |
| **Outcome** | **Comp. Date** |
| *1. Broader exploration of material & device alternatives based on stakeholder feedback* | *Jun. 30, 2023* |
| *2. Testing and demonstration of the PV inverter prototype to stakeholders* | *Jun. 30, 2023* |
| *3. Economic analysis, impact & feasibility assessment* | *Jun. 30, 2023* |

**III. PROJECT PARTNERS AND COLLABORATORS:**

The diversity in professional qualifications and technical backgrounds of team members is uniquely pronounced and undeniably necessary to accomplish project activities. Minnesota is home to several companies (Honeywell, 3M), electric utilities (Xcel Energy, Great River Energy), and a power-system operator responsible for guaranteeing supply reliability for 15 US and 1 Canadian province (Midcontinent System Operator), with interests directly tied to the project objectives and broadly aligned with the electricity infrastructure. Our team will also collaborate with Agnitron: a Minnesota-based company at the forefront of advances in technologies discussed in this proposal. Contextual relevance and alignment of proposed activities with the aspirations of Minnesota industries will be ensured via engagement of the University of Minnesota’s Energy Transition Lab (led by **Anderson**).

**IV. LONG-TERM IMPLEMENTATION AND FUNDING:**

The completion of this project requires 36 months from July 01, 2020 to June 30, 2030. We anticipate that successful project completion will not only outline optimal topologies, companion control methods, and engineering rules of thumb for UWBG power-electronics circuits, but also establish the foundational science that governs relationships between material engineering and device performance. The preliminary results generated through this effort will be leveraged for composing multiple federal grant proposals. Our plan is to target agencies such as the National Science Foundation and the U. S. Department of Energy which have mature research funding portfolios focused on advanced materials, novel devices, circuits design, and systems engineering for renewable and sustainable energy applications.