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Lux Biosensors: Real-Time Bioluminescent Tools for Modern Sensing Applications

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Lux biosensors are whole cell bioreporter systems that utilize bacterial bioluminescence for rapid and real-time detection of chemical and environmental stimuli. These systems are engineered by incorporating the *lux* operon, which encodes luciferase and the enzymes required for substrate synthesis, into host microorganisms under the control of stress or analyte responsive promoters. Upon activation, the engineered cells emit light without the need for external substrates, enabling non-destructive and continuous monitoring. Lux biosensors are widely applied in toxicological screening and environmental monitoring to detect genotoxicity, oxidative stress, and pollutant toxicity, often showing good agreement with conventional bioassays. In biomedical research, they serve as valuable tools for studying drug responses and cellular stress pathways in living cells. Despite advantages such as rapid response, cost-effectiveness, and real-time reporting, their performance can be influenced by environmental conditions and biological variability, and their use requires appropriate biosafety measures.

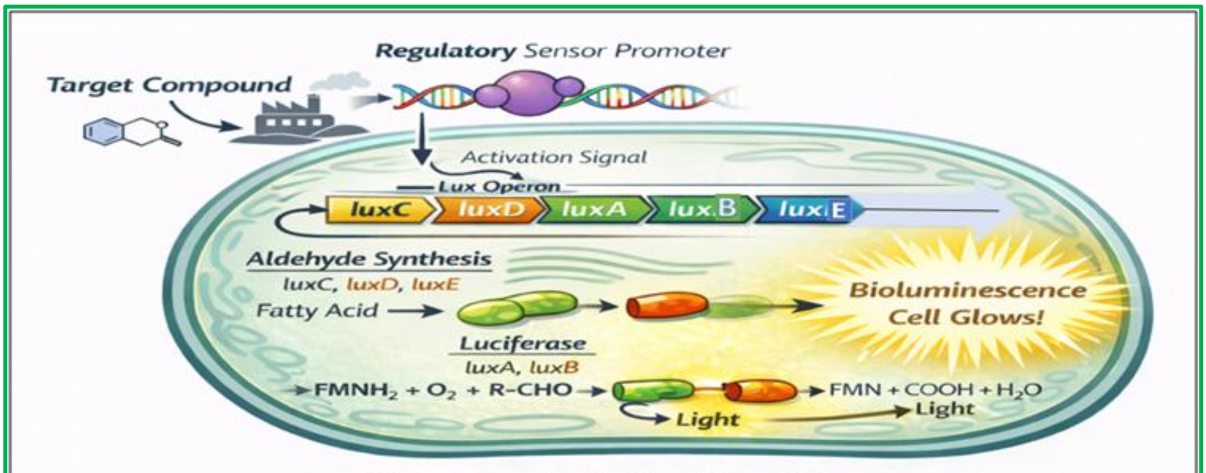
Keywords: Lux biosensors; Bioluminescence; Whole cell biosensing; Environmental and toxicological monitoring.

Introduction

Lux biosensors are a type of whole-cell sensing system that utilize the natural light-producing ability of certain bacteria for analytical detection. These biosensors are created by introducing the lux operon, a cluster of genes responsible for bioluminescence into suitable host microorganisms (Plyuta *et al.*, 2025). In these engineered cells, light production is triggered by the presence of specific chemicals or cellular stress signals. Unlike many traditional biosensing methods that require added substrates or reagents, Lux biosensors generate their own measurable light signal, allowing real-time and non-destructive monitoring in environmental, toxicological, and biomedical fields.

Molecular Basis of Lux Biosensors

The functionality of Lux biosensors is based on the lux operon, which encodes both the luciferase enzyme and the biochemical pathway needed to produce its substrate. The genes luxA and luxB code for the two subunits of bacterial luciferase, the enzyme directly responsible for light emission. Additional genes such as luxC, luxD, and luxE participate in the synthesis of a long-chain aldehyde molecule required for the luminescent reaction. Some operon variants may also contain auxiliary or regulatory genes that help connect the light-producing system to promoters activated under stress or in the presence of target compounds (Kusuma *et al.*, 2025). This design enables engineered cells to emit light independently, without requiring external substrate addition once the appropriate biological signal activates the linked promoter.



Lux Biosensor: Detecting Target Compound

Design and Engineering Approaches

The development of Lux biosensors involves placing the lux gene cluster under the control of inducible promoters that respond to defined environmental or physiological stimuli. By selecting promoters that are activated by oxidative stress, DNA damage, membrane disruption, or exposure to antimicrobial agents, researchers can tailor biosensors to detect specific cellular responses. Promoters such as soxS, recA, and pspA have been widely used for this purpose. When these promoters are triggered, the lux genes are expressed, producing light in proportion to the intensity of the biological response. This strategy enables rapid detection, quantitative analysis, and improved understanding of how cells react to various stressors or toxic substances (Bazhenov *et al.*, 2023).

Applications

- **Toxicology and Environmental Monitoring**

Lux biosensors play an important role in assessing environmental safety and chemical toxicity. They are capable of detecting DNA damage, oxidative stress, and general toxic effects caused by diverse pollutants and hazardous compounds (Plyuta *et al.*, 2025). In many cases, their responses correlate well with established bioassays such as the Ames test. Because the light signal is generated directly within living cells upon exposure to contaminants, these biosensors support quick and on-site evaluation of water bodies, soil samples, and industrial discharge with minimal sample processing.

- **Biomedical and Mechanistic Investigations**

In the biomedical field, Lux biosensors are used to investigate how living cells respond to therapeutic agents and stress conditions. Genetically modified *Escherichia coli* strains carrying lux reporters can track alterations in gene activity and cellular pathways in real time after exposure to antibiotics or pharmaceutical compounds (Łaska *et al.*, 2024). This capability makes Lux systems valuable tools not only for screening drug effects but also for exploring the molecular mechanisms underlying cellular responses.

Technical Advantages and Limitations

Lux biosensors provide several practical benefits, including continuous signal output, relatively low operating costs, and suitability for high throughput testing platforms. Their light emission can be easily measured using luminometers, allowing sensitive detection even in complex sample mixtures. Nevertheless, certain limitations must be considered. The performance of living-cell sensors can be influenced by environmental conditions, background luminescence may interfere with signal clarity, and biological variability can affect reproducibility. Furthermore, the use of genetically modified microorganisms requires adherence to appropriate biosafety guidelines.

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