

niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **THE INTARRATIONALE** Sensors for Monitoring Industrial Bioreactors **Contraction of Optical Fiber Sensors** for Monitoring Industrial Bioreactors University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors Soares et al., Technical and Economic Viability Analysis of Optical Fiber



# Technical and Economic Viability Analysis of Optical Fiber Sensors for Monitoring Industrial **Bioreactors** ECSA-7 15-30 November 2020<br> **Technical and Economic Viability Analysis of<br>
Optical Fiber Sensors for Monitoring Industrial<br>
Bioreactors**<br>
Marco César Prado Soares 1,\*, Thiago Destri Cabral <sup>1</sup>, Beatriz Ferreira Mendes 1,2, **Technical and Economic Viability All Optical Fiber Sensors for Monitoring<br>Bioreactors<br>Bioreactors<br>Discrement Prado Soares 1.\*, Thiago Destri Cabral 1, Beath<br>Vitor Anastacio da Silva <sup>2</sup>, Elias Basile Tambourgi <sup>2</sup> an<br>pol** Conomic Viability Analysis of<br>
sors for Monitoring Industrial<br>
Bioreactors<br>
Thiago Destri Cabral <sup>1</sup>, Beatriz Ferreira Mendes <sup>1,2</sup><br>
Elias Basile Tambourgi <sup>2</sup> and Eric Fujiwara <sup>1</sup><br>
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industrial<br>
atriz Ferreira Mendes <sup>1,2</sup>,<br>
and Eric Fujiwara <sup>1</sup><br>
pinas, São Paulo , Brazil**

**Marco César Prado Soares**  $1, *$ , Thiago Destri Cabral <sup>1</sup>, Beatriz Ferreira Mendes  $1, 2$ ,  $\mathcal{L}$ tri Cabral <sup>1</sup>, Beatriz Ferreira Mendes <sup>1,2</sup>,<br>le Tambourgi <sup>2</sup> and Eric Fujiwara <sup>1</sup><br>versity of Campinas, São Paulo , Brazil<br>ersity of Campinas, São Paulo, Brazil<br>ECSA-7 2020 – marcosoares.feq@gmail.com 1

1 School of Mechanical Engineering, University of Campinas, São Paulo , Brazil

2 School of Chemical Engineering, University of Campinas, São Paulo, Brazil







### 1. Introduction

### Bioprocesses:

**sensors** 

- Bioprocesses at all, Technology of Photonic Materials and Devices<br>
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Saires at al., Technology Industrial Bluesdard<br> **1.** Introduction<br>
Bioprocesses:<br>
 Relevant to different **1. Introduction<br>Discrete Monitoring Industrial Bloreadors<br>Relevant to different industries: pharmaceut<br>biomedic and food [1].**<br>These processes are still difficult to monitor. **1. Introduction<br>
Bioprocesses:**<br>
• Relevant to different industries: pharmaceutics, energy,<br>
biomedic and food [1].<br>
• These processes are still difficult to monitor.<br>
• Assessment is usually performed by techniques unsui
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- **Bioprocesses:**<br>
 Relevant to different industries: pharmaceutics, energy, biomedic and food [1].<br>
 These processes are still difficult to monitor.<br>
 Assessment is usually performed by techniques unsuitable for automat **oprocesses:**<br>Relevant to different industries: pharmaceutics, energy,<br>biomedic and food [1].<br>These processes are still difficult to monitor.<br>Assessment is usually performed by techniques unsuitable for<br>automatic control, Relevant to different industries: pharmaceutics, e<br>biomedic and food [1].<br>These processes are still difficult to monitor.<br>Assessment is usually performed by techniques unsuitak<br>automatic control, like: microscopes, centri<br> ECSA-7 2020 – marcosoares.feq@gmail.com<br>ECSA-7 2020 – marcosoares.feq@gmail.com<br>ECSA-7 2020 – marcosoares.feq@gmail.com<br>ECSA-7 2020 – marcosoares.feq@gmail.com

[1] Shuler, M.; Kargi, F. Bioprocess Engineering. Basic Concepts. Second Edition. Prentice Hall: 2002. [2] Bailey, J.; Ollis, D. Biochemical Engineering Fundamentals. McGraw-Hill: 1986. [3] Soares, M.C.P. et al. Sensors 2019, 19, 2493. doi:10.3390/s19112493.







### 1. Introduction

- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br> **1.** Introduction<br>
Traditional procedures for analysis:<br>
 Traditio University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Material Bluesdates<br> **1.** Introduction<br>
Traditional procedures for analysis:<br>
• Traditional procedures i **for the broad of the broth, or evaluating the glucose concentration with colorimetric assays [4]. 1. Introduction<br>
aditional procedures for analysis:**<br>
Traditional procedures include the quantifying<br>
from the broth, or evaluating the glucose con<br>
colorimetric assays [4].<br>
They are based on manual and time-consuming pr **Traditional procedures for analysis:**<br>
• Traditional procedures include the quantifying of the dry mass<br>
from the broth, or evaluating the glucose concentration with<br>
colorimetric assays [4].<br>
• They are based on manual a
- Me-consuming procedures [2].<br>Aldrich. Glucose (GO) Assay Kit. Available online: https://www.sigmaaldrich.com<br>igma/gago20 (accessed on 6 August 2020).<br>ECSA-7 2020 marcosoares.feq@gmail.com 3

[4] Merck Sigma Aldrich. Glucose (GO) Assay Kit. Available online: https://www.sigmaaldrich.com /catalog/product/sigma/gago20 (accessed on 6 August 2020).







### 1. Introduction

- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **1. Introduction**<br>
T University of Campinas – UNICAMP. Laboratory of Photonic Materials and Devices<br>
Somes et al., Technical and Eccentric Wabity Analysis of Optical Fiber<br> **1.** Introduction<br>
Traditional procedures for analysis:<br>
• More accura University of Campings - UNICAMP, Laboratory of Photonic Materials and Devices<br>
Scares et al., Technologian Chromatography (HPLC);<br> **1.** Introduction<br>
aditional procedures for analysis:<br>
More accurate techniques, capable o **1. Introduction**<br> **1. Introduction**<br> **1. Introduction**<br> **1. Introduction**<br> **1. Introduction**<br> **1. Introduction**<br> **1. Introduction**<br>
More accurate techniques, capable of evaluating multiple parameters: high<br>
performance li (ELISA). **1. Introduction**<br> **Traditional procedures for analysis:**<br>
• More accurate techniques, capable of evaluating multiple parameters: high<br>
performance liquid chromatography (HPLC); gas chromatography coupled to<br>
mass spectrom **aditional procedures for analysis:**<br>More accurate techniques, capable of evaluating r<br>performance liquid chromatography (HPLC); gas ch<br>mass spectrometry (GC-MS); and the enzyme-link<br>(ELISA).<br>They are also widely applied t ■ Require expensive and bulky instrumentation, highly specialized technicians,<br>
Nore accurate techniques, capable of evaluating multiple parameters: high<br>
performance liquid chromatography (HPLC); gas chromatography coupl More accurate techniques, capable of evaluating multiple parameters: high<br>performance liquid chromatography (HPLC); gas chromatography coupled to<br>mass spectrometry (GC-MS); and the enzyme-linked immunosorbent assay<br>(ELISA)
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- cal and biochemical analysis, since they<br>entation, highly specialized technicians,<br>p perform field analysis [3,5].<br>alla, V.K. In Electrochemical Sensors, Biosensors and their Biomedical Applications;<br>Wang, J. Ed.; Elsevier

[5] Ju, H.; Kandimalla, V.K. In Electrochemical Sensors, Biosensors and their Biomedical Applications; Zhang, X.; Ju, H.; Wang, J. Ed.; Elsevier: 2008.







### 1. Introduction

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Sons of *Binsors for Monitoring Industrial Bioreactors*<br>
Use of Sensors for Fermentation Monitoring:<br>
• The best alternative; University of Campinas – UNICAMP, Laboratory of Photonic Materials and I<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br>
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<br> **1. Introduction<br>Use of Sensors for Fermentation Monitorin<br>• The best alternative;<br>• The use of in-line sensors allow:<br>• obtaining useful data with shorter operation t**

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- **1. Introduction<br>
2. of Sensors for Fermentation Monitoring:**<br>
The best alternative;<br> **a** best alternative; **Example 18 Sensors for Fermentation Monitoring:**<br> **Example 18 Set alternative;**<br> **Example 18 Set alternative**<br> **Example 18 Set alternative set alternative set alternative solution only for the monitoring, but also for th** preliminary screening prior to the investment on more precise<br>preliminary screening prior to the investment on more precise<br>equipment [3,5]. Expect that the sensors allow:<br>
Expect the sensors allow:<br>
expect the sensors allow:<br>
detaining useful data with shorter operation<br>
obtaining useful not only for the monitorin<br> **preliminary screening** prior to the investr<br> rter operation times,<br>
e monitoring, but also for the<br>
b the investment on more precise<br>
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niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors Sensors for Monitoring Industrial Bioreactors **Contraction of Optical Fiber Sensors** for Monitoring Industrial Bioreactors University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **1. Introduction**<br> Soares et al., Technical and Economic Viability Analysis of Optical Fiber



### 1. Introduction

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Soares *et al.*, Technical and Economic Viability Ana<br>
Sensors for Monitoring Industrial Bior<br> **1.** Intro<br> **0** Biocompatible;<br>
• Immune to electromagnetic int

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- Examples Sensors for Montoring Industrial Bloreactors<br> **1. Introduction**<br> **9. Biocompatible;**<br>
 Immune to electromagnetic interference;<br>
 Show chemical and thermal stability;
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- **1. Introduction<br>
Optical Fiber Sensors (OFSs):**<br>
 Biocompatible;<br>
 Immune to electromagnetic interference;<br>
 Show chemical and thermal stability;<br>
 Show lower fabrication costs, being suitable for the **Optical Fiber Sensors (OFSs):**<br>● Biocompatible;<br>● Immune to electromagnetic interference;<br>● Show chemical and thermal stability;<br>● Show lower fabrication costs, being suitable for the mass-<br>fabrication of devices [3,6,7] Fried: The Poethors (OTDS).<br>Biocompatible;<br>Immune to electromagnetic interference;<br>Show chemical and thermal stability;<br>Show lower fabrication costs, being suitable fi<br>fabrication of devices [3,6,7]. lity;<br>
being suitable for the mass-<br>  $\frac{69 \text{ Li}, X. et al. Sens. Act. B: Chern. 2018, 269, 103-109.}{[7] Gorg. C. et al. Lab Chip 2017, 17, 3431-3436.}$ <br>
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[6] Li, X. et al. Sens. Act. B: Chem. 2018, 269, 103-109. [7] Gong, C. et al. Lab Chip 2017, 17, 3431–3436.







### 1. Introduction

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- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **1. Introduction**<br> University of Campinas – UNICAMP. Laboratory of Photonic Materials and Devices<br>
Somes et al., Technical and Economic Wabity Analysis of Optical Fiber<br> **1.** Introduction<br>
Objective of this Work<br>
• Analysis of the technical University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Biorectors<br> **1.** Introduction<br>
An **1. Introduction**<br> **1. Introduct 1. Introduction<br>
Objective of this Work**<br>
• Analysis of the technical and economic viability of implementing fiber optics<br>
fed-batch ethanol fermentation systems.<br>
• It is compared to traditional ELISA and HPLC systems.<br> **by jective of this Work**<br>
Analysis of the technical and economic viability of implementing fiber opt<br>
fed-batch ethanol fermentation systems.<br>
• It is compared to traditional ELISA and HPLC systems.<br>
Fed-batch is very pre
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- **Ethanol production and acconomic viability of implementing fiber optics**<br>
 Analysis of the technical and economic viability of implementing fiber optics<br>
 It is compared to traditional ELISA and HPLC systems.<br>
 Fed-<ul>\n<li> Analysis of the technical and economic viability of implementing fiber optics fed-batch ethanol fermentation systems.</li>\n<li> It is compared to traditional ELISA and HPLC systems.</li>\n<li> Fed-batch is very prevalent in different fermentation industries.</li>\n<li> Ethanol production represents a major sector of the Brazilian economy, with an annual production in excess of 35 billion liters [8,9].</li>\n<li> A simple fiber sensing system is proposed and the advantages of real-time process control are verified.</li>\n</ul>\n<p><b>1</b> [8,5007, G.M.: Volotia, R.L.: Joly, C.A.: Veridade, LM. Ed. Bio energy and Sixdentability: orbiging the gross control are verified.</p>\n<p>1</p>\n<p>1</p>\n<p>1</p>\n<p>1</p>\n<p>1</p>\n<p Fed-batch ethanol fermentation systems.<br>
• It is compared to traditional ELISA and HPLC systems.<br>
Fed-batch is very prevalent in different fermentation ind<br>
Ethanol production represents a **major sector of the Bra**<br> **annua** Ecrear of the Brazilian economy, with an<br> **n liters** [8,9].<br>
Nosed and the advantages of real-time<br>
Mictoria, R.L.; Joly, C.A.; Verdade, L.M. Ed. *Bioenergy and Sustentability: bridging the*<br>
PESP - BIOEN - BIOTA - FAPESP Frement fermentation industries.<br>
Frement fermentation industries.<br> **a major sector of the Brazilian economy**, with **an<br>
35 billion liters** [8,9].<br>
I is proposed and the advantages of real-time<br>
(B) Souza, G.M.: Victoria,
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[8] Souza, G.M.; Victoria, R.L.; Joly, C.A.; Verdade, L.M. Ed. Bioenergy and Sustentability: bridging the [9] International Sugar Association (ISO), ISO Ethanol Yearbook 2019, ISO 2020.







### 1. Introduction

- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **Photonic Industry F** University of Campinas – UNICAMP. Laboratory of Photonic Materials and Devices<br>
Sonras et al., Technical and Economic Wability Analysis of Opitcal Fiber<br> **1.** Introduction<br>
Photonic Industry Facts<br>
• Important economic asp University of Campings - UNICAMP, Laboratory of Photonic Materials and Devices<br>
Scares at al., Technologian Chaustral Blockaclons<br> **1.** Introduction<br>
Otonic Industry Facts<br>
Important economic aspects regarding the photonic **1. Introduction**<br> **2. Introduction**<br> **2. Informal example Facts**<br> **9.** Important economic aspects regarding the photonic industry itself make it<br> **4.** In the United Kingdom (2017), it was estimated that the photonic indus **1. Introduction**<br> **2. Introduction**<br> **2. Introduction**<br> **2.** Interpretative for new investments such as the proposed in this work.<br> **1.** the United Kingdom (2017), it was estimated that the photonic indust<br>
• contributed **Stonic Industry Facts**<br>
mportant economic aspects regarding the photonic industry itself<br>
ttractive for new investments such as the proposed in this work.<br> **1** the United Kingdom (2017), it was estimated that the photonic **Example 111003619 Practs**<br> **Employed moreon** approximate than 65,000 people;<br> **EMPLONE MOREON MOREON CONTAINS SET AND MOREON MOREON CONTINUES ON THE United Kingdom (2017), it was estimated that the photonic in<br>
● contrib The United Kingdom (2017)**, it was estimated that the photonic industry itself make it<br> **1. the United Kingdom (2017)**, it was estimated that the photonic industry:<br>
● contributed with more than **£12.9 billion**;<br>
● with
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n;<br>
ed to exportation [10].<br>
ECS Research Centre (Part of the Russell Group). Key photonics industry facts (June<br>
philne: https://www.orc.solon.ac.uk/who-we-are (accessed on 14 August 2020).<br>
ECSA-7 2020 – marcosoares.feq@ [10] Optoelectronics Research Centre (Part of the Russell Group). Key photonics industry facts (June 2017). Available online: https://www.orc.soton.ac.uk/who-we-are (accessed on 14 August 2020).







### 1. Introduction

- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **Photonic Industry F** University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Source et al., Technical and Economic Wables of Optical Fiber<br> **1.** Introduction<br>
Photonic Industry Facts<br>
• According to Gong et al. [7], fib University of Campinas - UNICAMP, Laboratory of Photoine Mehinia and Devices<br>
Source et al. Technical and Economic Visibility Analysis of Optical Fiber<br> **1.** Introduction:<br>
According to Gong et al. [7], fiber optic sensors **1. Introduction**<br> **1. Introduction**<br> **2.** Common optical fibers may be produced with lengths as high as ~50 km;<br> **4.** Common optical fibers may be produced with lengths as high as ~50 km;<br> **9.** Due to the economies of sca **1. Introduction**<br> **1. Introduction**<br> **2.** Consider to Gong et al. [7], fiber optic sensors are also advantageous in terms<br> **4.** The low costs involved in the waveguide production:<br>
• Common optical fibers may be produced
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- **1. THEFOCUCEFT<br>
2. Example 1.1** per meters of the low costs involved in the waveguide production:<br>
 Common optical fibers may be produced with lengths as high as ~50 km;<br>
 Due to the economies of scale, the average fab Find the mattery **Facts**<br>ording to Gong et al. [7], fiber optic sensors are also advantageous in terms<br>e low costs involved in the waveguide production:<br>Common optical fibers may be produced with lengths as high as ~50 km ording to Gong et al. [7], fiber optic sensors are also advantageous in terms<br>
in **common optical fibers may be produced with lengths as high as ~50 km;**<br>
Due to the economies of scale, the average fabrication cost is in t of the **low costs involved in the waveguide production:**<br>
● Common optical fibers may be produced with lengths as high as ~50 km;<br>
● Due to the economies of scale, the average fabrication cost is in the order of **US\$**<br> **0**
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Sensors for Monitoring Industrial Bioreactors **Contraction of Optical Fiber Sensors** for Monitoring Industrial Bioreactors University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **GOBOYAL Ethanol Eor** Soares et al., Technical and Economic Viability Analysis of Optical Fiber



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Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **General Ethanol Fe** 2. General Ethanol Fermentation Industry



In: Biofuel Production. Recent Developments and Prospects; Bernardes, M.A.S. Ed.; IntechOpen: Rijeka, Croatia, 2011. doi: 10.5772/17047







### 2. General Ethanol Fermentation Industry

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Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **2. General Ethanol** University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Source of al., Technical and Economic Wability Analysis of Opical Fiber<br> **2. General Ethanol Fermentation Industry**<br>
Costs — **Preliminary Anal** University of Campins - UNICAMP, Change of Photon Mateural School of Campins and Devices<br>
Surges of all Technical and Economic Values of Concert Fiber<br>
Surges for Both that and the instrumented and<br>
Once the main objective **2. General Ethanol Fermentation Industry**<br>Sts — **Preliminary Analysis**<br>Once the main objective is to analyze the gains involved in adopting an<br>instrumentation system, it is possible to admit that both the instrumented and **2. General Ethanol Fermentation Industry**<br>
Soldicants and the main objective is to analyze the gains involved in adopt<br>
Solnce the main objective is to analyze the gains involved in adopt<br>
Solnt-instrumented processes pre **Samingther Community Community State of University Community Share (edse)**<br>
Share the main objective is to analyze the gains involved in adopting an<br>
strumented processes present same costs of:<br>
• Acquisition of reactants STS — **Prellminary Analysis**<br>
Dhoce the main objective is to analyze the gains inversity<br>
neutricon-instrumented processes present same costs of:<br>
• Acquisition of reactants and raw materials;<br>
• Acquisition of utilities
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	- terials;<br>gy, steam, and cooling water);<br>ECSA-7 2020 marcosoares.feq@gmail.com 11
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### 2. General Ethanol Fermentation Industry

- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **Costs Previously Ev** University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al. Technical and Economic Wability Material Bioreccios<br> **2. General Ethanol Fermentation Industry**<br>
Costs Previously Evaluated<br>
• V
	- Last figure, capable of processing 123.6 tons of sugarcane molasses/year.<br>
	States figure, capable of processing 123.6 tons of sugarcane molasses/year.<br>
	 Cost estimated for plant construction: USD 88.7 millions, whereas US **2. General Ethanol Fermentation Industry**<br> **Experiously Evaluated**<br>
	Frace et al. [12]: analyzed a fermentation process plant similar to the one of the<br>
	figure, capable of processing 123.6 tons of sugarcane molasses/year.<br> **2. General Ethanol Fermentation**<br> **Separate 316.19**<br> **Separate 316.9**<br> **Separate 316.9**<br> **Separate 316.9**<br> **Cost estimated for plant construction: USD 88.7 million**<br>
	are referent to the equipment acquisition (includin<br>
	st **Solution Character Standard Standard Standard Standard Standard Standard Standard Standard Standard Costs: estimated for plant construction: USD 88.7 millions, whereas USD 39.4 millions are referent to the equipment acqui Previously Evaluated**<br>
	ra et al. [12]: analyzed a fermentation process plant similar to the one of the<br>
	figure, capable of **processing 123.6 tons of sugarcane molasses/year**.<br>
	Cost estimated for plant construction: USD 88
		- sition (including a fermentor fabricated in<br>
		.3 millions/per year for reactants and raw<br>
		ions/year for the acquisition of utilities.<br>
		et al. Ind. Crops Prod. 2016, 89, 478–485, 2016. doi: 10.1016/j.indcrop.2016.05.046.<br>
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[12] Vieira, J.P.F. et al. Ind. Crops Prod. 2016, 89, 478–485, 2016. doi: 10.1016/j.indcrop.2016.05.046.







### 2. General Ethanol Fermentation Industry

- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **Costs Previously ev** University of Campinas - UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Wability Material Bioreccios<br> **2. General Ethanol Fermentation Industry**<br> **2. General Ethanol Fermentati** Capable of processing 2205 tons of corn/day, producing 61 million gallons of<br> **Capable of processing 2205** tons of corn/day, producing 61 million gallons of<br>
ethanol/year.<br>
• Cost estimated for plant construction: USD 422. **2. General Ethanol Fermentation Industry**<br>**Sts Previously evaluated**<br>Humbird et al. [13]: analyzed the ethanol production from corn, for a plant<br>capable of processing 2205 tons of corn/day, producing 61 million gallons of **Example 12 Example 12 Set of the example 12 Set of the ethanol production from corn, for a plant apable of processing 2205 tons of corn/day, producing 61 million gallons of thanol/year.**<br>• Cost estimated for plant constru **Previously evaluated**<br>
mbird et al. [13]: analyzed the ethanol production from corn, for a plant<br>
able of processing 2205 tons of corn/day, **producing 61 million gallons of**<br> **anol/year.**<br>
Cost estimated for **plant constr** producting 61 million gallons of<br>
r plant construction: USD 422.5 millions, whereas USD 154.5<br>
nt to the equipment acquisition.<br>
stimated in USD 65.64 millions/per year for reactants and raw<br>
ion, and USD 4.72 millions/yea
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: **USD 422.5 millions,** whereas **USD 154.5**<br> **acquisition.**<br> **64 millions/per year for reactants and raw**<br> **lions/year** for the acquisition of **utilities.**<br> **onding**, C.; Hsu, D.; Aden, A.; Schoen, P.; Lukas, J.; Olthof, [13] Humbird, D.; Davis, R.; Tao, L.; Kinchin, C.; Hsu, D.; Aden, A.; Schoen, P.; Lukas, J.; Olthof, B.; Worley, M.; Sexton, D.; Pretreatment and Enzymatic Hydrolysis of Corn Stover. U.S. Department of Energy: National Renewable Energy Laboratory (NREL), Golden, CO, USA. Technical Report NREL/TP-5100-47764, Contract No. DE-AC36-08GO28308, 2011.







# 2. General Ethanol Fermentation Industry University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **Costs Previously ev** University of Campings - UNICAMP, Laboratory of Photonic Materials and Devices<br>
Somes et al., Testing are disconsite Membring Industrial Blowestors<br>
2. General Ethanol Fermentation Industry<br>
Costs Previously evaluated<br>
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- **2. General Ethanol Fermentation Industry**<br>Star Previously evaluated<br>The overall company cash flow;<br>• Impact the overall company cash flow;<br>• Do not directly affect the analysis of the viability in adopting instrumentation **2. General Ethanol Fermentation Industry<br>
Star Previously evaluated**<br>
Do not this basic costs are essentially constant, they:<br>
• Impact the overall company cash flow;<br>
• Do not directly affect the analysis of the viabilit **Example 12 Server and Example 12 Server and Server Algebra 2013**<br> **Example 2013 Server Algebra 2014**<br>
Impact the overall company cash flow;<br> **Do not directly affect the analysis of the viabili**<br>
Instrumentation strategy.<br>
- **Costs Previously evaluated**<br>
 Once this basic costs are **essentially constant**, they:<br>
 Impact the overall company cash flow;<br>
 Do not directly affect the analysis of the viability in adopting a new<br>
instrumentation s Once this basic costs are **essentially constant**, they:<br>
• Impact the overall company cash flow;<br>
• Do not directly affect the analysis of the viability in adopting a new<br>
instrumentation strategy.<br>
It is important to eval Once this basic costs are **essentially**<br>
• Impact the overall company cash flow;<br>
• Do not directly affect the analysis<br>
instrumentation strategy.<br>
It is important to evaluate if<br>
undesirable disturbances may resu<br>
cash fl is of the viability in adopting a new<br>f the premature detection of<br>esult on real gains, affecting the<br>ECSA-7 2020 – marcosoares.feq@gmail.com 14







# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers Shares et al., Technical and Economic Materials and Devices<br>
Sons et al., Technical and Economic Materials and Devices<br> **Benefits of Real-Time Monitoring over HPLC**<br>
• To demonstrate the benefits of monitoring over HPLC<br>
• Benefits of Real-Time Monitoring of Fed-Batch Bioreactors<br> **Benefits of Real-Time Monitoring of Fed-Batch Bioreactors**<br> **Parameters** and the benefits of Real-Time Monitoring over HPLC<br>
• To demonstrate the benefits of moni University of Campinsa - UNICAMP, Laboratory of Photonic Materials and Dowess<br> **Conduction of a simulation study of Fed-Batch Bioreactors**<br> **Conduction of a simulation study of a fed-batch reactor subjected to a**<br>
disturba

- **3. Real-time Monitoring of Fed-Batch Bioreactors**<br> **with Optical Fibers**<br> **Benefits of Real-Time Monitoring over HPLC**<br>
 To demonstrate the benefits of monitoring ethanol bioreactors in real time:<br>
conduction of a simul
- 

**Benefits of Real-Time Monitoring over HPLC**<br>
• To demonstrate the benefits of monitoring ethanol bioreactors in real time:<br>
conduction of a simulation study of a fed-batch reactor subjected to a<br>
disturbance.<br>
• The mode To demonstrate the benefits of monitoring ethanol bioreactors in real time:<br>conduction of a simulation study of a **fed-batch reactor subjected to a**<br>disturbance.<br>The model is derived from the general fermentative reaction To demonstrate the benefits of monitoring ethanol bioreactors in real time:<br>
conduction of a simulation study of a **fed-batch reactor subjected to a**<br>
disturbance.<br>
The model is derived from the general fermentative react EFIMENTALIVE TEACTION:<br>  $(X + \Delta X)$ <br>
In (*Saccharomyces cerevisiae*), *S* is the<br>
ucts concentration (ethanol) and  $\Delta X$  an<br>
rroduction. [2,3,14].<br>
[14] Doran, P. *Bioprocess Engineering Principles*, 2nd ed; Elsevier, 2013.<br>

[14] Doran, P. Bioprocess Engineering Principles, 2nd ed; Elsevier, 2013.







# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Sensors for Monitoring Material Bioreactors<br> **Benefits of Real-Time Monitoring over HPLC**<br>
• Applying the Monod model [2,14], we arrive at the **Applying the Monod model [2,14], we arrive at the set of Equations (1) through (4) [15]:**<br> **applying the Monod model [2,14], we arrive at the set of Equations (1) through (4) [15]:**<br> **a**<br> **a** Applying the Monod model [2,

$$
\frac{dV}{dt} = F \Rightarrow V = V_0 + F(1)
$$

$$
\frac{dX}{dt} = \mu X - \frac{FX}{V} \tag{2}
$$

$$
\frac{dP}{dt} = q_p X - \frac{FP}{V} \tag{3}
$$

$$
\frac{dP}{dt} = \mu X - \frac{FP}{V} \text{ (2)}
$$
\n
$$
\frac{dP}{dt} = q_p X - \frac{FP}{V} \text{ (3)}
$$
\n
$$
\frac{dS}{dt} = -\mu_s X + \frac{F(S_F - S)}{V} \text{ (4)}
$$
\n[15] Soares, M.C.P. et al. Blucher Chem. Eng. Proc. 2018, 1, 2010-2014. doi: 10.5151/cobeq2018-PT.0532. ECSA-7 2020 – macrosoares.feq@gmail.com 16

[15] Soares, M.C.P. et al. Blucher Chem. Eng. Proc. 2018, 1, 2010-2014. doi: 10.5151/cobeq2018-PT.0532.









# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers Benefits of Real-Time Monitoring over HPLC<br>  $\frac{dV}{dt} = F \Rightarrow V = V_0 + F(1)$ <br>
Sons for Nonting **Industrial Since Construction**<br>
Sensor for Monitoring of Fed-Batch Bioreactors<br>
Benefits of Real-Time Monitoring over HPLC<br>  $\frac{dV}{dt}$ Fed-Batch Bioreactors<br>Fibers<br>Thers<br>Salism and Devices<br>Fibers<br>HPLC<br>Salism and Devices<br>HPLC<br>Salism and Devices<br>In the specific rate of substrate<br>ponsumption;<br>Figures and the specific rate of product formation.  $\mathbf{F}^{\text{L Materials and Devices}}$ <br> **of** Grightial Fiber<br> **cal Fibers**<br> **er HPLC**<br>
•  $\mu_s$  = specific rate of substrate<br>
•  $\mu_s$  = specific rate of substrate<br>
•  $q_p$  = specific cell growth rate;<br>
•  $q_p$  = specific rate of product formati Fed-Batch Bioreactors<br>
Fibers<br>  $\text{LIPLC}$ <br>  $s = \text{specific rate of substrate}$ <br>  $p = \text{specific cell growth rate}$ ;<br>  $p = \text{specific rate of product formation.}$ <br>  $p \text{ in fed-batch operation mode:}$ <br>  $\cdot$  initial concentrations  $X_0, P_0$  and  $S_0$ ;<br>  $\cdot$  initial volume of fermentation broth **of Fed-Batch Bioreactors**<br> **cal Fibers**<br> **er HPLC**<br> **e**  $\mu_s$  = specific rate of substrate<br>
consumption;<br> **e**  $\mu$  = specific cell growth rate;<br> **e**  $q_p$  = specific rate of product formation.<br> **on fed-batch operation mod Fibers**<br> **Fibers**<br> **Fibers**<br> **Figure 1997**<br> **Figure 199**

$$
\frac{dV}{dt} = F \Rightarrow V = V_0 + F(1)
$$

$$
\frac{dX}{dt} = \mu X - \frac{FX}{V} \tag{2}
$$

$$
\frac{dP}{dt} = q_p X - \frac{FP}{V} \tag{3}
$$

$$
\frac{dS}{dt} = -\mu_s X + \frac{F(S_F - S)}{V} \tag{4}
$$

- $0 + F(1)$  consumption;  $\mu_s$  = specific
	-
	- $q_p$  = specific rate of product formation.
	- -
- **Fibers**<br> **Figure 1988**<br> **Figure 1988**<br> **Figure 1989**<br>  $V_0$ ;
- initial concentrations  $X_0$ ,  $P_0$  and  $S_0$ ;<br>• initial volume of fermentation broth<br> $V_0$ ;<br>• A constant feed flow F supplies the<br>reactor with fresh substrate with<br>concentration  $S_F$ .<br>or at 33 °C (temperature for maxim • A constant feed flow supplies the = specific rate of substrate<br>umption;<br>pecific cell growth rate;<br>specific rate of product formation.<br>d-batch operation mode:<br>initial concentrations  $X_0$ ,  $P_0$  and  $S_0$ ;<br>initial volume of fermentation broth<br> $V_0$ ;<br>A cons  $q_p$  = specific rate of product formation.<br>
On fed-batch operation mode:<br>
• initial concentrations  $X_0$ ,  $P_0$  and  $S_0$ ;<br>
• initial volume of fermentation broth<br>  $V_0$ ;<br>
• A constant feed flow F supplies the<br>
reactor wi

 $\frac{dX}{dt} = \mu X - \frac{FX}{V}$  (2)<br>  $\frac{dY}{dt} = \mu_X - \frac{FX}{V}$  (2)<br>  $\frac{dP}{dt} = q_p X - \frac{FP}{V}$  (3)<br>  $\frac{dS}{dt} = -\mu_s X + \frac{F(S_F - S)}{V}$  (4)<br>
Simulation parameters for a fed-batch reactor at 33 °C (temperature for maximum cell<br>
growth [3]):  $X_$  $rac{dA}{dt} = \mu X - \frac{F A}{V}$  (2)<br>  $\frac{dP}{dt} = q_p X - \frac{FP}{V}$  (3)<br>  $\frac{dS}{dt} = -\mu_s X + \frac{F(S_F - S)}{V}$  (4)<br>
Simulation parameters for a fed-batch reactor at 33 °C<br>
growth [3]):  $X_0 = 50 \text{ gL}^{-1}$ ,  $P_0 = 0$ ,  $S_0 = 30 \text{ gL}^{-1}$ ,  $V_0 = 1 \text{ L$ ,  $P_0$  = 0,  $S_0$  = 30 gL<sup>-1</sup>,  $V_0$  = 1 L,  $F$  = 0.66 Lh<sup>-1</sup> and  $S_F$  = 192 gL<sup>-1</sup>. -  $\frac{FA}{V}$  (2)<br>
•  $q_p$  = specific rate of p<br>
• On fed-batch operation<br>
• initial concentration<br>
• initial volume c<br>  $\frac{V(S_F - S)}{V}$  (4)<br>
• A constant feed<br>
reactor with f<br>
concentration  $S_f$ <br>
a fed-batch reactor at 33 °C 2)<br>
•  $q_p$  = specific rate of product for<br>
• On fed-batch operation mode:<br>
• initial concentrations  $X_0$ ,  $P$ <br>
• initial volume of ferment<br>  $V_0$ ;<br>
• A constant feed flow  $F$  s<br>  $S$ )<br>
(4)<br>
• reactor with fresh sub:<br>
conc





Sensors for Monitoring Industrial Bioreactors **Contraction of Optical Fiber Sensors** for Monitoring Industrial Bioreactors University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br> **Dividends Soares of Analysis of Optical Fiber**<br> **Dividends Soares** Soares et al., Technical and Economic Viability Analysis of Optical Fiber



# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers



**sensors** 

- es<br> **Batch Bioreactors**<br> **FS**<br>
 Without real-time monitoring,<br>
(such as using HPLC for process<br>
control): *X* follows the red curve<br>
and *P* the pink curve; **Example 12 Separation**<br> **Solution Bioreactors**<br>
(such as using HPLC for process<br>
control): *X* follows the red curve<br>
and *P* the pink curve;<br>
If in-line real-time instrumentation **incomposity of the Sing Control):**  $X$  follows the red curve<br>
(such as using HPLC for process<br>
control):  $X$  follows the red curve<br>
and  $P$  the pink curve;<br>
If in-line real-time instrumentation<br>
can detect the disturbanc
- **Batch Bioreactors**<br> **Pand the pink curve;**<br>
(such as using HPLC for process<br>
control): *X* follows the red curve<br>
and *P* the pink curve;<br> **Control** in the pink curve;<br> **Control** is restored to the original levels<br>
just **in the disturbance of the disturbance and** *B* follow the disturbance and *P* the pink curve;<br>
If in-line real-time instrumentation<br>
can detect the disturbance and  $S_F$ <br>
is restored to the original levels<br>
just after 20 **is respect to the original levels to the original levels in the original levels (such as using HPLC for process control):**  $X$  **follows the red curve and**  $P$  **the pink curve;<br>If in-line real-time instrumentation can detect itch Bioreactors**<br>
S<br>
Without real-time monitoring,<br>
(such as using HPLC for process<br>
control): X follows the red curve<br>
and P the pink curve;<br>
If in-line real-time instrumentation<br>
can detect the disturbance and  $S_F$ <br>
i Without real-time monitoring,<br>(such as using HPLC for process<br>control): *X* follows the red curve<br>and *P* the pink curve;<br>If in-line real-time instrumentation<br>can detect the disturbance and  $S_F$ <br>is restored to the origina **FS**<br>
• Without real-time monitoring,<br>
(such as using HPLC for process<br>
control): *X* follows the red curve<br>
and *P* the pink curve;<br>
• If in-line real-time instrumentation<br>
can detect the disturbance and  $S_F$ <br>
is restore Without real-time monitoring,<br>
(such as using HPLC for process<br>
control): *X* follows the red curve<br>
and *P* the pink curve;<br>
If in-line real-time instrumentation<br>
can detect the disturbance and  $S_F$ <br>
is restored to the o
- Follow the black and blue<br>
branching curves, respectively.<br> **EXECUTE:**  $\frac{11.6\%}{\text{detection}}$ <br> **EXECUTE:**  $\frac{11.6\%}{\text{detection}}$ <br> **EXECUTE:**  $\frac{1}{10}$ <br> **EXECUTE:**  $\frac{1}{10}$ <br> **EXECUTE:**  $\frac{1}{10}$ <br> **EXECUTE:**  $\frac{1}{10}$ <br> **EXECUT** cells and 13.5% reduction in the members of such as using HPLC for process control): *X* follows the red curve and *P* the pink curve;<br>If in-line real-time instrumentation can detect the disturbance and  $S_F$  is **restored** control): *X* follows the red curve<br>control): *X* follows the red curve<br>if in-line real-time instrumentation<br>can detect the disturbance and  $S_F$ <br>**is restored to the original levels**<br>**just after 20 minutes:** *X* and *P*<br>fo and P the pink curve;<br>and P the pink curve;<br>If in-line real-time instrumentation<br>can detect the disturbance and  $S_F$ <br>is restored to the original levels<br>just after 20 minutes: X and P<br>follow the black and blue<br>branching cu F in-line real-time instrumentation<br>If in-line real-time instrumentation<br>can detect the disturbance and  $S_F$ <br>**is restored to the original levels**<br>**just after 20 minutes**: *X* and *P*<br>follow the black and blue<br>branching cu the minimizer and the disturbance and  $S_F$ <br>is restored to the original levels<br>just after 20 minutes: *X* and *P*<br>follow the black and blue<br>branching curves, respectively.<br>After a 12 hours cycle: 11.6%<br>reduction in the con





# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br> **3. Real-time Monitoring Industrial Bioreactors**<br> **19. Real-time Mo** Beach of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br> **1997 - The Form of Science of Consideration**<br> **1997 - The Form of Fed-Batch Bioreactors**<br>
Instrumentation Setup and Costs<br>
• For instrumentation c



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[17] Soares. M.C.P.et al. Proc. 26th International Conference on Optical Fiber Sensors 2018. doi: 10.1363/OFS.2018.ThE39.







# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Ecosymptem Fiber<br> **3. Real-time Monitoring of Fed-Batch Bioreact**<br> **with Optical Fibers**<br> **Instrumentation Setup** University of Campinas - UNICAMP. Laboratory of Photonic Materials and Devices<br> **3. Real-time Monitoring of Fed-Batch Bioreactors**<br> **11. Instrumentation Setup and Costs**<br>
• Light from a 1310 nm laser is guided to the biore University of Campinas – UNICAMP. Laboratory of Photonic Materials and Devices<br>
Soarce of al. Technological from the fermentation broth.<br> **Real-time Monitoring of Fed-Batch Bioreact**<br> **with Optical Fibers**<br>
strumentation S **B. Real-time Monitoring of Fed-Batch Bioreactors**<br> **Instrumentation Setup and Costs**<br>
• Light from a 1310 nm laser is guided to the bioreactor by a single mode optical<br>
fiber submerged in the fermentation broth.<br>
• The l **Couplem Control Cont**

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Somes et al., Technical and Economic Material Bioreactors<br> **3. Real-time Monitoring of Fed-Batch Bioreaction**<br> **with Optical Fibers**<br> **Instrum BEREAD THE INTENSITY OF THE INTENSITY OF THE INTENSITY OF THE INTERNATIONAL IS SERIES WITH OPICIAL FIBERS**<br> **3. Real-time Monitoring of Fed-Batch Bioreactors**<br> **Instrumentation Setup and Costs**<br>
• The intensity of the re **Example 2** Technical and Economic Wability Analysis of Optical Fiber<br> **Solitis Art A. Technical and Economic Wability Analysis of Optical Fiber<br>
<b>Solitis Art A. Technical and Economic Wability Analysis of Optical Fiber<br>**

$$
I_R = k \cdot I_0 \left[ \frac{\left( n_f - n_b \right)}{\left( n_f + n_b \right)} \right]^2 \tag{5}
$$

**Instrumentation Setup and Costs**<br>
• The intensity of the reflected signal is given by Equation (5)<br>
equation [18]:<br>  $I_R = k \cdot I_0 \left[ \frac{(n_f - n_b)}{(n_f + n_b)} \right]^2$  (5)<br>
•  $I_R$  is the reflected signal intensity,  $I_0$  is the emitted l **Costs**<br>
is given by Equation (5), which is Fresnel's<br>  $\left(\frac{n_f - n_b}{n_f + n_b}\right)^2$  (5)<br>
is the emitted light intensity, *k* is a coupling<br>
losses, and  $n_f$  and  $n_b$  are the refractive<br>
entation broth, respectively. The intensity of the reflected signal is given by Equation (5), which is Fresnel's<br>equation [18]:<br> $I_R = k \cdot I_0 \left[ \frac{(n_f - n_b)}{(n_f + n_b)} \right]^2$  (5)<br> $I_R$  is the reflected signal intensity,  $I_0$  is the emitted light intensity,  $k$  is coefficient that accounts for optical losses, and  $n_f$  and  $n_b$  are the refractive which is Fresnel's<br>sity, *k* is a coupling<br>are the refractive<br>ly. The intensity of the reflected signal is given by Equation (5), which is Fresnel's<br>equation [18]:<br> $I_R = k \cdot I_0 \frac{\left(n_f - n_b\right)}{\left(n_f + n_b\right)}^2$  (5)<br> $I_R$  is the reflected signal intensity,  $I_0$  is the emitted light intensity, k is  $\left[\frac{n_b}{m_b}\right]$  (5)<br>
he emitted light intensity, *k* is a coupling<br>
sses, and  $n_f$  and  $n_b$  are the refractive<br>
ation broth, respectively.<br>
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Somes et al., Technical and Economic Material Bioreactors<br> **3. Real-time Monitoring of Fed-Batch Bioreactor**<br>
With Optical Fibers<br>
Instrumenta **BEREVIS DESCRIPTION AND AS DESCRIPTION AND AS DEMONSTRATED BEFORE AN INCREDIBLE SCRIPTION CONCENTRATED SETTING MODEL CONCENTRATED SETTING MODEL CONCENTRATED IN A DEMONSTRATED IN A DEMONSTRATED IN A DEMONSTRATED IN A DEMO in the broth, and therefore can be used as the monitoring parameter.**<br> **Such as the monitoring of Fed-Batch Bioreactors**<br>
As demonstrated before in [17],  $n_b$  is directly related to S and P concentrations<br>
in the broth,

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- **3. Real-time Monitoring of Fed-Batch Bioreactors**<br> **with Optical Fibers**<br> **Instrumentation Setup and Costs**<br>
 As demonstrated before in [17],  $n_b$  is directly related to S and P concentrations<br>
in the broth, and therefo **sufficiently diluted (until ~0.12 gL-1)**, the sensor may be used for the directions of the other hand, this sensor is quite robust: as shown on [3,17], if the broth is sufficiently diluted (until ~0.12 gL-1), the sensor **Instrumentation Setup and Costs**<br>
• As demonstrated before in [17],  $n_b$  is directly related to *S* and *P* concentrations<br>
in the broth, and therefore can be used as the monitoring parameter.<br>
• On the other hand, this As demonstrated before in [17],  $n_b$  is directly related to *S* and *P* concentrations<br>in the broth, and therefore can be used as the monitoring parameter.<br>On the other hand, this sensor is quite robust: as shown on [3,17 As demonstrated before in [17],  $n_b$  is directly<br>in the broth, and therefore can be used as the<br>On the other hand, this sensor is quite robust<br>sufficiently diluted (until ~0.12 gL<sup>-1</sup>), the se<br>quantifying of the biomass c
- The sensor may be used for the direct<br>
DR X.<br>
, a small sample may be collected to<br>
ted and diluted to a known volume to<br>
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Somes et al., Technical and Economic Material Bioreactors<br> **3. Real-time Monitoring of Fed-Batch Bioreactor**<br>
W**ith Optical Fibers**<br>
Instrumen **EXERCISE ON THE PARTICULATE CONNECTIVE CONSUMPLANE CO Real-time Monitoring of Fed-Batch Bioreactors**<br>**with Optical Fibers**<br>**strumentation Setup and Costs**<br>On the particulate system, light that reaches cells is scattered, generating<br>random fluctuations that are coupled back

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- **3. Real-time Monitoring of Fed-Batch Bioreactors**<br> **with Optical Fibers**<br> **Instrumentation Setup and Costs**<br>
 On the particulate system, light that reaches cells is scattered, generating<br>
random fluctuations that are co **Summer Summer Summer Summer Summer Summer Summer Strumentation Setup and Costs**<br>On the particulate system, light that reaches cells is scattered, generating<br>random fluctuations that are coupled back to the fiber core [3] **Summer Summer Strumentation Setup and Costs**<br>
On the particulate system, light that reaches cells is scattered, generating<br>
random fluctuations that are coupled back to the fiber core [3].<br>
The assessment of X is then ba **strumentation Setup and Costs**<br>
On the particulate system, light that reaches<br>
random fluctuations that are coupled back to the<br>
The assessment of X is then based on obtaining<br>
the light intensity  $I_R$ ,  $G_2(\tau)$ , where t the instant of the measurement, T is the<br>otal of measurements collected, and  $\tau$  is<br> $\approx \lim_{N \to \infty} \frac{1}{N} \sum_{j=1}^{N} I(j) \cdot I(j + \tau)$  (6)<br>ECSA-7 2020 – marcosoares.feq@gmail.com 23

$$
G_{2}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} I(t) \cdot I(t + \tau) dt \approx \lim_{N \to \infty} \frac{1}{N} \sum_{j=1}^{N} I(j) \cdot I(j + \tau) \tag{6}
$$







# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Somes et al., Technical and Economic Material Bioreactors<br> **3. Real-time Monitoring of Fed-Batch Bioreactor**<br>
W**ith Optical Fibers**<br>
Instrumen **BEREVIS COMPRIME LUNCAMP, LUNCAMP, LUNCAMP, LUNCAMP, LUNCAMP, LUNCAMP, LUNCAMP, LUNCAMP, CONDICAL PRIME OF CONDICATION<br>
3. Real-time Monitoring of Fed-Batch Bioreactors<br>
With Optical Fibers<br>
Instrumentation Setup and Cos Equation (6) may be fitted by Equation (7) (Siegert Equation) [3]:**<br> **Equation (6) may be fitted by Equation (7) (Siegert Equation) [3]:**<br>  $G_2(\tau) = \alpha + \beta \exp(-2T\tau)$  (7)

$$
G_2(\tau) = \alpha + \beta \exp(-2\Gamma \tau) (7)
$$

- **Instrumentation Setup and Costs**<br>
 When the quasi-elastic light scattering (QELS) phenomenon takes place,<br>
Equation (6) may be fitted by Equation (7) (Siegert Equation) [3]:<br>  $G_2(\tau) = \alpha + \beta \exp(-2\Gamma \tau)$  (7)<br>
 In Equation ( **Instrumentation Setup and Costs**<br>
• When the quasi-elastic light scattering (QELS) phenomenon takes place,<br>
Equation (6) may be fitted by Equation (7) (Siegert Equation) [3]:<br>  $G_2(\tau) = \alpha + \beta \exp(-2\Gamma \tau)$  (7)<br>
• In Equation ( <ul>\n<li> When the quasi-elastic light scattering (QELS) phenomenon takes place, Equation (6) may be fitted by Equation (7) (Siegert Equation) [3]: <math display="inline">G\_2(\tau) = \alpha + \beta \exp(-2\Gamma \tau)</math> (7)</li>\n<li> In Equation (7), <i>α</i> and <i>β</i> are the fitting adjustable parameters. The adjustment is used to calculate <i>Γ</i>, the average decay rate, which is directly proportional to X.</li>\n<li> Therefore, depending on the control goals and on the available infrastructure, the sensor can easily monitor <i>S/P</i> and/or X.</li>\n<li> The assessment can be directly performed in-line or in a parallel vessel.</li>\n<li> <b>SCHSONS</b> <b>MDPI</b> <b>ESA-7 2020 – matrices
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# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers Sares of all, Technical Edeoporations Campinas - UNICAMP, Laboratory of Photonic Materials and Devices<br> **3. Real-time Monitoring of Fed-Batch Bioreact**<br> **19. Real-time Monitoring of Fed-Batch Bioreact**<br> **Instrumentation Se 3. Real-time Monitoring of Fed-Batch Bioreactors**<br> **with Optical Fibers**<br> **Instrumentation Setup and Costs**<br>
• Table 1: list of all necessary components to implement the sensor setup, along<br>
with the cost per unit and sup **Example 1: Instant Proprise of Fed-Batch Bi**<br> **with Optical Fibers**<br> **strumentation Setup and Costs**<br>
Table 1: list of all necessary components to implement the servith the cost per unit and supplier.<br>
The total cost in B

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- **Example 18 The total cost in Brazilian Costs**<br> **example 1:** list of all necessary components to implement the sensor setup, along<br>
with the cost per unit and supplier.<br>
 The total cost in Brazilian *Reais* (BRL) and Unit **Strumentation Setup and Costs**<br> **Strumentation Setup and Costs**<br>
Table 1: list of all necessary components to implement the sensor setup, along<br>
with the cost per unit and supplier.<br>
The total cost in Brazilian *Reais* (B **strumentation Setup and Cos**<br>Table 1: list of all necessary components<br>with the cost per unit and supplier.<br>The total cost in Brazilian *Reais* (BRL)<br>presented in the last row: an exchange i<br>was used. ECSA-7 2020 – marcosoares.feq@gmail.com





Sensors for Monitoring Industrial Bioreactors **Contract Sensors for Sensors for Sensors for Sensors** for Sensors f University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br> **Dividends Soares of Analysis of Optical Fiber**<br> **Dividends Soares** Soares et al., Technical and Economic Viability Analysis of Optical Fiber



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Somes et al., Technical and Economic Visibly Analysis of Optical Fiber<br>
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# niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Il-time Monitoring of** 3. Real-time Monitoring of Fed-Batch Bioreactors with Optical Fibers University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Somes et al., Technical and Economic Visiblity Analysis of Optical Fiber<br>
3. Real-time Monitoring of Fed-Batch Bioreact<br>
with Optical Fibers<br> ● Aside from the individual components, qualified personnel are required to Supervise the implementation **Setup and Costs**<br>Supervise the implementation **Setup and Costs**<br>Supervise the implementation of the optical **Fibers**<br>To that end, we are also considering in our calculations the cost of hiring **3. Real-time Monitoring of Fed-Batch Bioreactors**<br> **with Optical Fibers**<br> **Instrumentation Setup and Costs**<br>
• Aside from the individual components, qualified personnel are required to<br>
supervise the implementation of the

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- **S. Real-time information Setup and Costs**<br> **Instrumentation Setup and Costs**<br>
 Aside from the individual components, qualified personnel are required to<br>
supervise the implementation of the optical fiber reflectometer.<br> **strumentation Setup and Costs**<br>Aside from the individual components, qualified personnel are required to<br>supervise the implementation of the optical fiber reflectometer.<br>To that end, we are also considering in our calcula Stide from the individual components, qualified personnel are required to<br>supervise the implementation of the optical fiber reflectometer.<br>To that end, we are also considering in our calculations the **cost of hiring a**<br>qua side from the individual components, qualified personnel are required to<br>upervise the **implementation** of the optical fiber reflectometer.<br>
o that end, we are also considering in our calculations the **cost of hiring a**<br>
ua supervise the implementation of the optical fiber reflectometer.<br>
To that end, we are also considering in our calculations the **cost of hiring a**<br>
qualified engineer for a six months period.<br>
According to Brazilian law 4.9
- 1<sup>st</sup>-year cost of implementing the fiber optic sensing setup (components +







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Soares et al., Technological fiber Material Bloveadors<br>
Sensibility of Fiber Optics Sensing<br>
 Comparison of the costs of implementing the in-University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technical and Economic Valaphy, Materia Hotel Fiber<br>
Soares et al., Technical And Contouring Industrial Blorescore<br>
Soares of o **4. Economic Viability of Fiber Optics Ser**<br>
• Comparison of the costs of implementing the in-line of reflectometer with traditional HPLC analysis.<br>
• We have considered **two scenarios:**<br>
• in the first scenario, an ethano
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- **4. Economic Viability of Fiber Optics Sensing**<br>
Comparison of the costs of implementing the in-line optical fiber<br>
eflectometer with traditional HPLC analysis.<br>
We have considered two scenarios:<br>
 in the first scenario, **ECONOTITE VIADITY OF TIDET OPTICS SETISTING**<br>mparison of the costs of implementing the in-line optical fiber<br>ectometer with traditional HPLC analysis.<br>have considered **two scenarios:**<br>in the first scenario, an ethanol pla mparison of the costs of implem<br>ectometer with traditional HPLC a<br>have considered **two scenarios:**<br>in the first scenario, an ethanol plant a<br>but acquisition and maintenance costs<br>be prohibitive;<br>and so in the second scenar ● and so in the second scenario, the plant hires a third party specialized in ectometer with traditional HPLC analysis.<br>
have considered **two scenarios**:<br>
in the first scenario, an ethanol plant acquires their own H<br>
but acquisition and maintenance costs for a chromatograp<br>
be prohibitive;<br>
and so i nt acquires their own HPLC equipment,<br>osts for a chromatography column may<br>plant hires a third party specialized in<br>ECSA-7 2020 – marcosoares.feq@gmail.com 28
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# 4. Economic Viability of Fiber Optics Sensing University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
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- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
Source et al., Technology Material Blockedics<br>
4. Economic Viability of Fiber Optics Sensing<br>
First Scenario: acquiring HPLC equipment<br>
 We h **4. Economic Viability of Fiber Optics Sensing**<br>t Scenario: acquiring HPLC equipment<br>We have contacted several suppliers and arrived at:<br>• an average cost of 27,500.00 USD (150,700.00 BRL) for a refurbished benchtop<br>• plus equipment,
	-
	- **4. Economic Viability of Fiber Optics Sensing**<br>
	t Scenario: acquiring HPLC equipment<br>
	We have contacted several suppliers and arrived at:<br>
	 an average cost of 27,500.00 USD (150,700.00 BRL) for a refurbished benchtop<br>
	eq cenario: acquiring HPLC equipment<br>have contacted several suppliers and arrived at:<br>an average cost of 27,500.00 USD (150,700.00 BRL) for a refurbished benchtop<br>equipment,<br>plus 200.00 USD/hour (1,096.00 BRL/hour) installati **CENTRIO:** acquiring HPLC equipment<br>have contacted several suppliers and arrived at:<br>an average cost of **27,500.00 USD (150,700.00 BRL)** for a refurbished benchtop<br>equipment,<br>plus 200.00 USD/hour (1,096.00 BRL/hour) instal HPLC); ■ an average cost of **27,500.00 USD (150,700.00 BRL)** for a refurbished benchtop<br>
	equipment,<br>
	■ plus 200.00 USD/hour (1,096.00 BRL/hour) installation costs.<br>
	■ Acquisition and installation costs already far surpass those an average cost of **27,500.00 USD (150,700.00 BRL)** for a refurbished bend<br>equipment,<br>plus 200.00 USD/hour (1,096.00 BRL/hour) installation costs.<br>Acquisition and installation costs already far surpass those from acquirin<br> ur) **installation costs.**<br>Exady far surpass those from acquiring all<br>cs setup (the **assembly of the reflectometer**<br>**relation to the acquisition of a refurbished**<br>re to invest more resources to maintain a<br>column.<br>ECSA-7 20
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4. Economic Viability of Fiber Optics Sensing<br>
Second Scenario: plan BRAZIM OF CHINGAMP, Laboratory of Photonic Materials and Devices<br> **4. Economic Viability of Fiber Optics Sensing**<br>
Second Scenario: plant hires a third party laboratory<br>
• On Brazilian market the average cost of contractin
- **4. Economic Viability of Fiber Optics Sensing**<br>Second Scenario: plant hires a third party laboratory<br>• On Brazilian market the average cost of contracting HPLC analysis services is of<br>100 BRL/hour (18.25 USD/hour).<br>• It **4. Economic Viability of Fiber Optics Sensing**<br>
cond Scenario: plant hires a third party laboratory<br>
On Brazilian market the average cost of contracting HPLC analysis services is of<br> **100 BRL/hour (18.25 USD/hour)**.<br>
It cond Scenario: plant hires a third party laboratory<br>
On Brazilian market the average cost of contracting HPLC analysis services is<br> **100 BRL/hour (18.25 USD/hour).**<br>
It is possible to estimate the yearly cost by considerin **Second Scenario: plant hires a third party laboratory**<br>
● On Brazilian market the average cost of contracting HPLC analysis services is of<br> **100 BRL/hour (18.25 USD/hour).**<br>
● It is possible to estimate the yearly cost b Supply that the contribution of<br>
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### 4. Economic Viability of Fiber Optics Sensing

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4. Economic Viability of Fiber Optics Sensing<br>
Hypotheses used to est University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
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Sensors for Monitoring Industrial Bioreactors<br>
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4. Economic Viability of Fiber Optics Sensing<br>
in Film III, we can u University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Soares et al., Technola Park Montoling Industrial Blovectors<br>
Senes for Montoling Industrial Blovectors<br>
Finally, we can use this data to calc University of Campinsa - UNICAMP, Laboratory of Photonic Materials and Devices<br>
Somes of all The fiber optics Sensing<br>
Finally, we can use this data to calculate, with a Weighted Average Capital Cost<br>
(WACC) model [19], th Soares et al., Technical and Economic Viability Analysis of Optical and Economic Viability Analysis of Optical Sensors for Monitoring Industrial Bioreactors<br>Finally, we can use this data to calculate,<br>(WACC) model [19], th **4. Economic Viability of Fiber Optics Sensing**<br>
• Finally, we can use this data to calculate, with a Weighted Average Capital Cost<br>
(WACC) model [19], the 5-year cash flow of an ethanol plant after<br>
implementation of the **4. ECONOMIC VIADIIITY OT FIDET OPTICS SENSING**<br>Finally, we can use this data to calculate, with a Weighted Average Capital Cost<br>(WACC) model [19], the **5-year cash flow** of an ethanol plant after<br>implementation of the fib Finally, we can use this data to calculate, with a Weighted Average Capi<br>(WACC) model [19], **the 5-year cash flow** of an ethanol plan<br>**implementation of the fiber optic instrumentation** in detriment of con<br>HPLC services.<br> • Finally, we can use this data to calculate, with a Weighted Average Capital Cost (WACC) model [19], **the 5-year cash flow** of an ethanol plant after **implementation of the fiber optic instrumentation** in detriment of co Finally, we call use this data to calculat<br>(WACC) model [19], **the 5-year calculat**<br>**implementation of the fiber optic insti**<br>HPLC services.<br>**WACC:** this methodology consists on **e**<br>**cost (interest on the amount) and the**<br>
- return demanded by shareholders (cost<br>de [19].<br>Derior than the debt and capital costs to<br>Analysis for Investment and Corporate Finance, 2nd ed; John Wiley & Sons. 2011.<br>ECSA-7 2020 marcosoares.feq@gmail.com 33 ethodology consists on **evaluating the contribution of the debt**<br> **on the amount) and the return demanded by shareholders (cost**<br> **the investment to be made** [19].<br>
ect must show return superior than the debt and capital c
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• Considering:<br>
• depreciation rat

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Soares et al., Technical and Economic Viability Analysis of Optical Fiber<br>
Soares et al., Technical and Economic Viability of Fiber Optics Sen **4. Economic Viability of Fiber Optics Sensing**<br>
Considering:<br>
• depreciation rate of 20% per year;<br>
• Net present value (NPV) discount rate of 2.25% per year (current 2020<br>
Brazilian rate as per Brazil's Central Bank - BA **Example: Configure 1: All of Schools Central Bank - Bank Schools**<br>depreciation rate of 20% per year;<br>Net present value (NPV) discount rate of 2.25% per year (current 2020<br>Brazilian rate as per Brazil's Central Bank - BACE **Economic Viability of Fiber Optics S.**<br>Insidering:<br>depreciation rate of 20% per year;<br>Net present value (NPV) discount rate of 2.25% per yea<br>Brazilian rate as per Brazil's Central Bank - BACEN), we d<br>Internal Rate of Retu Considering:<br>
■ depreciation rate of 20% per year;<br>
● Net present value (NPV) discount rate of 2.25% per year (current 2020<br>
Brazilian rate as per Brazil's Central Bank - BACEN), we can calculate an<br>
IRR is an estimate of
	- platform. ity of the investment in the fiber optic<br>ECSA-7 2020 – marcosoares.feq@gmail.com 34







# 4. Economic Viability of Fiber Optics Sensing University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
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4. Economic Viability of Fiber Optics Se<br>
Main Financial Indicators

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- **4. Economic Viability of Fiber Optics Sensing**<br>
in Financial Indicators Obtained<br>
 Internal Rate of Return (IRR): **742.11%.**<br>
 Discounted payback (amount of time for the investment to pay<br>
for itself): **0.14 years, or a ECONOTITIC VIADITLY OF FIDET Optics Sensing.**<br>Financial Indicators Obtained<br>Internal Rate of Return (IRR): **742.11%.**<br>Discounted payback (amount of time for the investment to pay<br>for itself): **0.14 years, or approximately** ECSA-7 2020 – marcosoares.feq@gmail.com and also<br>ECSA-7 2020 – marcosoares.feq@gmail.com and also





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Other monitoring alternatives<br>
• For the sake of completeness, we also provide a quick assessment **4. Economic Viability of Fiber Optics Sensing<br>
For the sake of completeness, we also provide a quick assessment of alternative<br>
For the sake of completeness, we also provide a quick assessment of alternative<br>
solutions to**
- **4. Economic Viability of Fiber Optics Sensing**<br> **Other monitoring alternatives**<br>
 For the sake of completeness, we also provide a quick assessment of alternative<br>
solutions to HPLC and the proposed fiber optic reflectome **4. Economic Viability of Fiber Optics Sensing**<br>her monitoring alternatives<br>For the sake of completeness, we also provide a quick assessment of alternative<br>solutions to HPLC and the proposed fiber optic reflectometer.<br>That
- **Other monitoring alternatives**<br>
 For the sake of completeness, we also provide a quick assessment of alternative<br>
solutions to HPLC and the proposed fiber optic reflectometer.<br>
 That is important especially for the cas For the sake of completeness, we also provide a quick assessment of alternative<br>solutions to HPLC and the proposed fiber optic reflectometer.<br>That is important especially for the case where the industry only wishes to<br>acce nentation broth.<br>
, an optical density measurement with a<br>
metric kits such as [4].<br>
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4. Economic Viability of Fiber Optics Sensing<br>
Other monitoring alternati University of Campinas – UNICAMP, Laboratory of Photonic Materials and Device Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>
Soares *et al.*, Technical and Economic Viability Analysis of Optic
- **4. Economic Viability of Fiber Optics Sensing**<br>
pectrophotometers: available for reasonably low prices starting at only a few<br>
housands of dollars.<br>
 Disadvantages of requiring regular sampling of the broth, and the meas **Economic Viability of Fiber Optics Sensing**<br>monitoring alternatives<br>trophotometers: available for reasonably low prices starting at only a few<br>sands of dollars.<br>Disadvantages of requiring regular sampling of the broth, an **Other monitoring alternatives**<br>
■ Spectrophotometers: available for reasonably low price<br>
thousands of dollars.<br>
■ Disadvantages of requiring regular sampling of the broth, and<br>
direct, since different concentrations of **example is alternatives**<br>
pectrophotometers: available for reasonably low prices starting at only a few<br>
housands of dollars.<br>
• Disadvantages of requiring regular sampling of the broth, and the measurements are not as<br>
d of pectrophotometers: available for reasonably low prices starting at only a few<br>housands of dollars.<br>• Disadvantages of requiring regular sampling of the broth, and the measurements are not as<br>direct, since different conc Unity and the measurements of dollars.<br>
Disadvantages of requiring regular sampling of the broth, and the measureme<br>
direct, since different concentrations of other components will also affere<br>
density.<br>
Of colorimetric ki
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- h in regular intervals.<br>alyzed on the spectrophotometer for a given<br>ECSA-7 2020 marcosoares.feq@gmail.com 39







# 4. Economic Viability of Fiber Optics Sensing University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
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Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>
Sensors for Monitoring Industrial Bioreactors<br> **4. Economic Viabi** University of Colorimetric and Economic Viewity Analysis of Optical Fiber<br> **4. Economic Viability of Fiber Optics Sensing**<br>
er monitoring alternatives<br>
Use of colorimetric kits:<br>
• If each test should be conducted once an Sensors for Monitoring Industrial Bloeactors<br> **1. Economic Viability of Fiber (**<br> **monitoring alternatives**<br>
of colorimetric kits:<br>
If each test should be conducted once an hour (w<br>
optical fiber setup):<br>
• Each kit in [4] **Economic Viability of Fiber Optics Sensing**<br> **Example 10** nonitoring alternatives<br> **Example 10** for analyzing 20 samples.<br> **Example 10** for analyzing 20 samples.<br> **Example 12** analysis/day, 200 days per year, it results i **ECONDITITE VILATIFY OF TINCT OPTICS SCHISHING**<br> **Solution**<br> **Solution**<br> **Solution**<br> **Solution**<br> **Each kit in [4] can be used for analyzing 20 samples.**<br> **•** Considering 12 analysis/day, 200 days per year, it results in a
	-
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	- **nitoring alternatives**<br>plorimetric kits:<br>ch test should be conducted once an hour (which is simple to do with the<br>al fiber setup):<br>Each kit in [4] can be used for analyzing 20 samples.<br>Considering 12 analysis/day, 200 day **Example 11 This scenario, the conducted once an hour (which is simple to do with the bottical fiber setup):**<br>
	• Each kit in [4] can be used for analyzing 20 samples.<br>
	• Considering 12 analysis/day, 200 days per year, it r order that should be conducted once an hour (which is simple to do with the<br>al fiber setup):<br>Each kit in [4] can be used for analyzing 20 samples.<br>Considering 12 analysis/day, 200 days per year, it results in a total usage See of colorimetric kits:<br>
	• If each test should be conducted once an hour (which is simple to do with the optical fiber setup):<br>
	• Each kit in [4] can be used for analyzing 20 samples.<br>
	• Considering 12 analysis/day, 200 optical fiber setup):<br>
	• Each kit in [4] can be used for analyzing 20 samples.<br>
	• Considering 12 analysis/day, 200 days per year, it results in a total usage of<br>
	year, or about **9,360.00 USD/year (51,292.80 BRL/year)** in c 20 samples.<br>
	per year, it results in a total usage of 120 kits per<br> **92.80 BRL/year)** in costs.<br>
	alone, not including inflation and other required<br>
	is **almost twice the costs of acquiring all the**<br> **meter**.<br>
	ach is still v
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niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors Sensors for Monitoring Industrial Bioreactors **Contract Sensors for Sensors for Sensors for Sensors** for Sensors f Experience of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
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### 5. Conclusions

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- University of Campinas UNICAMP, Laboratory of Photonic Materials and Devices<br>
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Sensors for Monitoring Industrial Bioreactors<br> **5.** CONCLUSIONS<br>
T University of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>
Source et al., Technical and Economic Valenting Industrial Bluecacles<br>
Source at al., Technical and Economic Valenting Industrial Bluecacles<br> Sources of the complementing to determine the source of the complement with a source of the control of 5. Concl<br>There is considerable medium- and long-term<br>systems for monitoring fed-batch bioreactors ;<br>The average Brazilian ethanol plant is expecte<br>50 days, together with a 5-year NPV of 525,08<br>Similar results are expected ■ There is considerable medium- and long-term financial gains from implementing fiber optic systems for monitoring fed-batch bioreactors as a substitute for traditional HPLC analysis.<br>■ The average Brazilian ethanol plant
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- here is considerable medium- and long-term financial gains from implementing fiber optic<br>ystems for monitoring fed-batch bioreactors as a substitute for traditional HPLC analysis.<br>he average Brazilian ethanol plant is expe Sterns for monitoring rea-batch bibreactors as a substitute for traditional first entarysis.<br> **he average Brazilian ethanol plant is expected to see a return for their investment in about 0 days, together with a 5-year NPV** average Brazilian ethanol plant is expected to see a **return for their investment in about**<br>ays, together with a 5-year NPV of 525,088.06 USD, corresponding to an IRR of 742%.<br>lar results are expected for any industry worl ays, together with a 5-year NPV of 525,088.06 USD, correspond<br>lar results are expected for any industry worldwide that utiliz<br>bioreactors.<br>proposed fiber optic setup is comparatively a very low-cost anal<br>lt does not demand Ily a very low-cost analytical solution:<br>
hel to operate and maintain it;<br>
hel can be adapted for most industrial needs<br>
s, being able to detect from sucrose to even<br>
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niversity of Campinas – UNICAMP, Laboratory of Photonic Materials and Devices<br>Soares *et al.*, Technical and Economic Viability Analysis of Optical Fiber<br>Sensors for Monitoring Industrial Bioreactors<br>**Example 2.1 Analysis** Sensors for Monitoring Industrial Bioreactors **Contract Sensors for Sensors for Sensors for Sensors** for Sensors f Soares et al., Technical and Economic Viability Analysis of Optical Fiber





**sensors** 

### Thank you for your attention!

# Questions?

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