



**BNE BIOENERGY COMPANY INC.**

**ACQUIRED ASSETS & INTELLECTUAL PROPERTY FROM BNE**

**STT® SYSTEM TECHNOLOGY & APPLICATIONS OVERVIEW**

**FOR DEVELOPMENT OF A  
50 MILLION GALLONS PER YEAR BIODIESEL  
AND FOR USE IN CHEMICAL,  
PHARMACEUTICAL AND OTHER INDUSTRIES**



## The STT<sup>®</sup> System

### About BNE Laboratories

At BNE Laboratories, we are pioneering a breakthrough system for the manufacturing of chemicals and pharmaceuticals. Named STT<sup>®</sup> after its spinning tube-in-tube design, the system's unique two-dimensional flowing film format produces significant time and cost savings over traditional production methods. The STT<sup>®</sup> advantage lies in avoiding the problems and inefficiencies which are present in most conventional manufacturing processes. With its broad applicability and flexibility, STT<sup>®</sup> allows us to accelerate the rates of chemical reactions by up to three orders of magnitude, increase conversions and yields, control the quality of chemical processes in real-time, and lower costs, and dramatically decrease the time required for manufacturing scale-up.

We have successfully applied the STT<sup>®</sup> system to the manufacturing of electronics materials. Working with our corporate partners as well as our academic collaborators, we are now applying the STT<sup>®</sup> system to the manufacturing of a number of commercially important chemicals, and generic and branded pharmaceuticals. We are also exploring the advantages of the STT<sup>®</sup> system for the manufacturing of biodiesel, ionic liquids, and biopharmaceuticals.

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Our patented STT<sup>™</sup> approach provides simple and effective solutions to many of the manufacturing issues related to the production of chemicals and pharmaceuticals caused by intense competition, intellectual property issues and government regulation. The key is STT<sup>®</sup>'s two-dimensional flowing film approach that improves manufacturing efficiencies and enhances cost savings as well as providing novel and unique formulation methodologies. Advantages of STT<sup>®</sup> relative to conventional mixing methods include:

- **Rapid and Uniform Mixing** - The high shear flow that is responsible for the mixing within STT<sup>®</sup> is much more energetic than that achievable in a conventional volume-based mixer, resulting in mixing at the molecular level. This more vigorous type of mixing leads to faster reaction processes and higher yields. In addition, the flowing format results in less waste due to production failures. The system can process gases, liquids, and viscous solids, and is suitable for mixed-phase reactions. Use of our STT<sup>®</sup> system can also reduce solvent and catalyst requirements lowering production costs.
- **Precise Temperature Control** – The two dimensional format of STT<sup>®</sup> enables precise temperature control. This differs from a conventional, three dimensional environment of a volume-based system where considerable temperature variations between one part of the mixing vessel and another may exist due to distance from the heating source. Precise temperature control increases yield and leads to better product quality control and less likelihood of batch loss.
- **Broad Range of Uses** - STT<sup>®</sup>, in modified configurations, has a number of commercially important uses. STT<sup>®</sup> can be used to control the size or morphology of chemical crystals, to optimally combine different types of chemical substances, and to produce uniform particle coatings. It can also be used to formulate very high potency drugs for which it is necessary to uniformly mix a small amount of the active pharmaceutical ingredient with a relatively large amount of excipient. Each of these processes serves an important role in the formulation of specialty chemical and pharmaceutical products. In addition, STT<sup>®</sup> has demonstrated an ability to improve the yield of bioproducts from tissue culture systems, and is also capable of producing customized micro-composite materials for electronics.



## The STT® System

- **Scalability** - STT® is highly scalable because important reaction parameters of STT® that affect rate of mixing and heat transfer, such as flow rate and the gap between the system. Thus, the transition of the chemical process from pilot scale to production scale systems is seamless. We have demonstrated the scale-up of pharmaceutically-relevant chemistry from research bench to pilot plant levels in a single day.
- **Customizability** – The STT® flowing film format approach permits an unprecedented level of control of reactions, resulting in the more efficient and less costly manufacture of products. The operating parameters of STT® can be adjusted to match those of the process being run, including matching the STT® reactor's mixing speed with the reaction rate, controlling the stoichiometry of the reaction through the proper introduction of reactants, adjusting the flow pattern of reactants in STT® with the reaction mechanism, setting residence time in STT® with the reaction, and balancing the heat transfer characteristics of STT® with the reaction isotherm.
- **Dynamic Monitoring** - STT® allows for the progress of the chemical reaction to be monitored continuously and in real time. If a problem occurs, a process can be halted and the problem corrected with a minimal loss of valuable reagents. In contrast, conventional volume-based systems require a significant degree of additional effort, expenditure and complexity to attain and maintain a continuous oversight of reactions. As such, a production problem generally leads to a loss of most or all of the reagents since they are all combined at one time.
- **Unique Approach** - STT® incorporates a novel and unique approach to the production of chemicals, branded and generic pharmaceuticals and materials used for electronic applications.

Our unique spinning-tube-in-tube design is covered by 7 issued patents and 8 pending patents. We believe that our patent position will afford additional protection for new products as well as an ability to circumvent outstanding patents that our competitors may possess.

- **Size** – Our commercial scale STT®,s are small in size but can produce the same amount of product as a much larger conventional reactor. This process intensification is possible due to the increase in reaction rates that we achieve from the intense shear generated in the reactor. STT® achieves these advantages by inducing a physical phenomenon that is conceptually ideal for the mixing of reactants called Couette flow. We induce Couette flow by mixing reactants in a narrow annular gap between a stationary stator and a quickly rotating, concentrically positioned internal rotor so that the reactants move as a coherent thin film. We are the first company that has been able to practically apply Couette flow to manufacturing.

Until the advent of STT®, Couette flow was not suited to manufacturing applications because it often generates tiny radical whirlpools called Taylor vortices that disrupt the mixing process. The Taylor vortices create boundaries between the different materials entering the system and hindering their interaction. Thus, for example, if a red and a white liquid were introduced into a standard Couette mixer with its Taylor vortices, the thin film created would resemble a Barber pole. We have developed STT® to induce Couette flow without the production of disruptive Taylor Vortices by modifying conditions relating to circumferential rotor speeds, the smoothness of the rotor and stator surfaces, and the size of the annular gap.

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## The STT® System

The STT® system is a combination of patented processes and equipment for the manufacture of chemicals and pharmaceuticals. Named the STT® system after its spinning tube-in-tube design, the system's unique two-dimensional flowing film format produces significant time and cost savings over traditional production methods.

The STT® system allows our customers to avoid serious inefficiencies resulting from uneven mixing, temperature gradients, scale-up constraints, and excessive waste which are prevalent in most conventional manufacturing processes. With its broad applicability and flexibility, the STT® system allows acceleration of chemical reaction rates by up to three orders of magnitude, increase conversions and yields, control the quality of chemical processes in real-time, reduce costs, and dramatically decrease the time required for manufacturing scale-up.

The STT® process and equipment are covered by several patents and patents pending worldwide.

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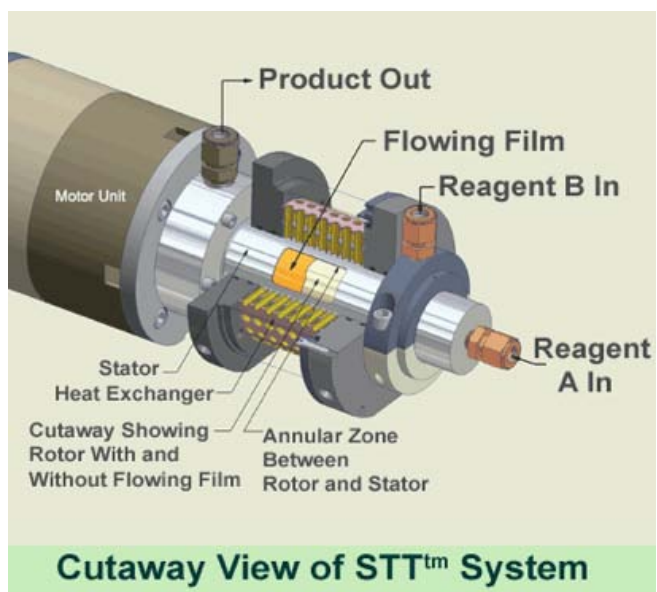
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Our STT® system employs a flowing film, rather than a batch, approach. Reactants enter the system at one end of the narrow annular zone between the stator and the rapidly spinning rotor, and are quickly and thoroughly mixed by high shear forces in a few milliseconds. Additional starting materials or catalysts can be added, and partially-reacted products removed, at any point as the mixture transits to the other end of the rotor/stator assembly, where the final product is collected. The temperature of the mixture is controlled precisely by the heat exchanger jacketing the stator. An additional heat exchanger can also be incorporated into the rotor for increased temperature control. Sensors for measuring temperature, monitoring reaction progress, or gathering other information relative to the manufacturing process can also be incorporated along the rotor/stator assembly to dynamically monitor the reaction process.

Two material entry ports and the product exit port are shown in the figure below. The reaction takes place in the annular zone between the rotor and the stator.

The highly effective type of flow that occurs in our STT® system is not achieved in other flow-through reactor systems, even those that also employ a rotor-stator design. This flow pattern is a result of our proprietary and patented system design.





## Controlling Reactor Variables

The STT® reactor allows for the isolation and independent control of reaction variables. The following is a list of reactor and reaction variables and how they can be used to engineer a faster, more selective and/or more complete reaction.

- **Shear Rate** – This is responsible for the improved rate and is the driving force of the technology. Shear rate and Residence Time are independent. Shear rate is the surface velocity of the rotor divided by the gap size or  $D/d$  (where is RPS (revolutions per second),  $D$  is the inner rotor diameter, and  $d$  is the annular gap. Shear rate is measured in  $s^{-1}$ . Typical shear rate values are 30,000/sec to 70,000/sec but higher or lower values are possible.
  - **Residence time (RT)** – Residence time is controlled by reactor gap size, reactor working volume, and feed rate of reactants. Again, RT is independent of Shear Rate.
  - **Temperature** – BNE Laboratories offers a broad range of heat exchanger designs to maintain a constant temperature as well as to rapidly add or remove large amounts of heat to control the temperature of the reaction. The actual ability to do this for a given chemistry will depend on the configuration of the reactor; choice of heat exchangers; and the ancillary equipment used. Several of the heat exchangers are patent pending and designed specifically to give the STT® system tight temperature control.
  - **Pressure** – The reactor can be run under pressure (up to 600 PSIG depending on the configuration and choice of seals), open to the atmosphere, or under vacuum. There is some flexibility in where gasses are added or removed from the reaction stream.
  - **Port Positioning and Use** – The STT® system behaves in a plug flow manner, so multiple reactants can be introduced to the system as the reactions progress, if desired.
  - **Reaction Initiation** – Initiation of the reaction can be controlled by preheating the reactants and shearing one reactant into the other at a side port. This ensures the reactants cannot begin to react before they are mixed in the STT® reactor. Temperature sensitive reactants can also be mixed at a lower temperature in the STT® reactor and then allowed to rapidly reach the reaction temperature due to
- shear heating and heat transfer from external heat exchangers.
- **Feed Rate** – The STT® reactor permits easy metering of multiple feeds into the reactor with varying miscibility and phases (solid, liquid, gas, slurries) – more so than could be tolerated in a traditional stirred tank reactor (STR) or plug flow reactor (PFR) system. For example, one can ensure that a particular hydrogen or oxygen to reactant ratio is obtained so the reaction is not run reagent rich or poor verses the desired stoichiometry. This capability has broad implications in selectivity. Another advantage is the ease of mixing or blending of components with great differences in viscosity where other technologies struggle to achieve homogeneity under these conditions.
  - **Types of Feed** – A broad range of feed material is possible. Any mixture of gas, liquid and solid suspension; density; and miscibility can be accommodated as long as there is an adequate way of getting the feed to the reactor in a homogenous state of particle size of solids is kept below one fourth of the gap dimension.
  - **Reactor Positioning** – Vertical or horizontal positioning can lead to different results depending on the reaction. In reactions where a gas is a reagent or a byproduct, a horizontal position is best if the desire is to keep the gas emulsified. In reactions where solids are present, such as the use of a heterogeneous catalyst, a horizontal reaction is best for keeping them suspended. Vertical positioning can enhance off-gassing when a gas byproduct is generated and separation is desired to promote reaction completion.
  - **Working Volume** – The working volume is the volume between the rotor and stator where the reaction actually occurs. It is determined from the last feed entry port to the product exit port. This is distinguished from the total volume of the STT® reactor cavity which includes the volume from where the first reactant enters the reactor to the last reactant port (this can be a few milliliters) and the space that exists between the product exit port and the seal (minor volume). The working and total volumes are a function of the gap size (or annulus) and changes as the size of the rotor is changed.
  - **Materials of Construction** – Typically the materials of construction are SS 316L, Hastelloy C or titanium. Other materials are available based on client requirements and the machineability of the desired materials.

## Applications

Our STT® system has been successfully used by us and our partners to perform a number of commercially important chemistries, including those listed in the table. Accelerations in the rate of reaction of up to three orders of magnitude, and increases in product yield of up to seven-fold, have been produced. In addition to its increased efficiency, the STT® system has other features which can dramatically improve chemical manufacturing including ease of process scale-up, elimination of bath failures, continuous process monitoring, and a smaller footprint.

We have also employed the STT® system in the manufacturing of electronic materials, and are exploring its utility in the production of bioproducts from cell culture systems.

## Partial Listing of Chemistries Benefiting from the STT® System

Type of Reaction	Examples
Addition	Hydrosilylation
Condensation	Claisen-Schmidt (Aldol) reaction Esterification Polyesterification Biginelli reaction
Polymerization – Free Radical Initiated	Olefinic Styrenic Acrylic
Substitution Chlorosulfidation	Diazonium coupling
Exchange/Metathesis	Grubbs Olefin Metathesis
Addition Amine Protection	Carbonation Sulfidation
Coupling Amino Acid Synthesis	(via boronic acid) Benzyl acetate synthesis Heck reaction Pd catalyzed Buchwald reaction Suzuki reaction
Selective Partial Oxidation	Swern reaction Ethyl Benzene oxidation (EPA) Trichloroisocyanuric acid oxidation
Selective Reduction	Reductive Amination Partial Reduction
Materials/Fine Particle Synthesis	Barium sulfate precipitation

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