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Supplement to the Treatise

WOLFGANG RUNGE: TECHNOLOGY ENTREPRENEURSHIP

How to access the treatise is given at the end of this document.

Reference to this treatise will be made in the following form:
[Runge:page number(s), chapters (A.1.1) or other chunks, such as tables or figures].

The current case deals with entrepreneurship referring to a technology push situation in the context of a competitive group of firms. It includes the German firms IoLiTec GmbH and Solvent Innovation GmbH and Bioniqs Ltd. and Scionix Ltd. from the UK for which also case documents were created [Runge:B.2].

Wolfgang Runge

Ionic Liquids Technologies (IoLiTec) GmbH

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The Technology and Markets

The overall business and competitive situation of ionic liquids is described in an overview [Runge:A.1.5] and in the Solvent Innovation GmbH case (B.2). However, as ionic liquid technologies offer myriad applications it is important for the current case to inquire into those markets providing ultimately opportunities for IoLiTec.

The current product lines of IoLiTec entering its revenue model and the estimated related market potentials are given in Table 1.

Table 1: Product lines and estimated related market potential of IoLiTec [Schubert 2008a:27].

	Contract R&D	**Ionic Liquids**	**Nano-Products & Coatings**	**Energy /CleanTech**	**Sensors**
Products	▪ R&D project ▪ Joint developments ▪ Contract analytics ▪ Consulting ▪ Internal R&D ▪ Publicly financed projects	▪ Lubricants ▪ Solvents ▪ Process chemicals ▪ Functional fluids ▪ Special reagents ▪ Tensides	▪ Ultrasmall nano-particles ▪ Dispersions of nano-particles	▪ Materials for heat transport and storage ▪ Electrolytes for batteries & supercapacitors ▪ Materials for DSSC *)	Sensors concerning ▪ Explosives ▪ Hazardous materials
Market Potential 2012	> €100 mio. Global R&D expenditures (companies, universities, institutes	€100 mio. (excluding CleanTech applications)	€850 mio. (estimation of total market 2006 for all kinds of nano-materials)	Heat storage €150-250 mio.; Electrolytes €5-10 mio.; DSSC-Electrolytes €13-26 mio/Chem.	€800-100 mio.

*) Dye-sensitized solar cell.

By 2004 the total market of ionic liquids for public and industrial research, essentially via catalog distributors (Merck KGaA, Sigma-Aldrich, Acros etc.), was estimated to amount to €2.5 million per year [Schubert 2004].

The Entrepreneur(s)

Though originally founded by a team of three chemists the key person associated with the foundation and further development of IoLiTec is Dr. Thomas Schubert (born in 1970). He studied chemistry at the German universities of Karlsruhe and Cologne and obtained the diploma degree in 1997 with Prof. Dr. A. Berkessel: of the Universality of Cologne. In 2001 he obtained his doctoral degree also with Professor Berkessel (in bioorganic chemistry).

Thomas Schubert came into contact with ionic liquids in 1999 during a conference on catalysis where a young scientist presented a related topic. After about two years he worked together with this scientist – Dr. Peter Wasserscheid in Aachen who was a co-founder of Solvent Innovation GmbH (B.2) [Schubert 2006a].

During his time in Aachen Thomas Schubert met Andreas Bösmann.

From October 2001 until March 2003 he worked as the Leader of Distribution for the ionic liquids firm Solvent Innovation GmbH (B.2) in Cologne, founded Ionic Liquid Technologies GmbH & Co. KG (IoLiTec) in April 2003 together with Andreas Bösmann and a further co-founder and became managing director of IoLiTec.

Dr. Andreas Bösmann studied chemistry at the Technical University (RWTH) Aachen and his diploma and doctoral theses already focused on ionic liquids. His doctoral thesis was performed in the group of Prof. Dr. Peter Wasserscheid.

In 2003 he was the co-author of 16 publications and inventor of 8 patents [Schubert 2004; Dr. Andreas Bösmann].

In 2003 Peter Wasserscheid left RWTH Aachen to become full professor at the University of Erlangen-Nürnberg (Germany) where he heads the Chair of Chemical Reaction Engineering. In the same year Andreas Bösmann became co-founder of IoLiTec. In 2006 he left IoLiTec to pursue his scientific career with Prof. Wasserscheid in Erlangen- Nürnberg. Prof. Wassserscheid is viewed as one of the pioneers of research and development and renowned expert in the field of ionic liquids (Solvent Innovation GmbH, B.2).

The Business Idea, Opportunity and Foundation Process

Enabling success in future technology (IoLiTec's current motto)

The firm IoLiTec was born in a *climate of excitement with ionic liquid technologies in Germany* and also the UK (Scionix Ltd. in the Bioniqs Ltd. case, B.2) that was shared between *academia and industry* and embedded in a "green" attitude of society and policy in Germany.

IoLiTec took advantage from the general interest in the field. There was (and is) much support of related joint projects ("Verbundprojekte") [Runge:ch. 1.2.6; Figure I.40, Table I.90) supported by federal and state governments and non-governmental organizations (NGOs), such as the Deutsche Bundesstiftung Umwelt (DBU). The German Federal Environmental Foundation (DBU) is one of the largest foundations in Europe. It promotes and funds innovative and exemplary projects for environmental protection. And IoLiTec's developments represent what in Germany is called "sustainability innovation" [BMBF 2007].

As there are myriad applications for the new technology grasping related opportunities would have meant to *identify and/or build promising markets* in the sense of a "*technology push*" approach [Runge:ch. 1.2.5.1; Figure I.26]. Hence, when people with experience with ionic liquids and an entrepreneurial mindset met and discussed the technology and were seeing startups founded in 1999 in Germany and the UK, setting up a team to found a firm appeared to be rather obvious.

IoLiTec was founded in Aachen/Cologne (Germany) by the end of 2002 [Danzeisen 2005] during a tough time for entrepreneurship due to the impacts of the Internet "Dot-Com Recession" which affected financing considerably.

Foundation was by *a team of three chemists of different specialties, and all having had different experiences in ionic liquids* [Schubert 2008a]:

1. Physical chemistry (38 years old; experience in industrial R&D, having worked already with ionic liquids, contributed the first customer and its related order to foundation)
2. Technical chemistry (34 years old; working on his PhD-thesis in the group of Prof. Dr. Peter Wasserscheid of the Technical University of Aachen (RWTH) who was a co-founder of Solvent Innovation GmbH (B.2) – Andreas Bösmann
3. Organic chemistry (33 years; 2 years of commercial experience with the ionic liquids startup Solvent Innovation GmbH (B.2) in production and distribution; technical synthesis and marketing of ionic liquids [Schubert 2004]) – Thomas Schubert.

Founder No. 1 left the startup already after three months and Andreas Bösmann left the firm in 2006 to continue his academic career (with Peter Wasserscheid, who became professor at the University of Erlangen/Nürnberg).

IoLiTec was founded with the German legal status of GbR (which is similar to a General Partner (GP) structure in the US). Germany-wide search for the firm's *location* led finally to a decision (February 2003) for the city of Freiburg and its BioTechPark [Schubert 2004] – in the Southern part of Germany with a university and a number of research institutes, particularly of the Fraunhofer Society (FhG) [Runge 2006:143-144; Runge:p. 167-168]. These included, for instance, the Fraunhofer Institute for Solar Energy Systems (FhG ISE) and the Freiburg Materials Research

Center. In Freiburg IoLiTec was also embedded into the versatile scientific environment of the Germany, Switzerland, France triangle. Start at the BioTechPark location was in May 2003 [Schubert 2004].

> Massive *networking* with academia, public research institutes, and industrial firms as *external resources* became a typical feature of IoLiTec's further development.
> In particular,"secondary networking" occurred by IoLiTec's Academic Network/Scientific Advisors [Schubert 2006b]

The first staff was hired in October 2003. In early 2004: custom synthesis was established and by mid of 2004 distribution of ionic liquids was established by agreements with the German firms Merck KGaA (Darmstadt) and Degussa AG (now Evonik Industries) [Schubert 2004].

During its start phase IoLiTec offered its ILs exclusively via the Internet. Many firms sought for direct contacts with IoLiTec (e-mail, telephone). Since 2005 IoLiTec used its profit to attend conferences and only in 2008 it was present for the first time at a fair [Schubert 2008a].

In 2004 the team of Schubert and Bösmann as Managing Directors was *complemented by a business angel* Peter Unkelbach who took over roles in taxes, finances and law.

In 2004 the relatively stable constellation of IoLiTec led to a new legal status of the firm which became IoLiTec GmbH & Co. KG. Simultaneously the *new legal construct* was supported by a firm IoLiTec Liquid Technologies Verwaltungs GmbH. This firm took over just the legal functions of a so-called "Komplementär" in the KG part. The partners in the firm were Dr. Thomas Schubert and Ulrike Unkelbach. The structure of the leadership team of IoLiTec and its networking with academia (as "external resources") is given in Figure 1.

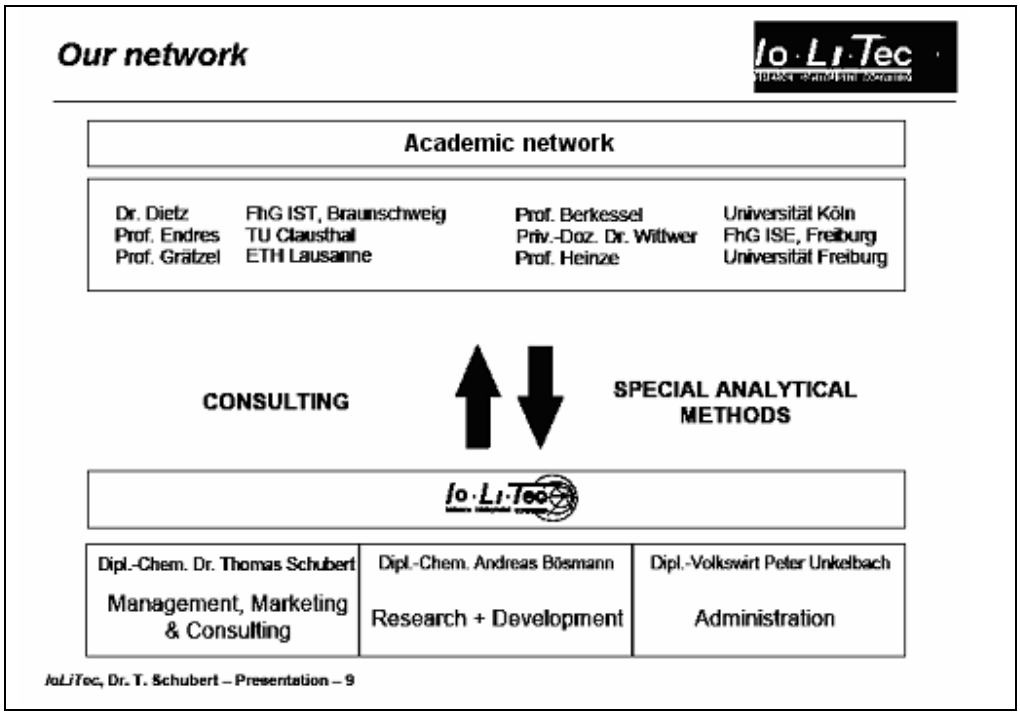


Figure 1: 2004 Leadership team of IoLiTec GmbH & Co. KG and its networking with academia (founded in 2003) (Source: [Schubert 2004]).
Note: Dipl.-Volkswirt = graduated economist, MA-equivalent.

IoLiTec startet with a customer. The first R&D contract was signed in March 2003 [Schubert 2004]. It grasped an order valued at €180,000 from a medium-sized Swiss firm. This customer was caught by founder No. 1.

IoLiTec was *financed* by Sparkasse Freiburg – Nördlicher Breisgau (Sparkasse – savings bank [Runge:p. 224-225]) with subsidies of the State Bank (Landesbank) of the State of Baden-Württemberg of Germany [Schubert 2004].

The first order had a notable impact of financing IoLiTec via a bank loan of €200,000. Due to this order financing via banks was without major problems and consisted of two components:

- A classical bank loan of €120,000 with preferred rates for firm foundation and a guarantee of the KfW bank [Runge:p. 225] owned by the German Federal Government
- A bank loan of €50,000 with normal rates.

In 2005 and 2006 more loans for financing investments of IoLiTec could be gained.

> IoLiTec finished its first short fiscal year 2003 in the black [Schubert 2004]. Furthermore, *since its foundation, IoLiTec always made a profit* [Schubert 2008a].
>
> During its first three to four years of existence, its *startup thrust phase* [Runge:ch. 4.3.2; Figure I.125], IoLiTec was *in search for lucrative applications and markets* and developing "experimentally" its business model. *Major customers were from academic and industrial research groups* [Schubert 2006a].

IoLiTec elaborated an *opportunity options set* [Runge:Box I.13, ch. 5.1] from which to select the most promising opportunities for the firm (Figure 2). In Figure 2 the options are related to the various relevant properties which make ionic liquids a platform technology.

But publicizing and illustrating the broad spectrum of applications for ionic liquids was not only meant to show what choices IoLiTec could make from existing options and which ones it finally made. The spectrum of applications was additionally made public to prevent any entrant to patent a particular application and thus constrain IoLiTec's further expansions into other applications of interest to them.

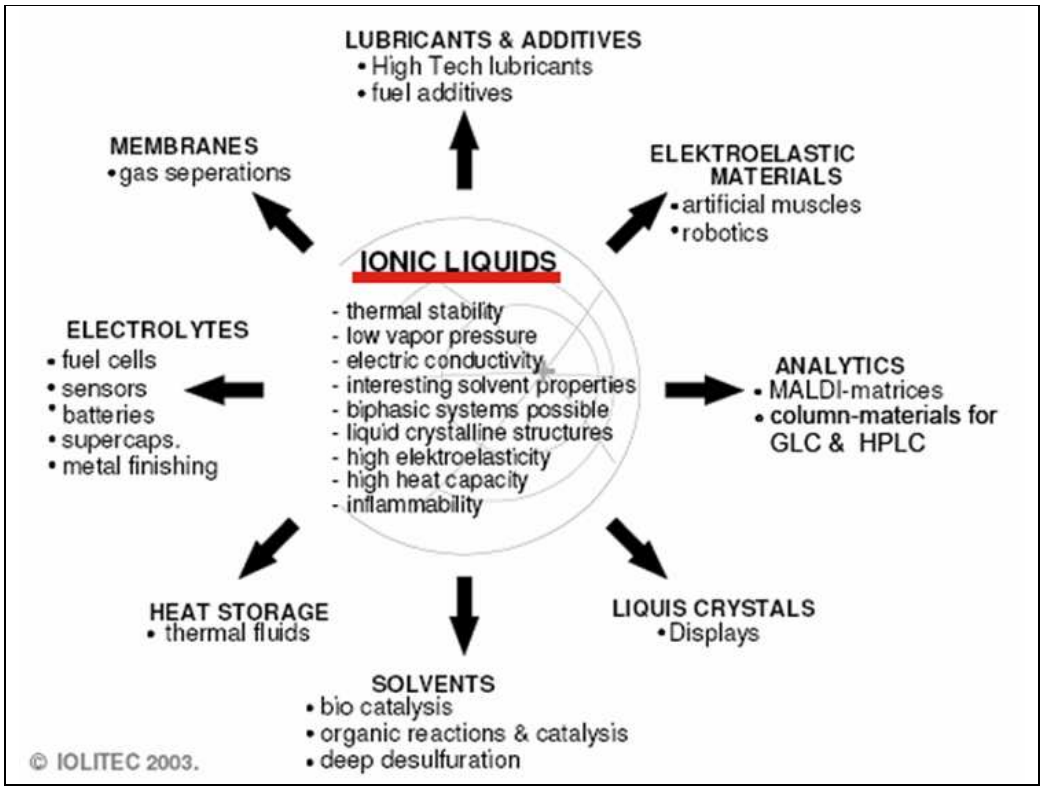


Figure 2: An early options set of IoLiTec [Schubert 2004; Schubert 2005].

Probably the scientific background of T. Schubert (bioorganic chemistry) influenced the *early direction of IoLiTec's offerings* [Schubert 2004], particularly *analytical services* which could also make use of IoLiTec's network with universities and public research institutes (Figure 1).

In particular, matrix-assisted laser desorption-ionization time-of-flight mass spectrometry (MALDI-TOF MS) had become an important tool in the analysis of biomolecules. High-performance liquid chromatography (sometimes referred to as high-pressure liquid chromatography), HPLC, is a chromatographic technique used to separate a mixture of compounds in analytical chemistry and biochemistry; gas-liquid chromatography (GLC) is a common type of chromatography used in analytical chemistry for separating and analyzing compounds that can be vaporized without decomposition.

Its early revenue model of applications and offerings had two components [Schubert 2004].

A. (Bio-)analytical applications (IoLiTec offers new materials that could make the life of biochemists and scientists from other disciplines much easier; Schubert has a doctoral degree in bioorganic chemistry)
    - Protein-crystallization: Ionic-Liquid-Kits for the fast and efficient crystallization of proteins
    - Water-determination of enzymes, pharmaceuticals and food: Ionic Liquids for the fast determination of water-content
    - MALDI-TOF-MS: New materials for the analysis of proteins, antibodies, nucleotides and amino-acids.
B. Consulting & Custom R&D
    - Energy: Tailor made ionic liquids for the use as thermal fluids, electrolytes for fuel cells, batteries and capacitors.
    - Galvanics: anti-corrosive or functional coatings (electro-deposition, electroplating).

Custom synthesis of ionic liquids covered a portfolio of 16 ionic liquids. Additionally, anti-static-fluids – functional fluids for the use on glass-surfaces – were offered. Activities in nano-particles and sensors were planned.

Concerning *intellectual properties* (IPs) by 2005 IoLiTec had submitted eight patent applications and owned some brands (IoLiTive®, IoLiTive®, IoLiTherm® and IoLiSens®).

Then IoLiTec decided to focus on the following five areas [Schubert 2005]:

1. Contract R&D services
2. Special Chemistry (Ionic Liquids)
3. Sensor technology
4. Energy
5. Nanotechnology

Organizationally, each focus should be developed in an independent division-type unit with the core technology "Ionic Liquids" serving as a platform. IoLiTec ran *own R&D*, but *contract R&D* to generate revenues.

> Fundamental and necessary R&D for all these areas was partially pursued by participating in publicly funded projects.

As a *marketing instrument for technology push* in March 2005 IoLiTec launched its free newsletter "Ionic Liquids Today" [Schubert 2005]. It does not only provide news about IoLiTec's products and their applications and cooperation set up by IoLiTec, but reports also on scientific and technical progress in ILs. The related required systematic technology intelligence activities of running "current awareness" and keeping "state-of-the-art" knowledge based on scientific literature and patents could become the basis for related databases (which could later be used for identification of suitable ILs for particular applications; Figure 3). In June 2006 there were already more than 1,300 subscribers to the newsletter.

In January 2005 IoLiTec was awarded with the “Innovation Prize of the City of Freiburg” (Innovationspreis der Stadt Freiburg) [Schubert 2006b].

In 2005 IoLiTec moved out of BioTechPark Freiburg to a *new location* in Denzlingen very close to Freiburg due to more favorable cost of needed facilities [Danzeisen 2005]. At the Denzlingen location IoLiTec occupied an area of 500 m^2 with three development laboratories, a production lab and a pilot facility.

Since 2006 IoLiTec acted also as a distributor for other IL firms. It made phosphonium ionic liquids of the US firm Cytec Industries available. These ILs provide notable performance in biotech applications, for instance, protein-stabilization and crystallization [Schubert 2006a].

In 2006 Ingo Krossing, another internationally renowned expert in ionic liquids, accepted the Chair of Inorganic Chemistry of the University of Freiburg which meant “to have another state-of-the-art working group just around the corner.” [Schubert 2005]. Similarly, in the context of internationalization IoLiTec established in 2009 a US subsidiary in Tuscaloosa and one reason was the presence of a globally renowned expert in ILs there at the University of Alabama.

With the increasing number of employees (10 in 2006) and established applications and related activities the increase in (organized) complexity drove IoLiTec to a new, *distinct organizational structure* based on a leadership team and Scientific Advisors with key persons concerning networking (Figure 3). Related to the ten employees five research chemists indicated IoLiTec to be a *research-driven startup*.

The five research scientists (chemists with doctoral or master degrees) were attributed responsibilities for business units as well as networking contacts to selected networking partners in academic environments. And, moreover, they took functional roles for the firm. In particular, three roles combine the essence of *computer-supported technology intelligence*. Roles included unit embracing activities. The business units were run as “profit centers.” [Schubert 2006b]

Literature and patent search activities are the basis of knowing the state of the art und current awareness about new developments – to provide information for consulting activities and design of new ILs or customized ILs as well as for the IoLiTec newsletter. By the end of 2006 its literature database contained 1,200 scientific/technical articles and the compounds database had 1,500 entries [Schubert 2006a].

Running almost continuously R&D projects, publicly financed by the German Federal Ministry of Education and Research (BMBF), Federal Ministry for Economics (BMWi) and the Deutsche Bundestiftung Umwelt (DBU), was (and still is) central for financing IoLiTec and also running its own internal R&D (Table 1).

The type of project was usually the German type of a “Verbundprojekt (“*joint project*” [Runge:ch. 1.2.6; Figure I.40, Table I.92]) which involves partners working on components of process chains along a value system [Runge:Figure I.7] with a common goal and a responsible coordinator. The partners usually will involve NTBFs, mid-size private firms, universities and public research institutes.

Furthermore, joint projects often originate or are associated with the German “Kompetenznetze” (*competence networks*) [Runge:Figure I.39] and IoLiTec is a member of several of these, for instance,

Kompetenznetz Pro3 (Competence Network Pro2 – Process Engineering)
Kompetenznetz UmweltTechnologie – KNUT (Competence Network Environmental Technology)
Kompetenznetzwerk für nachhaltige chemische und und biotechnologische Produktionsprozesse – ChemBioTec (Competence Network for sustainable chemical and biotechnological production processes).

> As a basic strategy, to achieve a lead in R&D and secure also its future, IoLiTec participated in *distinctly selected* joint projects to exploit and expand specifically and continuously the application fields of its technology.

By December 2004 IoLiTec participated in the BMBF-Verbundprojekt NEMESIS (Jan 1, 2005 - Sep. 30, .2008), dealing with the *production of high purity ionic liquids* using continuous flow micro reactors [Schubert 2006b; Schubert 2009a] and Dr. Thomas Schubert acted as the coordinator of NEMESIS.

Economies of scale for ILs as, for instance, for biofuels [Runge:A.1.1] or solar cell or module manufacturing [Runge:Figure I.154], do not exist yet for ionic liquids. Hence, their slow reduction of expense will also slow their adoption.

"The success of ionic liquids will not necessarily be equated with large-scale chemistry," noted Prof. Robin D. Rogers, at the University of Alabama, Tuscaloosa [Ritter 2008]. As most applications will be small, usually only a couple of tons of ionic liquid per application per year, a micro-reactor that can quickly be configured to produce different types of ionic liquids on a kilogram-per-day scale could be an advantage.

Within NEMESIS IoLiTec engaged intensively itself with the *scaling-up* technology via micro-reactor-systems. Micro-reactor technology (MRT) is the *technology of choice for small and mid-sized companies to face the challenges of scale-up*.

Another aspect during the project was the development of concepts for efficient recycling of used ionic liquids. Recycling of ILs is usually associated with extraction.

The overall project subsidies amounted to ca. €3.3 million, €400,000 for IoLiTec. The partners of NEMESIS were:

- BIAS (Bremen Institute for Applied Radiation Research): Measuring-technique on the micro-reactor system
- IFAM (Fraunhofer Institute for Manufacturing Technology and Applied Materials Research): From the component part to the system by powder-technological manufacturing technology, production of the reactor-system
- IoLiTec (Ionic Liquids Technologies GmbH & Co KG): Offers R&D-services concerning applications of ionic liquids and supplies high-quality ionic liquids.
- Merck (Merck KGaA): Global supplier: production and development of customized ionic liquids.
- SCHULZ (Schulz Automatisierungstechnik GmbH): Specialized in EMSR (Elektro-, Mess-, Steuerungs-, und Regelungstechnik – electro, measuring, control technology and control engineering and automatization technology)
- UFT (Zentrum für Umweltforschung und Umwelttechnologie of the University of Bremen): Micro-process-engineering and toxicology.

The broad participation in joint projects enlarged and strengthened IoLiTec's network considerably. In line with its intention to focus on nanotechnology in 2006 it broadened its scope of cooperation and set up relationships with the University of the Saarland (Prof. Hempelmann, Figure 3) [Schubert 2006b]. Looking at its current Web site shows an impressive list of cooperation partners.

Under a general heading of "Energy – CleanTech" IoLiTec ran several projects in 2005/2006 [IoLiTec].

A joint project financed by the DBU started in 2005 (Feb. 1, 2005 – Apr. 30, 2006) emphasizing ionic liquids as heat media (carriers). The whole project was supported by €120,000 [DBU 2005; Schubert 2006b]; IoLiTec was given €40,000 [Danzeisen 2005]. The project "Wärmeträgermedien für die Solarthermie" (Heat transfer media for solar thermics) involved as partners IoLiTec, Tyforop Chemie (Hamburg), the Fraunhofer-Institute for Solar Energy Systems (Freiburg, FhG ISE) and UFT (Zentrum für Umweltforschung und Umwelttechnologie, University of Bremen) [DBU 2005a].

A related DBU project of IoLiTec in 2005 together with the KIT/Karlsruhe University "Institut für Technische Thermodynamik und Kältetechnik (ITTK)" focused on sorption cooling ("Sorptionskälte") utilizing technical principles of utilizing heat to generate cold (refrigeration technology). Support was €265,000 [DBU 2005b].

Another 2005 project ("Latentwärmespeicher" with the BMWi) of IoLiTec dealt with ionic liquids for latent heat storage and as phase changing materials (PCM; Phasenwechselmedien). The physical effect to be utilized concerns the fact that PCMs can deliver thermal energy at the transition from liquid to solid state, which they have previously captured during the melting of the substance. Latent heat storage refers to materials, which can store thermal energy without loss, reversibly and over a long period of time. The release of this energy is initiated, generally by a nucleation initiating the crystallization of the super-cooled medium, whereby the previously absorbed heat is released [ioLiTec].

The BMWi-supported project "Phasenwechselfluide" (PCS; Phase Change Slurries; Sep. 2005 – Mar. 2007) involved IoLiTec together with FhG ISE (Fraunhofer-Institute for Solar Energy Systems) and FhG UMSICHT (Fraunhofer Institut für Umwelt-, Sicherheits- und Energietechnik) and Rubitherm Technologies GmbH – Innovative PCMs and Thermal Technologies.

In 2006 two new DBU-projects "Deposition of iron and aluminum from ionic liquids" ("Eisen"- und "Aluminiumabscheidung" aus ionischen Flüssigkeiten") started [Schubert 2006b; DBU 20120]. For instance, the joint project "Electrolytic deposition of iron from ionic liquids (supported by ca. €125,000, Oct. 1, 2006 – Mar. 31, 2008) was run by IoLiTec, the Fraunhofer Institute of Chemical Technology (FhG ICT), the FEM Research Institute (Forschungsinstitut Edelmetalle & Metallchemie), and the firms IPT (International Plating Technologies) GmbH). One of the selected electrolytes of the project, choline chloride – urea – iron trichloride (FeCl3), focused on choline chloride and urea as were used also by Scionix Ltd. in the UK (in Bioniqs Ltd, B.2).

By 2011 IoLiTec offered specifically two products based on choline (choline cation with dihydrogen phosphate ($H_2PO_4^-$) or bis(trifluoromethylsulfonyl)imide ($(CF_3SO_2)_2N^-$;NTf2) anions.

Funded by the BMBF in the context of a German "competence network" in 2006 the joint project ColorSol (COLORSOL®) started around the subject of dye-sensitized solar cells (DSSCs), also called Grätzel-Cells, [ColorSol; Kompetenznetze Deutschland; BMBF 2007]. Note that Prof. Grätzel was a scientific advisor of IoLiTec (Figure 1).

IoLiTec's contribution to the project focused on [Schubert 2008b]:

- DSSC electrolytes
- Sensitizer dyes
- Formulations of TiO2 (as the dye carrier).

In contrast to common silicon-based solar cells in DSSCs organic dyes on a carrier convert sunlight into electrical energy. The working principle of a DSSC is given by Schubert [2008b:4]. The production of dye solar cells is easily done by screen printing (in German: Siebdruck). Major applications are seen for integrating photovoltaics into construction design and buildings like bridges and mobile computers and devices (cf. ionic liquids for DSSCs as described in the case Solvent Innovation GmbH).

The tasks and activities of ColorSol included [Kompetenznetze Deutschland; Schubert 2008b]:

- Technology and product roadmapping (market studies)
- Identifying development and application areas for DSSCs (for instance, for facades) including early integration of application developers and users (identification of lead users)
- Working out success factors of the product innovation for the solar industry (development of production strategies)
- Development of design concepts for environmentally compatible product development (for instance, for recycling compatible design and manufacturing; design studies)
- Development of printing pastes (dyes) for DSSCs
- Development and optimization of electrolytes
- Development of a resource-efficient production process using environmentally friendly chemicals and to further improve the energy payback time
- The establishment of an efficient innovation cooperation between several companies along an emerging value system (supply chain; cf. [Runge:Figure I.40])
- Build-up demonstrators.

The COLORSOL®-consortium consisted of the following organizations:

- BDF (Bundesverband Deutscher Fertigbau e. V. (BDF), Bad Honnef)
- BGT Bischoff Glastechnik AG (Bretten): Established in 1938 the firm is one of Europe's leading companies for flat glass processing and finishing. With its broad range of functional glasses and special glasses it includes glass products for the solar energy market, BGT is predominately active in the construction industry and in various other industrial sectors.
- Borderstep Institut (Borderstep Institut für Innovation und Nachhaltigkeit gGmbH, Berlin): The Borderstep Institute for Innovation and Sustainability provides special consulting concerning innovation and sustainability.
- Engcotec (Engco Advanced Technologies GmbH, Stuttgart): Engcotec, founded in 1987 is specialized in renewable energies, and especially in photovoltaics. Its focus is the design, manufacture and execution of projects in the field of renewable energy (especially in solar energy), PV technology systems, particularly building-integrated PV systems.
- FhG ISE (Fraunhofer-Institut für Solare Energiesysteme (ISE), Freiburg)
- FhG IAO (Fraunhofer-Institut für Arbeitswirtschaft und Organisation (IAO), Stuttgart; (coordination)
- IoLiTec GmbH & Co. KG
- Pröll KG (Weißenburg i. Bay.): Development & production of special inks, screen printing inks, pad printing inks, lacquers & coatings.

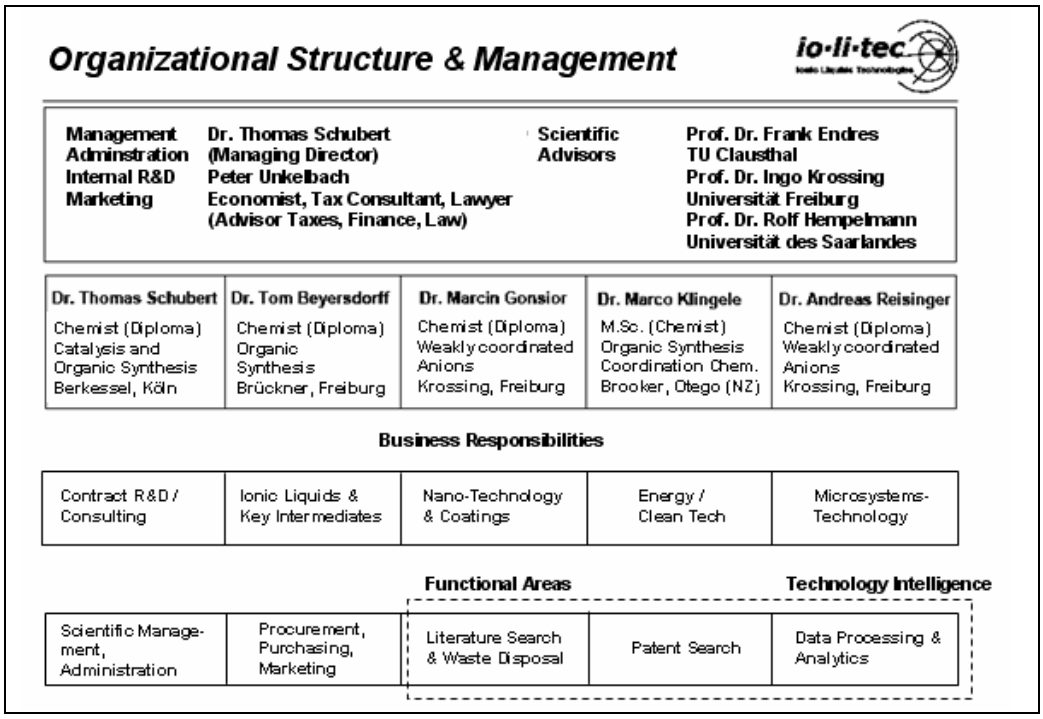


Figure 3: Organizational structure of IoLiTec GmbH in 2006 (Translated source [Schubert 2006b]);
Economist = graduated, MA-equivalent); the dashed rectangle cover intelligence activities.

Further Development and Adapted Business Model

With 4-5 years of existence the 2007/2008 period of IoLiTec was a time of further development, but also a time for consolidation of what has been achieved.

IoLiTec saw an increase in sales from 2004 to 2005 of 200 percent [Schubert 2006b]. Its growth of sales were +30 percent in 2007 and +40-50 percent in 2008 [Schubert 2008b]. However, it is not obvious how much money from externally financed projects have contributed to revenues.

By 2007 and 2008 its numbers of employees (10, 12, Tab) reached a "critical magnitude", which according to the "10-25-150 rule" [Runge:ch. 4.3.1, Table I.70] is usually associated with a *change in organizational structure*. Furthermore, it was about to achieve a scale-up of its production technology by MRT.

One goal was to become able to *reduce the prices of ILs*, another one was to establish a subsidiary in the US which after Europe is the most important market for ILs – and simultaneously there was no IL startup [Schubert 2008a].

Apart from ionic liquids as a platform technology IoLiTec's main direction and *core competences* had turned out to be dispersions of nano-materials.. IoLiTec showed up also as a component supplier for a number of solar applications, such as. DSSCs (Figure 4, Table 1).

Nano-materials promised to be rather lucrative. IoLiTec offered, for instance, carbon nanotubes (Single Wall Carbon Nanotubes (SWNT), Double Wall Carbon Nanotubes (DWNT) and Multi Wall Carbon Nanotubes (MWNT)) and fullerenes.

For instance, the global market for nano-structured coatings was $1,317 million in 2010. It was predicted to grow across all sectors over the next 5-10 years, with the medical, household care and food processing markets all experiencing large growth, driven by the need for improved sanitary facilities and also pushed by the vast improvements nano-structured coatings offer, from both a protective and destructive perspective. The global market for nano-structured coatings was estimated to be valued at $3,515 million in 2015 [Future Markets 2011].

Together with the Fraunhofer Institute for Chemical Technology (FhG ICT) IoLiTec developed a sensor-platform for dangerous substances that combines nano-scale-components and ILs ((IOLISens®-Technology) [Schubert 2008a].

IoLiTec had become *a goal- and application-oriented company*. By 2008 six *patent* applications were filed. According to its flyer from 2007 it could offer ca. 100 ILs utilized, for instance, for synthesis, analytics, catalysis, heat and refrigeration engineering, electroplating and sensor technology. It could offer 15 key intermediates to prepare ILs and 80 nano-materials, particularly for coatings, and put an emphasis on *R&D services* and *custom synthesis* and new, commercially not available ILs for specific applications of customers. And it focused on *high quality*.

The *services* ranged from consulting and feasibility studies to the development of marketable applications based on ionic liquids. It offered to produce every patent-free IL that is known from the literature or that predictably can be synthesized from lab scale to pilot plant scale (50 g to 10 kg).

IoLiTec's approach to identifying suitable ILs is based on the fact that ionic liquids can rarely be associated with a dominating property.

> *For each IL product* there are no individual characteristics that mark its unique selling proposition as a material, but rather *a unique, characteristic profile of properties* [Schubert 2008a].
>
> "It is the mix of physical and chemical properties that makes a certain ionic liquid unique." [Schubertt 2013]

The issue often is a trade-off between properties, for instance, hydrophobicity, thermal stability and price versus biodegradability and corrosiveness (cf. Note 1 of the case Solvent Innovation).

Physical properties of ionic liquids show a strong dependency on ionic impurities, such as both halides and non-ionic impurities like water. IoLiTec's claim of providing *high quality* and *quality management* for ILs means [Schubert 2009a; Schubert 2013]:

- R&D/Fine Chemicals: working with materials of known and defined purity guarantees that results can be reproduced and are not affected by impurities
- Industrial applications/Special Chemistry: a process has to be performed in a certain framework of well-defined specifications.

Networking (Figure 5) allowed performing special measurements of ILs by partner institutes [Schubert 2008a:34] as more detailed by Sahin and Schubert [2012:12]. Furthermore, IoLiTec is part of the Freiburg Ionic Liquid Group (FRIL) centered with Freiburg University.

Furthermore, micro-reactor technology (MRT) was assumed to be not only a means for scale-up, but also for quality management.

Capacities for production achieved the following levels [Schubert 2008a].

- Batch:20-50 kg per week
- Micro-reactor: 50-100 kg per week.

The steps to the MRT-based ionic liquid synthesis and comparisons between batch versus continuous flow synthesis are presented by Schubert [2009a] and Beyersdorf [2010]. In 2009 it had built its second micro-reaction system [Schubert 2009a].

For contract research and services a comprehensive database existed with data and information from the scientific literature and data from its own R&D efforts with more than 2,500 assessed and categorized entries (a compound library with >600 ionic liquids [IoLiTec 2011]). Physical and chemical properties of substances can be predicted by a *computer model* (COSMO RS) [Schubert 2008a].

IoLiTec continued also to act as a *distributor* of phosphonium-based ILs of Cytec Industries.

The international portfolio of *IoLiTec's clients* included both *small and medium enterprises* as well as *globally operating companies*.

In its usual approach to strengthen R&D, it participated, for instance, in a joint project concerning "sustainable sorption-aided air conditioning and dehumidification with ionic liquids" funded by the BMBF (Jul. 1, .2009 - June 30, 2012) to develop ILs as part of standard components of ventilation and air conditioning. The partners included the University of Applied Sciences (Hochschule für Technik) Suttgart as a coordinator, IoLiTec and the firm Ahlberg + Hennrich GmbH whose business emphasizes air conditioning systems and being a producer of dehumidification equipment and facilities) [HfT 2009].

But *for further growth*, a strong move into "Thermal Storage" and "Energy Storage", scaling-up and marketing and sales efforts, it needed ca. €3.5 million (Figure 4).

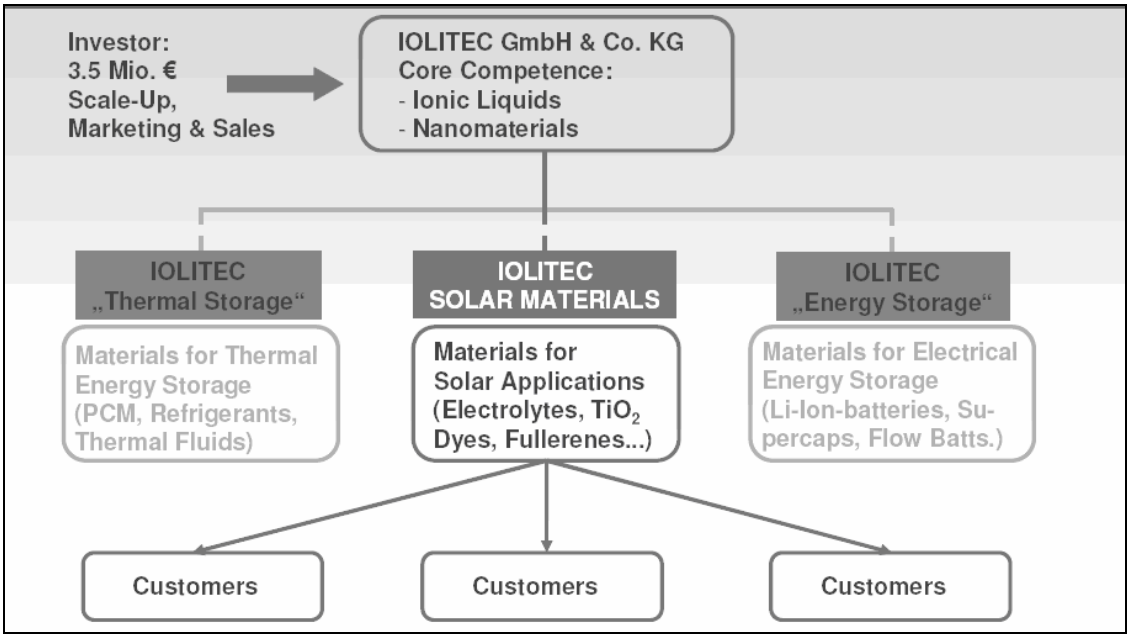


Figure 4: IoLiTec's states of commercializing ionic liquids and investment requirements for market entries into further fields [Schubert 2008b].

Momentum for IoLiTec

By 2007/2008 IoLiTec had a growth strategy in place with a corresponding organizational structure (Figure 5). Figure 4 of 2008 exhibits the needed investment for further growth of IoLiTec. For his NTBF T. Schubert tried to get a corresponding loan via the State Bank of Baden Württemberg and the KfW bank of the Federal Government and also public funds or financial support. He tried for two years in vain to get them and commented "With the State Bank and the KfW it was really a tragedy" ("Mit der Landesbank und der KfW war das wirklich ein Trauerspiel"). For his startup he had managed public financing rather easily [Werner et al. 2009].

Schubert wanted to hire professional sales personnel, graduated chemist with special knowledge in nanotechnology who, of course, would ask for high salaries. The banks rejected his request as they felt IoLiTec's revenues were too low and, according to Schubert's opinion, the bankers did not understand the technology.

However, by September 2008 Schubert succeeded in getting a private investment firm on board. The investment firm "Zukunftsfonds Heilbronn" (ZFHN) entered with €1.75 million [Werner et al. 2009]. The ZFHN is endowed with capital by several families of the region and works exclusively with own equity [Stockburger 2008].

ZFHN invests primarily as a lead investor or, within bigger rounds as a co-lead investor, financing with an order of € 0.5 - 8 million [ZFHN]. One condition of the ZFHN was that IoLiTec shall move its location from Denzlingen to that of the investor, to Heilbronn (Germany). Consequently, IoLiTec operates since January 2010 in Heilbronn. And the legal status of the firm was changed to the simple limited liability company situation, *IoLiTec GmbH*.

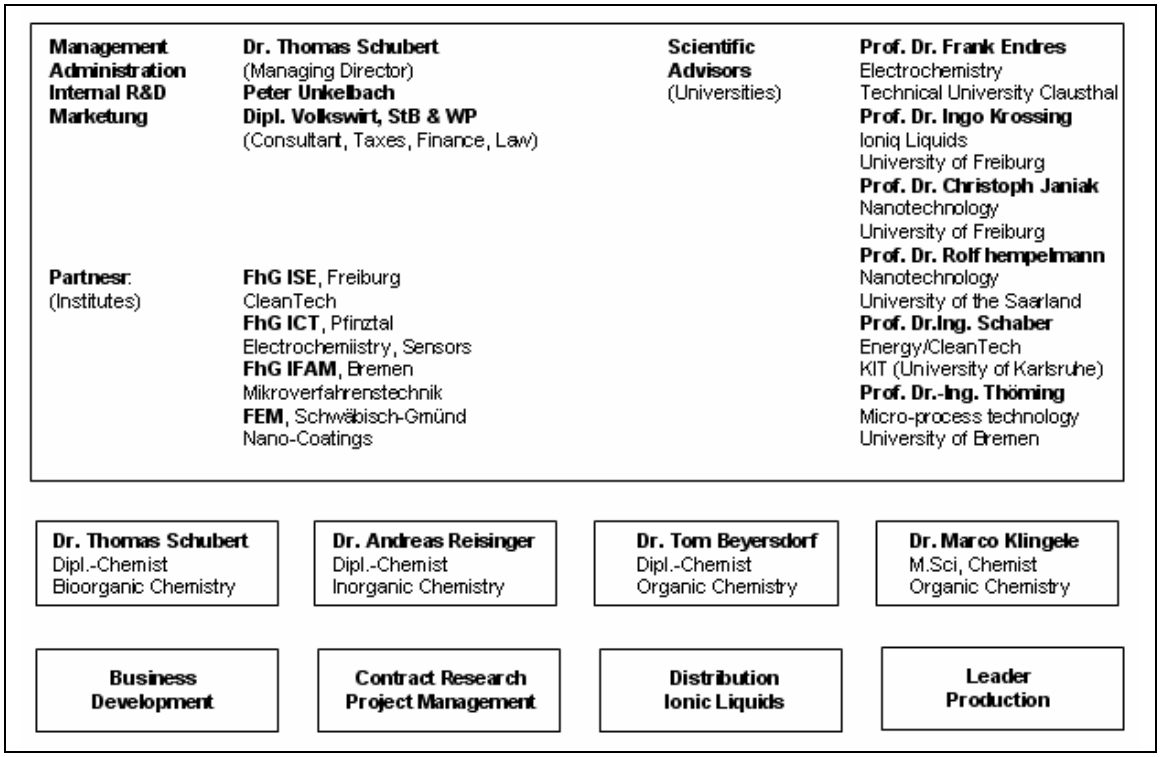


Figure 5: Management, roles for key personnel and networking of IoLiTec in 2008 (Translated source: [Schubert 2008a]).

Schubert was attracted by the ZFHN as it does not invest with an eye to a quick “exit “, but accompanying the firm over a longer time period – also in the phase of expansion as long as it is reasonable for both parties. The venture capital fund acquired a 30 percent stake in the technology firm [Stockburger 2008].

Preparing for the move to Heilbronn had consequences of the original plans of IoLiTec. Activities in R&D projects were reduced and its intention to establish a subsidiary in the US was delayed. Though in 2009 *IoLiTec, Inc.* was incorporated as a one-man-firm in the Business Technology Incubator at the University of Alabama in Tuscaloosa, but started the operative business only in April 2010. Apart from Europe the US represents the most important market for IoLiTec – with no IL startup [Schubert 2008a].

The selection of the location in Tuscaloosa was in line with the presence of Robin D. Rogers, a chemistry professor, founder of the Center for Green Chemistry and Director of the Center for Green Manufacturing at the University of Alabama, Tuscaloosa who is a renowned expert in ionic liquids. Prof. Rogers's initial work focused on the use of ionic liquids as VOC (volatile organic compounds) replacements in liquid/liquid separations [Ritter 2008]. The use of ILs as thermal fluids was also first suggested by Rogers. Furthermore, a number of German firms reside in that area. For instance, Daimler AG has its Mercedes-Benz facility in Tuscaloosa County.

And, in 2006, German chemical giant BASF and the University of Alabama formalized a license and cooperative agreement giving BASF exclusive rights to patents covering the use of ionic liquids to dissolve, regenerate, and process cellulose. "This technology enables us to produce blends of polymers and cellulose that provide excellent plastics performance," said Robin D. Rogers. Among the possibilities one finds: packaging film blends of cellulose and polypropylene that have exceptional tear strength, and encapsulation of pharmaceutical or crop protection ingredients together with magnetic particles to provide focused treatments [Short 2006].

Out of a small office at the University of Alabama's AIME building, Dr. Tom Beyersdorff was contacting North American companies, universities and researchers interested in ionic liquids. ILs

were shipped to Tuscaloosa, and Beyersdorf then filled the orders for North American customers. Usually orders are for small amounts with about 60 percent going to academia.

Reflecting customer development in 2009, IoLiTec sold $60,000 in ionic liquid in the US from sales made out of Germany. In 2010 it was able to more than double its sales. From April through December 2010, its sales were more than $150,000 and in early 2011 its sales exceed $80,000. It was predicted that, if it continues at that pace, IoLiTec will more than double last year's US sales [ADO 2011]. Indeed ,in 2012 for IolLiTec, Inc. an annual sales volume of $501K - $999,999 was given [Chamber of Commerce].

In 2011 IoLiTec Inc. won $50,000 in cash plus in-kind services for its second-place finish in the Alabama Launchpad Governor's Business Plan Competition. Launchpad team members were: Drs. Tom Beyersdorff, president; Rachel Frazier, a research engineer within UA's Alabama Innovation and Mentoring of Entrepreneurs; and Whitney Hough, who holds a doctorate in chemistry and is pursuing an MBA at UA. [UA 2011].

Having established its distribution organization for ILs, marketing and sales of ionic liquids *have remained tough as they remained expensive* due to the difficulty of manufacturing them. Much of the difficulty is associated with purification. Hence, *recycling* of ILs played an important role to support sales. But, in 2010 IoLiTec opened another revenue stream, i*onic liquids rental service*. IoLiTec claimed to be an industry first with renting ionic liquids to customers [Turley 2010].

Customers effectively rent two batches of liquids, which can be cycled for continual use. When the performance of the batch in use begins to drop, the customer sends it back to IoLiTec for cleaning and switches to the spare one. IoLiTec would not comment on the '"commercially sensitive"' cleaning process. Rental prices similarly vary, but an ionic liquid that costs €100/kg to buy might cost just €10/kg/month to rent. IoLiTec has rented ionic liquids for use in metal plating, gas compression and sorption cooling [Turley 2010].

By the end of 2011 IoLiTec achieved a status concerning the level of progression from R&D via piloting to commercialization of offerings which is depicted in Figure 6 (cf. also Table 1). Whereas Figure 2 and Figure 4 reflect IoLiTec's *technology strategy* Figure 6 indicates the state of *executing the strategy*. IoLiTec *views itself as the leading experts in the field of nano-dispersion technology* [IoLiTec 2011]. Comparing the statuses of R&D and Pilot concerning technology development in Figure 6 with the above described joint projects IoLiTec participated in reveals that this participation reflects executing technology strategy.

IoLiTec has positioned its ionic liquids in the "*low volume, high value*" segment of specialties. The diversified orientation of offerings and industry segments makes *IoLiTec rather independent from economic ups and downs* of the addressed industries.

Services include consulting and feasibility studies as well as development (custom synthesis of those compounds that are not covered by IPRs of third parties) of marketable products and applications based on ionic liquids and also custom R&D [IoLiTec 2011]. How to identify suitable ionic liquids for customers is outlined by Schubert [2013:25].

Together with customers IoLiTec developed ionic-liquid-screening-kits ("MyKit"; 10g) on the basis of 59 common ILs which should suffice to satisfy most screening purposes.

Continuous and intense cooperation is at the heart of IoLiTec [IoLiTec 2011], with partners from various industries, but also universities and public research institutes like those of the Fraunhofer Society.

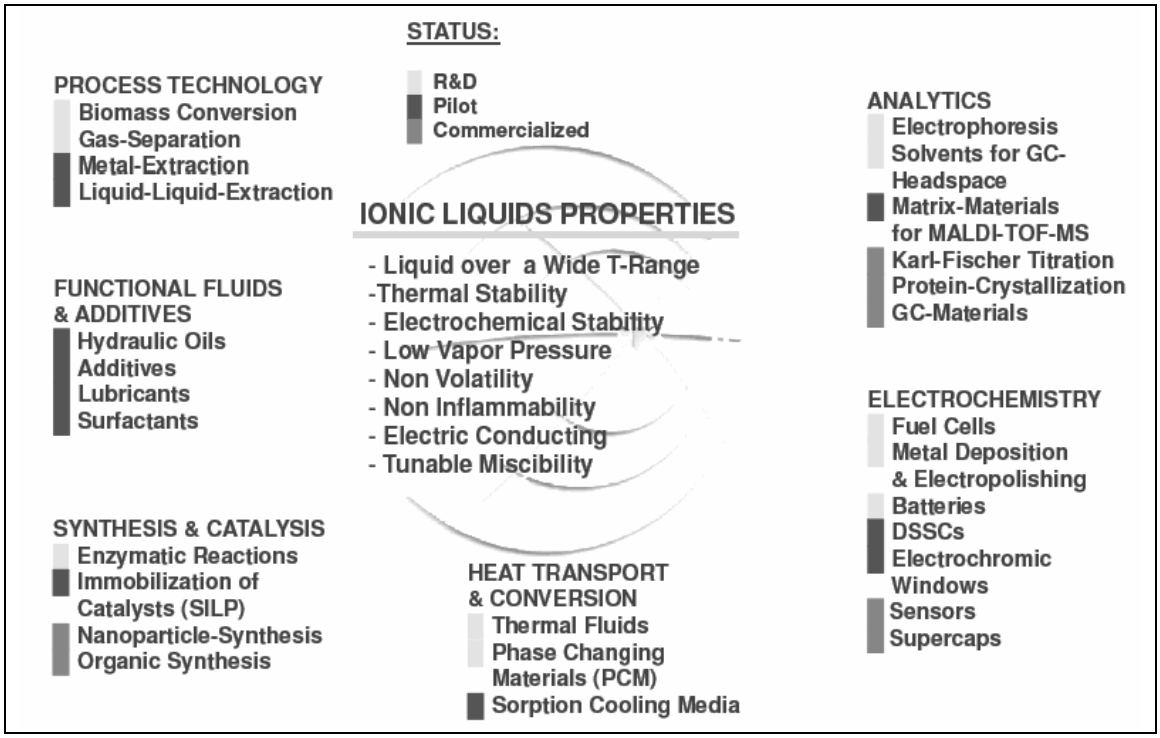


Figure 6: IoLiTec's status of executing its technology strategy in terms of applications and products (Source [Iliev et al. 2011]).

The organization and related persons of IoLiTec's leadership team and functional leaders as given on its current Web site is displayed in Figure 7. Here it is interesting to note that (*technical) project managers also have responsibilities for sales*.

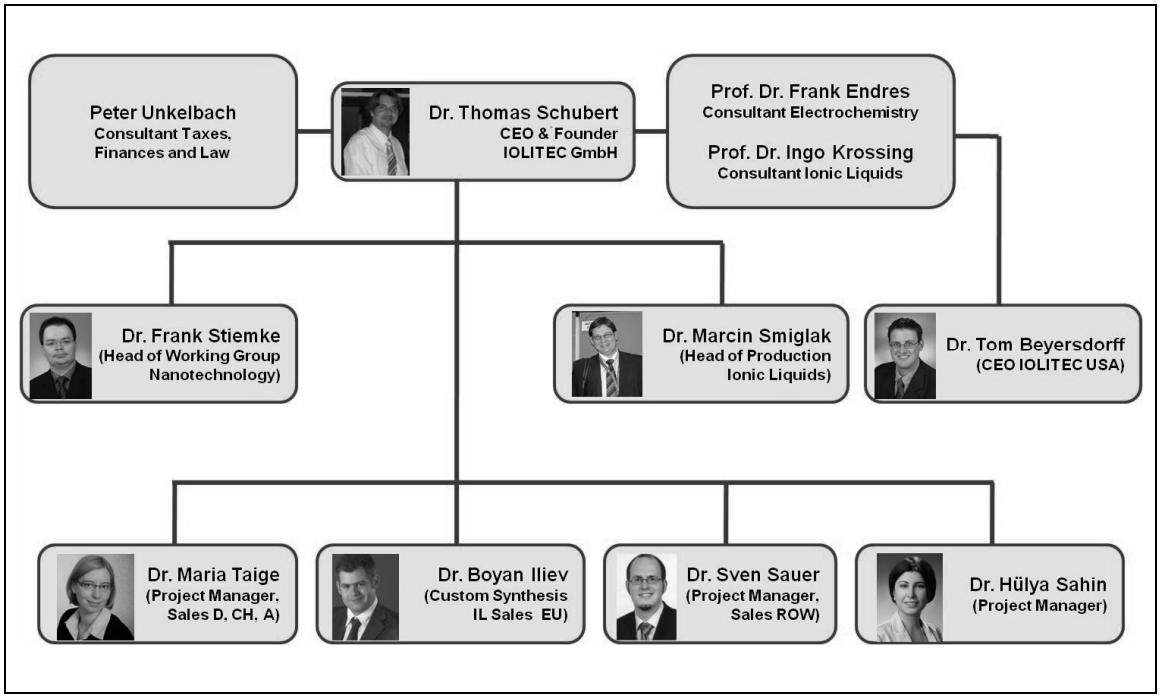


Figure 7: IoLiTec's leadership team and functional managers by 2012 (ROW – Rest of world).

According to Ionic liquids Today (November 23, 2011) IoLiTec's "sales shifted again a bit more towards industry." By 2013 IoLiTec's portfolio of offerings focused on:

- Lubricants
- Electrolytes for electroplating, particularly for processing aluminum
- High-performance electrolytes for lithium-ion batteries, supercapacitors and fuel cells
- "Green" solvents for process engineering and biotechnology
- Products for heat or cold storage
- The "catalog business."

But the 2014 Web site of IoLiTec is more structured and explicit on offerings [IoLiTec 2014] – reflecting often results of IoLiTec's participation in joint projects mentioned above:

- Ionic liquids (catalog products, custom synthesis, IL screening Kits)
- Nanotech & Coatings (ready-to-use dispersions of various nanoparticles of controlled size in different solvents and concentrations, especially metals and metal oxides, carbides, nitrides, fullerene, graphene, carbon nanotubes (CNTs) as well as synthesis of custom-made dispersions)
- Energy & CleanTech (photovoltaics, supercap electrolytes, battery electrolytes and heat carriers, phase change materials (PCM), media for sorption refrigeration machines; lubricants)
- Fine Chemicals (key intermediates for preparing ILs)
- R&D Services (consulting; R&D services – the development of "tailor-made" Ionic Liquids, with task-specific, optimized physical and/or chemical parameters including analytics).

More than 200 products are provided with purities between 98 percent and 99+ percent (cf. Note 1 in case Solvent Innovation). By far most of the products are based on the imidazolium-cation in combination with different anions such as triflate, tetrafluoroborate, thiocyanate or dicyanamide and various halides. Additionally also ionic liquids are produced with ammonium, pyrrolidonium and sulfonium-based anions, such as NTf2-anions.

Lubricants provide the main source of revenue and also *electrolytes for electroplating* are successful [ZFHN 2013]. The overall situation for offerings is [Schubert 2013]:

Capacity	**Products and Services**
25 metric tons; fast scale up	> 300 ionic liquids, Custom synthesis
	10 are industrial available (> 1 metric ton), ca. 175 nanomaterials and dispersions

Looking Ahead

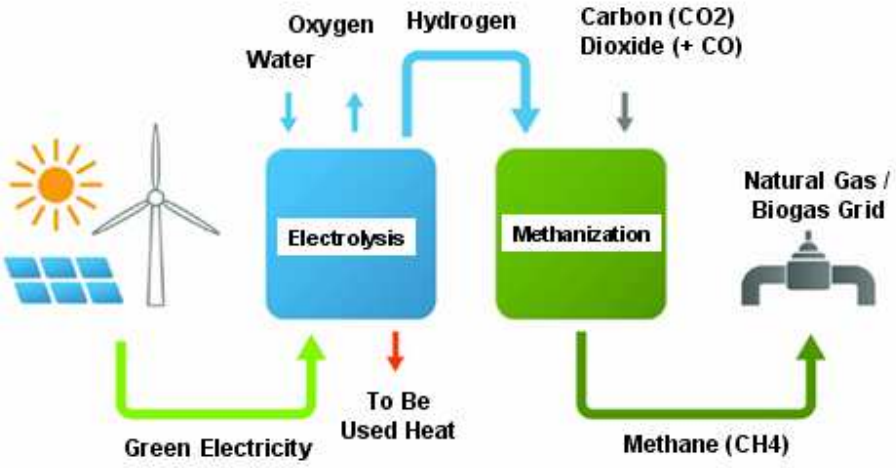
The field of ionic liquids continues to be associated with *intense scientific activities*. According to Ionic liquids Today (November 23, 2011) there are more than 15,000 publications about ionic liquids.

IoLiTec *continues with its intense participation in publicly funded projects* (cf. for instance [Sahin and Schubert 2012:29] concerning thermal fluids subsumed under Energy & CleanTech). A rather detailed list of projects is given by the database of the German Environmental Agency (Umweltbundesamt – UBA) [UBA 2011]. This kind of *networking* represents a key *resource* for IoLiTec [Runge:Figure I.170] for further development.

With its "Energy & CleanTech" orientation and its strength in electrolysis IoLiTec participates in a joint project funded by the German Ministry of Education and Research (BMBF) (Figure 8) emphasizing "Storage of Electrical Energy from Renewable Resources in the Natural Gas Grid – Water Electrolysis and Gas Component Synthesis (SEE). This is a Power-to-Gas approach and IoLiTec is responsible for the development and synthesis of appropriate ILs. [Luterbach 2012].

The goal of the joint project is to develop chemical storage technology to help manage the fluctuating supply of electricity from wind and solar power based on the production of “substitute natural gas” (SNG). Carbon dioxide (CO2) and to some degree also monoxide (CO) will provide the source of carbon for methanization. Germany has an excellent natural gas storage and distribution infrastructure. Huge porous and cavern reservoirs are already available.

A Power-to-Gas approach brings new economic and technology flexibility between the traditional energy silos of power grids, energy storage, gas pipelines and transport. It is a further development of the power-to-hydrogen approach of Enertrag AG. Here the coupled electrolysis to hydrogen and its conversion to methane are central [Runge:Figure I.104].



Partner	
4 x Industry	h-tech, Outotec, IoLiTec, EnBW
3 x Research Organizations	Fraunhofer ISE, DVGW-EBI, KIT-EBI
Project Period	2011 - 2014
Project Leadership	DVGW-Research Unit of the Engler-Bunte-Institute of KIT

Figure 8: IoLiTec as a partner of a publicly funded joint project referring to a “Power-to-Gas” approach focusing on its strength of preparation of ionic liquids for electrolysis (modified graphic from [Luterbach 2012]).

Key Metrics

To the author’s knowledge there is no information on IoLiTec’s revenues publicly available, an important variable and indicator of an NTBF’s development. Furthermore, it is unknown in how far public financial support by projects IoLiTec participated in is added to sales of products and services. For research-oriented startups it is not uncommon that public funds contribute up to 50 percent to revenues. On the other hand, we heard several times from the founder that *IoLiTec made always a profit since its foundation* [Schubert 2008a].

IoLiTec saw an increase in sales from 2004 to 2005 of 200 percent [Schubert 2006b]. Its growth of sales were +30 percent in 2007 and+40-50 percent in 2008 [Schubert 2008b]. However, it is not obvious how much money from externally financed projects have contributed to revenues. Increase of profit in 2008 was +41 percent compared to the previous year [Schubert 2008c].

However, one may come up with an estimate for the current revenue. Currently the ZFHN funds twelve firms which are all located at its Heilbronn including IoLiTec. In 2011 these firms had 325 employees which generated total revenues of €33 million per year [Stockburger 2011]. This translates into €100,000 per employee (Table 2) on average and therefore sales of roughly €2.2 million, and as estimated sales of €2 – €3 million for 2012.

But there are other metrics for IoLiTec to show that the firm grew continuously and considerably and since 2006/2007 it has accelerated its development. Characteristics of IoLiTec's growth are:

- *Innovation persistence* [Runge:ch. 4.2.3, Figure I.115, Figure I.127]
- Strong *customer orientation* and focus on customer/market development
- Intense *cooperation* with industry and academia
- *Execution* of a longer term strategy and
- *Diversification* of applications and continuous expansions of its basis of ILs as its *platform technology*.

In Table 2 development of the numbers of employees per year are shown and the proportion of PhDs for research. The overall employees' Compound Annual Growth Rate (CAGR) [Runge: Equation I.10] between 2005 and 2012 is 17.8 percent.

In 2006 [Schubert 2006b] the proportion of R&D people in relation to all employees was 49 percent (during a presentation the founder spoke of 40-45 percent [Schubert 2008a]). This high proportion of research characterizes IoLiTec as belonging to the class of NTBFs running a "top value technology" (TVT) [Runge:ch. 1.1.1,Table I.1].

The reduction of the number of PhDs in relation to all employees from 2010 to 2012 indicates a shift of the firm's personnel from research to more production, marketing and sales activities.

Irrespective of the distinct growth of IoLiTec according to its founder the focus of his company is still on research [Juratovic 2012]. Its current direction is summarized by Schubert [2014].

Table 2: Numbers of IoLiTec's employees per year (2003: 3 + 1 in October).

2005	2006	2007	2008	2010	2011	2012
7	10	10 (5 PhD)	12 (5 PhD)	15 (8 PhD)	20 (8 PhD)	22 (9 PhD)
	49% PhDs	50% PhDs	42% PhDs	53% PhDs	40% PhDs	41% PhDs
Schubert 2005	Schubert 2006b	Schubert 2008a	Schubert 2008b	Beyersdorf 2010	Iliev et al. 2011	Sahin and Schubert 2012

Other indicators for IoLiTec's growth exhibit qualitatively synchronous developments with the numbers of employees, such as its production capacities (Table 3).

Table 3: IoLiTec's production capacity (metric tons) per year *).

2002/2003	2005	2006	2008	2009	2010	2011
Founded	xx g - xx kg	1 ton	–	5 tons	10 tons	25 tons
Source		Schubert 2006b		Beyersdorf 2010; Schubert 2009b	Iliev et al. 2011	Sahin and Schubert 2012 *)

*) 10 are industrially available (> 1 metric ton) in 2013.

IoLiTec is a small NTBF which differs from most other NTBFs by a rather large number of products and also large number of customers. During the period 2007 – 2012 the number of prod-

ucts doubled as did employees. The increase of the number of ILs offered (standard portfolio) is given in Table 4. The related growth indicates IoLiTec to pursue *innovation persistence*.

Table 4: Cumulative numbers of ionic liquids offered by IoLiTec.

2004		**2007**	**2008**	**2009**	**2010**	**2011**
25 a)		ca. 150	ca. 200	ca. 250	–	ca. 300
Source		Schubert 2007	Schubert 2008a	Schubert 2009a		Iliev et al. 2011

 Product list in Ionic Liquids Today 1/05, Mar. 3, 2005.

At the same time as firms develop new ILs for larger scale applications companies are coming to grips with the commercial reality of product registrations for materials used in quantities larger than lab-scale – registration of compounds to comply with legal requirements of chemicals to be distributed into the markets. It will be about six to nine months for full registration and IL providers will include registration cost in the development costs [Short 2006]. For instance, IoLiTec spoke about 3-5 products to be registered till 2010 {Schubert 2008a}.

In a corresponding way the growth of the number of customers in Table 5 would reflect strong growth of IoLiTec.

Table 5: Numbers of IoLiTec's customers worldwide.

No. of Customers	**Year**	**References**
> 1,600	2012	[Sahin and Schubert 2012]
> 1,400	2011	[Iliev et al. 2011]
> 1,000	2009	[Schubert 2009b]
≈ 500	2008	[Schubert 2008c]
> 400	2007	[Schubert 2008a]; Jan. 2008
> 200	2006	[Schubert 2006b]

However, it is not clear whether the number of customers covers "regular customers" with more than one order of products or services or "different parties" interested in ionic liquids who just order one time to experiment with ionic liquids. Indeed in 2013 one reads that IoLiTec supplied its products to more than 550 customers in about 100 countries [ZFHN 2013].

In the sense of " *technology push*" IoLiTec used its newsletter rather early as a *marketing instrument* to increase awareness of and interest in the emerging field of ionic liquids and their broad scope of applications and what IoLiTec can offer here. Therefore, the development of the numbers of subscribers to the newsletter is indicative of how successful IoLiTec achieved this. Just supplying a new technology is not sufficient. Much market development is needed. In Table 6 it is shown that also the growth of this indicator is in line with all the previous ones.

Table 6: Numbers of subscribers of the IoLiTec Newsletter *)

2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Launched	>1,300	> 2,600	Ca. 3,500	>5,000	–	6,500
			Schubert 2008			IoLiTec 2011

*) If not given otherwise data are from Ionic Liquids Today.

Competition

All IL startups are confronted with the issue that it is hard to estimate which of the very many conceivable business areas are most likely to be successful.

Fundamentally competition in the ionic liquids field may show up as a fight for market share, if ILs occur as an *emerging technology* or, if ILs appear as an *enhancing* or a *generic technology* [Runge:Table I.12],as a fight against other, often well established technologies.

Basically due to its diligent tracking and watching scientific and technical developments managed by its related database systems (*technology intelligence*, Figure 3) IoLiTec was and is well armed to respond to moves of competitors.

In particular, IoLiTec and his key founder T. Schubert can be assumed to be well aware of what other *competitive startups* (Solvent Innovation GmbH in Germany, Bioniqs Ltd. and Scionix Ltd. in the UK; B.2) were doing, particular concerning Solvent Innovation (B.2), of which Schubert was a former employee. For instance, co-founder Bösmann illustrated very early [Bösmann 2005] that he was aware of Dr. (then Prof.) Abbott's work on ionic liquids based on choline chloride at the University of Leicester (UK) and his involvement in the startup Scionix Ltd. (Scionix in Bioniqs Ltd. – B.2).

There are a number of large global players like German BASF or Merck KGaA which have added ionic liquids to their portfolios of dedicated offerings or "auxiliary intermediates" for applications in a range of technologies (cf. [Runge:A.1.5]).

IoLiTec established a "mode of co-existence" with the large firms, for instance, by cooperation in joint projects (with Merck KGaA in NEMESIS) or by distribution agreements – Merck distributing IoLiTec's ILs, IoLiTec distributing Cytec's ILs ("catalog business"). As a general strategy, IoLiTec has positioned its ionic liquids essentially in the "*low volume, high value*" segment of specialties where it met only some startups – and perhaps Merck KGaA.

"We are exquisite in a niche on the go," said Schubert ("Wir sind in einer Nische exquisit unterwegs.") For the big companies such as BASF smaller production volumes as that of IoliTec are less interesting. As his company was set up complementary, Schubert explained, these are no competitors for us [ZFHN 2013].

IoLiTec's basic *competitive advantage* compared to its competitors (see also end of text) is the unique and wide knowledge about the scientific and technical developments of the whole new class of materials, including their applications and potential markets.

It achieved a unique selling proposition (USP) by *flexible integrated innovative micro-reactor based production* of high purity materials and quality management as well as *nano-dispersions*. *IoLiTec is well known to the industry and academia* and has broad presence in industry as a member of German competence networks and continuous participation in many diverse joint projects. Additionally also its permanent international exposure to the field via fairs, exhibitions and conference is notable.

The magnitude of IoLiTec's portfolio of ILs and IL applications outstrips those of the startup competitors. This is even true for biotechnological applications and generally for "Synthesis & Catalysis" (Figure 6).

Concerning the IL startups Bioniqs Ltd. (B.2) it has never been a serious competitor of IoLiTec. Furthermore, Bioniqs focused largely on ionic liquids as solvents and its application in just the chemical and pharmaceutical industries.

Both the UK IL startups offered ILs for cleaning, Scionix concerning metal surfaces, Bioniqs concerning chemical process reactors. Cleaning with ILs is a function which for IoLiTec did not play a significant role.

With regard to services including consulting all the IL startups provide very similar offerings. However, with regard to breadth and deepness IoLiTec excels the other startups.

If Scionix would leave its UK markets fields of competition with IoLiTec would include

- Electrochemistry (metal deposition and electropolishing, metal recovery – Scionix),
- Process technology (metal extraction including catalyst recycling – Scionix)
- Functional fluids & additives (hydraulic oils, lubricants, additives, like plastics additives, and dispersing agents for nano-particles – Solvent Innovation).

Concerning Solvent Innovation GmbH (B.2) in Germany most of the products had still a status of *prototypes* and, during SI's period of independency until 2008, also IoLiTec's related products were mostly in a state of piloting (Figure 6).

Scionix Ltd. (B.2) based its ILs on *ammonium salts* as did later Bioniqs, but different from IoLiTec. Scionix' ionic liquids are essentially based on choline chloride promising mass product related ionic liquids which could be assumed to be applicable to large scale processes. One basic orientation of Scionix is ILs to offer *a clean way to carry out chemical processes, in contrast to strong acids*. In particular, concerning electrodeposition (electroplating) Scionix focuses on steel, iron and nickel, whereas IoLiTec emphasizes aluminum.

Finally, Scionix pursued *an entrepreneurial process which is quite different from IoLiTec's approach*. It follows the narrow path of a university/industry cooperative organization. This Private-Public-Partnership (PPP; [Runge:A.1.3]) allows fundamental and applied research to be carried out at the university while providing the production, marketing and licensing capability by the private organization. The essential structure in case of Scionix (B.2) attributed a dual role to Prof. A. Abbot of the University of Leicester (UK): Be a research leader at the university and as a co-founder act as the Research Director of Scionix.

The PPP construct involves Whyte Group Ltd. which is Britain's largest privately owned chemical company which follows a number of diverse activities, including manufacturing, distribution and R&D. The flagship of the group is Whyte Chemicals Ltd., one of the largest private distributors of chemicals and polymers in the UK and it also manufactures pharmaceuticals – and ultimately also ILs. One can assume that this constellation of Scionix decreases its options of cooperating with other industrial partners.

Contrary to IoLiTec which pursues many links with industrial firms and universities and public research institutes Scionix concentrates essentially on only the University of Leicester and Whyte Group. This means, Scionix' access to external resources for research, development and commercialization and competitive strength are rather small compared with those of IoLiTec.

IoLiTec has the key attributes to provide competitive advantage (VRIO) [Runge:ch. 4.3.3; Table I.75].

- Through its value (V): IoLiTec can exploit opportunities or neutralize threats in its external environment with internal and external (network) resources and experiences to capture and run collaborative projects.
- The few (three) startup competitors do not have a comparable set of combined internal and external resources due to the specific German systemic organization of cooperation by joint projects This means IoLiTec operates under conditions of "rarity" (R).
- The other firms have great difficulties to obtain corresponding resources and capability (a "*bundle*" of assets or resources to perform a business process). There is almost no "imitability" (I).
- Finally, IoLiTec has an appropriate organization (O) with associated execution capability to take full advantage of the resources/capabilities in order to realize a competitive advantage. Its strong customer orientation is associated with an emphasis on sales.

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Notes

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