

WHITE PAPER

Building The Digital Biotech Company: Why and How Digitization is Mission-Critical for Moderna

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INTRODUCTION

Moderna is focused exclusively on advancing messenger RNA (mRNA) medicines. Using mRNA – a fundamental component of human biology – as a drug, our medicines are sets of instructions that direct cells in the body to make proteins to prevent or fight disease. This approach represents an entirely new drug class, and the chance to treat and prevent diseases that aren't druggable with small molecule drugs or biologics. Additionally, the inherent software-like, digital nature of mRNA technology presents the opportunity to build a completely novel type of biopharmaceutical company specifically tailored to explore and exploit the potential of mRNA science to treat human diseases.

Our Mission:

Deliver on the promise of mRNA science to create a new generation of transformative medicines for patients.

Our business strategy involves progressing mRNA medicines for many therapeutic areas and diseases simultaneously, all built from our core mRNA platform. To propel this strategy, we have created a business model and infrastructure quite distinct in the biopharmaceutical space. **Digitization is a core attribute and key enabler.**

We have infused a digital approach and seamlessly integrated digital tools across every aspect of our strategic planning, business and R&D processes. Ultimately, this will extend to our commercial efforts. This enterprise-wide focus on digitization has positioned Moderna to execute against our strategy, while also yielding a distinct competitive advantage. Six years since commencing operations, Moderna has amassed a pipeline with a breadth, speed and scale not common in our industry.

In this white paper, we explore the factors that have both driven and enabled Moderna to be fully digital, present a high-level overview of implementation, and discuss the impact digitization has had, to date, in helping us advance our mission.

DIGITIZATION DRIVERS

A confluence of four key factors has impelled our pervasive digital approach:

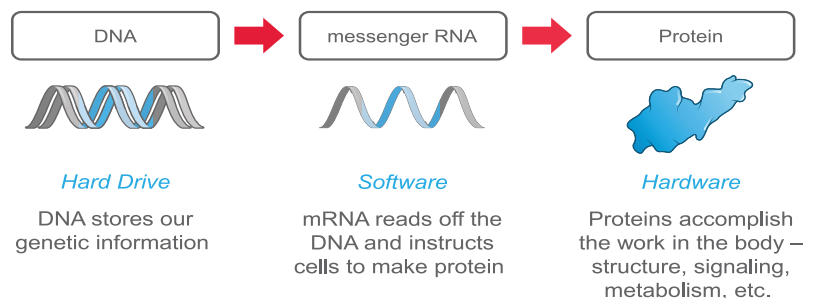
- 1.) Our Technology
- 2.) Our Platform
- 3.) Our Business Strategy
- 4.) The IT Revolution

SOFTWARE-LIKE NATURE OF mRNA TECHNOLOGY

Our mRNA medicines aren't small molecules, like traditional pharmaceuticals. And they aren't biologics (recombinant proteins and monoclonal antibodies), which were the genesis of the biotech industry. Instead, they are sets of instructions – a software-like code – that we deliver to cells in the body. The body's own cells then produce the proteins needed to prevent or fight disease.

mRNA plays a fundamental role in human biology. It carries genetic code from DNA in a cell's nucleus to ribosomes, the cell's protein-making machinery, directing it to make proteins. Each day, trillions of mRNA molecules are directing protein production in the body.

Central Dogma of Molecular Biology



By using mRNA as a drug, Moderna takes advantage of this normal biological process to express proteins and create a desired therapeutic effect. **mRNA is the software of life – so the very essence of our medicines is digital.** For each mRNA medicine, we are encoding for one or more mRNA molecules, which we then deliver to cells.

The software-like, digital nature of mRNA is the distinctive and foundational characteristic upon which we have fashioned our platform, business strategy, preclinical and clinical manufacturing efforts, and propelled our need for digitization.

For Moderna, digital is not a ‘nice to have’ but a ‘must have.’

Drug Design Studio: Using Digitization to Exploit Software-Like Nature of mRNA

The software-like nature of mRNA led to creation of the Drug Design Studio, a proprietary digital tool developed by our in-house software engineering team. It enables scientists at Moderna to digitally design and order mRNA constructs for use in research.

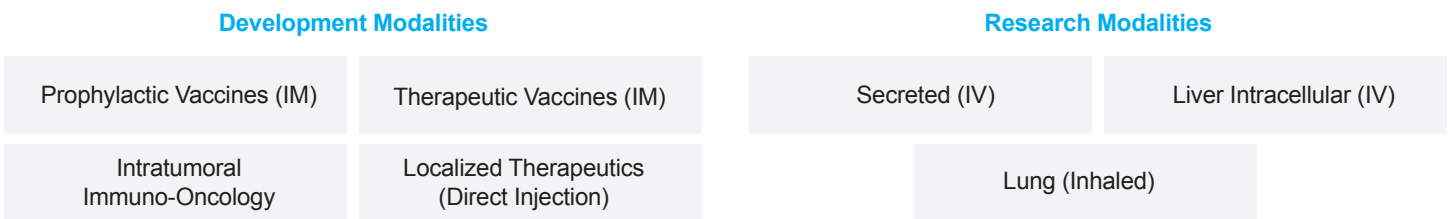
MODALITY-CENTRIC PLATFORM TO ENSURE REPEATABILITY

We have created an mRNA technology platform that functions very much like an operating system on a computer, enabling us to exploit the software-like nature of mRNA technology and ensure repeatability in our R&D efforts.

Our platform comprises five key elements – Chemistry, Bioinformatics, mRNA Engineering, Process, Formulation – that we combine to develop toolkits called modalities. We deploy our modalities to create a family of medicines for different diseases. Due to the software-like nature of mRNA, our belief has always been that, if we can make mRNA work as a medicine with a given modality, we should be able to make many mRNA medicines using that same modality. Prophylactic vaccines was the first modality for which this belief has translated to reality.

We began pursuing the prophylactic vaccine modality in 2014. As of January 2017, we have eight prophylactic vaccine development candidates (DCs) – four of which are in clinical studies, and four more are advancing toward the clinic. Additionally, we are moving more prophylactic vaccines through research toward the development stage.

We now have four development modalities (development programs in the clinic or advancing toward the clinic) and three research modalities (research programs advancing toward DC nomination) – designed around different therapeutic needs and routes of administration. All seven modalities have been created from the five key elements of our platform technology.



Abbreviations: IM = Intramuscular; IV = Intravenous

To date, utilizing our mRNA technology platform, Moderna and our partners are advancing prophylactic mRNA vaccines for infectious diseases, personalized cancer vaccines, immuno-oncology mRNA therapeutics, and mRNA therapeutics for cardiometabolic, rare and pulmonary diseases.

Many large pharma companies also focus on different disease areas, but they do so by applying a medley of scientific and drug technology platforms. Emerging biopharma companies that are applying a scientific platform typically focus on just one or a small number of therapeutic areas.

Conversely, at Moderna, a single scientific and drug technology platform is the basis for creating all medicines across a spectrum of therapeutic areas and diseases. **Digitization is the backbone upon which our platform is built. It is both an enabler of our science and core to our science.**

BUSINESS STRATEGY: MASSIVELY PARALLEL R&D, ECOSYSTEM MODEL

If it were possible to direct cells in the body to make proteins, we knew that, in theory, the potential to address many diseases was expansive. However, we did not know where the mRNA approach would work best. For this reason, we did not want to limit our exploration.

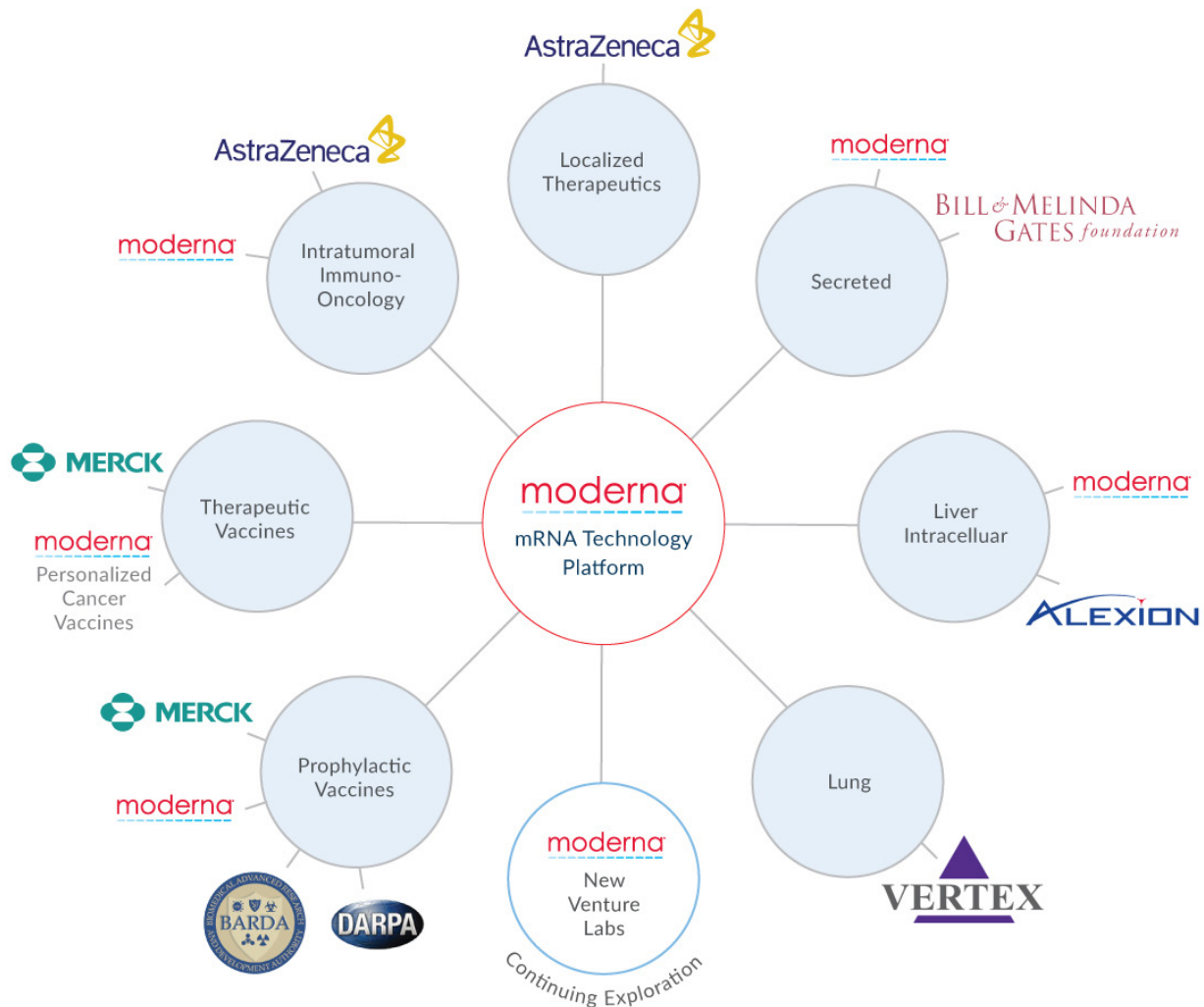
If we took a sequential approach, focusing on one therapeutic area or disease, and that program failed, we feared it could prematurely shake stakeholder confidence, leading to the abandonment of a promising technology. This would have been a lost chance to help many, many patients. We did not want to fail this technology.

So, our business strategy is to advance a broad array of mRNA drugs for many diseases **simultaneously** in order to deliver on the promise of mRNA science for patients as quickly as possible. Central to this strategy has been the creation a unique ecosystem to enable **parallel progress** and **shared learnings**.

Scientists within Moderna, as well as scientists at our pharma partners and academic collaborators, are progressing dozens of mRNA R&D programs concurrently – all leveraging our platform technology.

This model elicits a dynamic **network effect** that is feeding a cycle of continuous data and learnings, which in turn, are informing and accelerating future R&D efforts. We are seeing this network effect on two levels – the first is within modalities. For example, within the prophylactic vaccines modality, there is research underway at both Moderna and Merck. Scientists take learnings and data readouts from preclinical and GLP toxicology studies to inform ongoing and future efforts. The second network effect is between and among modalities. Scientists across the ecosystem have access to real-time data and information; learnings in one therapeutic area often are reapplied to another therapeutic area.

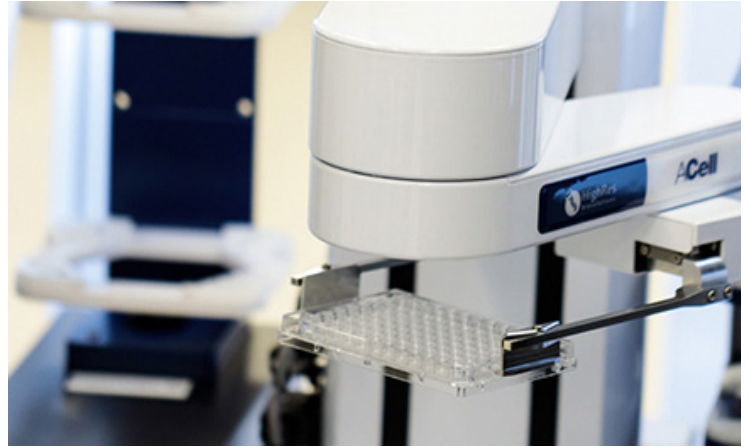
We rely on digitization to ensure seamless integration across the ecosystem, enable the ability to share and access data, permit the capability to scale, satisfy ever-increasing demands for research mRNA for preclinical and GLP toxicology studies, as well as GMP mRNA to supply an expanding number of clinical studies.



FORTUITOUS TIMING: THE IT REVOLUTION

Moderna was 'born' at an auspicious time, in the midst of astonishing technological innovations. Digital technologies, such as Robotics, Automation, Artificial Intelligence and Cloud, are reinventing and reimagining businesses across every sector. We have fully embraced digital technologies to advance our pipeline and our company. In fact, digitization is one pillar of our company vision.

Life science technologies likewise have been progressing at a remarkable pace. Thanks to advancements such as human genome and proteome sequencing, and next-gen sequencing, we are able to access ever-expanding molecular insights about human biology and diseases. Without these advancements, an mRNA approach would not even be feasible.

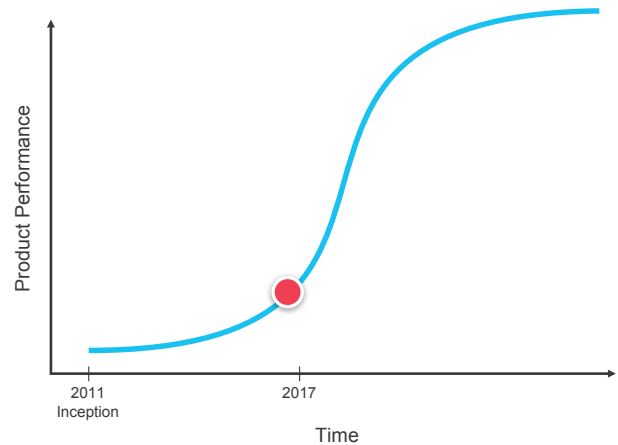


ENABLING A 20-YEAR INNOVATION CYCLE

We are at the beginning of a 20-year mRNA innovation cycle that most technologies go through before their performance has been optimized and is on the 'flatter' part of the performance curve. We do not believe we have to be on the tail end of the 20-year cycle to see our medicines reach the market. We hope to find early successes and advance ongoing improvements to the technology that will permit an ever greater number of opportunities as we invest in the platform.

Achieving success involves several factors, including learning the fastest and scaling rapidly, all while maintaining the highest quality. The only way to ensure this will happen is through digitization. Since Moderna's inception, we have invested over \$50 million dollars on information technologies and robotics/automation. Given our growth, we will invest more than \$50m over the next 5 years.

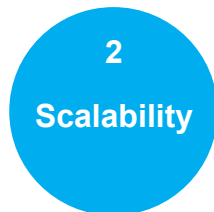
20-YEAR mRNA INNOVATION CYCLE



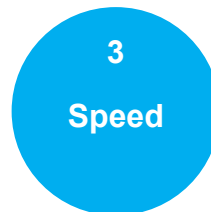
BENEFITS OF DIGITIZATION



Reduce human errors by enabling automation, repeatability and seamless integration wherever possible.



Accommodate an ever-increasing number of mRNA R&D programs within and across modalities.



Provide large quantities of mRNA across the ecosystem in a rapid timeframe to permit the acceleration of rational mRNA drug design; gather, analyze and share data in real time to inform decision making.

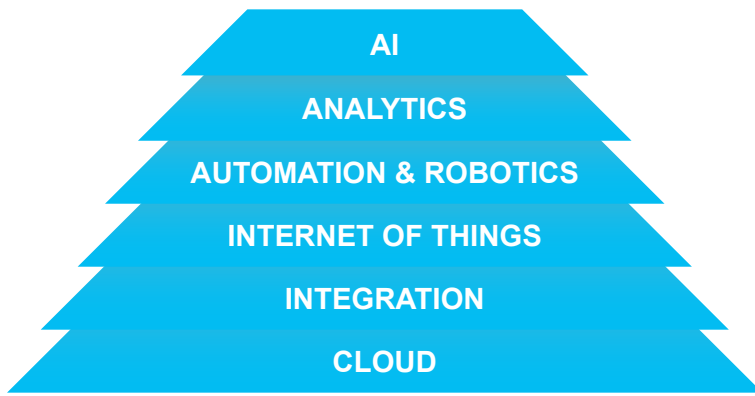


Create an infrastructure that can be leveraged across all R&D programs to maximizing efficiencies.

DIGITIZATION BUILDING BLOCKS

We have built a digital landscape that not only satisfies the operational needs to advance research programs, but also provides seamless integration along the R&D continuum as programs advance into and through the development stage, with a need to comply with the stringent requirements and regulations that surround clinical development.

Our digital strategy entails six key building blocks that are enabling us to advance and continually enhance our platform technology, exploit the software-like nature and inherent replicability of mRNA, drive our business strategy of massively parallel R&D of mRNA medicines, and support progress and shared learnings across our unique ecosystem.



- 1. Cloud enablement** is a must-have component of our digital infrastructure. Our science is rich in complex data sets, and our scientists need computational power, agility to operate, cost effectiveness and efficiencies in organizing and processing data without being hindered by the limitations of traditional computing technology.
- 2. Integration (Business Processes)** includes looking for every opportunity to bring our processes and data together in a consistent manner, avoiding 'silos of information' and manual intervention. This flow of data between systems, internally and/or externally, enables the automation of our business processes, and the real-time synchronization of our operations. Many companies struggle due to legacy systems, siloed data and processes, and inherent inefficiencies. To that end, as we grow, we have been organizing and managing our data around systems of records. These data are then shared and synchronized, enabling real-time data correlations and other learnings.
- 3. Internet of Things** is based on smart, interconnected devices producing information about their environments and operations. This immense new source of data from instruments and environments provides real-time guidance to our scientist and engineers, and helps us in supply chain and manufacturing with compliance and traceability, including tracking material, controlling inventory and optimizing energy consumption, among other benefits.
- 4. Automation** is radically transforming businesses and driving a new technology-driven revolution worldwide. With the help of Robotics, we reach an unprecedented level of automation, that increases our operations' accuracy, repeatability and throughput, and reduces human errors, dramatically improving our quality and compliance.
- 5. Analytics** are necessary to harness the power of our data. Using the latest tools and analytical methods, we have designed an environment that enables us to undertake any kind of analysis. Having rich and complex data readily available enhances our capability to generate scientific and business insights to make informed decisions.
- 6. Artificial Intelligence (AI)** is enabling key breakthroughs in analytics and predictive modeling, that will help accelerate our learning cycle drastically, providing us with critical insights into research and production data that were otherwise inaccessible and unachievable.

FULLY DIGITIZED R&D INFRASTRUCTURE

We have applied our digitization blocks to build, from the ground up, every aspect of our business. Key digitization buckets include:

- **Research Engine** – to move many mRNA research programs from idea to development candidate (DC) nomination simultaneously
- **Early Development Engine** – to move many mRNA development programs from DC nomination into and through clinical studies to human proof-of-concept (POC) data
- **Commercial Engine** – to move many mRNA development programs from human PoC to Phase 3 studies, pre-launch, launch and commercialization
- **Personalized Cancer Vaccines unit** – to create mRNA-based personalized cancer vaccines individually tailored for each patient in a rapid turnaround time
- **Business Foundations** – including human resources, finance, legal infrastructure, investor relations and other activities

DIGITAL TEAM – AN INTEGRATED BUSINESS PARTNER

Building an optimized digital landscape requires the digital team and their business stakeholder counterparts to work closely together. Our digital team is not simply a service provider to the organization, but rather an integrated business partner. The digital team is dedicated to work on specific business problems with their business counterparts. Both have a solid, mutual understanding and the ability to think creatively about innovative solutions, reduce unnecessary complexity in our processes and/or IT systems, interact frequently, and see the other side's perspective. Additionally, in my role as Chief Digital Officer, I sit on the Executive Committee to ensure that digital needs have a voice in all management discussions.

PROGRESS TO DATE

We have made significant progress advancing our mission and vision, largely enabled by our digitization efforts. Our development pipeline, which we announced in January 2017, currently comprises 12 development programs spanning infectious diseases, immuno-oncology and cardiometabolic diseases. Clinical studies are underway for five of these programs; seven additional programs are advancing toward the clinic, including our personalized cancer vaccines, a development program that is only made possible through the implementation of a digital infrastructure specifically designed to produce an individually tailored cancer vaccine per patient.

Moderna Pipeline as of January 9, 2017

	Development Candidate (DC)	Lead	Indication / Target	Formulation	GLP Toxicology	IND/CTA Filed	Ph I	Ph 2	Funding
Viral Vaccines	mRNA-1440	Moderna	Influenza H10	In Licensed	✓	✓	Started: Dec '15		
	mRNA-1851	Moderna	Influenza H7	In Licensed	✓	✓	Started: May '16		
	mRNA MRK-1777	Merck	Undisclosed	In Licensed	✓	✓	Started: Nov '16		
	mRNA-1388	Moderna	Chikungunya	In Licensed	✓	✓	Safe to Proceed to Clinic		DARPA
	mRNA-1325	Moderna	Zika	In Licensed	✓	✓	Started: Dec '16		DARPA, BARDA
	mRNA-1706	Moderna	Zika	V1GL	Ongoing				
	mRNA-1647	Moderna	CMV	V1GL					
	mRNA-1653	Moderna	HMPV/PIV3	V1GL					
Immuno-Oncology	mRNA-4157	Moderna Merck	Personalized Cancer Vaccine	V1GL	Ongoing				
	mRNA-2416	Moderna	OX40L	N1GL	✓	✓			
	mRNA-2905	AstraZeneca Moderna	IL-12	N1GL	Ongoing				
CV	mRNA AZD-8601	AstraZeneca	VEGF-A	Citrate / Saline	✓	✓	Started: Jan '17		

Abbreviations: GLP = good laboratory practice; IND = investigational new drug; CTA = clinical trial authorization; CMV = cytomegalovirus; CV = cardiovascular; HMPV = human metapneumovirus; PIV3 = parainfluenza virus 3; IL-12 = interleukin-12; VEGF-A = vascular endothelial growth factor A.

Through continual investment in our platform and our digital infrastructure, we believe we are well positioned to continue to rapidly and seamlessly advance mRNA medicines from concept through the R&D stages to commercialization—making strides toward realizing our mission to deliver on the promise of mRNA science for patients.

About the Author

Marcello Damiani

Chief Digital Officer, Moderna Therapeutics

As Chief Digital Officer of Moderna, Mr. Damiani brings a wealth of experience from both tech companies and life science companies, and a true passion for making digital a reality. He has 20 years' experience working in the IT field, with the last 10+ years spent in leadership roles for multinational companies in Europe and in the U.S. Prior to joining Moderna, Mr. Damiani was instrumental in conceiving and building creative IT solutions to help solve business challenges, first at Motorola and then at bioMeri  ux.